Co-ordination Action for Autonomous Desalination Units Based on Renewable Energy Systems

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Work Package 2

"AUTONOMOUS DESALINATION UNITS USING RES"

WP2 Participants CRES, GREECE

JRC, EU

WIP, GERMANY

ITC, SPAIN

CREST, U.K.

FhG- ISE, GERMANY

FM21, MOROCCO

INRGREF, TUNISE

RSS, JORDAN

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WP2 Participants

ORGANIZATION	Participant Researchers
Centre for Renewable Energy Sources, (CRES) GREECE	Eftihia TZEN
Joint Research Centre (JRC), EU	Neringa NARBUTIENE Robert EDWARDS
WIP, Germany	Christian EPP Michael PAPAPETROU
Instituto Tecnologico de Canarias, (ITC), Spain	Baltasar Penate SUAREZ Vicente Subiela ORTIN Gonzalo Piernavieja IZQUIERDO
CREST, U.K.	Murray THOMSON David INFIELD
Fraunhofer ISE, Germany	Ulrike SEIBERT Joachim KOSCHIKOWSKI
FM21, Morocco	Abdelkader MOKHLISSE Mohamed ABOUFIRRAS
National Institute for Research on Rural Engineering, Water and Forestry (INRGREF), Tunisia	Thameur CHAIBI Mohamed Nejib REJEB
Royal Scientific Society (RSS), Jordan	Mohammad SAIDAM

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Executive Summary

Water scarcity has always been part of the history of the Mediterranean. Through history, water has been the essential element for economic and social development and for the stability of Mediterranean cultures and civilizations.

Water in most countries and regions of the Mediterranean is a limiting factor. The arid and semi-arid countries of the Mediterranean combine a low rate of rainfall and a high rate of evapotranspiration, therefore only small amount flows into rivers or percolates to aquifers.

Furthermore, the level of exploitation of the water resources is generally high in most countries and pressure over water resources is increasing. Exploitation ratios are over 50%, or even nearing 100% in many parts of Mediterranean countries such as in Egypt, Palestinian Authority, Tunisia, Libya, etc., making the need of non-conventional water resources vital.

Desalination is becoming a major option particularly in the islands where the effects of severe droughts cannot be overcame by expensive transportation of water from the mainland. The cost of desalination is still high as compared to other conventional sources of supply. However, many islands are using desalination technologies to cover from 18% to 50% of the water use in the domestic sector.

Research on increased energy efficiency and use of renewable energy is achieving important results and is expected to make this option increasingly implement able, with the possibility of reducing stress on existing water supplies. Most of the Mediterranean countries exhibit significant Renewable Energy Sources (RES) potential. The coupling of renewable energy sources with desalination processes is seen as having the potential to offer a sustainable route for increasing the supplies of potable water. It is unlikely to solve the world's water problem in the immediate future but it does offer the potential of providing a sustainable source of potable water to some communities, particularly those in arid areas where there are no indigenous sources of fossil fuels.

Although RES desalination has interested those involved in desalting, the applications were mostly confined to isolated locations where continual transport of fuel posed a serious problem. However, with the rapid increase in fossil fuel costs during the past decade there has been renewed interest in the use of new energy sources from desalination throughout the world.

Aim of the present work is to promote the use of sustainable energy technologies for water production and to convey existing results of previous related EC or other Programmes to industrial entities, decision makers and end-users. Under this point of view, a list of available technologies, sizing and cost information, case studies results are provided.

The present work concerns with small autonomous systems approximately up to $50m^3$/day product water capacity and mainly focused on the three most applicable technologies combination (solar thermal distillation, Photovoltaic-Reverse Osmosis, Wind Energy - Reverse Osmosis). An overview of desalination technologies driven by RES is presented, focusing on the most promising combinations.

Technically mature technologies reviewed are: solar thermal energy and distillation desalination process which include solar collectors coupled with Multiple Effect Distillation (MED) desalination process; photovoltaic and membrane desalination processes: photovoltaic (PV) coupling with Reverse Osmosis (RO); wind energy and membrane desalination process: wind energy conversion coupling with RO process; as well as wind energy and distillation process; wind energy and Mechanical Vapor Compression.

Several installations around the world are examined in detail. Technical characteristics, design data, lessons learnt as well as cost data are also presented.

A number of projects, co-financed by the European Union and Middle East Desalination Research Centre, were overviewed focusing on R&D areas in coupling RES with desalination processes. It was noted that the use of RES in desalination is convenient in remote small areas as the cost of produced water is not compatible with conventional fuel-driven production. The latter problem influenced the attempts to develop less expensive systems with minimal requirements for their operation and maintenance. Reverse Osmosis-focused projects tried to solve corrosion problems in PV or wind-driven desalination plant. It was concluded that many demonstration projects failed due to the lack of further financing and support of local communities consequently the most recent projects involve the target groups in most of the stages of the projects implementation.

Furthermore, several models concerning with the design and financial analysis of desalination technologies with RES is also included in the present document.

Below a description of the chapters included in this document is presented:

The *First Chapter* is an introduction on what this desalination with renewables document presents and its main subjects.

The *Second Chapter* presents the state-of-the-art of the possible couplings of desalination with renewables.

Chapter Three describes a set of basic guidelines for the selection and design of a RES-Desalination system.

In *Chapter Four*, the fundamental and more promising desalination renewable energy technologies are described via several applications. The cases refer to photovoltaic and wind energy technologies coupled with Reverse Osmosis desalination process, wind energy and distillation, solar thermal technology coupled with distillation desalination processes as well as hybrid Reverse Osmosis plants.

Chapter five presents several conclusions and recommendation concerning the matching of the two technologies.

Chapter 6 presents a brief overview of desalination RES projects co-financed by the European Commission Programmes, and non-EC Programmes.

Chapter 7 presents the simulation software packages that have been developed in the field of desalination RES.

In the *Appendix* a database of the most known Desalination RES installation is provided.

1. INTRODUCTION

The need of water is rising in many parts of the world including the Mediterranean rim, due to domestic, agricultural, industrial as well as tourist pressures. Moreover all around the world there is a number of small isolated communities like islands and remote villages without access to electricity grid and potable water. New water supplies will increasingly be required and desalination of seawater and brackish water provides an attractive solution.

The anxiety for providing communities with adequate water supplies coupled with environmental concerns regarding the burning of hydrocarbons as well as the lack of electricity in remote areas has stimulated the interest in developing renewable energy powered desalination systems.

The interface between the renewable energy system and the desalination system is where the energy generated by the RE system is made available to the desalination plant. This energy can be in different forms such as thermal energy, electricity or shaft power.

Production of fresh water using desalination technologies driven by Renewable Energy Sources (RES) is thought to be viable solution to the water scarcity at remote areas characterized by lack of potable water and lack of electricity grid.

Desalination units driven by RES, such as those driven by solar and wind energy, guarantee friendly to the environment, cost effective and energy efficient production of desalinated water in regions with severe water problems, which nevertheless are fortunate to have renewable energy resources.

There are a number of possible combinations of desalination processes with different RE sources as it is shown in Figure 1 [CRES, 1998]. Many of these possible combinations may not be viable under certain circumstances, but they are included in the researchers assessment.

Renewable Energy driven Desalination technologies fall into two categories. The first category includes distillation desalination technologies driven by heat produced by RES, while the second includes membrane and distillation desalination technologies driven by electricity or mechanical energy produced by RES.

Numerous desalination RES plants have been installed, most of them for demonstration projects and were consequently of small capacity. Most of the applications referred to the combination of photovoltaics with reverse osmosis technology.

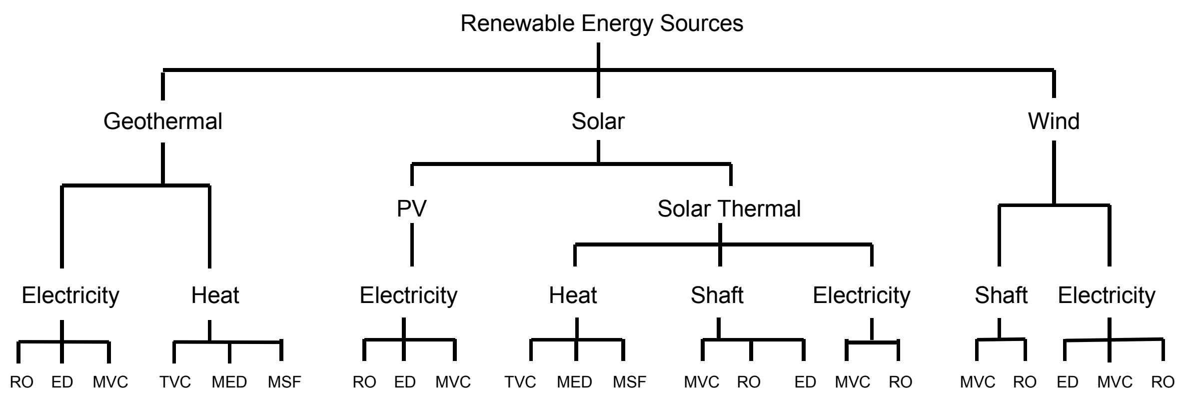


Fig 1. RES Desalination combinations

PV is particularly good for small applications while wind energy is more attractive in larger systems or in small sizes in combination with an alternative source, such as PVs. The sizes of the installed desalination RES plants in average are small since most of them are installed for research and demonstration.

The matching of the desalination process to a RE source is not very simple mainly because desalination process is best suited to continuous operation. The majority of the renewable energy sources is distinctly non-continuous and is in fact intermittent often on a diurnal basis. Unpredictable and non-steady power input, force the desalination unit to operate in non-optimal conditions and this may cause operational problems [R. Morris, 1999].

Each desalination method has its problems regarding the intermittent operation, for instance in reverse osmosis the variable operation has to cope with the sensitivity of the membranes while in thermal processes the variable operation may cause fouling and scaling problems [64]. Thus, in small autonomous systems, small energy systems such as batteries are used. However, research has been done by ITC, Spain; by CREST in UK, and by other Institutes and Universities, on the performance of desalination plants with RES under variable power conditions.

Researchers are still in the process of optimizing the combinations of the two technologies. The success will be achieved with the development of reliable, market available systems, which will have the capability to provide sufficient quality and quantity of water at a reasonable cost.

The present work concerns with small autonomous systems approximately up to 50m^3/day product water capacity and mainly focused on the three most applicable technologies combination. An overview of desalination technologies driven by RES is presented, focusing on the most promising combinations.

Technically mature technologies reviewed are: *solar thermal energy and distillation desalination process* which include solar collectors coupled with Multiple Effect Distillation (MED) desalination process; *photovoltaics and membrane desalination processes*: photovoltaics (PV) coupling with Reverse Osmosis (RO); *wind energy and membrane desalination process*: wind energy conversion coupling with RO process; *as well as wind energy and distillation process; wind energy and Mechanical Vapor Compression.*

Typical combinations of renewable energies and desalination plants are shown. Important factors, which have to be considered in the selection process, are discussed.

2. DESALINATION RES COUPLING-State of the Art

Over the last two decades in particular, numerous desalination systems utilizing renewable energy have been constructed. Most of these plants have been installed as research or demonstration projects and were consequently of small capacity. Several of these plants do not exist most likely the majority are pilot units and after the end of the project there is no interest or budget to continue their operation. The "post-project" period in an economical point of view is a very important issue and should be considered at the beginning of a demonstration or a real plant installation. However, the lessons learned have hopefully been passed on and are reflected in the plants currently being built and tested [E. Tzen, R. Morris, 2003]

Figure 2 presents the installations of the several desalination processes in conjunction with renewables, regarding small-scale systems up to 50 m^3/day. In this figure, a percentage of 32% for PV-RO, a 19% for Wind-RO, a 6% for PV-ED, a 6% also for Hybrid-RO, a 10% for Solar MSF and a 16% for Solar MED as well as a 7% for other technologies combinations, is shown. As it is obvious from the figure, the most popular combination is PV with Reverse Osmosis followed by wind.

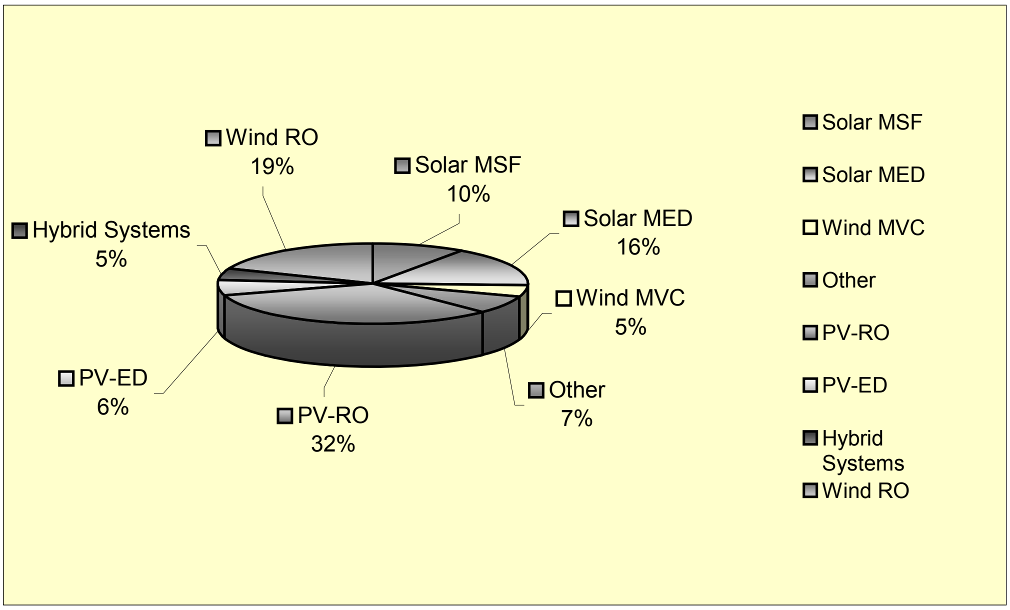


Fig 2. Desalination processes used in conjunction with RES

Figure 3 presents the progress of small-scale RES desalination installations within the years. The figure shows that between the years 1988 to 2003 just 2 peaks regarding the number of installations were considered.

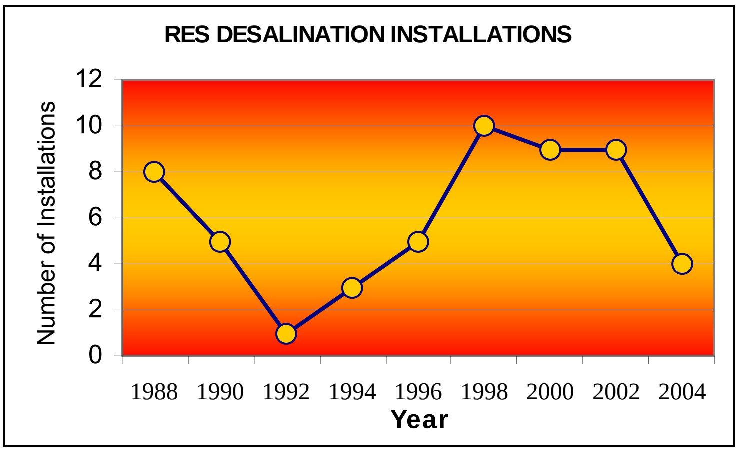


Figure 3 RES desalination installations progress

Figure 4 provides the RE sources for desalination. From this figure it is shown that the most widely used RES technology for desalination in small-scale systems, is PV followed by solar thermal energy.

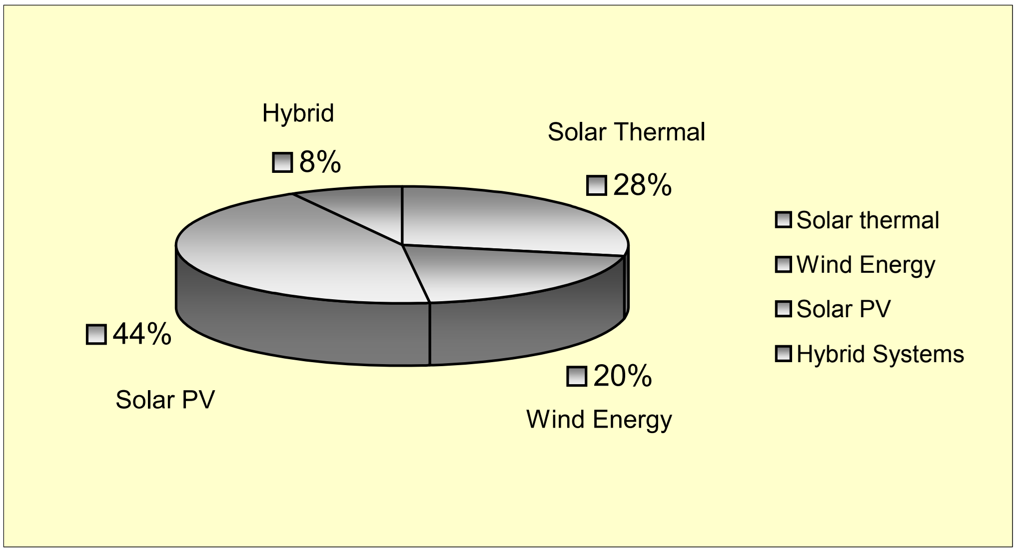


Fig 4 Energy Sources for Desalination

Several examples of these combinations do exist around the world.

Solar Thermal distillation plants include a field of solar collectors, where a thermal fluid is heated. This hot fluid, by means of a heat exchanger, is used to warm up the feed water circulating through the distillation plant. The collectors must be able to heat the thermal fluid up to medium temperatures so that after appropriate heat transfer, the water fed to the evaporator reaches temperatures between 70 °C and 120 °C.

The most known solar thermal distillation combination is solar Multistage Flash (MSF) and solar Multi-Effect (ME) evaporation. From the energy point of view, the main supply to the desalination plant is a large thermal input. Like all thermal processes, distillation demands a high-energy input (due to the energy required for change of phase). Besides, some auxiliary electricity is also required for pumping (electricity could be produced via photovoltaics).

On the other hand, the solar thermal systems are so much dependent on the radiation (day/night) that some heat storage is always required. The accumulator may thus become the main subsystem of the plant and the adopted control strategies become of particular importance.

For MSF evaporators, the performance ratio increases with temperature, so that high temperatures (up to 120°C) are preferred. This in turn increases the risks of suffering from scaling and corrosion. MED evaporators operate nowadays at lower temperatures (around 70 °C) and those hazards are reduced.

Finally, the control of such evaporators must be very accurate, and particularly the flash equilibration in MSF. The system is unstable in small sizes. This leads to the use of medium and large size evaporators (thousands of m^3/day capacity) which do no quite fit with the sizes and capacities usually applied with renewable energies, unless a huge solar field could be built, which in turn implies large ground surfaces. Therefore, the combination solar thermal - distillation seems best suited for medium and high production capacities. However research has be done also in small capacities. An example is the MSF plant installed in 1987 in El Paso, Texas. The combination was somewhat unusual involving a 3,355 m^2 solar pond and a cogeneration system, producing electricity in a Rankine cycle and water in a 24 stage MSF evaporator capable to produce 19 m^3/d.

More reference cases can be found at S. Luis de la Paz (Mexico) where a double solar field (194 m^2 flat collectors plus 160 m^2 concentrating) provides heat for a 10 m^3/d MSF unit, with 10 stages. The plant was commissioned in 1980. One more example is found in Lampedusa island in Italy. The plant was commissioned in 1983. The MSF plant had a capacity of 7.2 m^3/day driven by 408 m^2 solar collectors. Also, another solar MSF system has been installed in Safat, Kuwait in 1981. The MSF plant had a capacity of 10 m^3/day driven by 220 m^2 solar collectors.

Concerning solar MED applications in 1981 a solar MED plant of 10 m^3/day was installed in Takashima island in Japan, and in the same year a 2 m^3/day solar MED plant start its operation at the Black Sea, Bulgaria. Another solar MED example is located at the Plataforma Solar de Almeria (Spain), and is described in Chapter 4.

Furthermore, solar energy could be directly converted into electricity by the photovoltaic conversion. The main advantages of the coupling of PVs with desalination units are the ability to develop small size desalination plants, the limited maintenance cost regarding PVs, as well as the easy transportation and installation.

Reverse Osmosis usually uses alternating current (AC) for the pumps, which means that DC/AC inverters have to be used.

Energy storage is again a matter of concern, and batteries are used for PV output power smoothing or for sustaining system operation when no sufficient solar energy is available. The main disadvantage of this coupling is the high cost of PVs.

The typical PV-RO applications are of stand-alone type, and there exist some interesting examples. A case is located at El Hamrawein, edge of Red Sea, since 1986. The PV array is rated at 19.84 kWp, delivering voltage at 104 V for the pumps as main consumption, plus a secondary array rated 0.64 kWp at 24 V for instruments and control. The battery storage unit has a capacity of 208 kWh and is designed for 3-days of autonomy. The RO plant has a capacity of 10 m^3/h, operating at a pressure of 13 bar. The feed water is brackish water having a salinity of 4,400 mg/l TDS. The unit energy consumption is 0.89kWh/m^3. Other more recently applications are presented in Table 2.

Table 2 RES-RO Existing applications

Plant Location	Year of Commission	Water Type	Capacity	RES installed power
Univ. of Almeria, Spain	1990	Brackish	2.5 m^3/h	23.5 kWp PV
Lipari island, Italy	1991	Seawater	2 m^3/h	63 kWp PV
Sicily, Italy	1993	Seawater	-	9.8kWp PV, 30 kW diesel

Punta Jandia, Fuerteventura island	1995	Seawater	56 m^3/d	225 kW W/G, diesel generator
St. Lucie Inlet Park,Florida, USA	1995	Seawater	2×0.3 m^3/d	2.7 kWp PV, diesel
Riyadh, Saudi Arabia	1995	Brackish	0.6 m^3/h	10 kWp PV
Therasia island, Greece	1997	Seawater	0.2 m^3/h	15 kW W/G
Maagan Michel, Israel	1997	Brackish	0.4 m^3/h	3.5 kWp PV, 0.6 kW W/G, 3 kW diesel
Pozo Izquierdo, Gran Canaria	1998	Seawater	15 m^3/d	15 kW W/G
Heelat ar Rakah camp Sultanate of Oman	1999	Brackish	1 m^3/h	3.2 kWp PV
Pozo Izquierdo, Gran Canaria	2000	Seawater	0.8-3 m^3/d	4.8 kWp PV
INETI, Portugal	2000	Brackish	0.1-0.5 m^3/d	50-100 Wp PV
Lavrio, Attiki, Greece	2001	Seawater	130 m^3/h	4 kWp PV, 0.9 kW W/G

Furthermore, a 1.54 kWp PV powered seawater RO unit without batteries has been developed and tested by the Centre for Renewable Energy Systems Technology, CREST, U.K. The system operates at variable flow, enabling it to make efficient use of the naturally varying solar resource, without need of batteries. The same RO unit has also coupled and tested with a wind turbine without any battery bank. Both systems are presented analytically in Chapter 4.

As regards Wind energy and Reverse Osmosis combinations, a number of units have been designed and tested. As early as 1982, a small system was set at Ile du Planier, (France). A turbine providing 4 kW, coupled to a 0.5 m^3/h RO desalination unit. The system was designed to operate via either a direct coupling or batteries.

Another case where wind energy and reverse osmosis combined is that of Island of Drenec in France, in 1990. The wind turbine in this case was rated at 10 kW and used to drive seawater RO unit.

More recently some R&D projects have been carried out, such as the wind desalination system built at Drepanon on a cement plant, near Patras, Greece. The project, including a 35 kW wind turbine, was initiated in 1992, and completed in 1995. The project called for full design and construction of the wind generator turbine (blades, etc.), plus installing two RO units with a production capacity of 5 m^3/d and 22 m^3/d. Unfortunately, since 1995, operational results have been poor due to the low wind regime.

A very interesting experience has been carried out at a test facility in Lastours, France, where a 5 kW wind turbine provides energy to a number of batteries (1,500 Ah, 24 V). The energy is supplied via an inverter to an RO unit with 1.8 kW nominal power.

Another Wind-RO unit was installed in Therasia island in Greece in 1997. The seawater RO unit has a capacity of 0.2 m^3/day and the nominal power of the wind turbine is of 15 kW. The system is presented analytically in Chapter 4.

Also, a lot of work has been done by ITC and University of Las Palmas in Canaria Islands, Spain. A Wind RO system without energy storage have been developed and tested within JOULE Programme, (OPRODES-JOR-CT98-0274) in 2001 by the Univ. of Las Palmas. The RO unit has a capacity of 43-113 m^3//hour and the wind generator has a nominal power of 30 kW. Furthermore, in 1996, ITC developed 2 RO units of 10 and 15 m^3/day driven by a 15 Wind turbine respectively with mechanical and hydraulic coupling.

Regarding Wind-MVC coupling only a few applications are known. A pilot plant was installed at the German island of Borkum in 1991 where a wind turbine with a nominal power of 45 kW was coupled to a Mechanical Vapor Compression (MVC) evaporator in a system capable of desalinating seawater and producing up to 48 m^3/day of fresh water. The compressor required 36 kW power, and the system was controlled by varying the compressor speed, and assisted by a resistance heating when the compressor run at its speed limit.

The experience was followed by another larger plant at the island of Rügen in 1995. The wind turbine was now rated at 300 kW and the MVC unit at a maximum 12.5 m/h. Again a resistance heating is used for auxiliary power when required. The energy consumption ranges between 9 and 20 kWh/m^3.

The main problem of these systems is the high-energy consumption of the MVC unit, which usually is in the order of 15 kWh/m^3.

Another MVC-Wind energy system under operation has been installed by ITC in Gran Canaria, Spain within SDAWES project. The system has a water production of 50 m^3/day. The system is described analytically in Chapter 4.

Although, there is an experience on the RES Desalination and successfully applications exist, there is much room for improvement the combination of both technologies by a technical and economical point of view. Therefore it is imperative to carefully analyze the numerous options and to take the right decisions on a comparative basis and according to the characteristics of each specific case. This work constitutes an effort towards this objective.

3. GENERAL GUIDELINES FOR TECHNOLOGIES SELECTION

Among the several possible combinations of desalination and renewable energy technologies, some seem to be more promising in terms of economic and technological feasibility than others. However, their applicability strongly depends on the local availability of renewable energy resources and the quality of water to be desalinated. In addition to that, some combinations are suited for large size plants, whereas some others are modular and small sizes are achievable (see Table 3).

RE resources are site specific to a large degree. The identification and evaluation of the renewable energy resources in the area, completes the basic steps to be performed towards the design of a RES driven desalination system. Following this, the true cost of water in the locality should be established. Solar energy is considered, as a rather stable source while wind energy could be available also during the night. Additionally, a high correlation between solar energy and water demand (water needs increased in summer where solar potential is increased) makes the use of solar energy more attractive. The selection of the appropriate RES desalination technology depends on a number of factors. These include:

- plant size,
- feed water salinity,
- remoteness,
- availability of grid electricity,
- technical infrastructure and the
- type and potential of the local renewable energy resource.

Before any process selection can start, a number of basic parameters should be investigated. The first is the evaluation of the overall water resources. This should be done both in terms of quality and quantity (for brackish water resource). Should brackish water be available then this may be more attractive as the salinity is normally much lower, and hence the desalination of the brackish water should be the more attractive option. In inland sites, brackish water may be the only option. On a coastal site seawater is normally available. Also the plant capacity is an important factor. Desalination plants using membrane technologies are available in a wide range of capacities. Concerning distillation desalination processes, large sizes are more attractive due to the big requirements of energy in small sizes.

Table 3 Recommended RES-Desalination combinations

Water output	Water input	System Size	Small (1-50 m3/d)	Medium (50-250 m3/d)	Large (>250 m3/d)
Potable	Brackish Water	Conventional Energy + RO, ED	*	*	*
Distillate		Solar Distillation	*		
Potable		PV - RO	*		
		PV - ED	*		
		Wind - RO	*	*	
		Wind - ED	*	*	
Potable / Distillate	Sea Water	Conventional Energy + RO, ED, MSF, VC, MED	*	*	*
		Solar Distillation	*		
Potable		PV - RO	*		
		PV - ED	*		
		Wind - RO	*	*	
		Wind - ED	*	*	
		Wind - VC		*	*
Distillate		Solar Thermal - MED		*	*
		Solar Thermal - MSF			*
		Geothermal - MED		*	*
		Geothermal - MSF			*

(CRES, 1998)

Additionally, desalination systems have traditionally been designed to operate with a constant power input. Unpredictable and non-steady power input, force the desalination plant to operate in non-optimal conditions and may cause operational problems.

Energy cost is one of the most important elements in determining water costs where the water is produced from desalination plants. Some energy consumption data for traditional desalination plants using different desalination techniques are given below. These data refer to conventional operated plants in operation at their nominal power consumption and production [E. Tzen, R. Morris, 2003].

- for RO systems: 5-10 kWh/m^3 without energy recovery (large production plants), 2.5-4 kWh/m^3 with energy recovery
- for ED systems: 1.22 kWh/m^3 (for feed water salinity of 3000 ppm and product salinity of 500 ppm TDS). This consumption is increased by the operation time: increment of 50% after 2.5 operation years
- for VC systems: 8.5 - 16 kWh/m^3, depending on size.

Among the technologies selection another parameter is the type of connection of the two technologies. A renewable desalination plant can be designed to operate coupled to the grid and off-grid (stand alone or autonomous system). Autonomous systems mainly are developed in remote areas where no electricity grid is available. Due to the dispersed population that characterizes the South Mediterranean and Gulf areas, relatively small systems are used to cover the potable water needs in remote villages. The main desirable features for such systems are the low cost, low maintenance requirements, simple operation, as well as the high reliability.

Furthermore, any candidate option resulting from the previous parameters should be further screened through constraints such as site characteristics (accessibility, land formation, etc), availability of local support and financial requirements.

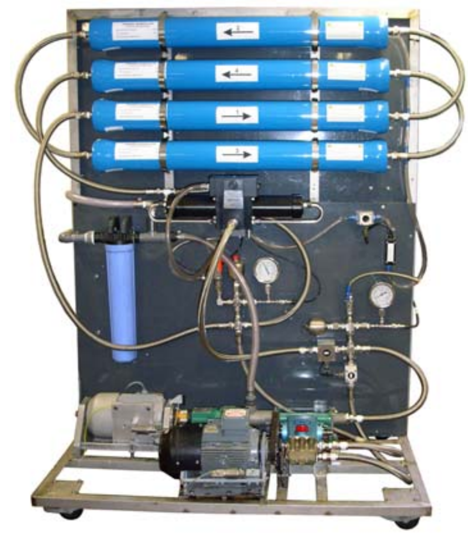
4. OVERVIEW OF DESALINATION RES APPLICATIONS

4.1 WIND ENERGY DRIVEN REVERSE OSMOSIS TECHNOLOGY

4.1.1 Autonomous Wind RO system without batteries, CREST, Loughborough Univ., UK

a. Introduction

A small-scale wind-powered seawater-RO system without batteries was demonstrated in 2003 at CREST, Loughborough University, UK. The system operated at variable flow and variable pressure in accordance with the variable power available in the wind. The system pressure ranged between 38 to 51 bar during this test. [M. Miranda, 2003].



Pic. 1 View of the RO unit of CREST pilot plant

b. System Description

Energy recovery is provided by a Clark pump from Spectra Watermakers Inc., and the use of a variable recovery ratio extends the energy efficiency over a very wide operational range, allowing the system to make efficient use of the available wind power without need of batteries.

The feed water used for testing was straight NaCl solution at around 32,800 mg/L, to emulate the osmotic pressure of seawater. Its temperature was held at 25°C and the system has only cartridge filters for pre-treatment. The concentration of the product water varied between 470 and 800 ppm.

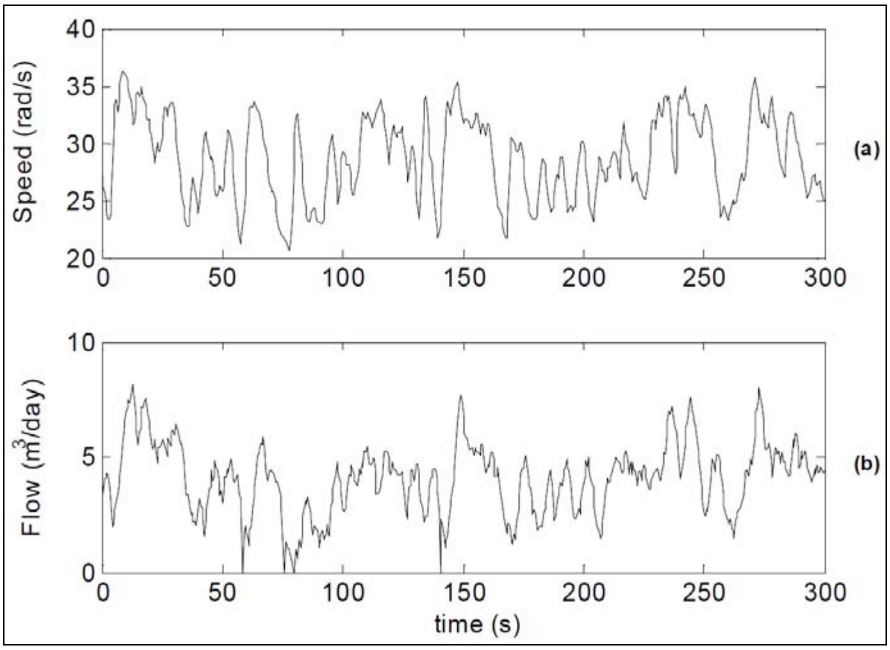


Fig 5 a) Wind turbine rotational speed, b) Product flow rate

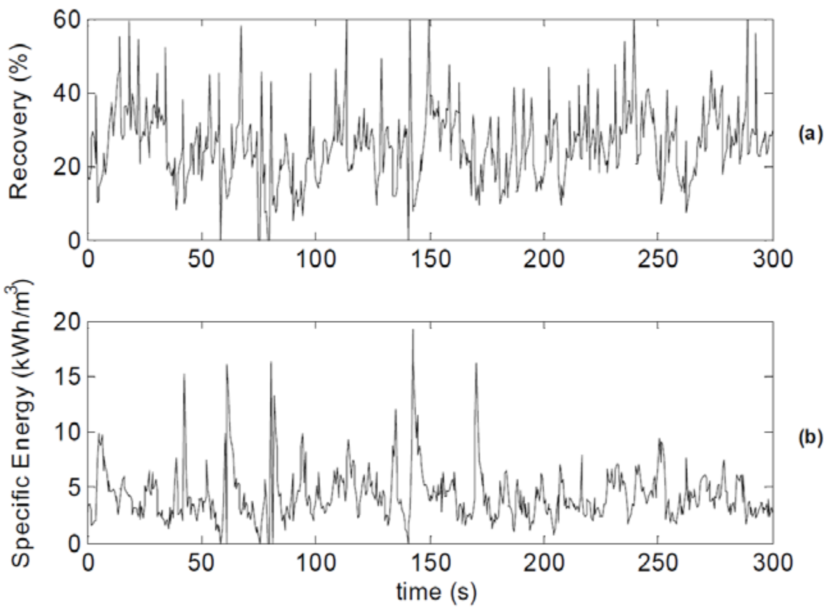


Fig 6 a) Water recovery ratio b) Specific energy

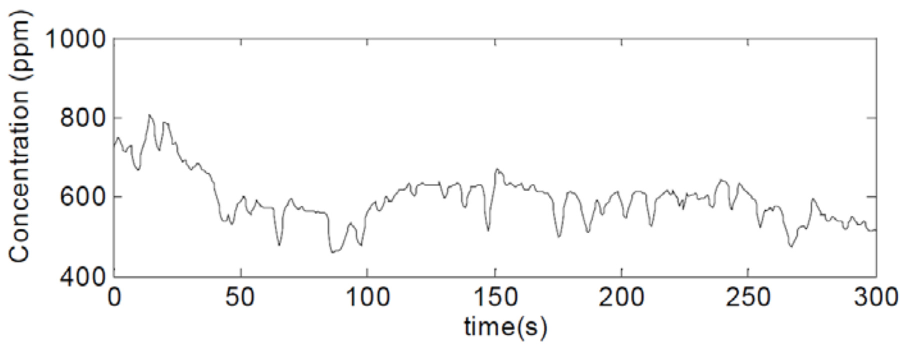


Fig 7 Product concentration

The medium-pressure pump is a Moineau (progressing cavity) pump. It sucks seawater from a beach well or a tank in the case of the demonstration unit. A submersible version of the same pump is available, at extra cost, and could readily be substituted. The Clark pump raises its medium-pressure feed water to high-pressure by virtue of the energy it recovers from the brine. The flow ratio of the Clark pump is fixed by design, which normally gives a 10% water recovery at the membranes. However, the high-pressure plunger pump injects an additional feed, which increases the water recovery to any desired value. The two pumps are driven independently by two induction motors, rated at 1.5 kW and 3 kW respectively but operated at well below these values. The speeds of the two pumps are carefully controlled through the inverters (variable-frequency drives) in order to maximize the overall system efficiency. The unit includes four 4-inch by 40-inch pressure vessels in series, each housing a Koch high-flow seawater membrane type: TFC1820HF. No post-treatment is included and, in the test rig, the product water is simply returned to the feed tank.

The wind turbine is manufactured by Proven Energy, Scotland and is rated at 2.5kW. It is gearless with and uses a variable-speed permanent-magnet generator. It has 3 blades, a rotor diameter of 3.5 m and a rated rotor speed of 300 rpm. It is mounted on a 13m un-guyed tapered steel tower.

The AC from the generator is rectified and limited (voltage regulator) then fed directly to the inverters. No batteries or other energy storage or backup are installed.

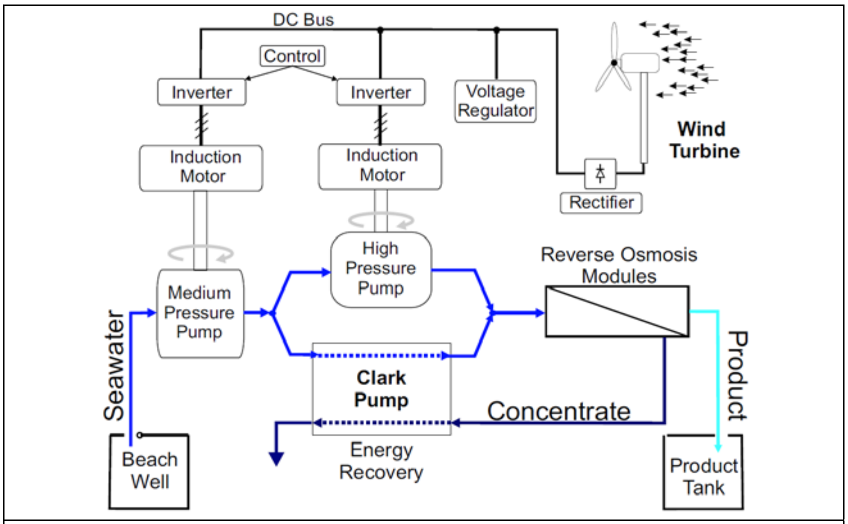


Fig 8 Block diagram of the Wind RO pilot unit at CREST

c. Experiences and Lessons Learnt

Direct coupling of rapidly varying wind energy to a small-scale seawater reverse osmosis system was demonstrated and good energy efficiency achieved. However, the testing was brief and thus the long-term reliability of the system and the effect of the variable and intermittent operation on the lifetime of the membranes remain unknown.

d. Cost Data

The total capital cost of the system, including the wind turbine, RO unit and installation was estimated at £33000 with running costs of £1500/year. The predicted product flow and resulting water costs are very dependent on wind regime at the site of installation.

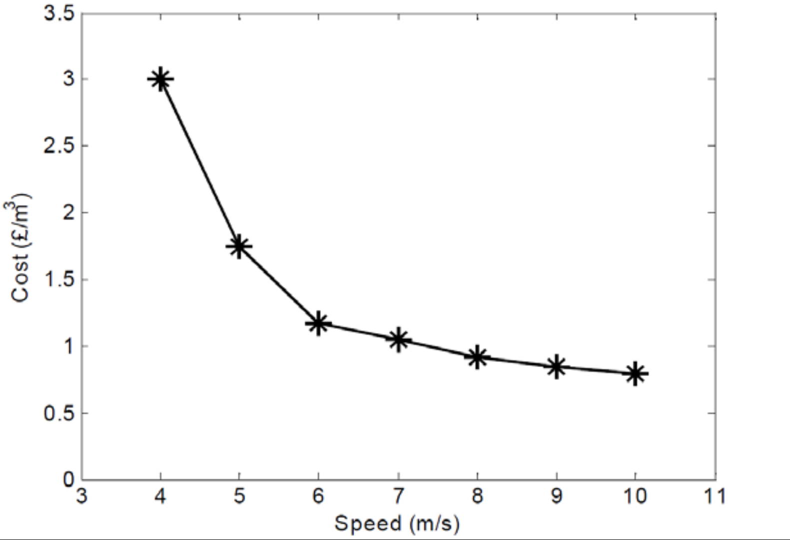


Fig 9 Estimated water cost versus site annual mean wind speed

The project was supported by the UK Department of Trade and Industry, CNPq Department of Science and Technology Brazil, Dulas Ltd, Proven Energy Ltd, and CREST Loughborough University.

4.1.2 Autonomous Wind RO plant in Therasia island, Greece

a. Introduction

The purpose of the project in Therasia island in Greece, was to demonstrate the feasibility of developing an off grid autonomous wind powered water desalination unit for remote areas. The project addresses the installation of an autonomous wind powered small desalination system in Therasia, a small island located in the Aegean Sea close to Santorini. The water desalination system utilizes a reverse osmosis technology with a nominal water production capacity of 5 m^3/day. A single VERGNET wind turbine GEV10/15 was driven the RO unit. Local technicians were trained to manage the pilot installation [CRES, 1998].

The unit was commissioned in summer 1997 in the framework of the APAS Program funded by the European Commission DG- XII. The project, entitled “Wind Powered Desalination for Small Coastal and Island Communities in Mediterranean Regions” (contract no RENA-CT94-0055). The prime contractor of this project was Vergnet SA (France) working together with Commissariat de l’Energie Atomique (France), Centro Marino Internazionale (Italy), Loughborough University (UK), Heliodynami Ltd. (Greece) and Societe Lorientaise de Construction Electromecanique (France).

The permanent population of the island is around 170 inhabitants. This population increases to approximately 700 during summer. The water scarcity problems at the island are severe. Water needs are covered by rainwater collection in private and public tanks as well as by water transportation from Santorini at a cost of around 10 €/m^3. Since there is no water distribution network in the island, water is transported by the inhabitants. There exists only elementary piping system supplying water to school and to the local clinic from a public tank. More analytically the island had the following requirements:

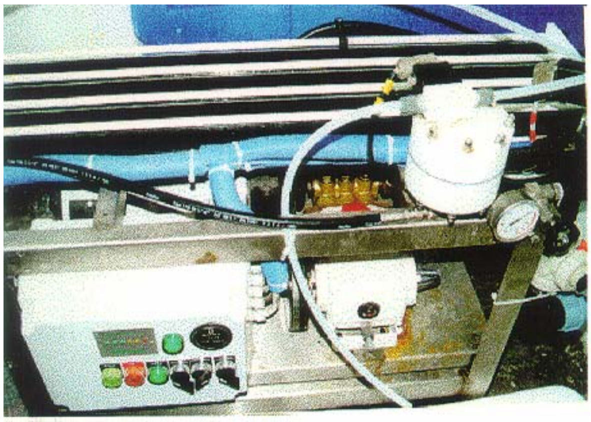
- A define need for the supply of drinking water in the range of 1 to 20 m^3/day

- No available supply of water on site other than water being shipped over long distances at high cost
- A sufficiently high wind resource for a viable exploitation of wind energy to power (average annual wind speed 7m.sec at a hub height of 24 m).

b. System Description

The Therasia Wind RO system is a small autonomous system with a product water capacity of around 200 l/h. The reverse osmosis unit is driven by 15 kW wind turbine. Furthermore, the power supply system consists of a battery storage system battery charger / rectifier, and an inverter [A. Fabre, 2003]. The desalinator is of one stage RO unit operating with seawater. Aegean sea water concentration is around 42,000 ppm TDS. The seawater enters the RO unit through a rock hole of around 18 meters depth. This seawater intake system makes the pumping of seawater simpler and also acts as a natural pre-filter, reducing the pre-treatment requirements. A submerged booster pump of 0.37 kW (220 VAC, 1 phase) drives the seawater from the well to the RO unit. The seawater is of good quality and the pre-treatment required is filtration with two cartridge filters of 50μ and 5μ, respectively. There is no addition of chemicals. The system operates at a recovery ratio of 21%-23%. The motorization of the RO booster pump and the building electrification are on the AC current side, while the high-pressure pump of the RO unit as well as the control system is on the DC current side. By using a direct current motor, the losses due to the inverter are alleviated. This increases maintenance costs, for the replacement of the brushes of the direct current motor every 6 months. This is acceptable when the heavy cleaning requirements of the RO unit and membranes are taken into consideration. By using 120 V instead of 24 V the transformation losses from the wind turbine output are reduced.

The high-pressure pump is a positive displacement one of 2.8 kW, 2170 rpm, and its operating pressure is around 60 bar.



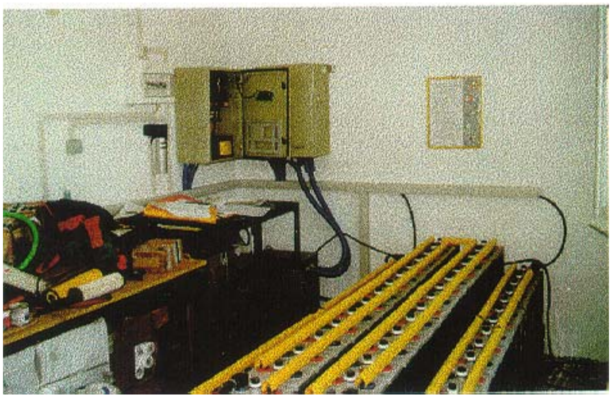
Pic. 2 The RO unit in Therasia island

Three spiral wound membranes in three pressure vessels produce around 200 l/h fresh water with a concentration less than 500 ppm TDS. The energy requirements of the RO unit are of the order of 16 kWh/m^3 of produced water. The post-treatment system consists only of filtration (coal filter), (see Table 4).

Table 4 Technical Characteristics of the RO Unit

Product water capacity	200 l/h (0.2 m^3/h)
Feed water type	sea water (42,000 ppm TDS)
Product water concentration	< 500 ppm
Recovery Ratio	21-23 %
Nominal Pressure	55 - 60 bar
Temperature of operation	18 ^{o} C
Membranes type	spiral wound
No of membranes	3
No of pressure vessels	3
Module arrangement	single array
Energy Consumption	16 kWh/m^3
Installed Power	3.17 kW
Hours of operation	depends on energy availability
Operation	Automatic

The power supply system consists of a 15 kW wind turbine, feeding into a short-term battery storage used as a buffer. The control system allows operation of the RO unit only when the wind is sufficient, meaning that battery storage acts more as a smoothing component rather than as energy storage one.



Pic. 3 The battery storage system of the Wind-RO system in Therasia

According to the developers, the main functions of the battery storage are:

- to ensure that the start-up and shut down procedures of the RO unit are performed appropriately
- to maintain an acceptable frequency (i.e. low) of start up and shut down sequences of the RO unit.

Moreover, to reduce the energy loss in batteries, the RO unit is not run solely from the batteries i.e. when there is not sufficient power available from the wind turbine (except 30 minutes daily run sequences) to avoid membrane clogging. The running conditions to ensure the good operation of the system were not as demanding as foreseen - the battery storage strictly needed is only three hours (due to the fact that RO unit has been determined to accept operation in a relatively high cycling mode). This means that the battery storage has to be designed taking in account that the RO unit has to run 30 minutes per day whether there is wind or not. The batteries used have a storage capacity of 440 Ah (C10), 60 elements of 2 V (total 120V) connected in series. A single-phase inverter is used to convert the dc current to ac for the booster pump and secondary electricity needs. An initial option of using 2 kWp of photovoltaics was abandoned, mainly due to the low power output relative to cost and to the output of the 15 kW wind turbine made its cost prohibitive for such a system, (see Table 5).

Table 5 Technical Characteristics of the Power Supply System

RES Type	Wind Energy/Turbine
Nominal / Installed Power	15 kW
Ave. wind speed	8 m/s

System type (stand alone/grid)	Stand-alone
RE system Characteristics	
Wind Turbine	VERGNET GEV 10.15
Rotor diameter	10 m
Blades	2
Rated power	15 kW @ 10 m/s
Output voltage	380 V three-phased
Tower	tubular mast with guy wires
Height	24 m
Battery bank	
Number of units	60 elements of 2V (120 Vdc)
Capacity	440 Ah
Charge	C10
Battery Charger	AINELEC/120V/15 kW

c. Experiences and Lessons Learnt

Several problems have been encountered during the operation of the unit. These are as follows:

- presence of debris on the surface of the sea water in the bore hole, the hole is sealed and the immersed pump is contained within a stainless steel grate
- sea water and produced water had a bad smell, a charcoal filter was added and removed the nuisance
- the variation of membrane pressure with battery voltage was a problem:
    - 55 bar at 118 V
    - 65 bar at 124 V

A high-pressure control may be necessary if this problem becomes important.

- the wind turbine is over powerful, but supplies plenty of energy at low wind speeds
- air purge from the filters needs to be facilitated

The use of a 15 kW wind turbine to power a seawater desalination unit has been made possible, combining good overall system efficiency and minimum electricity storage. The system works satisfactorily, although it can be improved. From the short experience of the Therasia plant the following remarks can be made:

- the use of a battery system is necessary for an autonomous unit

- in order to avoid the reduction of membrane efficiency due to clogging, the reverse osmosis unit needs to be run at least 30 minutes per day. This means that the system has to be sized with sufficient battery storage to account for low wind periods
- to avoid losses due to voltage transformation, the battery voltage was chosen high (120 V)
- the losses due to the inverter have been avoided as this has been removed; since DC motor for the high-pressure pump is used.
- High energy consumption of the RO unit in small scale systems (20kWh/m^3)

Furthermore, the system manufacturer concluded that the development of a wind desalination system should be concentrated on small to medium scale systems. Larger desalination systems are connected to local electricity grids, in which case development work on the interface between wind energy and desalination techniques is no longer relevant.

The experience that system's manufacturer obtained from this project has shown that emphasis for further development must be on:

- Reliability and acceptable maintenance requirements for remote sites
- total system cost (function of overall water output, specific energy - kWh/m^3 of fresh water) and
- appropriate wind power to desalination interfaces.

At present time the unit is out of operation even if it is an important water resource for the inhabitants. Therasia island is now belongs to the Municipality of Oia in Santorini. The local Authorities of Oia is planning to replace the unit.

d. Cost Data

No data is available.

4.1.3 Wind Turbine electrical coupled to a RO plant, AEROGEDESA® Project, Gran Canaria

a. Introduction

The plant has been installed in Pozo Izquierdo, Gran Canaria Island. The plant commissioned in 2003, started its operation at the end of 2004 and is still in operation. The project has been financed by the Government of the Canary Islands (FEDER) and has been carried out by Instituto Tecnologico de Canarias, ITC. The scope of the project was the electrical coupling of a commercial wind turbine to a RO unit for seawater desalination, operating under a constant regime and managing the storage and available wind energy use through minimum battery bank. The battery bank mainly guarantees that the washing system is filled with fresh water, providing a longer working life of the membranes. The whole system is fully automatic. The wind speed at the area is ranged from 4.5 to 13 m/s.

b. System Description

The system consists of a 15 kW Wind turbine (by VERGNET, France), a 190 Ah lead acid battery bank, an inverter and a 0.80 m^3/hr Reverse Osmosis unit (by Tecnologia Canaria del Aqua and ITC). The RO unit consists of 2 pressure vessels in series with 2 membranes each (SW30-4040). The salinity of the feed water is 35.500 ppm TDS. The produced water has a salinity of less than 500 ppm TDS. The nominal pressure of operation of the RO unit is 55 bar and the recovery ratio is of 37%. The high-pressure pump, which is the main load of the RO unit, is 7.5 kW. The pump motor is a three-phase motor. The energy consumed by the RO unit is 7 kWh/m^3. The pretreatment system consists only of filtration (sand filter and cartridge filter). No chemical addition. A fresh water storage tank of 250m^3 is also available.

The hours of RO‘s operation depend on the availability of the wind, which are in winter: 15 hr/day in average and in summer: 20 hr/day in average.

The power supply system consists of a wind turbine with a rated power of 15 kW, a three-phase self exciting induction generator for a static condenser battery, a charger and a three-phase sine-wave inverter, both micro-processed. It also has battery storage with autonomy of more than 1 hour.

The RO unit adapted to a frequent start/stop configuration coupled to the system. It is an electric coupling from a commercial wind turbine of 15 kW to RO unit, operating on a constant basis and managing the storage and use of the available wind energy through the battery bank.

The technical characteristics of the power supply system are shown in Table 6.

Table 6. Technical Characteristics of the power supply system

Wind turbine nominal power	VERGNET GEV 10-15/15 kW
Rotor diameter	10 m
Rotor speed	139 rpm
Power regulation	Pitch control
Number of blades	2
Generator type	asynchrronous
Output power	15 kW
Output Voltage	400V / 50 Hz
Start-up wind speed	4 m/sec
Maximal wind speed (tower up)	50 m/sec
Tower	Tubular
Height	20 m
Control System	Charger CB120/15 kW
No of chargers	1
Charger characteristics	CB120/15 kW, 380 Vac/120Vcc, 125 A
Battery capacity (Ah or kWh)	190 Ah
Purpose of use	Autonomy to disconnect the RO unit when the wind speed is under the average wind speed, more than 1 hour autonomy
Type of battery	Lead-acid batteries
Max battery discharge (%)	70%
Battery efficiency (%)	85%
Number of cells	60
Cell voltage (V)	2
Type of connection	Series

Nominal Voltage	120 Vc
Inverter type	Sinus 3 phase 120 V/15 KVA/400Vac-50Hz
No of inverters	1
Inlet voltage (V)	90-160 V_{cc}
Output Voltage (V)	400 V_{ac}
Power supply backup system (diesel, etc)	no

The control and data acquisition systems are made up by a Programmable Logic Controller (PLC), receiving all the signs from the sensors in the plant and making decisions in relation to the start/stop configuration in the installation. It will also monitor the safety devices by using two microprocessors exclusively used to control and manage the available energy in the electric system. Finally, the battery bank guarantees that the washing system is always full with fresh water.

Pic 4 The wind generator

Pic 5 View of the RO unit

c. Experiences and Lessons learnt

- due to system's intermittent operation (some hours per day), scaling problems mainly $CaCO_3$ is considered

-operation behavior under extreme conditions: the operation of the pumps, membranes and several other equipment under non-maintenance processes is examined

The next step is the improvement in the design and the development of a specific know-how about the control and operation of the system.

d. Cost Data

The total estimated cost of the system is shown below:

Equipment	Cost
Wind turbine	67,000 €
RO	40,800 €
Other	15,000 €
Total Unit water cost	3-5 €/m^3

It should be mentioned that always the final unit water cost of such systems depends on several parameters such as the site, the wind potential, the feed water quality, etc.

4.1.4 Wind-diesel system for water and electricity, Fuerteventura island, PUNTA JANDIA Project, CIEMAT, ULPG, ITC

a. Introduction

Puerto de la Cruz, at the southernmost part of the Jandia Peninsula, on the island of Fuerteventura, is a small isolated fishermen village with a total lack of energy resources and water. The village is located 20km away from the residential and tourist resort Morro Jable, where the electrical grid ends. The area holds, according to local by-laws, a small housing development, accommodating up to a maximum of 450 inhabitants in summer, 60 residents, and 500 occasional daily visitors. Additionally, the area has a sufficient wind potential of 8 m/s in average.

In this context, a proposal was made to the VALOREN Programme of European Commission in August 1988 for the installation of a wind diesel system to fully cover the energy and potable water requirements of the village [J.A. Carta, 2003]. The participants in this project were the Municipality of Pajara, the Water Council at Fuerteventura Island, the Secretary for Industry (Canary Islands Regional Government), the University of Las Palmas and IER-CIEMAT (Spanish Ministry of Industry and Energy). The project is focused on the basic elements for living in a community.

The difficulties of a fishermen’s community, without power mains, have turned, by means of this project, into an increase of the living standards through a full-self supply of:

- Drinkable water, through a RO plant powered by wind energy
- Energy self-supply through a wind-diesel system isolated grid
- Improvement of the economic conditions of the fishermen with an ice generation plant and a cold-storage plant to freeze fish. These plants are also powered by a wind diesel system.

Before this project each house had a diesel generator for its own energy consumption. The water was supplied by a truck to the village from a town 30 km away, at a price of 3 €/m^3.

The technological complex is located to one side of the village, by the sea and at the same time sufficiently distant from the inhabited zone as to avoid the sound impact caused by the diesel generators and the wind driven generator itself. The area chosen for the plant and equipment facilities was conceived as an enclosed circular site, architecturally in harmony with its surroundings, and consists of a wind driven generator, and five buildings to house the control equipment, a generating plant consisting of 2 diesel generator sets with flywheels, a desalination plant an a freezer and ice-making plant.

The design specifications, which were drawn up established:

- the need to produce all the required potable water through the use of electrical energy drawn exclusively from a wind energy source
- the need for a maximum reliability of the energy supply, and a minimum use of the diesel generator sets

b. System Description

The system consists of a 225 kW wind energy converter and two 160 KVA diesel engines with flywheel and synchronous generator of 75 kVA each, to produce electricity for fishing conservation, to drive a 25 m^3/day sewage water treatment plant and a 56 m^3/d sea water desalination plant, as well as for public and private lighting, for an average of 300 people. Each one of the two diesel sets is mechanically connected through an electromagnetic clutch to the flywheel. Each flywheel can deliver half of the envisaged peak power demand - 100 kW - during 30 seconds approximately, without frequency decreases below the minimum level allowed (48 Hz).

For the design of the system the following criteria were taken into account:

The energy conversion subsystem was sized according to an agreement with the local population whereby they would be entitled to the standard energy consumption levels, that is, they would be able to use as much energy as any other site in the island, without any constraints.

Concerning the RO plant it was oversized (expected water consumption of around 60 lt/day/person) to a daily product water capacity of 56 m^3/d. Sizing was based on the fact that desalination plant will only work using wind energy, when available and to cover the water needs only for 2 months (July, August) within the year. No fossil fuel from the diesel generators would be spent for desalination. Thus, the RO plant should be of somewhat higher nominal capacity than would be required under a conventional power supply environment. Except of the desalination unit (having an average consumption of 7kWh/m^3) additional loads to the power supply system are the following:

- A freezer plant with a daily storage capacity of 1200 kg with a nominal power of 5 kW and an ice-producing machine of 3 kW nominal power both used by the local fishermen. The average consumption of these loads is 156kWh/day
- A hydro-compressor set consists of two electric pumps and a pressure feed tank with a nominal power of 2 kW, for the delivery of the fresh water from the storage tank to the points of consumption. The average consumption of these loads is 14 kWh/day.

Pic. 6 The RO unit in Fuerteventura

- Public street lights with an average consumption of 44kWh/day and the domestic consumption of the inhabitants of the village of 5000 kWh/month
- Sewage treatment plant with an average consumption of 96 kWh/day in summer and 24kWh/day for the rest months of the year
- Winch to haul boats in from the sea with an average power consumption of 250 kWh/month
- Binary dump loads consisting of resistance blocks from 390 to 50 kW

The control system consists of an industrial PC, the monitor of which permits, via specially developed software, the visualization in real time of the system in operation and the storage of data at an average rate of 300[7]s. Figure 10 shows the block diagram of all the devices controlled by the central control system (CCS). In addition to that, there are local control systems (LCS) in the wind and diesel generators, the hydro-compressor, the sewage plant, the freezer and the desalination plant.

The wind diesel system was designed for operation in the following three modes:

a. operation only of the diesel generator: occurs when the wind-driven generator is out of service, either because of lack of wind or other causes
b. operation of the wind and diesel: occurs during those periods where the wind is not sufficient for the wind-driven generator alone to supply the required active power
c. operation of only wind generator: occurs when sufficient wind is available. This mode is the only in which the desalination plant and the dump loads which stabilize the system are connected.

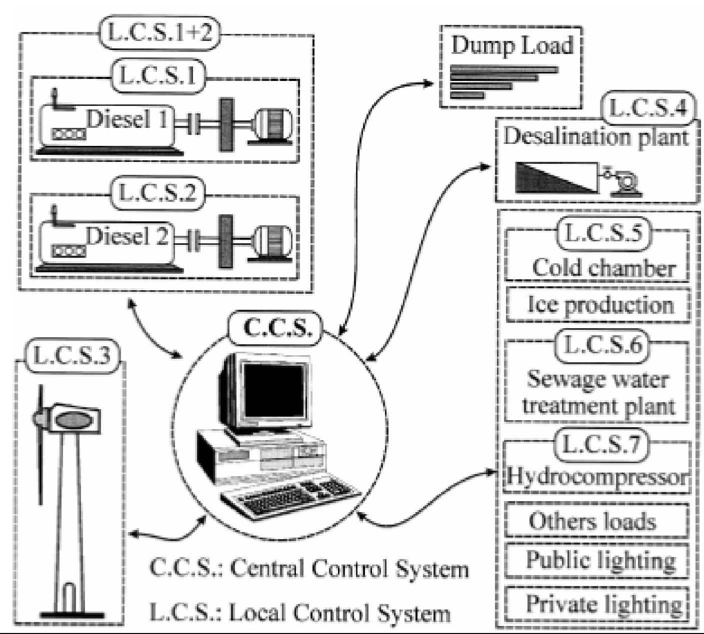


Fig 10 Diagram of the control system operation

Analytical technical data is provided in Table 7.

Table 7 Technical characteristics of the system

RO Unit	
Product water capacity	56 m^3/d
Feed water type	Seawater (in winter:36,000 ppm TDS, in summer:39,000 ppm TDS)
Product water concentration	< 500 ppm
Installed Power	16.5 kW
Water storage tank	2 x500 m^3
Power Supply System	
Nominal / Installed Power	Wind Turbine: 225 kW
Ave. wind speed	8 m/s
Wind Turbine	VESTAS-V27
Rotor diameter	27 m
Rotor speed	43/32 rpm
Power regulation	Pitch
Blades	Three of fiberglass and polyester
Generator	AC asynchronous, double windage of 6 and 8 poles
Output power	225 or 50 kW
Output voltage	400 V
Start-up wind speed	3.5 m/s

Nominal output	13.5 m/s
Cut-out wind speed	25 m/s
Tower	Tubular cone-shaped
Height	30 m
Control system	Made for VESTAS
Diesel engines:	2 engines
Power of each	160 KVA
Connection	Mechanically through an electromagnetic clutch to the flywheel
Flywheel	Each can deliver a half of the envisaged peak power demand -100 kW- during 30 seconds
Frequency minimum level allowed	48 Hz

The three-bladed wind driven generator, with variable pitch and constant velocity, and an induction type electricity generating machine, with double coil winding of six and eight pairs of poles, respectively, enabling the operation of the generator at two different wind speed regimes. Although the initial nominal power of the generator was 225 kW, at the beginning of 2001 this nominal power was restricted to 130 kW acting on the angle of pitch of the blades of the rotor.

c. Experiences and Lessons Learnt

The main observation during system operation, concerned with the mismatch between the power output from the wind generator and the load of the system. The generated energy exceeds the energy demand at the site, and hence a large dump load is required in order to make up with the excess power.

The need to limit the nominal power of the wind-driven generator was due to the fact that the actual energy demand turned out to be lower than had been estimated and far less than the generator is capable of supplying at nominal power (225 kW). As a result, when the wind speeds exceeded the 10 m/s at the height of the rotor shaft, the generator would shut down due to over-frequency. Though it would have been advantageous to be able to set variable nominal power limits lower than 130 kW as also the manufacturer is advised.

The system began its operation in May 1995. However, given the fact that the growth forecasts for the community as estimated by the Local Council of Pajara turned out to be inaccurate and given the incorrect technical and economic management of the

plant and equipment facilities, the actual energy and water consumption differed from the estimated figures with a consequent underutilization of the system.
In such cases, a careful sizing of equipment is required, not only to reduce the investment costs, but also to properly tune the operation.

Pic. 7 The General View of the Wind diesel desalination plant in Fuerteventura

Furthermore, an important issue addressed during the operation of the system, was the involvement of a local operator. Apart from the involvement of the various bodies acting in the joint effort, it was vital that an operator from the village itself was engaged in the operational phase of the project.
The restricting of the nominal power of the wind-driven generator from 225 to 130 kW, the changes to the dump load management strategy, which no longer operate only in transitional dynamic period but as a steady condition system balance, and the implementation of a suitable technical management strategy of the plant and equipment have led to the wind-diesel system making a substantial improvement to the quality of life of the inhabitants of the community.
They no longer suffer the frequent and prolonged interruptions to the system which where due to an inadequate maintenance service and the fact that the wind driven generator stopped operating when the wind speed rose above 10m/s at the height of the rotor shaft.
Furthermore, in the success of this project the fuel savings as well as the reduction of CO_2 emissions should be considered. Figure 11 shows the monthly figures for

tones of fuel replaced by wind energy, tones of CO_2 not-emitted to the atmosphere and fuel cost savings in Euros compared to a conventional diesel system without flywheels. This is translated to a non-emission of 130.44 tones of CO_2 and a saving of 19,730 Euros in the purchase of fuel at a cost of 0.47 €/lit.

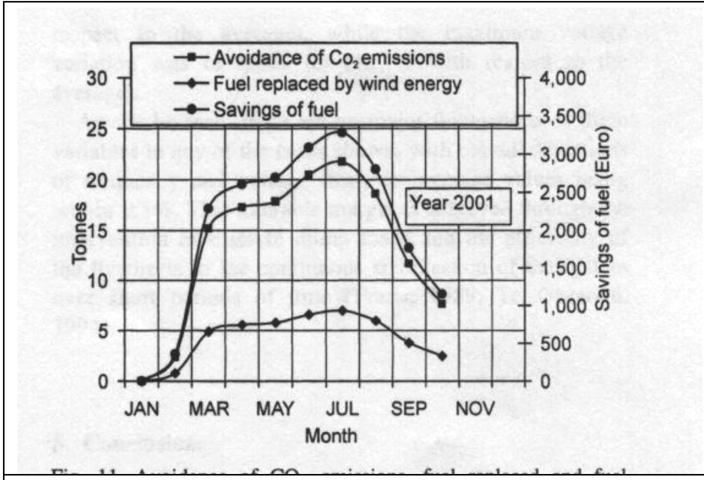


Fig. 11 Benefits of the use of wind energy

d. Cost Data

Due to the integrated design of the system including energy conversion and supply, water desalination and wastewater treatment, ice production, etc., there are no detailed cost figures, specific to the desalination system. O&M costs are shown in the following table.

Table 8 Estimated maintenance costs per year (1998 data in ECU)

Equipment	Cost
Wind Turbine	192000
RO unit	46500
Diesel Generator	132000
O&M Cost	ECU/ year
O & M personnel	20,000
Wind generator maintenance	2,000
Diesel maintenance	12,000
Fuel for Diesel generators	12,000
Total	46,000

4.2 WIND ENERGY DRIVEN VAPOUR COMPRESSION TECHNOLOGY

4.2.1 Desalination with RES, SDAWES Project, Pozo Izquierdo, Gran Canaria Island

a. Introduction

Desalination processes themselves are steady-state processes, which imply that they require continuous supply of energy. This means that a certain degree of adaptation and compromise has to take place to get them to operate in a satisfactory manner when coupled to a variable energy input. This in essence is what SDAWES project was designed to investigate.

The project “Seawater Desalination by an Autonomous Wind Energy System”, SDAWES, was developed within the JOULE programme (JOR3-CT95-0077) of the European Commission and was coordinated by ITC, Spain. Other participants in the project were the Univ. de Las Palmas de Gran Canaria (ULPGC); ENERCON, Germany; IER-CIEMAT, Spain; CREST, U.K., and NEL, U.K.

The basic concept of the project was the connection and the examination of the performance of three desalination processes: Reverse Osmosis (RO), Mechanical Vapor Compression (MVC) and Electrodialysis Reversible (EDR) connected with a stand-alone wind energy system to produce fresh water from seawater. Regarding this, 10 desalination plants have been installed. These are as follows:

- 8 RO units of 25 m^3/day each, with a specific consumption of 7.2 kWh/m^3
- 1 EDR unit of 190 m^3/day, with a specific consumption of 3.3 kWh/m^3
- 1 MVC unit of 50 m^3/day, with a specific consumption of 16 kWh/m^3

The objectives of this work were as follows:

a. to determine experimentally the feasibility of the stand-alone operation of wind farms isolated from conventional power grids and supplying energy to several desalination processes
b. to verify the operational feasibility of the various desalination processes when the driving energy source is intermittent


Pic. 8 View of the SDAWES system

c. to analyze the influence of various operational strategies on the volume and the quality of the desalinated water produced and on the useful working life of the main components of the desalination plants in order to provide reliable estimates of the unit water cost using these systems

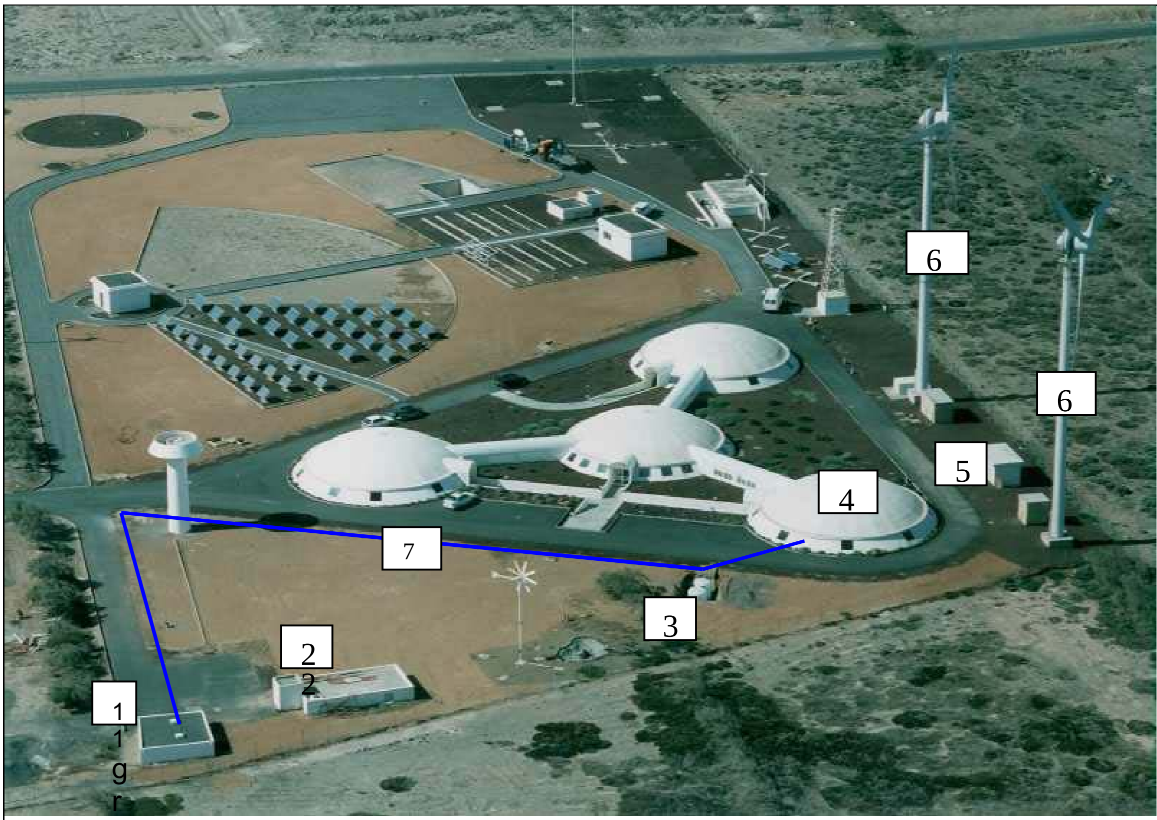
b. System Description

One of the characteristics of the SDAWES project, which differentiates it from other projects, is that the wind generation system behaves like a small mini power station capable of generating a grid similar to conventional ones without the need to use diesel sets or batteries to store the energy generated.

The MVC unit operates at a pressure of 0.2 bar with evaporation temperature of 62^oC. The aim to use the MVC technology was to study the technical feasibility of this technology when the speed of the compressor varies, again with the objective of adapting its electrical consumption to the variable wind energy supply

The technical and economical studies that were carried out led to the selection of a plant, model VVC50, by ALFA LAVAL with a compressor of a nominal power of 30 kW and electrical resistance of 20 kW for the start-up and 10 kW to maintain the temperature when operating under a stationary regime. The plant with 50m^3/day nominal capacity, was modified to be able to operate under a range of compressor speeds between 8,000 and 12,000 rpm. The plant commissioned in 1999 and started its normal operation in 2000. In the year 2003 the plant decommissioned.

The wind farm is composed by two 230 kW wind turbines manufactured by ENERCON, a 1,500 rpm flywheel coupled to a 100 kVA synchronous machine, an isolation transformer located in a specific building, and a UPS of 7.5 kW located in the control dome.



Pic.9 General view of the installations: (1) Pumping Station (2) Product water tank (3) Brackish water tanks (4) Desalination dome (5) Flywheel building (6) Wind Turbines (7) Feed water pipe circuit

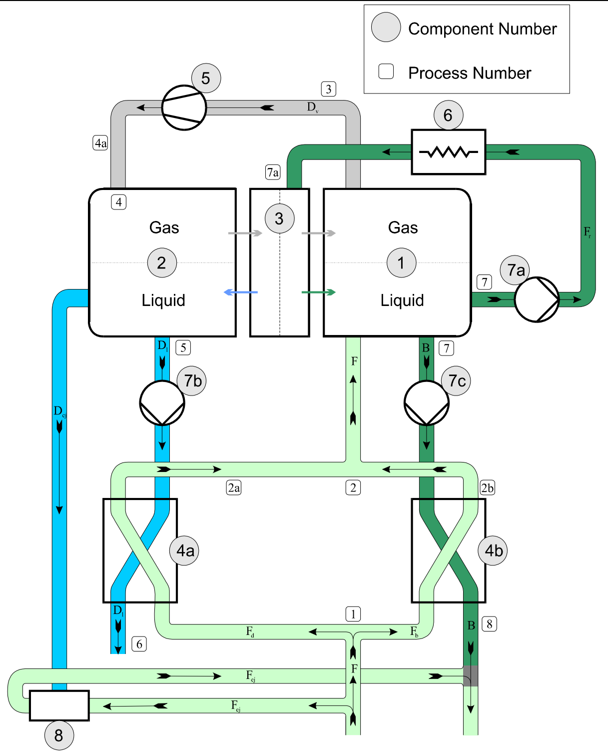
The wind turbines are of 3 bladed-rotor with variable speed and pitch-angle, and a synchronous-type electrical energy generator. These turbines use electronic devices to convert the wind energy into electrical energy that can be fed into the grid. The functions of the 100 kVA synchronous machine are as follows:

- for use as a grid frequency reference
- to maintain dynamic stability against disturbances when the loads are being connected or disconnected
- for use as a temporary energy storage

The purpose of the flywheel is to provide enough energy storage to smooth out minor fluctuations in the output of the wind farm. The flywheel is not intended to provide energy during periods of no wind.

The process of starting-up and operation of the stand-alone system can be essentially described as follows: when the start-up signal is given, the system checks the wind speed and the software control decides if there is enough wind to start up the isolated system (minimum average of 6 m/s during 5 min or similar).

Under these conditions, one of the wind turbines starts to accelerate the flywheel by a 22 kW start-up motor until it reaches 48 Hz; then the synchronous machine is activated to generate a 3-phase grid of 400V, which is detected as a reference by the wind turbine. Then the turbine introduces energy to the only connected load-the flywheel-until it reaches an upper speed limit of 52 Hz [J. Carta, 2004]



Component Number	Description
1	Evaporation Chamber
2	Condensation Chamber
3	Evaporator / Condenser Plates
4a	Product - Feed Water Heat Exchanger
4b	Brine - Feed Water Heat Exchanger
5	Compressor
6	Electric Heater
7a	Circulation Pump
7b	Product Water Pump
7c	Brine Pump
8	Ejector

Fig 12 Block diagram of the MVC plant

From that moment, the other wind turbine and the loads can be connected to the isolated grid; the W/T change the blade angle to adapt the supplied power consumed power. If the wind speed decreases, the control system will detect the reduction of frequency and will order a reduction in the consumption by disconnecting plants or modifying the working point until reaching the nominal frequency (52 Hz); if the wind is very weak, all the loads will be stopped.

c. Experiences and Lessons Learnt

One of the most important inconveniences was the start-up when the wind speed was close to the lower limit. The total process lasted around 30 min; this can delay the process 1 or 2 hours or even more, depending on the day. Also, during system's operation several minor failures in small components of the electric system came into view. The most common being located in the orientation blade motors of the W/T; this is presumed to be due to the continuous regulation to keep the nominal frequency (52Hz) stable [V. Subiela et al, 2004]

During the first years of the project, ENERCON carried out several tests to improve the start-up process. Finally, was decided to install an ansychronous motor mechanically connected to the flywheel, to start-up since it was very difficult to generate the isolated grid directly with the synchronous machine.

Additionally, concerning the operation of the flywheel, two main difficulties appeared. The first was the high mechanical friction, which consumed an important amount of energy. It was especially affected when the wind power was down and loads had to be switched off. The second difficulty was the overheating of one of the bearings with the consequent fault and haling of the start-up process. After installing the complete system, two problems were found inside the flywheel building: high temperature due to the heat produced by the flywheel-synchronous machine component, and the presence of dust from the outside. The ceiling of this building was designed to be mobile in order to install the flywheel into it by a crane, so the highest part of the walls were open, and the wind brought sand, dust and humidity inside.

Concerning the experience with the desalination unit the start-up of the VC was quite long (90 min) consuming 20 kW, and then the normal operation (30 kW in the compressor plus discontinuous 10kW in the electric heater. The on-grid tests demonstrated that the unit was not designed to operate under discontinuous power supply. After several weeks to start and stop operation, the plant stopped worked. The evaporation chamber was opened and a hard layer of scale was discovered. After acid cleaning, the plant was restarted, but as it was not operating 24h/day, the problem appeared again.

Pic. 10 Views of the MVC desalination unit

As a conclusion is that a special design would be necessary in order to prepare the plant for interrupted operation. Some ideas should be studied:

- inclusion of a hot water storage system with solar thermal energy contribution to reduce start-up time
- addition of a specific seawater washing of the evaporation plates to remove the rests of the concentrated brine
- improvement of the sealing system to preserve the vacuum for a longer time.

Most of the time to date has been spent in procurement, erection, commissioning and trouble-shooting. As a result only a limited amount of experience has been gained in the operation of the plant. Though enough experience of the plant has been gained to show that the combination works but not enough to draw any concrete conclusions.

d. Cost Data

No data is available.

4.3 PHOTOVOLTAIC DRIVEN REVERSE OSMOSIS TECHNOLOGY

4.3.1 Brackish Reverse Osmosis Unit driven by PV system, Portugal

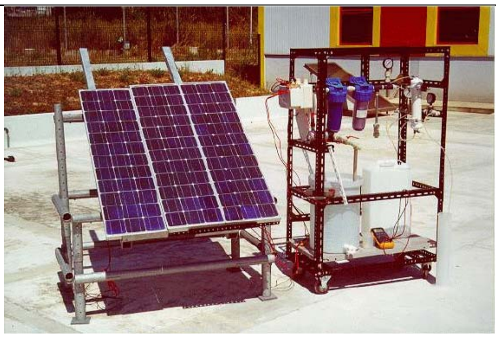
a. Introduction

The Renewable Energies Department of INETI in Portugal has developed a small pilot PV-RO unit for brackish water desalination in order to examine its operation and performance. The system developed around the year 2000 within the project named "Improved Processes for the Production of Water for Human Consumption in Rural Communities" in the framework of the CYTED Ibero-American programme [A. Joyce et al, 2001].

b. System Description

The feed water was prepared in laboratory with very low turbidity and neutral pH water. The feed water is brackish water having a conductivity ranged from 2000 to 5000μS/cm (at 20^{o}C). The feed water passed through a pre-filter (20μm), and then through a carbon filter to remove any amount of chloride. (see Fig 13). The RO unit has a daily production of 100-500 lt, and functioning with low pressure at the order of 5 bar. The RO membrane used is spiral wound, MP-TA50-J4. The produced water has a conductivity of less than 500 μS/cm.

The RO unit is driven by PV modules of 50 -150 Wp (3 modules of 50 Wp each). No batteries are used.



Pic.11 The PV-RO experimental pilot unit

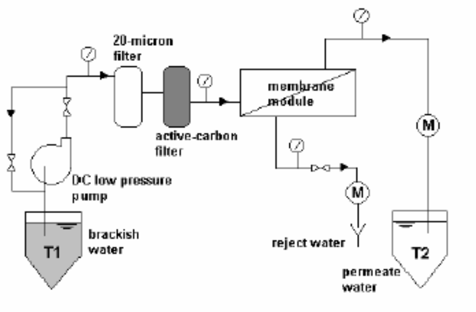


Fig 13 Schematic configuration of the unit

The RO unit was first connected to a DC power supply to perform previous testing and then coupled to a stand-alone PV system of 100 and 150 Wp directly connected to the pump with no batteries.

c. Experiences and Lessons Learnt

The objective of the experiment was to compare the permeate quality and specific energy consumption vs membrane working pressure for different conductivities. The conclusion was that the energy consumption decreases as feed water recovery and feed pressure increase. However, due to the short time of system's operation there is no data on the membrane performance under variable conditions, which is the most important parameter in the coupling of these technologies.

d. Cost Data

No data is available.

4.3.2 RO plant coupled to PV, DESSOL Project, Pozo Izquierdo, Gran Canaria Island

a. Introduction

DESSOL project has co-financed by the European Commission (JOULE Programme), and has been carried out by ITC, Spain in co-operation with the Sola-Institute Jülich in Germany. The aim of the project was the design, installation and optimization of a drinking water production system in coastal areas isolated from the electric grid [T. Espino, 2003].

The first version of the project considered in 1998 while the second in 2000. The second version is carried out by ITC directly. The pilot system installed in Pozo Izquierdo and is still in operation. The system consists of a seawater reverse osmosis unit with a nominal production of 0.4 m^3/hour. The pre-treatment system consists only of 2 cartridge filters of 20 and 10 μm. The produced water salinity is less than 1000 ppm TDS while the seawater salinity is of 35,500 ppm TDS. The RO unit operates at a working pressure of 55 bar and at a recovery ratio of 45%. The unit consists of 2 pressure vessels in parallel with 6 membranes each.

b. System Description

The total installed power of the RO unit is 3 kW, (high-pressure pump: 2.2 kW, membrane cleaning pump: 0.75 kW) and the specific energy consumption is 5.5 kWh/m^3. The unit is operated automatically on an average of 9 hours during summer and 7 hours during wintertime. The RO unit is driven by a 4.8kWp mono-crystalline

PV system (64 modules) and a 19 kWh battery backup system. The batteries are of Pb-acid type. The nominal voltage output is 48 V (24 elements in series of 2V each). The purpose of the batteries is the stabilization of voltage and to supply power the RO unit when energy from PV is not available. A charge controller of 75 A protect the batteries from overcharge. A pure sinusoidal inverter converts the 48V output voltage from the batteries to 220V for the RO unit.

Pic.12 View of the RO unit

The RO unit is equipped with a double flushing system with fresh water for the membranes and pumps during the daily periods when the plant is out of operation.

c. Experiences and Lessons Learnt

The unit is under study regarding its performance under different feed water temperatures, regarding membranes behavior due to non-continuous operation of the unit as well as its equipment behavior under “hard” working conditions.

d. Cost Data

An estimation of the cost of the system is shown below:

Equipment	Cost
PV system	25,200 €
RO	30,000 €
Total Unit water cost[1]	9.0 €/m^3

[1] the final unit water cost of such systems depends on several parameters such as the site, the solar potential, the feed water quality, etc.

4.3.3 PV-RO plant for brackish water desalination in Brazil

a. Introduction

The PV RO plant was installed in the community of Coite-Pedreiras, in the state of Ceara, Northeast Region of Brasil in 2000. The selected community has a population of about 150 families. The main water resource of the village is a well with a salinity of 1200 ppm TDS. The region is characterized by a high yearly solar potential of about 2000 kWh m^{-2} y^{-1}. The project was financed by the Banco do Nordeste and CNPq and developed by the DEE-UFC in cooperation with ARCE and CEFET in Brazil [Paulo Cesar Marques de Carvalho, 2004].

The aim of the project was the investigation of the coupling of the two technologies Reverse Osmosis and Photovoltaics for brackish water desalination considering two strategies: the first concerns with the use of a dc motor and secondly the use of a three-phase induction motor. Through the analysis of the stored data the second option is chosen as the better alternative.

b. System Description

The plant consists of 20 PV modules of 55W each, totally 1.1kW, 8 batteries of 12V, 100 Ah and a charge controller. The RO unit has a water capacity of 250 l/hr. The pressure of operation of the RO unit is of about 8 bar working in a recovery ratio of 27%. The plant is equipped with sensors for measuring the followings:

- Global solar radiation
- Ambient temperature
- Module temperature
- Wind speed
- Water flow
- Direct voltage of the PVs and batteries
- Direct current of the PV s and batteries

In the first case, the power from PVs drives only the high-pressure pump of the RO unit, which is the main load. The grid drives the booster pump. The dc motor used at the RO unit has a nominal power of 750 W and a nominal voltage of 24 V. The configuration of the PV-RO system is shown in Figure 14.

c. Experiences and Lessons Learnt

During the operation period great variations in the recovery ratio as well as in the electricity consumption were considered (see Fig.15,16). The specific electrical consumption was around 4.7 kWh/m^3.

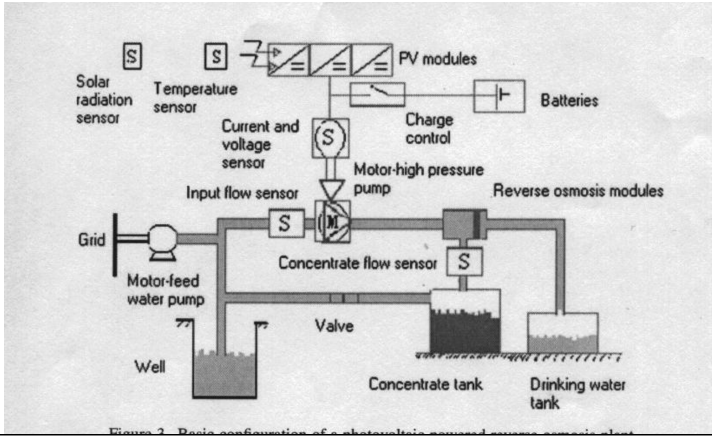
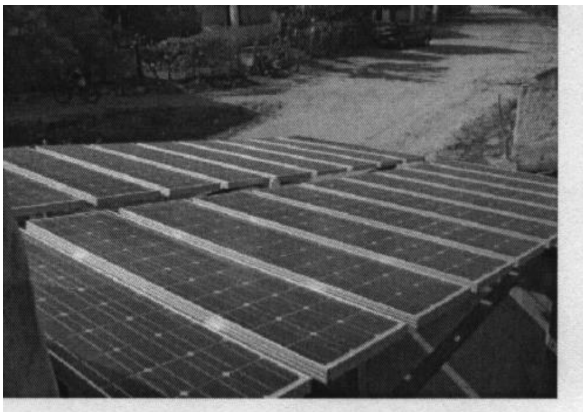


Fig 14 Basic configuration of a PV-RO plant

The produced water reduced in the duration of three months of its operation (September-November) due to damage of the motor. The plant was shut down for 10 days due to wear of the brushes of the motor and the lack of suitable brushes in the local market.



Pic. 13 View of the PV modules

Pic. 14 View of the batteries and RO unit

Finally, the motor wore out beyond any possibility of repair leading to a replace of it with a three-phase induction motor. The three-phase induction motor was of 2HP with a nominal voltage of 220V. A DC-DC converter was used to elevate the voltage from 24V (battery output) to 220V and an inverter with a nominal power of 750 W to invert the DC current to AC (see Fig 17).

During the period of plant's operation the recovery ratio and the electrical consumption shows no significant variation, which indicates the operational stability of the plant. The specific electrical consumption was around 3 kWh/m^3.

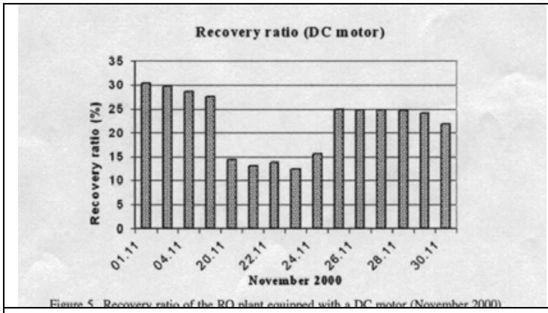


Fig 15 Recovery ratio of the RO with a DC motor

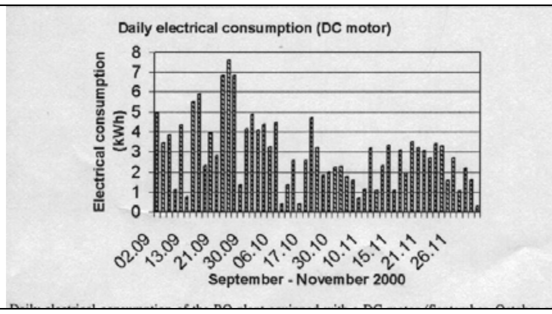


Fig 16 Daily electrical consumption of the RO with a DC motor

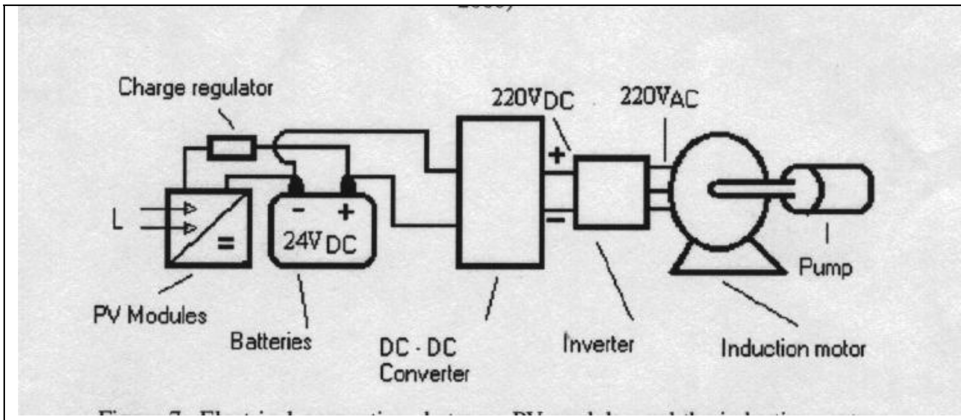


Fig 17 Electrical figure of the plant with the 3phase induction motor

From system's operation the following conclusions could be drawn:

- Due to the hard working conditions the DC motor is not adequate to operate in a stand-alone PV-RO plant
- With the use of the three-phase motor the specific electrical consumption is reduced to about 3kWh/ m^3
- The participation of the community is of great importance for the success of a project

Unfortunately, the plant in now days is not in operation.

d. Cost Data

In Table 9, the capital and O&M costs of the plant with the three-phase motor are presented. The unit water cost is estimated assuming an annual interest rate of 10%, a lifetime of the plant of 20 yrs, and an annual drinking water production of 200 m^3.

Table 9 Costs of the PV-RO plant

Equipment	Cost (US$)
RO	2667
PV modules (20×55 Wp)	7333
Batteries (8×00 Ah)	405
DC/DC Converter, AC/AC Inverter	1267
Charge controllers (2×30A)	187
Induction motor	133
Total	11992
Battery replacement	200
Membrane replacement	283
Filters replacement	10
Labor	200
Total O&M costs	693

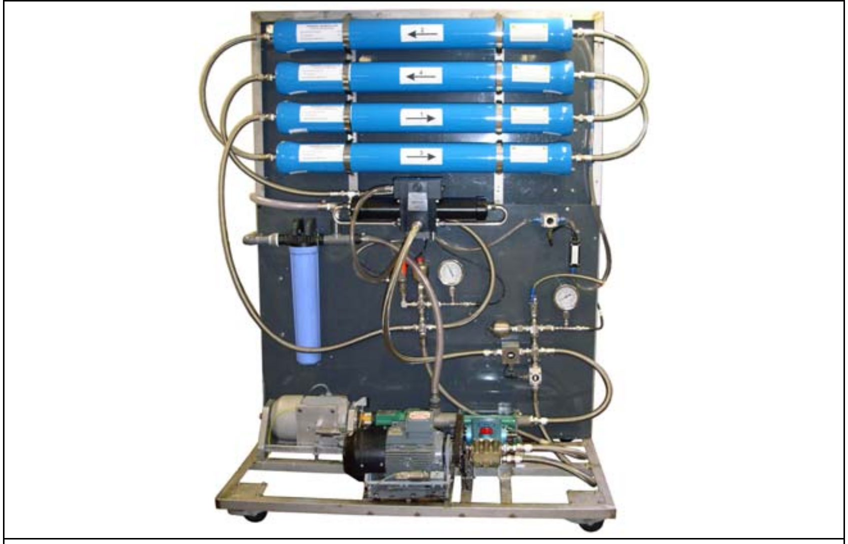
The drinking water cost is estimated to about 12.7 US$/m^3 (10.32 €/m^3). In order to compare bottled water is offered in 20 liters bottles at a price of 63 US$/ m^3 (around 51 €/m^3).

Pic. 15 View of the water source

4.3.4. PV-RO Plant without batteries, CREST, U.K.

a. Introduction

The small-scale seawater-RO system described in section 4.1.1 with wind power has also been demonstrated operating from solar photovoltaic (PV) power. Again, batteries were completely avoided: the system flow and pressure varied in direct response to the available solar power.



Pic. 16 View of the RO unit

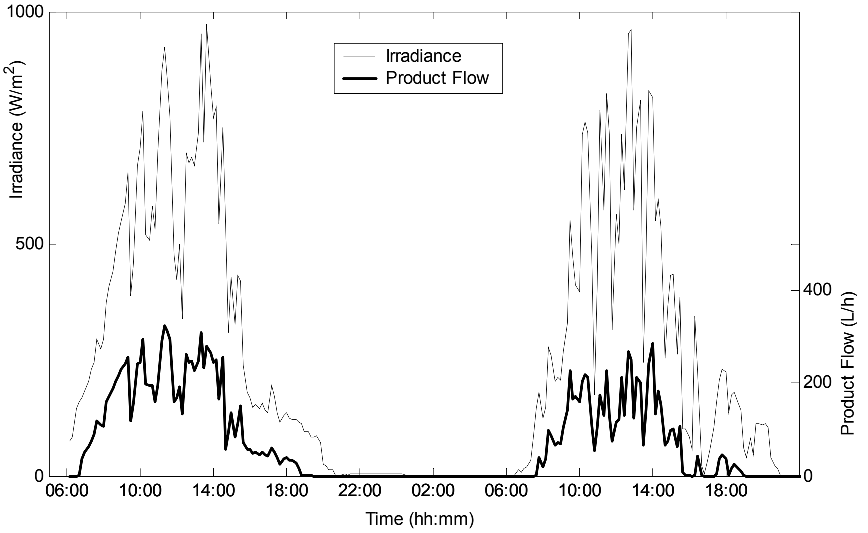


Fig. 18. Measured irradiance and product water flow June 9th and 10th 2003.

b. System Description

The photovoltaic array used for the demonstration has an area of 11.3 m^2 and consists of eighteen BP Solar Saturn BP585F mono-crystalline silicon modules. This array has a nominal power of 1.54 kWp and an open circuit voltage of up to 400 V_{dc}. The two inverters (industrial variable-frequency drives) convert this DC to 3-phase AC for the two induction motors.

Separate speed control of these motors provides full control of:

- the energy drawn from PVs for maximum power point tracking (MPPT), and
- the water recovery ratio, for maximum product flow.

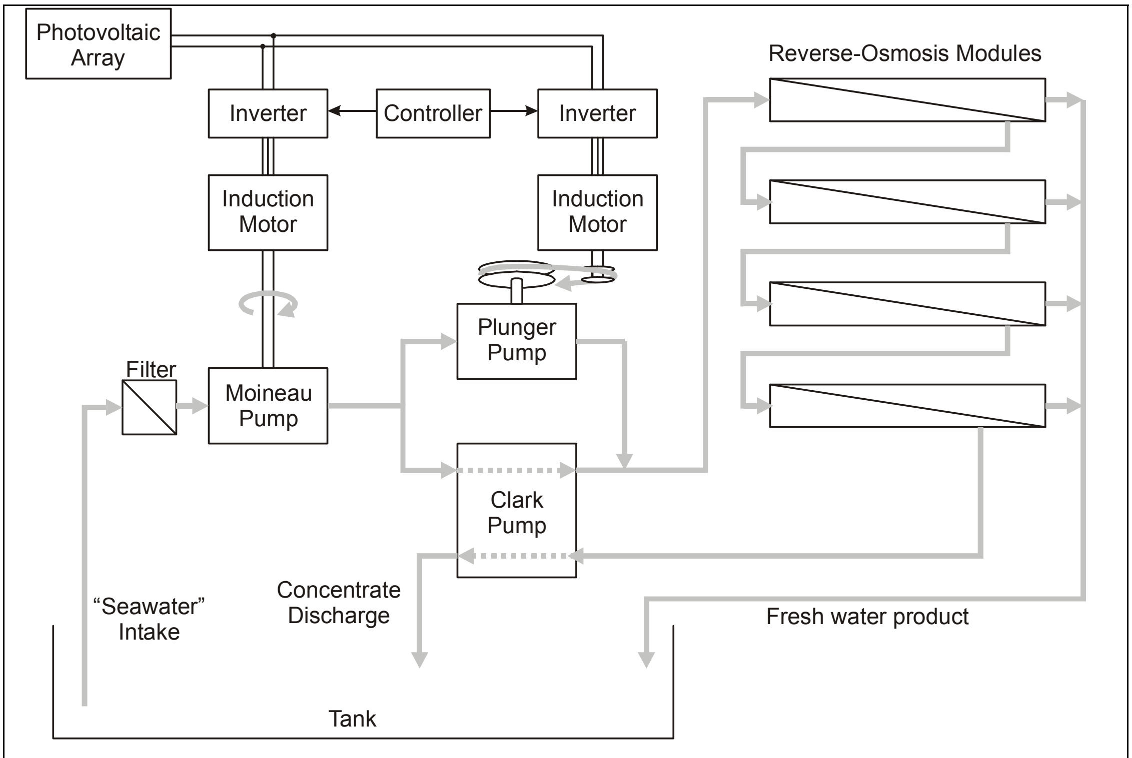


Fig. 19. CREST PV-RO test rig configuration

The average concentration of the product water was unacceptably high during the initial tests, but could perhaps be made acceptable by diverting a small proportion of the volume and without recourse to batteries.

c. Experiences and Lessons Learnt

- Batteryless operation of seawater PV-RO has been demonstrated, but the economic case for this concept has not been proven.

- Standard industrial inverters are efficient and economic but the PV array voltage must be carefully matched and maximum power point tracking requires external implementation.
- The Spectra Clark pump and variable recovery ratio combine to provide excellent energy efficiency over a broad range of operation, thus obviating the need of batteries.
- Intermittent operation of RO membranes may accelerate bio-fouling. This was not studied but membrane replacement every year was included in the cost estimates.
- More work is required on the reliability of the system.

d. Cost Data

The capital costs of the system were estimated as:

- PV modules £7300
- RO system £8400
- Manufacturing £7300

Assuming a 20-year life of the system as a whole, with pump replacements every 5 years and membrane replacement every year, the running costs were estimated at £2000/year and the overall cost of water was around £2/m^3.

4.3.5 Autonomous PV Water Pumping-Reverse Osmosis brackish water desalination plant in Saudi Arabia

a. Introduction

The PV water pumping - Reverse Osmosis system, located in Sadous Riyadh Region, was the first RES desalination plant in Saudi Arabia. The system installation completed in December 1994. The PV water pumping-Reverse Osmosis system is under continuous operation (24 h/day) since January 1995. The purpose of the system was to supply sufficient water of good quality to satisfy various needs of the consumers. The system designed by the Energy Research Institute of King Abdulaziz City for Science and Technology (KACST) in collaboration with NREL, USA as a result of a Saudi and USA cooperation program in the field of renewable energy research [S.A Alajlan, 1996].

The design of the plant was mainly based on the specification of the site, the depth of the well, the quality and quantity of the feed water, water needs, the autonomy period of the plant during cloudy conditions as well as other local climatic conditions. The design is based on the selection of equipment commonly available in the local market in order to make the operation and maintenance of the system highly reliable.

b. System Description

The plant consists of two main separate PV systems, first, PV water pumping system which is characterized by storing the water in two storage tanks and without battery storage and second, PV for the operation of the Reverse Osmosis (RO) unit which is characterized by battery storage. The battery storage system is used to provide the required energy to the RO unit during cloudy days and during the night. The battery storage system is designed to provide 5 days autonomy to the plant.

The total PV installed capacity is 10.89 kWp, 10.08 kWp to drive the RO unit and 980 Wp for water pumping. The head of the submersible pump is 50 m from the surface level and the product water capacity from the RO unit is about 600 lt/hour.

The PV generator is divided into 7 arrays; one PV array for the water pumping and six for the desalination unit with adjustable tilt angle.

The PV pumping system consists of the PV generator, an inverter to convert DC to 3-phase AC of variable frequency and the submersible pump. The PV generator needed to drive the submersible pump has an installed power of around 980Wp. The inverter is 1500 W. The measured efficiency of the inverter ranges from 90 to 96% for low and high irradiance respectively. This control unit is based on a microprocessor control unit to protect the motor and the PV array, and also has various functions during operation and standby mode. The control unit has a maximum power point circuit, which converts the possible maximum power available from the PV array to the motor. In addition, the control unit can start the operation of the motor with a low value of solar radiation and adjust the flow of water according to the available insolation. Also, because of the overall system performance efficiency must be as high as possible and the system's cost as low as possible, there is no storage of electric energy in the system. All the energy available from the PV array is used to pump water, which is stored in two tanks.

The submersible pump is around 2 kW and is installed approximately 50 meters from the ground surface. Two water storage tanks of 120 and 60 m^3, used to store the feed (brackish water) and product water respectively.

The PV desalination system mainly consists of the PV generator, the storage battery system, electric charge controller (ECC), the inverter, and the Reverse Osmosis unit.

The PV generator (10.08 kWp) consists of six PV arrays, 840 Wp each and charges two parallel battery banks, a total of 120 batteries, with a capacity of 1101 Ah each (C-100) and a 5-day storage capacity to drive the RO unit. Also, each battery is equipped with a recombinator to convert the generated gases (hydrogen and oxygen) during the charging to water.

The ECC is a DC to DC converter built in Maximum Power Point (MPP). The plant has six microprocessor-based, electronic charge controllers and is used to transfer the energy from the PV array to charge the batteries. The ECC also protects the PV generator and the battery from different dangerous conditions such as input and output reverse polarity, high and low voltage, and also provides protection in the case of overload and short circuit conditions.

The rated power of the inverter is 5 kVA and it is designed to match the inductive AC load in the system. The major AC load of the inverter consists of three AC motors with a total rating 3300 VA. The inverter is fully controlled and protected by a built-in microprocessor automatic controller to increase the system's reliability. The average efficiency of the inverter for variable loads of 50 to 125% of its rated capacity is equal to 90%.

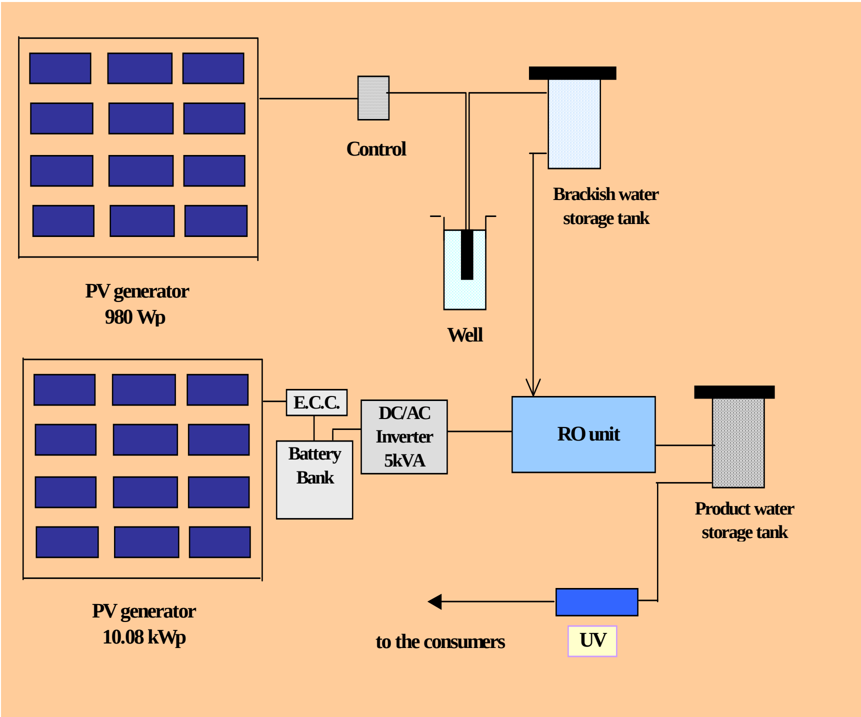


Fig 20 Block diagram of the PV water pumping desalination plant in Sadous Riyadh Region

The output power of the inverter at rated capacity has good sinusoidal wave, which corresponds to minimum total harmonic distortion. The shape of output power wave from the inverter is distorted if all the motors start at the same time. For this short duration of about 20 sec, the current drawn from the inverter is at least 6 times more than the rated. With distorted power wave, the control circuit of RO unit has no reliable operation; this critical condition was solved, first, by scheduling the starting time of the motors and, second by using a UPS (250 VA). The use of the UPS guarantees, even in case of distorted power, that the control circuit in the plant will continue to operate normally.

The RO system is operated intermittently, according to fluctuating demand for water. Typically, the unit goes through six start-up, shutdown cycles each day, staying on for 1 to 4 hours during each cycle. The automatic control flushes the membranes after each shutdown. The RO unit produces approximately 600 lt./hour, converting brackish water from 5700 ppm TDS to about 170 ppm TDS, having a pressure of operation around 14 bar. The RO unit consists of a booster pump, pre-treatment system, high-pressure pump, RO modules, post-treatment including a UV sterilization system as well as the control and distribution system.

Thin Film Composite (TFC) membranes are used. System’s recovery rate varies depending on the pressure, age of filter, time elapsed since the membranes were cleaned, and temperature. In the following tables, technical characteristics of the system are presented:

PV Pumping System

PV array Installed power Isc Voc	 980 Wp (2×7×70×Wp) 8.82 A 149.8 V
Inverter Nominal Power	 1500 W, DC/3 phase, Variable voltage and frequency (6-60 Hz), DC Input: 120 VDC ±20 V, 12.5ADC
Submersible pump Nominal power Pump model Motor model	 424 to 1990 W SP3A – 10 MS - 402

PV Reverse Osmosis System

PV array Installed power Isc Voc	 10.8 kWp (144×70 Wp), 6 arrays, each 12 series, 2 branches 8.82 A 256.8 V
DC system voltage	120 VDC
Storage batteries Number of batteries Capacity Type of connection	 120 1101Ah each, (C-100), with recombinator (2V×60 in series) × 2 parallel branches
Electric Charge Control Quantity Rated power Input Output	 6 1800W, with MPP 0-12 ADC, 40-25 VDC 0-20 ADC, 26-250 VDC
Inverter Nominal Power	 5 kVA, sinewave, 120VDC, 220 VAC, 60 Hz low and high voltage disconnect low and high input & output current protection
UPS	250 VA, for reliable supply to the control circuit of the PV plant
RO unit Product water capacity Conversion rate Pressure of operation	 600 lt/hr of product water 21 – 35% 14 bar

c. Experiences and Lessons Learnt

The system has tolerated intermittent operation well. Indeed, continuous operation for long periods in hot weather resulted in overheating of the motors. Membrane fouling is an on-going problem requiring membrane replacement every six months.

An UPS system for reliable supply to the control circuit of the PV plant is included. Additionally, the system is equipped with a data acquisition system (DAS) to store various measurements.

The major problems are related to membranes fouling and failure of some hardware. Membranes needed to be cleaned every 6 months. However no technical problem have been referred concerning the coupling of photovoltaics with the RO unit. A summary of the maintenance activities is given following:

Assembly	Description
Membranes:	cleaned every 6 months
High pressure pump:	replaced after 9 months of operation
Solenoid valve:	replaced after 7 months of operation
RO unit:	modified to include flushing of membrane after each stop of RO
Inverter distorted wave and RO control circuit:	Inverter stops 5 times due to overload caused by repetitive starting of RO unit and other motors
Pressure switch (booster pump):	replaced after 6 months of operation

d. Cost Data

The total cost of the plant includes the cost of the site preparation, civil work for the PV concrete foundation, pipe works and the cost of the water storage tanks. The percentage cost of the various items with respect to the total cost is as follows:

System Items	% Cost
PV modules + support structure	42%
Battery system +ECC	31%
Site preparation	18%
Miscellaneous Equipment (dosing pumps, filter)	9%

Generally, the PV power supply in connection with the water pumping and desalination system has excellent operation. However, the performance of the Reverse Osmosis unit was not satisfactory because of the frequent fouling of its membrane and the need of their replacement about every six months.

4.4 SOLAR THERMAL SYSTEM DRIVEN MULTI-EFFECT DISTILLATION TECHNOLOGY

4.4.1 MED Solar Thermal Plant, Almeria, Spain

a. Introduction

The following plant is above the size of the plants under consideration, however is one of the most successful applications and is the smallest one in the area of the Solar MED field.

The Solar thermal MED plant at PSA (Almeria, Spain) was developed by CIEMAT (Spain) and DLR (Germany) in 1987, initiating the Solar Thermal Desalination Project (STD), which was completed in 1993. The STD project was part of the Industrial Solar Energy Applications Research Program. The project was carried out in two phases [CIEMAT, Final project report, 1995]

Phase I included testing the reliability and technical feasibility of a solar thermal energy system consisting of a solar collector field connected to a multi-effect desalination plant.

Phase II aimed at developing an optimized solar desalination system by implementing improvements that could make the initial system more competitive with conventional desalination systems.

b. System Description

The solar desalination system implemented during Phase I was mainly consists of:

- a seawater 14 -effect Multi-Effect Distillation (MED) plant (ENTROPIE, France)
- a one-axis tracking parabolic-trough solar collector field, (ACUREX, USA)
- a 115 m^3 thermocline thermal storage oil tank.

The collector field (Pic 17) consists of one-axis tracking parabolic trough collectors, of total aperture area of 2,672 m^2. The daily thermal energy delivered by the collector field is about 6.5 MWh_t, while the daily thermal energy requirement of the desalination plant is less than 5 MWh_t for 24hour daily operation.

The MED plant consists of 14 effects (Pic 18) having a water production of 3 m^3/hour. The MED plant uses sprayed horizontal tube bundles for seawater evaporation, which must be limited to around 70^{o}C to limit scale formation. Since the feed water temperature is below 70°C to avoid scaling, the only feed water treatment required is the injection of a scale inhibitor to avoid frequent cleaning of the unit with acid.

The plant evaporator body includes 14 effects at successively decreasing temperatures and pressures from Cell 1 tube bundle and condenses as it is sprayed by feed water. The heat released evaporates part of this water at 67°C, 0.28 bar. The steam thus produced goes on to Cell 2, where it is also condensed in a tube bundle sprayed with feed water. The latent heat realized by condensation of the vapor allows part of the feed water entering the 2nd Cell to evaporate at a lower temperature/pressure of 64°C/0.24 bar. The same condensation/evaporation process is repeated in Cell to 14. The vapor produced in Cell14 at 33°C/0.05 bar is condensed in a final condenser cooled by seawater. The water condensed in each Cell goes through a U-shaped tube to the next Cell and finally to the condenser. The product water is then extracted from the condenser by means of the distilled water pump. The feed water required to spray the Cell1 tube bundle is part of the water coming out of the condenser. The desalination plant can also be fed with 16-26bar steam. High-pressure steam is produced in the PSA's Electricity Generation System o drive a turbine coupled to an electrical generator. A small fraction of this steam can be used to feed the desalination plant.

A vacuum system is used to evacuate the air from the unit at start up and to compensate for the small amounts of air and gases released from the feed water and from the small leaks through the gaskets.

The desalination plant is operated in a closed circuit in which the distillate and brine are mixed in an open pool, producing the seawater, which is again sent to the desalination plant, since the PSA facilities are 40 km from the sea.

The desalination plant is connected to a single 115m^3 thermocline vessel thermal storage system. The hot oil, which enters the tank through an upper manifold, acts simultaneously as a heat transfer fluid and heat storage medium. The tank is inertized by 4.8 m^3 of nitrogen. The thermal storage capacity is around 5 MWh_t at charge/discharge temperatures of 300/225°C. The thermal utilization factor (efficiency) is 92%. The energy storage system is required to provide thermal energy during the night (24-hours daily operation).

The most outstanding solar ME system evaluation results obtained during Phase I of the project were the following:

- Low thermal inertia - it usually took 35 minutes to reach continues operation of distillate after daily start up.
- Specific electricity consumption of 3.3 up to 5 kWh/m^3 of distillate the performance ratio (PR) of the plant was in the range of 9.4 -10.7 when the plant was operated with low -pressure steam (0.35 bar).
- When the plant was fed by high-pressure steam and thermo-compressors, the PR was in the range of 12-14.
- The MED system showed high reliability. No technical problem appeared when coupling the plant to the solar system

The aim of Phase II was the optimization of the plant mainly by

- reduction of the electricity demand by replacing the initial hydroejector –based vacuum system with a steam ejector system
- increase of the efficiency of the system meaning decrease of the thermal demand by coupling a double-effect absorption heat pump to the MED plant

<table>
<tr><td></td><td></td></tr>
<tr><td>Pic. 17 Solar Desalination System at the PSA</td><td>Pic. 18 Solar collectors field layout</td></tr>
</table>

The coupling of a double-effect absorption heat pump increases the system efficiency. This improvement reduces the thermal energy consumption of the desalination system by around 44% from 63 kWh/m^3 to 35.3 and electricity consumption by 12% from 3.3 to 2.9 kWh_e/m^3. The main problem faced during the heat pump testing was the difficulty in achieving steady-state conditions. Although many elements were checked and revised, the problem could not be solved due to lack of time and budget.

The system operates 24 hours per day. From November 1990 to December 1992, 576 hours of operation were achieved, and $828m^3$ of distillate water produced. From January to July 1993, 336 hours and $548m^3$ were achieved. Long shut downs occurred due to maintenance problems (significant corrosion problems of the elements) and improvement works.

	
Pic. 19 Corrosion of the heat pump absorber and evaporator	Pic. 20 Corrosion of the backside of the heat pump evaporator

c. Experiences and Lessons Learnt

The problems and failures of the heat pump prototype tested at the PSA must not be considered a barrier for the future commercialization of solar MED systems. These problems are normal and could be eliminated in future commercial units.

Currently, the solar MED plants of the PSA is, effectively still in operation. PSA continuous working on the improvement and modification of the plant within a project named “Enhanced Zero Discharge Seawater Desalination using Hybrid Solar Technology (AQUASOL). The project approved by the European Commission and has been initiated in 2002. AQUASOL project objective is the development of a least costly and more energy efficient seawater desalination technology proposed technological developments (new design of CPC collector and absorption heat pump, hydridization with natural gas and recovering of salt are expected to both improve the energy efficiency of the process and process economy. The expected result would be an enhanced MED technology with market possibilities and suitable to be applied in the Mediterranean area and similar locations around the world. If a fuel cost (i.e natural gas) of 4.5 €/GJ is considered, the needed cost of solar system (considering 50% solar contribution of the overall system) to the achievement of the same economic competitiveness as conventional MED plant, is equivalent to around 300 €/m^2 of solar collector.

d. Cost Data

The cost of the distillate water produced has been estimated to about 400 ptas (1994) about 2.5-3 €/m^3. According to an analysis developed within the project, concluded that the most important parameter affecting the unit water cost of the solar MED plant is plant size. Cost is greatly reduced for plants beyond 1000 m^3/day. The solar radiation available on site and the price of the solar collectors also influence the water cost, although to a lesser degree.

4.4.2 Solar Thermal Evaporation Plants in Tunisia

This paragraph presents the work have been done in Tunisia regarding Desalination with RES. The Tunisian experience mainly concerns solar distillation systems. The three installed units follow the solar distillation technology for sea and brackish water desalination. More analytically a 40-50 lt/h single-effect evaporation process for brackish water desalination have been installed in Hazeg, Sfax, a multi-effect distillation of 150-200 lt/day for seawater desalination in Beni Khiar, Nabeul and a solar multiple condensation evaporation cycle (SMCEC) system of 12-30 lt/h for brackish water desalination in University of Sfax in Sfax.

<u>Hazeg</u>

a. Introduction

A pilot single effect solar distillation unit has been installed at the area of Hazeg, Sfax in 1986 for greenhouse irrigation. The unit starts its operation in 1988 and is owned to the National Institute for Research on Rural Engineering Water and Forestry (INRGREF). The system is developed under a bilateral Tunis (INRGREF)-German (DORNIER) co-operation.

b. System Description

The desalination process is based on the solar single effect principle having a water capacity of 40-50 lt/hour. The feed water is pumped from a well having a salinity of 3000-4000 ppm TDS (brackish water) depending on season. The desalination unit consists of a typical pretreatment system, only filtration at the pumping system, the evaporator and the condenser. No post-treatment of the produced water is included. The salinity of the produced water is ranged from 20 to 200 ppm TDS. The desalination unit operates at a temperature of 60^{o}C (with a max of 92^{o}C) at a heat rate of 95%. As it is shown in Figure 21 during the forced convection from the bottom to the top of the condenser the vapor is mixed with fresh water from the heat exchanger sprayed at the top of the condenser. Through this cooling, a part of the vapor is condensed and collected in the bottom of the tank.

The distillation unit operates 10 hours per day in average. The unit within its 4 years operation has produced 3000 m^3. The thermal power of the unit is 22.7 kW while the electric installed power for pumping is 2.27 kW.

A storage tank of 3m^3 is used to store the produced water. The power supply system consist of a collector array having an area of 80 m^2 composed of three rows of heat pipes. Each row includes 12 heat pipe panels. The effective collector absorber area is of 64m^2, 36 panels. The annual mean solar radiation is 6 kWh/m^2/day and the average wind speed is 3.5 m/sec. The system has a circulation flow rate of 1200 lt/h and a max operating pressure of 2 bar.

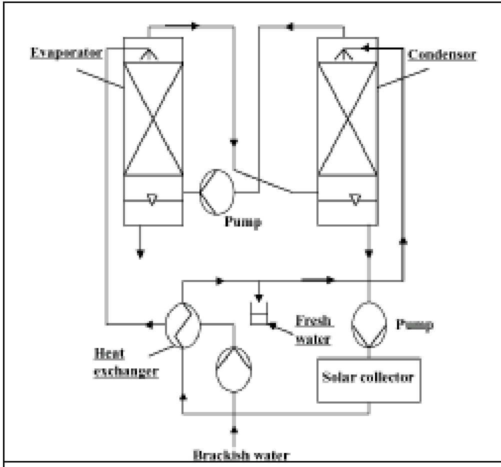
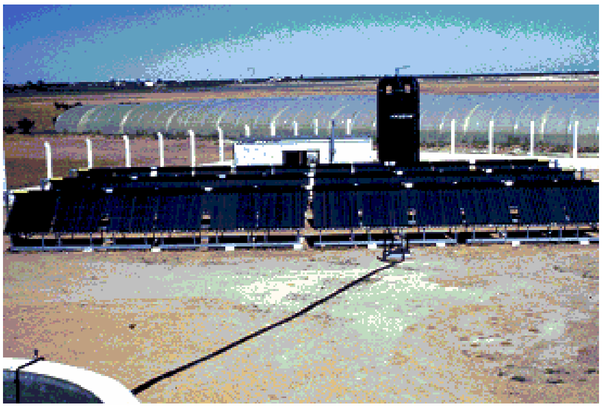


Fig 21 Diagram of the single effect distillation unit



Pic. 21 A view of the solar collectors in Hazeg

c. Experiences and Lessons Learnt

Concerning the experience gained from this project the following matters are mentioned:

- The fragility of the heat pipes collectors, present high risks to be damaged under hard weather conditions (hail storm, etc.)

- The condensation process should be improved in order to achieve a better efficiency of the process. The water production by this process is very low and could not be adopted to supply water for remote areas if it is considered that the unit water cost is prohibitive. It is obviously that the process is not attractive in small units.
- High unit water cost. The cost of water from other resources at the area is of 0.3 €/m3. However, it is of low quality and is coming from a well closed to the pilot unit. This water is commonly feed the population surrounding this area.

d. Cost Data

The capital cost of the unit is of $51,000 USD (41.400 €), the running cost is high of the order of $14,000 USD (11.382 €), proving a unit water cost of $21.5 USD/m^3 (17.47 €/m^3).

<u>Beni Khiar</u>

a. Introduction

The pilot solar multi-effect distillation process is developed in 2003 in Beni Khiar in Nabeul, Tunisia. The produced water used for domestic consumption. The system is owned to the Agence Nationale des Energies Renouvelables (ANER), Tunisia and installed by the Wärmepumpen und Solartechnik Service Gbr (WpSOL) in Germany.

b. System Description

The solar multi-effect distillation system consists of the following main parts:

- The collector array with an area of 100 m^2 for water heating
- The collector of 20 m^2 for air heating
- An evaporator with different stages
- Heat exchanger (tubular and plating)
- Water storage tank
- Ventilator
- Circulation pumps

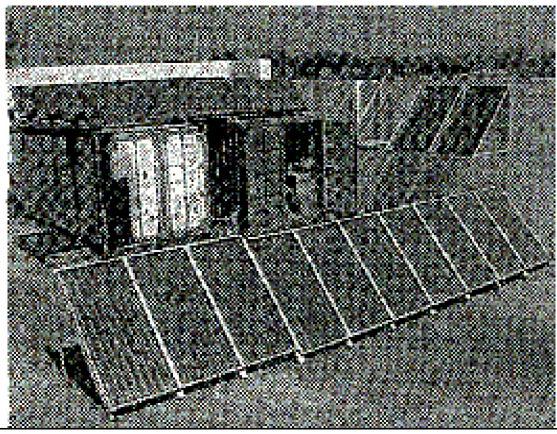
The effective collector absorber area is 108 m^2. The average wind speed at the area is 4.47 m/sec and the annual mean solar radiation is 6 kWh/m^2/day.

The distillation plant consists of 3 effects and has a capacity of 150-200 l/day from seawater of 38000ppm TDS. The salinity of the produced water ranged from 10 to 100ppm TDS. The temperature of operation is 80^{o}C. The high temperature of operation creates corrosion problems, which is the most common problem of this process. The distillation plant operates in average 10h/day.

The plant works under the basic principle of the evaporation/condensation cycle. The solar collectors assure the evaporation. In fact solar radiation heats the fluid calorific composed by a water mixture with glycolic, which with the help of a pump it is circulated around. The seawater is heated and evaporated. The vapor is evacuated to the two condensers equipped with fans. One using tubular-exchanger and the second use plate-exchanger. The water vapors will be cooled and condensed and the condensate is transported towards a basin. In order to increase the evaporation rate, and to heat the cold air coming from condensers and inside evaporation unity, an air solar collector has been added.

c. Experiences and Lessons Learnt

There is no data on the experience gained from the operation of the plant. The collected data from its operation is under evaluation.



Pic. 22 A view of the solar collectors in Beni Khiar

d. Cost Data

No data is available

Sfax

a. Introduction

A solar multiple condensation evaporation cycle (SMCEC) desalination unit installed in 1989 at Ecole Nationale d'Ingénieurs de Sfax, University of Sfax, Tunisia. The system developed within a project for research purpose. The produced water is used for greenhouse irrigation. At the area the water resources are of low quality having a cost of 0.3 €/m^3. The system is owned to the University of Sfax and is developed by AQUASOLAR in Germany.

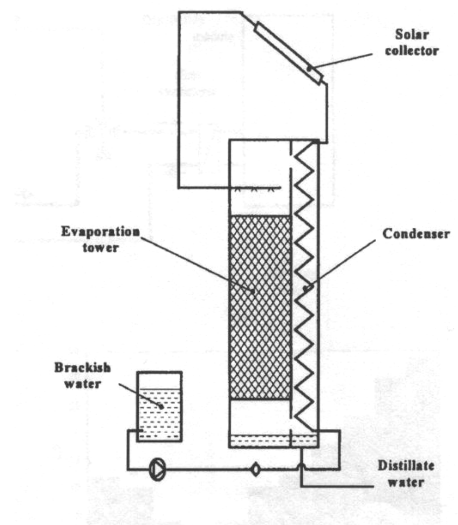


Fig 22 Configuration of the pilot distillation unit

b. System Description

The solar desalination plant consists of:

- the evaporation tower,
- the condenser,
- the flat plate collector field and
- the heat storage

The feed water is pumped from a well and has a salinity of 2500 to 6000 ppm TDS (brackish water) depending on season. The produced water is of low salinity in the range of 20 to 200 ppm TDS. The distillation unit has only 1 effect operating at a temperature of 55 ^oC with a max of 75^oC. The distillation unit has a product water capacity of 12-30 l/h. The plant has no pretreatment and post-treatment. The consumed energy is thermal and electric energy for pumping and auxiliary loads.

The electric power is of 4.5 kW. The thermal energy consumption is around 227 kWh/m^3.

The evaporation tower produces the water vapor rich air, which flows by natural convection to the condenser. The condenser is cooled by brackish water and reduces the temperature of the warm humid air. This result in a condensation of water vapor, and the cold water, which flows through the condenser, absorbs the condensation heat.

The solar flat collectors cover an area of 56 m^2. The effective collector area is 51 m^2.

The average wind speed is 3.5 m/s and the annual mean solar radiation is 6 kWh/m^2/day. The circulation flow rate is 1200 lt/h and the max operating pressure is 2bar.

c. Experiences and Lessons Learnt

From the operation of the solar distillation become the following conclusions:

- Flat solar collectors are very suitable for water heating and require no special maintenance.
- The cost of the collectors is still high to be used in solar water desalination field.
- This plant with heat recovery operates without high technical parts, which makes this concepts so outstanding
- The operation is simple and requires no special personals.
- Temperature and pressure are so low that simple and low cost materials can be used in rural areas.

d. Cost Data

The cost of the system was 24,000 USD (19,512 €), while the running costs is 6000 USD/year (4,878 €/year).

4.4.3 SODESA Project, Gran Canaria

a. Introduction

The SODESA project concerns with the design, installation and examination of the performance of a pilot distillation system working under 80^{o}C and under weather conditions driven by non-corrosive solar collectors. The system has a water capacity of 600 l/day and total collectors area of 50m^2. The project has been co-financed by the European Commission within JOULE Programme, DG XII, JOR3-CT98-0229. The project is co-ordinated by Fraunhofer ISE, Germany in collaboration with ITC, Spain, the ZAE-Bayern Centre for Applied Research, Germany and the Agricultural Univ. of Athens, Greece. The pilot plant commissioned in Pozo Izquierdo in Gran Canaria in 2000 and decommissioned in 2003 [M. Hermann, 2002].

b. System Description

The collector field consists of eight collectors, which are connected in series. The distillation module and the tank as well as the units for mineralization and disinfection are located in the house behind the collector field. The PV module to provide electricity for the post-treatment process is situated beside the house. All other pumps, valves, control units as well as the data acquisition system would use electric power from the grid.

 *Figure 1-3: Storage tank, 6.3 m³*	 *Figure 1-2: Collector field (approx. 50 m²)*	 *Figure 1-4: Distillation unit*
Pic. 23 The 6.3m^3 storage tank	Pic 24. The collector field	Pic. 25 The distillation unit

The system consists of a multi-effect humidification unit of around 600lt/day driven by corrosion-free collectors. The main task of the project was to find materials, which are resistant to seawater and can withstand stagnation temperatures up to 200°C, out of which appropriate absorber constructions had to be developed. Moreover, it had to be ensured that it was possible to apply a selective coating on the absorber.

The pre-treatment of the desalination unit consists only of filtration with cartridge filters of 10 and 20µ. The feed water is seawater of 35,000 ppm TDS. The distillation unit is of one effect working on GOR of 2.5-3.5 (max 5). The feed water has a temperature of 8-22°C while the temperature of operation of the unit is of 80°C. The post-treatment consists of mineralization and disinfection (UV). The thermal energy consumption of the desalination unit is 280-310 kWh/m^3 and the electrical energy required is 13 kWh/m^3. A tank of 250 m^3 for the storage of produced water is also available.

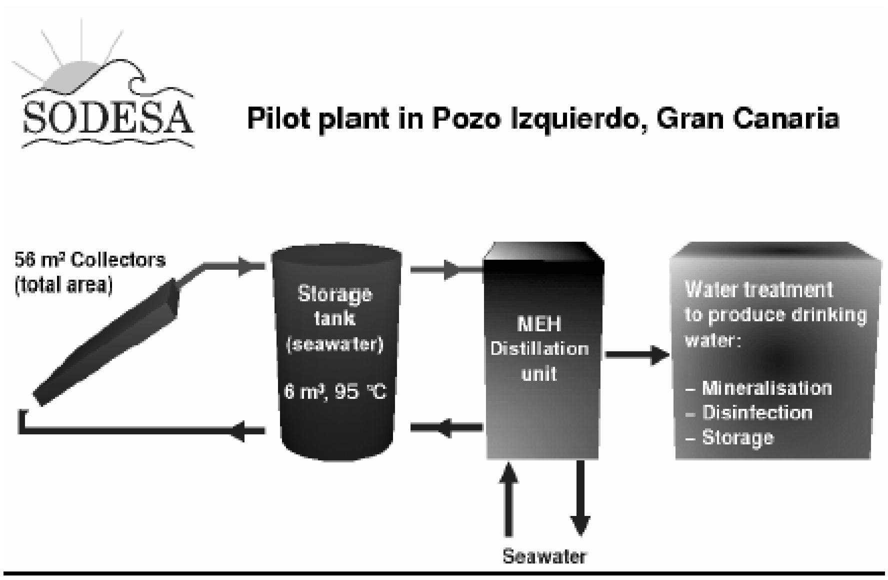


Fig 23 System Configuration

The distillation unit consists of an evaporator and a condenser, which are located in the same insulated chamber. The unit operates at ambient pressure. Hot seawater (80 to 85°C) is distributed on the evaporator where it slowly trickles downwards.

The air moves in a counter current low driven by natural convection and is thereby humidified due to partial evaporation. As a result, the brine is concentrated and cooled down to about 45°C. The humid air flows to the condenser where the steam condenses and is collected.

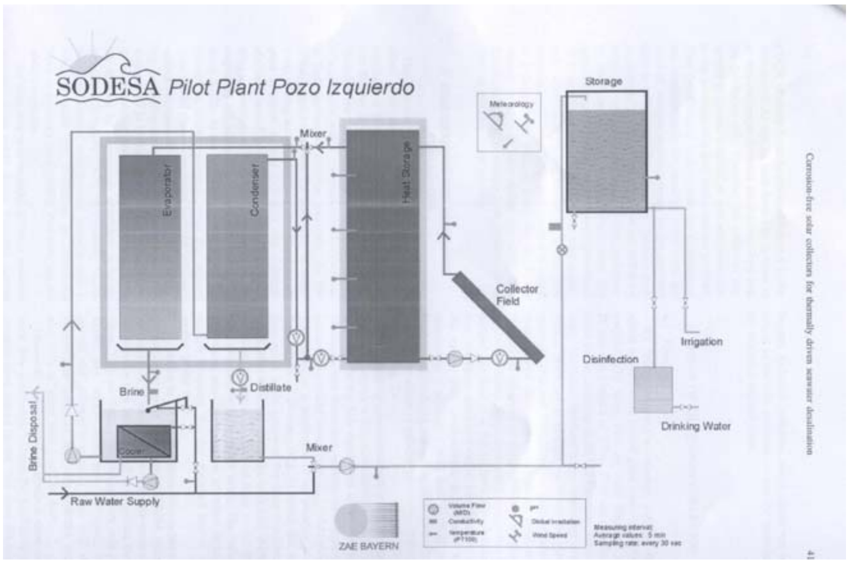


Fig 24 Block diagram of the pilot plant

In SODESA project, the produced distillate is subsequently mixed with a certain amount of seawater in order to add the minerals needed for potable water. Finally, the water is disinfected by means of a PV driven ultraviolet lamp. A substantial part of the heat of evaporation is recovered in the condenser, which acts as a pre-heater to the seawater flowing through it. Thus a GOR of about 5 can be obtained. As it shown in Figures 23, 24 there is no heat exchanger between the collector loop and the distillation unit. Therefore, the collectors can operate at a lower temperature and heat losses due to the presence of a heat exchanger are avoided.

Thus the efficiency of the system can be increased and simultaneously the resulting water costs are reduced, because heat exchangers for hot seawater have to be built of very expensive material such as titanium. It is one of the aims of this project, to investigate the effect of this fundamental modification on the resulting water costs. The seawater is preheated in the condenser up to about 75^{o}C, and flows directly through the solar collectors, where it is further heated up to the final temperature of about 90^{o}C. Afterwards it is stored in a large buffer tank to allow the distillation module to operate also during night.

The effective collector absorber area is 50m^2 consisting of 8 collector panels. The average wind speed at the area is 8m/sec and the annual mean solar irradiation is 7 kWh/m^2/day. The circulation flow rate is ranged between 0-65 lt/hour. The thermal storage tank is a cylindrical one with a capacity of 6.3 m^3 of seawater. The thermal storage capacity is 45 kWh, and the storage temperature is 67 ^oC.

c. Experiences and Lessons Learnt

From the operation of the system the main conclusion concern with the excellent behavior of the collectors regarding corrosion.

d. Cost Data

The only available data for the cost of the system is that it is too high in relation with the water production.

4.4.4 Small Solar MED plant, Sultanate of Oman, MEDRC Project

a. Introduction

The laboratory of “Lidasa” Ltd., Moscow, Russia has developed a solar powered desalination plant based on Multi-Effect Distillation (MED) with submerged boiling. The process and component designs fulfill the requirements to operate in remote rural areas. The project has been co-financed by the Middle Desalination Research Center (MEDRC) in Oman (Project No 98-AS-24A). The plant commissioned in 2002 and had a year of operation. The plant installed in Muscat in Sultanate of Oman, and is owned to the M/S Power System International.

The project includes the following main stages:

- design,
- manufacturing and indoors testing of the experimental unit,
- manufacturing of the pilot desalination plant,
- indoors testing in Moscow,
- transportation to Muscat and long term testing in natural conditions of Oman.

In fact, the plant runs at unsteady state due to variation in solar radiation during the day. Steady-state flow rates and temperatures are required to size the individual equipment for a specified load. This is obtained by steady state material and energy balances.

The pilot MED plant is designed to produce 1000 L/day in 9 hours of operation during the day using the solar energy. The desalination plant is designed and fabricated in Russia. Initially sub-systems and individual equipment of the pilot plant are tested in Russia and test results are used to improve the equipment and pilot plant designs. Improved pilot plant is fabricated in Russia and shipped to Oman for testing. The plant is tested in Oman climatic conditions for an extended period of time. This technology is further improved based on the test results of Oman and improved version is available for commercial application.

The innovative techniques and methods used in the plant including high temperature solar tubular collectors, scale preventing coating, and device for water softening are described in details.

The desalination system is a multi-effect distillation with top brine temperature of 100°C. Water recovery reaches 80-85%.

Chemicals are not used for water disinfection's and for anti-scale treatment. The pretreatment only consists of filtration of solid particles. Material and energy balances as well as process and equipment designs including the fabrication details of the plant are considered. To avoid scale formation the feed water is softened by specially elaborated water softener. Moreover the scale preventing coating for heat exchange surfaces of the plant was made by plasma deposition technology. The main components of the desalination system are a water softener, a series of heat exchangers (effects) in which repeated condensation / boiling processes occur, the feed pre-heaters to recover the heat from the hot distillate product water, and from the hot discharge brine as well as two last condensers having, accordingly, feed water and air as a coolants. The MED unit includes 12 effects and 6 pre-heaters. The unit operates 8 hours per day. The thermal energy consumption is of 64 kWh/m^3 while the electric energy consumption is 1.4 kWh /m^3. The plant was tested with a water salinity of 30,000-35,000 ppm TDS. The produced water salinity has a salinity of 80-120 ppm TDS.

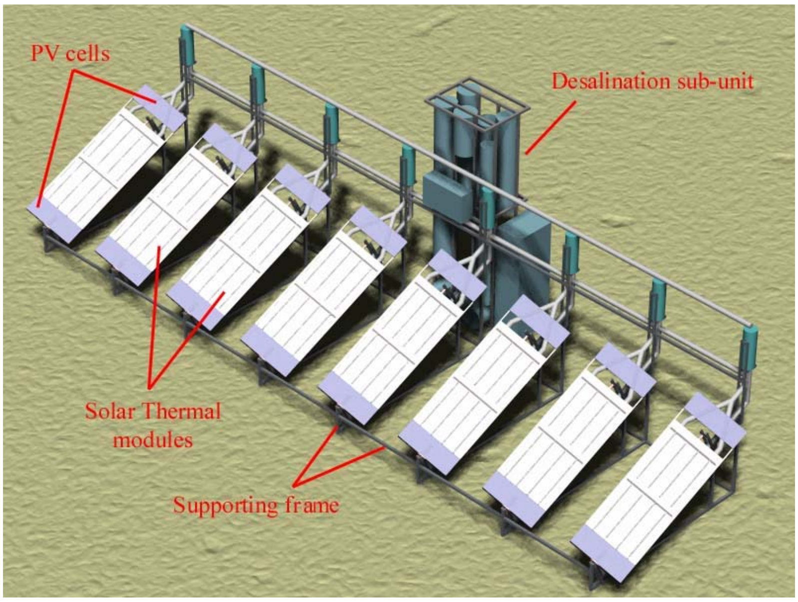


Fig 25 Pilot Plant layout

The number of effects incorporated in the plant depends on the working temperature range and on the required driving temperature between the condensing steam and evaporating liquid. Increasing the temperature range more number of effects can be accommodated for specified driving temperature, and it is possible in the proposed process since the hardness of the feed is reduced in the bubbler[2] to avoid scaling problems. Top temperature depends on the availability of heating source temperature and lower temperature on the coolant.

The range of the working temperatures of the plant is expanded up to 100^{o}C. Its electricity demand is satisfied with 2 m^2 PV-cells. Water for cooling of the last condenser is not used.

For powering the desalination process a solar thermal system was developed. The main elements of the solar thermal system are the solar modules consisting of high temperature vacuum tubular solar collectors with mirror concentrators, separator for steam and water separation and solar tracking system. The solar power plant include 16 collector panels, with an effective collector area of 5.34 m^2. The circulation flow rate through whole collector system is 460 lt/hour and the max pressure of operation is 1.05 bar.

Specially developed selective solar absorbing coating allows operation at 100°C and withdraws accidental temperature increase up to 350°C. The collectors with the

[2] Bubbler is a simple vessel in which a certain level of feed water is maintained containing seed particles

mirror concentrators are tracking the sun in fully automatic mode. Gain output ratio is directly proportional to number of effects in MED process.

Use of oil or pressurized water or pressurized steam as a heat carrying medium in the solar collectors allows increasing the temperature of the first effect above 100°C and consequently increasing the working temperature range. However, these schemes seem to be too complicated for small-scale plant intended for rural areas and need energy consuming pumps and heat exchanger. Therefore, pure distilled water under atmospheric pressure is used for feeling of the solar collectors. Steam / water mixture leaving the solar collectors enters the separator, and they get separated. The water separated goes back to the collectors and the steam passes through the bubbler as bubbling steam.

Pic. 26 View of the solar collectors

Steam generated in the solar thermal heater is bubbled through the feed water to heat it to 100°C. The scale forming compounds in the feed deposit on the seed particles (chalk powder) and new seeds are also formed due to nucleation[3]. Feed water is also de-aerated in the bubbler, and the concentration of non-condensing gases in the feed water decreased at least by 20 times. The steam leaving the bubbler at 100°C goes to the first effect as a heating medium and gets condensed starting the MED-desalination process. So, the water steam acts as the heat carrier. The steam from the last effect is condensed in two condensers. First one has fresh

[3] Seed particles are added only at the startup of the plant, and new seeds formed serve as seeds for subsequent operations

feed water as a coolant and second one has air as a coolant. The main advantages of the proposed process are the following:

- Comparable high performance ratio due to increased amount of effects
- Small solar absorbing area is required because of solar tracking system and solar concentrators
- The plant does not need the energy consuming water pumps for pumping large amounts of water through solar collectors, and for cooling. $2m^2$ PV-cells satisfy the plant electrical power requirements.
- The plant does not need additional water for cooling of last condensers. The first is cooled with the feed water and the second is cooled with fans powered by PV-cells.
- The plant does not need applications of chemicals for water disinfection and scale removal

c. Experiences and Lessons Learnt

Long term testing for 14 months from March 2002 to May 2003 was carried out to test the operation stability of the components of the pilot plant and to measure the performance of components and the entire pilot plant in natural conditions of Oman. At the first stage of the tests the individual systems of the plant were tested. Then the operation of entire pilot plant was tested. Totally, the complete pilot plant was tested for 6 months during this period.

During the earlier tests and during long-term test, it was not possible to measure the efficiency of the bubbler and to test the stability and performance of the scale preventing coating. Therefore, special measuring and testing stands were built in Moscow and in Muscat to test the bubbler and scale preventing coating. The tests with the help of these stands were conducted during spring and summer of 2002. Then in spring 2003, the stands in Moscow were modified with improved set of shutters for the effects and conducted the tests with improved stands. During this stage, number of defects was eliminated; some parts and elements of the plant were replaced.

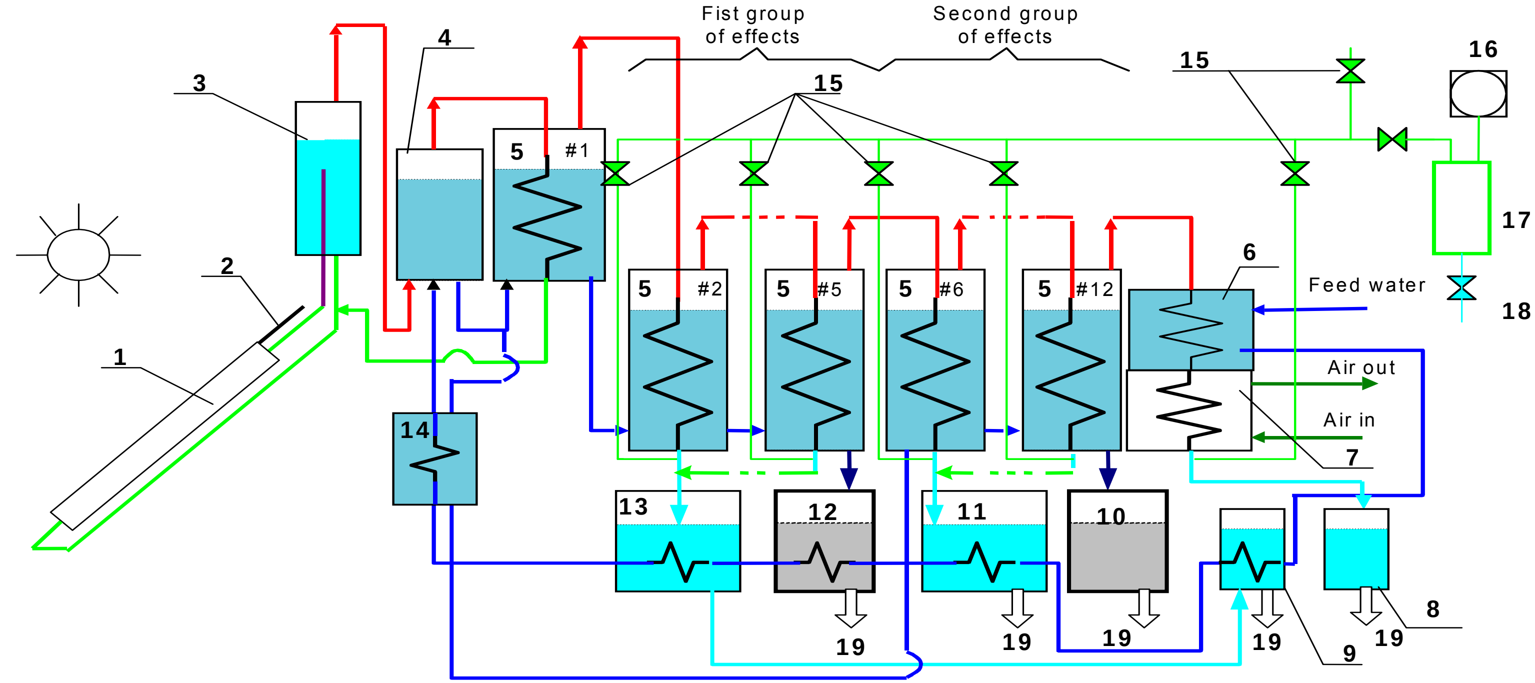
To make the test results useful to designers and operators of the solar thermal desalination plants, conclusions are provided after discussing the test results for each component of the pilot plant. These conclusions include the over all characteristics, crucial parameters, features and general conditions of operation of the systems and elements of the plant.

However, some disadvantages, namely, insufficient thermal insulation, damage of the solar concentrators and non- transparent deposition on the surface of the dust protecting glasses and concentrators could not be totally eliminated.

Due to above mentioned disadvantages the measured daily productivity of the plant in the testing period was between 850 and 910 liter of distillate per day.

The estimations show that after elimination of these disadvantages the productivity of the plant will increase at least 15% and will reach up to 950 – 1050 liter per day. Finally, in this project the following are achieved.

- Small-scale solar desalination plant process based multi-effect submerged boiling distillation (MEB) was visualized.
- Mass and energy balances have been performed for 1000 liters per day pilot plant operating 9 hours a day.
- Process and equipment designs including the fabrication details of individual equipment for 1000 liters per day pilot plant have been carried out.
- Based on the pilot plant designs an experimental plant has been built to test the performance of the critical equipment in the pilot plant. The measurements and testing program was carried out to evaluate the performance of the main elements and systems of the pilot plant.
- Based on the feed back from the experimental plant testing and measurements, designs of some of the equipment and systems of the pilot plant have been improved. Pilot plant is fabricated in Russia based on the updated designs. Indoor testing of the pilot plant has been carried out to test the performance of all elements and system of the pilot plant. It was observed



1. Solar collector field
2. PV Cell
3. Separator
4. Bubbler
5. Effects #1-12
6. Tight cask steam-water condenser (preheater N1)
7. Steam-air condenser
8. Collector of distillate of 12th effect
9. Preheater N2
10. Collector of brine of 2nd group
11. Collector of distillate of 2nd group (preheater N3)
12. Collector of brine of 1st group (preheater N4)
13. Collector of distillate of 1st group (preheater N 5)
14. Preheater N6
15. Pressure valve
16. Vacuum pump
17. Rough-vacuum tank
18. Ballast discharge
19. Blow down

vacuum pipe
feed water pipe
distillate pipe
steam pipe

Fig 26 Solar MED plant Configuration

that the performance of the pilot plant was not satisfactory due to insufficient thermal insulation to vessels and piping. Based the measurements, thermal insulation of some of the vessels has been improved.

- The pilot plant built in Russia was transported to Muscat for full-scale tests in natural conditions of Oman.
- The preliminary testing of the pilot plant after commissioning it in Oman has been carried out. The expected performance of the near closed heating circuit of the solar collector has been achieved after improving the thermal insulation.
- Long-term test of the plant has been carried out after rectifying some minor problems identified during preliminary testing. During long-term testing, the performance of all the elements and systems, as well as the performance of the complete plant has been checked. Some equipment not working properly has been replaced with appropriate ones and malfunctions of some of the equipment and systems have been rectified. Modified pilot plant has been successfully operated for more than a month in the automatic control regime.

A number of innovative techniques and methods has been used in the pilot plant and they are listed as follows:

- High temperature solar tubular collectors that operate in the solar tracking mode were demonstrated. Water steam is used in solar collectors as heat carrying medium in a closed circuit.
- The novel scale preventing coating for heat exchange surfaces of the effects and pre-heaters has been used. The coating has been tested in operating conditions that prevailed in the pilot plant with seawater and found very effective.
- The bubbler has been used for softening the feed water. The tests confirmed that the bubbler performance fully satisfied the requirements of the pilot plant.
- The pilot plant can be operated with more than 70% recovery without any problems.

The main conclusion considered from this project was that the presented solar powered desalination plant can serve as an autonomous source of drinking water for a small community in a remote location without any external thermal and electrical power supply and any additional cooling water.

More analytical, a solar energy powered desalination technology suitable for small-scale remote location application based on Multi-effect distillation principle is developed. The following considered as the most important features of this technology.

2. Submerged tube evaporators.
3. Plasma coating of heat transfer surfaces to reduce scaling.
4. Water softener to treat the feed water for reducing the hardness, which will reduce the scaling in the effects.
5. High temperature vacuum tubular solar collectors with mirror concentrators and automatic sun tracking system as energy supply source. Distilled water is used as heat carrier in the collectors.

d. Cost Data

The cost of the solar thermal system was 8,500$USD (6,910.5 €) and for the MED unit 8,500 $USD. As a conclusion from the indoors and outdoors tests confirmed that the presented MED-desalination plant can serve as an autonomous source of drinking water for a small community in remote locations without any external thermal and electrical power supply and any additional cooling water.

4.5 HYBRID POWER SUPPLY PLANT DRIVEN REVERSE OSMOSIS TECHNOLOGY

Autonomous hybrid systems are independent and incorporate more than one power source. Diesel generators are mainly used as backup systems, however fuel transportation to remote areas poses the same difficulties as water transportation.

RES penetration depends only on the economic feasibility and the proper sizing of the components to avoid out gages and ensures quality and continuity of supply. One important application is the use of photovoltaics and wind generator to drive Reverse Osmosis desalination units.

4.5.1 Autonomous Hybrid RO plant, Lavrio, Greece

a. Introduction

This work deals with the design and development of a small autonomous hybrid seawater Reverse Osmosis (RO) unit able to provide fresh water to a remote area with around 10 inhabitants. The work is performed within the Operational Programme for Competitiveness, Measure 4.3, of the Greek Ministry of Development in the frame of the Third Community Support Framework.

The aim of the work is the design and development of an autonomous PV-Wind power supply system to drive seawater RO unit of 130lt hourly product water capacity. The system has been installed at CRES Wind Park at Lavrio, Attiki [E. Tzen et al, 2004]. The plant start its operation in 2001.

Measurements of basic parameters, as well as control strategies have be taken into account in order to examine the performance and the reliability of the system, exploiting by the best way the RES potential and produce fresh water of sufficient quantity and quality.

The final intention of this project is to examine also the economic feasibility of such projects and disseminate the hybrid desalination schemes in remote areas characterized by lack of fresh water and electricity.

b. System Description

The Hybrid RO system mainly consists of 3.96 kWp Photovoltaic generators, 900 W Wind generator, 130lt/hr seawater RO unit, a battery bank of 1800Ah/100h and two inverters of 1.5 kW and 3 kW nominal power. More analytical technical data for the hybrid RO system is provided below.

The PV array is separated in three sub-arrays of 12 modules each, each one connected to a charge controller (3 controllers in total). The solar chargers are of 45A each. PV array has an adjustable tilt during the year (2 positions,) according to the solar altitude.

The 900W Wind generator (W/G) has its own charger, which controls voltage from the generator and prevents battery overcharging. A uniquely designed resistor bank is used as load dumping. A circuit breaker to stop the wind generator is also included. The energy produced from both, PVs and W/G drives the RO unit. A battery bank of 1850 Ah/100h is used as energy buffer and mainly to provide stable power to the RO unit. Two inverters are used in order to convert the DC voltage from the battery bank to AC to the main load (RO). An inverter (I) of 1.5 kW drives the booster pump and also is able to provide electricity to other auxiliary loads. A second inverter (II) of 3 kW drives the high-pressure pump of the RO unit. The reason for the use of two inverters mainly is the importance of increased reliability of the autonomous operation of the system. The RO unit, is important to be able to operate at least for flushing process in case where no energy is available.

More analytical technical data is given in Table 10.

Table 10. Power Supply System Technical Description

Equipment	Technical Characteristics
PV array	3.96 kWp SIEMENS SM110 36 modules in parallel, Adjustable tilt
Solar Charger	3×45A, STECA/Tarom PWM
Wind Generator	900 W, WHISPER H40, 24 V EZ-Wire Universal Charger
Battery Bank	1850 Ah/100h, FULMEN SOLAR 2V, 12 cells in series
Inverter I	1500 W, SIEMENS ESW 3024 24dc, 230Vac, (3000 VA-30min), 1 phase
Inverter II	3000 W, RESPECT 24Vdc, 230Vac, 1 phase

In order to be able to examine the performance of the power supply system the following measurements are taken:

- pyranometer to measure the solar radiation
- anemometer to measure the wind speed at the required height
- voltage sensors at the battery bank
- current sensors at the exit of the W/G, PV, at the battery bank and
- power transducers at the exit of the two inverters

Analogue instruments of 4-20 mA take all the above measurements. All the data is recorded in the developed software.

The RO unit operates in a close water circuit since no seawater is available at the site where the system is installed. The seawater for the unit is achieved by mixing fresh water from the water distribution network with salt in a water storage tank of $2m^3$.

A booster pump of 0.45 kW (1-phase motor) drives the feed water with a pressure of around 1.5 bar to the pre-treatment system (see Fig 27). This is supplied from the 1.5 kW Inverter (I) at 24 Volt.

The pretreatment system for the particular application is simple and consists of a carbon filter for water de-chlorination and a 5μ cartridge filter for polishing-filtration, to remove only very small amounts of materials.

A positive displacement high-pressure pump of 2.2 kW (3-phase motor) pressurizes the feed water at a pressure of around 58 bars to the RO membranes. This is supplied from the 3 kW Inverter (II) at 24 Volt. Positive displacement pumps are preferred for small units due to their high operating efficiencies. A frequency converter converts the 3-phase frequency of the high-pressure pump motor to 1-phase. Low inrush currents characterize 3-phase motors.

For the RO module system, 2″ FilmTec, SW30-2540 spiral wound membranes are used. Spiral wound membranes characterized by their availability in small sizes and also by their sufficient operation on highly fouling feed water, consequently of water without excessive treatment, having easy membrane cleaning process and is cost effective. Two pressure vessels connected in series with one membrane of 2 inches diameter each are used to desalinate seawater (around 36,500 ppm TDS) to fresh water of around 230 ppm TDS salinity. The hourly product water capacity is of around 130 lt. The unit operates at a recovery ratio of 15%. The brine exit from the membrane is transferred to the water storage tank. Due to the small size of the unit the use of energy recovery system to exploit he high pressure of brine was not possible.

An amount of the produced water firstly stored at an elevated flushing tank having a capacity of 0.1 m^3. This amount is used to flash the membranes with fresh water at every shut down of the RO unit by the use of a 0.420 kW pump driven by the 1.5 kW inverter. The tank is also elevated so that flow due to gravity insures complete flushing of the membranes under all circumstances. After the flushing tank achieves the required amount of water the produced water is transferred to the water storage tank. In practice important is in autonomous desalination systems to include a potable water storage tank able to provide some days of autonomy.

The technical characteristics of the system are as follows (see Table 11):

Table 11 RO Unit technical description

Equipment	Technical Characteristics
RO Membranes	2×SW30-2540 FilmTec
Capacity	130 lt/hour
Recovery Ratio	15%
Oper. Pressure	58 bar
Feed Water Salinity	36,000 ppm TDS
Product Water Salinity	~230 ppm TDS
Booster Pump	0.45 kW
High-Pressure Pump	2.2 kW
Total Installed Power	2.65 kW

In order to be able to follow the performance of the unit and record keeping, sensors and control systems such as flow, conductivity, pressure meters and temperature switches, having 4-20 mA output are included. The measurements are as follows:

- Pressure gauge at the entrance of the membrane
- Pressure gauge at the exit of the membrane
- Temperature of the feed water
- Conductivity of the product water
- Flow rate of the product water
- Flushing water level

The first five above signals are also inputs to the RO PLC, which is used to control the operation of the RO unit.

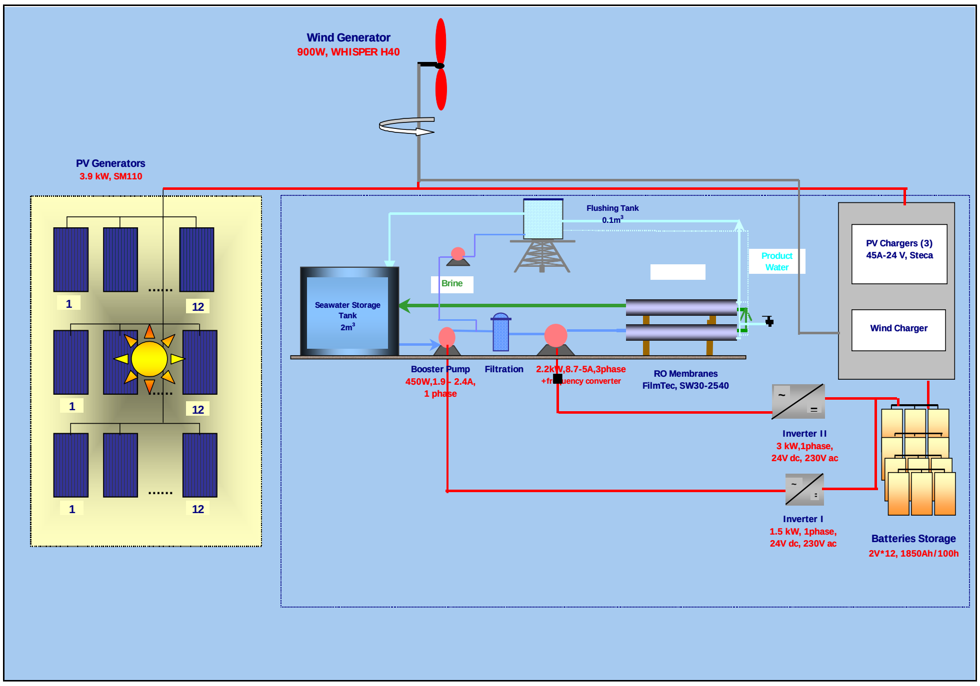


Fig 27 Hybrid RO Block Diagram

Some principles and assumptions have been followed during the design of the Hybrid RO unit, as well as for the selection of the system's components. Because the main objective is to develop a rational system, which can be operated in a remote area, and due to the need of stable power to the RO unit the following assumptions and considerations are taken into account:

- a battery storage system is necessary since RO unit requires stable power supply
- the RO unit is sized so to operate based on the available energy from the RE power supply unit. No operation is permitted in case where battery SOC is less than 60% and no RE power is available
- the less frequent the RO unit is shut down the better is its performance
- in every shut down of the RO unit an amount of the produced water is used for flushing
- two inverters used to increase system's reliability and to separate the loads (RO, auxiliary loads)
- AC equipment is considered for the RO unit. AC simplifies wiring by allowing the use of low cost, readily available switches outlets, etc.

- battery bank's capacity is able to provide some hours of RO unit operation in case where no energy from RES is available.

The control and monitoring system has been developed in Visual Basic in order to record the measurements from the analogue instruments, to elaborate the data and to decide on the operation of the RO unit based on the availability of RES energy, battery state-of-charge (SOC) and flushing water level.

The main operational parameters of the hybrid RO system are also displayed on a PC screen for demonstration purposes (Fig 28, 29).

The programme has the capability to provide instantaneous data of 1 min period from the analogue instruments and to present the results of several algorithms based on the 13 signals that are considered. These results are the followings:

- available time of RO unit's operation
- battery state of charge
- total hour of operation of the RO unit
- daily water production
- total water production

The operation strategies of the system concerns with the:

- Energy availability from RES (solar and wind energy)
- Sufficient battery capacity (≥60%)
- Sufficient water for flushing

The hybrid desalination system has a sufficient and reliable operation providing sufficient quantity and quality of fresh water. The autonomous desalination system is able to provide in average 5h of RO operation within wintertime and more than 8 hours within summer.

c. Experiences and Lessons Learnt

During the operation of the system no serious technical problems have been considered. The only problems faced during the operation of the system concerns with short-circuit of several sensors, cables damage due to the high wind speed and due to rodent's attacks. Almost after 4 years of operation no maintenance is required for the PV, the Wind generator and the battery bank. For the reverse osmosis unit the only maintenance concerns with the replacement of the membranes (once), and the replacement of the carbon and the cartridge filters (three times within its time of operation). Also, at the beginning of system's operation due to the humidity and over-voltage, 2-3 sensors, voltage and current sensors, was replaced.

In December 2004 and after the end of the project, CRES replace the RO unit with a new one and bought the whole system in order to continue its operation and improvement. The new reverse osmosis unit has similar characteristics with the first one, but more efficient high-pressure pump. The high-pressure pump, of 2.2 kW, is an axial piston pump (DANFOSS, APP1.0) with 95% efficiency. The pump does not require any maintenance. The booster pump is of one phase and has a nominal power of 0.37 kW. The unit operates at a recovery ratio 13%. The RO unit during its operation within summer 2005 provides a production of 150lt/hour with a conductivity of 240μS/cm from 37000 ppm TDS seawater.

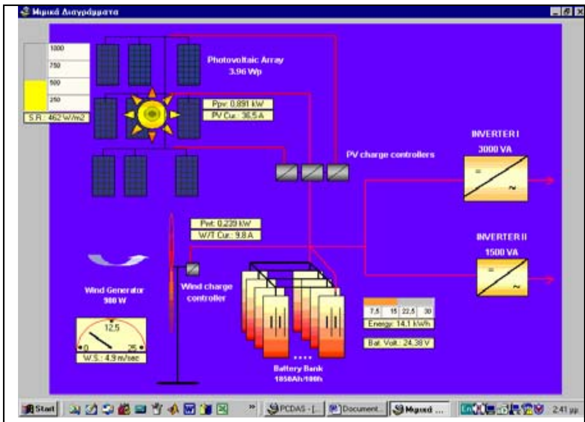


Fig 28 The screen image of the PSS

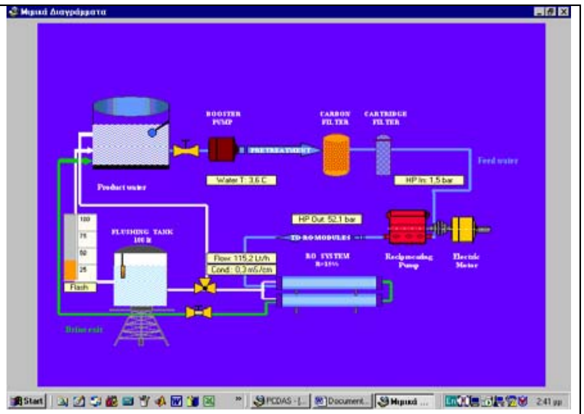


Fig 29 The screen image of the RO unit

Pic. 27 4 kWp PVs at Lavrio

Pic. 28 View of the first RO unit at Lavrio

Pic. 29 The 900W wind generator

Pic. 30 The battery bank, the inverters and the chargers of the autonomous system

Pic. 31 The W/T charger

Pic. 32 The solar chargers

Pic 33 View of the new RO plant

d. Cost Data

The unit water cost was estimated around 23 €/m^3, relatively high mainly due to the small size of the pilot system, to the high cost of PVs as well as due to the extra equipments required for the study. More analytically the cost of the main equipments of the system are as follows:

Equipment	Cost (€)
PV array (3.96 kWp)	28,185
Wind Generator (900 W)	2,934
Battery Bank (1850 Ah/100h)	2,347
Inverter I, (1500 W)	900
Inverter II, (3000 W)	2,500
RO unit (3m^3/day)	17,000
Other (control system, sensors, etc)	6,200
Total	60,066

Assuming replacement of the membranes every three years, replacement of the battery bank as well as of the pumps every five years for 20 year system lifetime, the unit water cost is of 23 €/m^3 , (discount rate=10%, inflation rate=0.0).

The cost of the produced water could be decreased with the addition of membranes on the same unit with the same installed power. Since cost is an important parameter on the promotion of such systems the next step is to develop economical attractive solutions for the water production and electricity generation by RES, for remote areas characterized by lack of potable water and electricity grid. Issues like this are important to be solved to the nearby future.

Pic. 34 900 W W/G, 4kWp PVs at Lavrio

4.5.2 Hybrid Wind/PV-RO UNIT, MAAGAN, ISRAEL

a. Introduction

The autonomous hybrid solar wind system developed in around 1999 by the Planning, Development and Technology Division of Israel Electric Corporation. The purpose of the system was to develop and promote an autonomous desalination system in remote and isolated areas, which are devoid of water resources [Dan Weiner et al, 2001]. The project partially financed within the 4^{th} Framework Programme of the European Commission. The project goal was to fulfill two purposes:

- To test and analyzing the battery behavior of the autonomous system
- To reduce overall system cost by using readily available standard hardware

b. System Description

The system consists of a reverse osmosis unit, designed to produce $3m^3$/day fresh water from brackish water. The feed water has a salinity of 3500 to 5000 ppm TDS. The feed water is pumped from nearby brackish water well. A water storage tank of $5m^3$ stores the produced water.

The system has been designed based on the premise that the average on-site wind velocity is about 4-5 m/sec and an isolation level of about 5-5.5 kWh/m^2/day. The power supply system consists of a 3.5 kWp PV system (32 modules$\times$2 modules in series) and a 600W wind generator, which is used only as backup. A DC-AC power inverter is used to invert the DC power from the battery bank.

Table 12 presents the technical characteristics of the system. A deep cycle battery bank was installed to ensure constant power input to the system. The system, the battery backup and the RO unit are installed in a container. The container is separated into two well-insulated rooms, one for the battery system and the other for the RO unit. An already existing diesel generator was connected to the system for backup purposes, although never used during the entire period of system testing. The control system for an autonomous system must allow an operation in isolated areas where qualified personnel, scarce and remote. That imposed special consideration regarding the design philosophy in order to reach as close as possible a maintenance free system. To ensure water availability in the area several backup systems had been considered, such as the battery bank and the diesel generator.

The battery bank than serving provides 2.5-day battery storage autonomy as an integral part of the main generators.

Two controllers are responsible for autonomous operation of the system. The first is a process controller, which takes care of the water quality and production and is integral part of the RO unit, while the second controller manages the data collection and other control tasks. All the basic parameters of RO operation such as pressure of operation, water quality, etc. are taken care by the controller. If a certain problem persists, the controllers alert the system operator either by audio or visual means. The controllers are connected to an on-site computer, which in turn, is connected to the IEC main computer in Haifa.

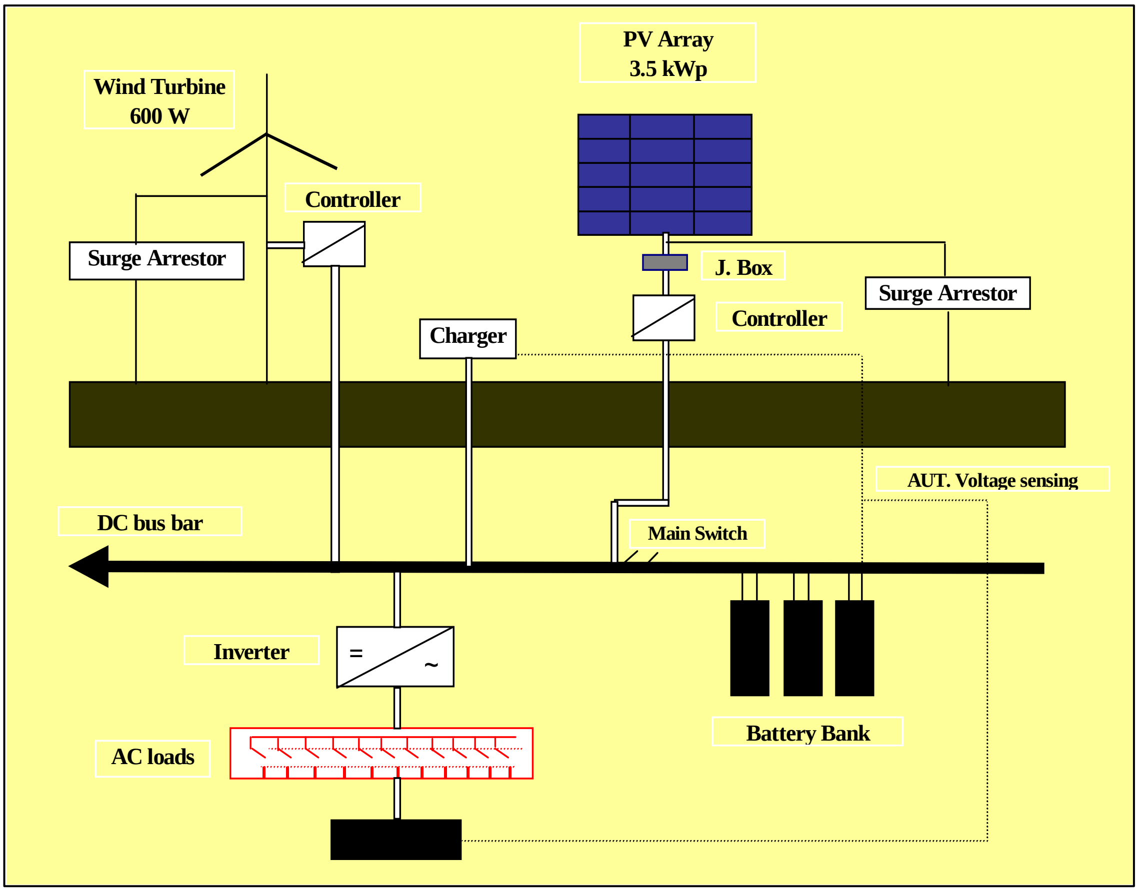


Fig 30 Electrical diagram of the hybrid brackish water desalination system in IEC, Israel

Table 12 Technical description of the system

Equipment	Technical Characteristics
PV array	
Model and nominal power	55 Wp SIEMENS Solar (SM55), Single-crystal flat plate, 3.5 kWp
Configuration	32 parallel ×2 modules in series
Short circuit current, Isc	110.4 A
Open circuit voltage, Voc	43.4 V
Maximum power current Im	100.8 A
Maximum power voltage Vm	34.8 V
Wind Turbine	600 W, WHISPER 600, SouthWest, USA
Battery bank	
Type	Hoppecke lead acid, industrial tubular, deep cycle, type OPZS
Capacity	1500 Ah, 3 strings of 500 Ah
Configuration	24 V (2V×12 CELLS)
Inverter	
Nominal power	3000 W, 1 PHASE
Input voltage range	21-32 Vdc
Output voltage	True sine wave, 230 V, 50Hz
Output current	13A
Input current	140 A
Efficiency	92%
RO unit	
Type	Brackish water
Recovery ratio	50%
Nominal flow	400 l/h
Pressure o operation	14-16 bar
Membrane type	2 spiral wound membranes, DOW
Feed water salinity	4000 ppm TDS
Product water salinity	200 ppm TDS

A special customized code was built to simulate the operation of the system in order to allow appropriate selection of the system components. Site meteorological data were used to enable performance prediction. The code integrates the data continuously to find and compare the instantaneous water level as well as the current associated with the accumulators. Depending on these two variables, a logical decision tree was built in to decide whether the cumulated wind and solar energy can satisfy the energy need of the plant or additional energy should be provided from the auxiliary diesel generator.

c. Experiences and Lessons Learnt

During system's testing no major problems were considered. Concerning components reliability, almost all system components functioned normally after 1.5 years of operation. Concerning PV's performance, any deviation from the promised performance by the manufacturer was mainly due to unsuitable tilt angle at the time of testing. Also, after a testing of the Wind turbine's (WHISPER 600) mechanical and electrical performance has been found that the charger has no signs of fatique. Also, concerning the power output of the wind generator, based on its power curve, the generator displayed 10% less power output in a range of 3-8 m/sec wind speed. This deviation was a fault on the current inhibition of the battery while operating near its saturation level. An added fault was on the side of asymmetric performance of the four chargers. Eliminating the fuzzy-logic option solved this problem. As for the battery bank all 36 individual cells were tested, showing 2.2V and normal water level. A temporary problem arose due to the frequent power failures of the local grid. The problem solved with the installation of a UPS.

	
Pic. 35 General view of the system layout	Pic. 36 General view of the battery room

Pic. 37 View of the RO unit

d. Cost Data

The cost of the water produced has been estimated to about 7.5 ECU/m^3. The economic calculations of the water cost are based on the following assumptions:

System Lifetime:	20 years
Interest rate:	5%
Spare parts & Operating materials	2% of investment
Labor	1000 ECU/year
Membrane replac. + chemicals	0.1 ECU/m^3
Hours of system operation	8 hr/day, 330 days/year

System capital and operational costs are described in the following table:

Costs	Unit
Total investment cost	67.2 KECU
O & M Cost	2445 ECU/year
Total Cost	7955 ECU/year
Total cost of water produced	7.53 ECU/m^3

5. CONCLUSIONS & RECOMMENDATIONS

Keeping in mind the climate protection targets laid down in the Kyoto protocol and strong environmental concerns, future water desalination around the world should be increasingly powered by wind, solar and other clean natural resources. Such environmentally friendly systems are now becoming potentially available at economic costs. [R.Morris, 1999]. The lessons learnt from the installed units have hopefully been passed on and are reflected in the plants currently being built and tested.

As mentioned in the previous chapters the matching of the desalination process to a renewable energy source is technical feasible however is quite complex. Desalination processes are best suited to continuous operation. In contrary the majority of the renewable energy sources are distinctly non-continuous and are in fact intermittent often on a diurnal basis.

Each desalination system has specific problems when it is connected to a variable power system. Reverse Osmosis has to deal with the sensitivity of the membranes regarding fouling, scaling, as well as unpredictable phenomena due to start-stop cycles and partial load operation during periods of oscillating power supply. As it shown in Chapter 4 several RO units with intermittent or not frequent operation have to replace their membranes very often. On the other hand, units, which are, include storage back up system like a battery bank, increase system's initial cost and in hard climate conditions the maintenance requirements. Though, data quantifying battery failure and frequent replacement is not considered.

Another example on the intermittent operation of the desalination systems concerns the vapour compression system. VC has considerable thermal inertia and needs to consume a great deal of energy to get to the nominal working point. Also, scaling problems have been considered due to discontinuous power supply.

There are many other problems involved in coupling a desalination plant to a renewable energy source. As stated earlier, most of the plants constructed to date have been either as research or demonstration projects. With the end of the project most of the systems stop their operation due to limited budget and staff unavailability.

The success of an installation has to do with the quantity and the quality of the produced water, the energy consumption and the final unit water cost. Following basic guidelines such as to choose the correct desalination technology for the required size or for the specific feed water quality (brackish or seawater), are the first steps for the success. The next steps have to do with the design of the RES desalination system, the selection of the proper equipments and the design and development of the control system.

As it is concluded there is much room for the improvement of RES desalination systems. What it is required is to accelerate the development of novel water production systems driven by renewables. In particular there is a need for much stronger effort on R&D and real installations in the Mediterranean area, Middle East and Africa; close collaboration between the R&D institutes and the industry as well as provision of reliable compact RES desalination devices by the market at a reasonable cost. Finally, the acceleration of information dissemination, education and training is also of vital importance.

6. DESALINATION RES PROJECTS

The survey of desalination projects is based on information found via Community Research & Development Information Service (www.cordis.lu) and Middle East Desalination Research Centre (www.medrc.org) as well as other official websites of organisations and the projects. The Cordis database has great potential to bring together the results of EU-funded projects. It has an efficient search engine. However, there are many gaps, especially in information on the participating institutions, the results, which were achieved, and the final conclusions. Moreover, some of the recent projects were not entered in the database. Furthermore, DG Research has no centralised paper archive with the final reports or any other relevant information on the conclusions of the projects. The list of coordinators of the projects was made and the emails were sent in order to ask their contribution in this report by providing basic information on the projects. Scientific papers, which were part of the outcomes of the projects, were used in summarising and writing the report. Web-search of coordinators and projects was made in order to collect the missing information.

First part of the Chapter 6 is concentrated on brief overview of the projects co-financed by the European Commission Programmes, then the main projects developed in the framework of Middle East Desalination Research Centre are analysed and the last section present some the most representative projects which were developed with the high interest of national states or private organisations.

6.1. EU co-financed projects

Table 13 and Figure 32 show the type of the programmes, which supported or support projects on desalination using renewable energy sources. There were selected twenty nine research projects and eighteen demonstration projects which were dealing with the application of solar and wind energy as well as photovoltaics in desalination processes (see Fig.31). The projects were co-financed by DG Energy and Transport and DG Research mostly. The financial share of European Commission varies from 30 % for demonstration projects to 50-75 % for research projects. The biggest share of contractors comes from Southern EU countries

(Spain, Italy, and Greece) where water scarcity problems are the biggest. Most of the applications are dedicated to remote areas (small villages or islands).

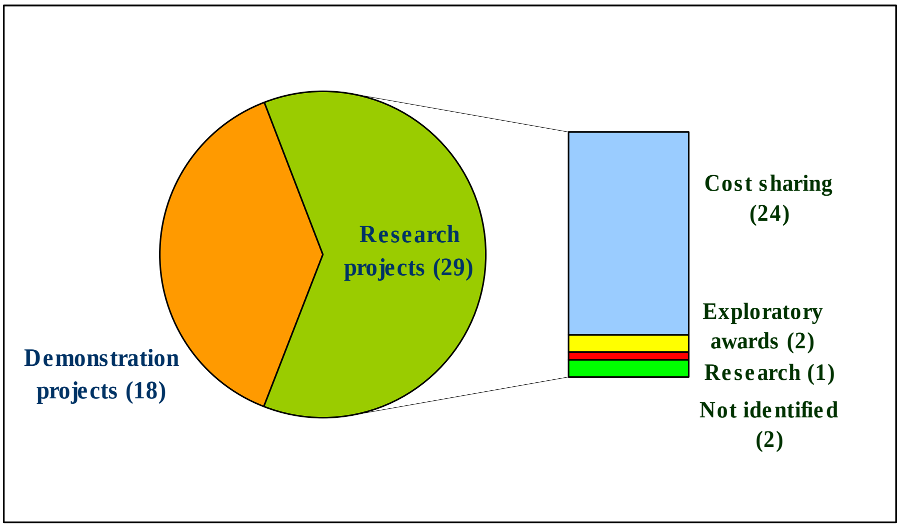


Fig 31 The share of overviewed research and demonstration contracts on desalination using RES

Table 13 EU programmes to finance desalination projects

Title	Programme Acronym	Programme type	Year	Commission Service	Types of contracts
Programme (EEC) of financial support for projects to exploit alternative energy sources	ENALT 1C	Energy programmes (ENG)	1979-1984	Energy and Transport DG	Demonstration; Industrial pilot; Study, assessment
Programme (EEC) of demonstration projects relating to the exploitation of alternative energy sources and to energy saving and the substitution of hydrocarbons	ENALT 2C	Energy programmes (ENG)	1983-1985	Energy and Transport DG	Demonstration; Study, assessment
Programme (EEC) of demonstration projects and industrial pilot projects (EEC) in the energy field	ENDEMO C	Energy Programmes (ENG)	1985-1989	Energy and Transport DG	Demonstration; Industrial pilot
Programme (EEC) for the promotion of energy technology in Europe (THERMIE)	THERMIE 1	Energy Programmes (ENG)	1990-1994	Energy and Transport DG	Demonstration
Promotion of renewable energy sources in the Community	ALTENER 1	Energy programmes (ENG)	1993-1997	Energy and Transport DG	Cost-sharing; Study, assessment
Multiannual programme for the promotion of renewable energy sources in the Community	ALTENER 2	Energy programmes (ENG)	1998-2002	Energy and Transport DG	Cost-sharing; Study, assessment
Competetive and sustainable growth	growth	5th FWP	1998-2002	Energy and Transport DG	Research

Title	Programme Acronym	Programme type	Year	Commission Service	Types of contracts
Energy, environment and sustainable development	EESD	5th FWP	1998-2002	Energy and Transport DG	Research
Research and development programme (EEC) in the field of non-nuclear energy	ENNONUC 3C	1st FWP	1985-1988	Research DG	Cost-sharing
Specific research and technological development programme (EEC) in the field of energy – non-nuclear energy (JOULE)	JOULE 1	2nd FWP	1989-1992	Research DG	Bursaries, grants, fellowships; Coordination of research actions; Cost-sharing; Study; Assessment
Specific research and technological development programme (EEC) in the field of non-nuclear energy	JOULE 2	3rd FWP	1990-1994	Research DG	Coordination of research actions; Cost-sharing
EU preparatory action on renewable energies	RENA	3rd FWP	1994	Research DG	Cost-sharing
Speecific programme for research and technological development, including demonstration in the field of non-nunclear energy	NNE-JOULE C	4th FWP	1994-1998	Research DG	Coordination of research actions; Cost-sharing; Exploratory awards; Exploratory
Specific research, technological development and demonstration programme in the field of cooperation with third countries and international organisations	INCO	4th FWP	1994-1998	Research DG	Preparatory; Coordination of research actions; Cooperative research; Cost-sharing; Exploratory, etc.

Title	Programme Acronym	Programme type	Year	Commission Service	Types of contracts
Regulation (EEC) establishing a financial instrument for the environment	LIFE 1	Environment (ENV)	1992-1995	Environment DG	Demonstration
Financial instrument for the environment	LIFE 2	Environment (ENV)	1996-1999	Environment DG	Cost-sharing
Financial instrument for the environment	LIFE 3	Environment (ENV)	2000-2006	Environment DG	Cost-sharing; Demonstration

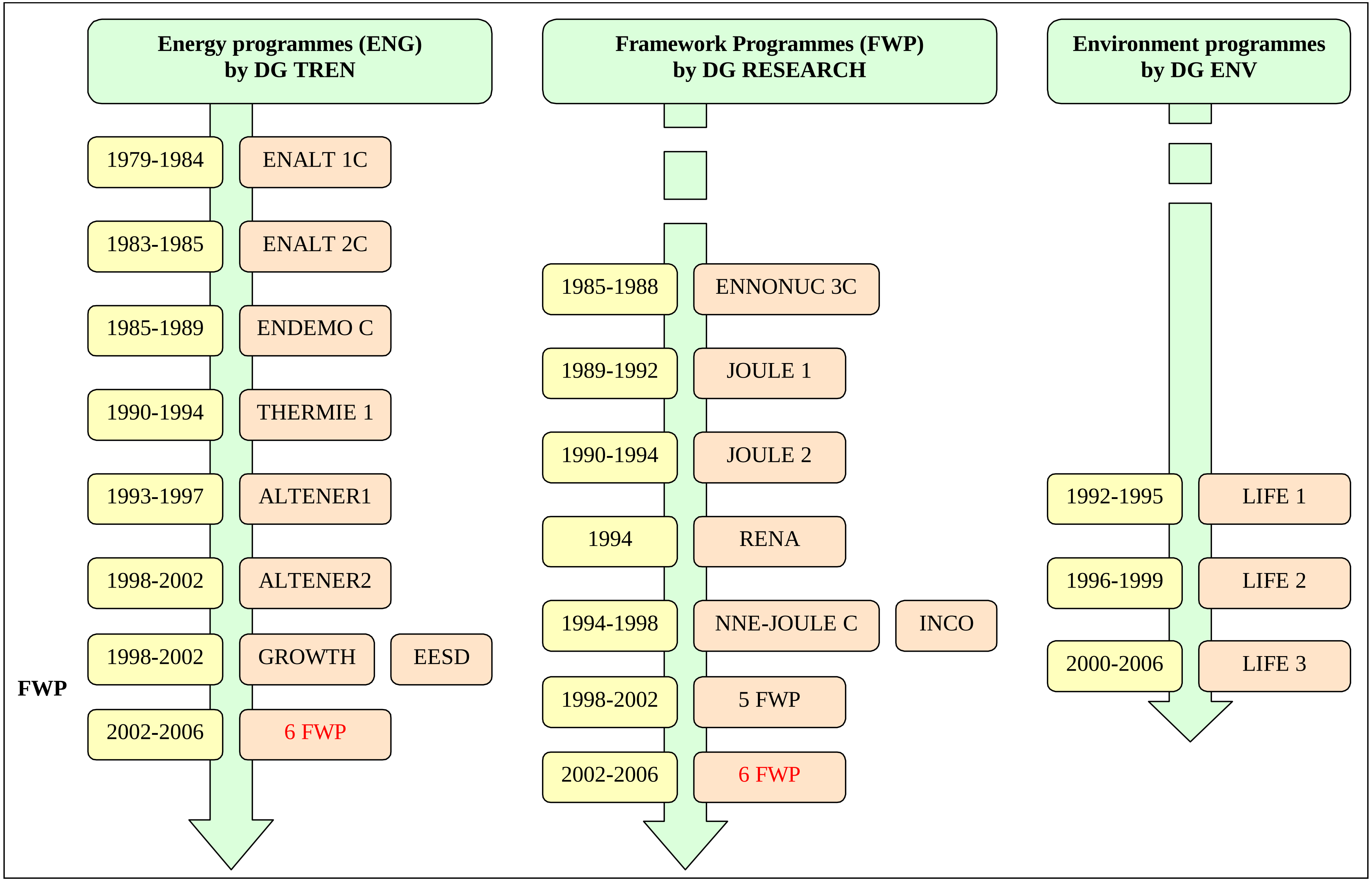


Fig. 32 EU programmes and responsible Directorates to finance projects on desalination using RES

6.1.1. Research / Cost sharing projects

There were selected twenty-nine research projects co-financed by the European Union. Not all of the projects were overviewed in more detail in the report below: some information was not available as they were implemented long time ago.

Not all renewable energy sources were taken into account selecting the project to describe. The project group was interested in PV, solar energy and wind energy driven desalination projects among which solar energy based desalination projects are slightly leading (see Fig. 33). The most recent projects focus on the analysis of all possible desalination technologies and processes while the previous ones were dedicated to solve some particular technical problems using one source of renewables. Moreover, the latest projects are lead by supporting software to simplify the decision making on choosing the best fitted desalination process and RES under the climate, social, economic, financial, etc., conditions of particular region.

Although all the projects selected are research-based projects, most of them are rather specific: innovating to existing (pilot) plants or the tests were restricted to certain conditions in a chosen country or region (see Fig. 34).

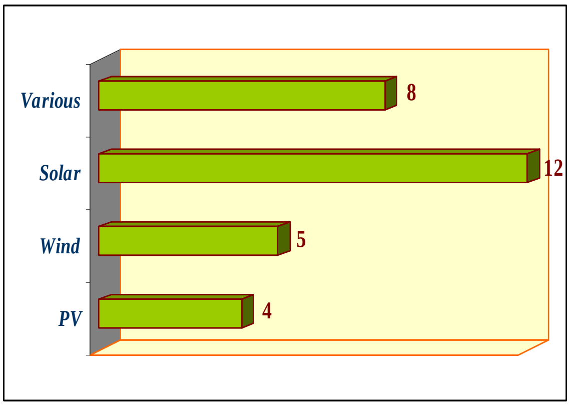


Fig. 33 Type of renewables analysed in the projects

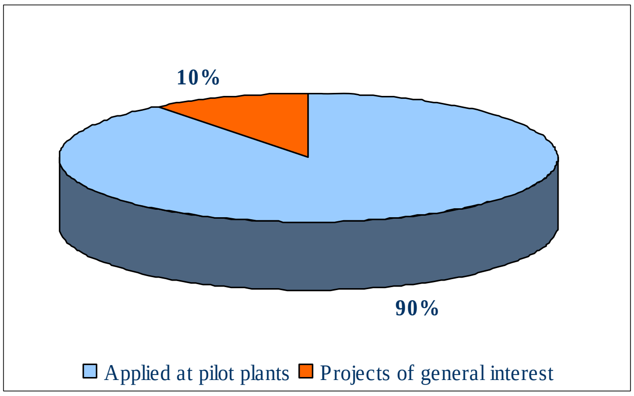
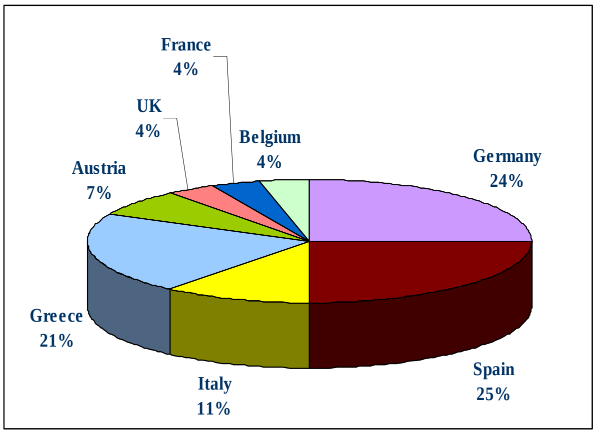


Fig. 34 Specific and non-specific research

Germany, Spain and Greece are the leaders of initiating the research projects (see Fig. 35) though most of them were implemented in the Mediterranean Sea area: Greece, Spain, Italy as well as in some non EU members states such as Jordan, Morocco, Turkey, Egypt (see Fig. 36). Moreover, it can be noted that most of the pilot plants were built in islands and not in interior (about 80 %) and are of small and medium scale.



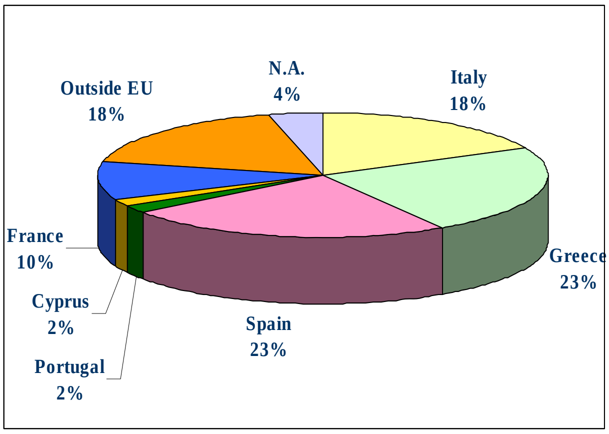


Fig. 35 The origin of the project coordinator	Fig. 36 The countries where the research results were tested or the research itself was applied

6.1.1.1. PV-powered plants

Research projects, which were related to the desalination processes based on photovoltaics energy coupled with, reverse osmosis processes (PV-RO) were focused on one of the biggest problems using this kind of energy – corrosion. The projects overviewed below tried to reduce corrosion of the water pipelines and the plants themselves. The first of three projects from the list below (“Tremiti plant”) tried to eliminate corrosion caused by chlorine sterilisation, by disinfecting the water using anodic oxidation. The second involved pre-conditioning the seawater to avoid corrosion/deposition and the third improved the system for acid injection to avoid acid-induced corrosion.

The improvement of water quality and water storage as well as efficiency increase were the next crucial research areas in these projects. Automation of operation, AC replacement with DC, involvement of electrical motors, pressure pumps and the membranes, etc. were dedicated to solve these problems.

Most of the projects were dealing with existing or pilot desalination plants and tried to improve their lifetime. Most of the plants designed/renovated/constructed in the framework of the projects were small or medium sized stand-alone ones.

Table 14 PV-powered projects

Title	Year	Reference No.	The basic features of the project
Tremiti island desalination plant	1988-1989	EN3S0132	*Type of RES:* PV-RO *Specific aims of the project:* Technological improvements; Water storage optimisation *Plant:* Tremiti island, Italy *Capacities:* 65 kW *Type:* grid-connected
Improvement of the PV reverse osmosis desalination process	1991-1994	JOUR0115	*Type of RES:* PV-RO *Specific aims of the project:* Modernising membranes-chemical pre-treatment; Optimisation of energy flows and savings *Plant:* Tremiti island, Italy *Capacities:* 65 kW *Type:* grid-connected
A new photovoltaic desalination plant	1992-1994	JOU20061	*Type of RES:* PV-RO *Specific aims of the project:* PV-RO membrane efficiency *Plant:* Tremiti island, Italy *Capacities:* 100 kW *Type:* grid-connected
Development of stand-alone PV power system for remote villages, making use of pumped water energy storage: an intelligent integration of a PV power system in a remote village with partial central and partial de-central PV power supply	1992-1996	JOU20155	*Type of RES:* PV-RO *Specific aims of the project:* Coupling PV desalination plant with storage system in order to provide 24 h functioning *Plant:* Cyclades islands, Greece *Capacities:* 18 kW; 144 m^3/d *Type:* stand-alone

Project title	Tremiti island desalination plant
Project acronym	-
Project Contract No.	EN3S0132
Name of Programme	ENNONUC 3C, 1 FWP
Contract type	Cost sharing
Year of development	1988-1989
Contractor / Responsible	Italsolar, Italy Fulvio Fonzi

Project title	Improvement of the PV reverse osmosis desalination process
Project acronym	-
Project Contract No.	JOUR0115
Name of Programme	JOULE 1, 2 FWP
Contract type	Cost sharing
Year of development	1991-1994
Contractor / Responsible	Italenergie SpA, Italy

Project title	A new photovoltaic desalination plant
Project acronym	-
Project Contract No.	JOU20061
Name of Programme	JOULE 2, 3 FWP
Contract type	Cost sharing
Year of development	1992-1994
Contractor / Responsible	Italenergie, Italy Fulvio Fonzi

Short description and achievements of the projects

The 65kW$_P$ photovoltaic-RO desalination plant of Tremiti islands was realised in 1984 in the framework of DG XII pilot project. The adopted criteria for dimensioning the plant was that one of stocking the water produced with the solar energy during spring and autumn time to cover the water need of the island Saint Nicola in tourist period and in winter time. The 4 operating years of the plant have shown some weaknesses, which have to be eliminated within the later projects.

The plant was not automated fully, the plant itself and water pipe lines face troubles with corrosion, water storage and the capacity of the batteries did not satisfy the demand and the expectations.

The following projects were focused on improvement of the above described PV-RO desalination plant.

The first project (EN3S0132) was related to automation of the plant as well as technical improvements of PV-RO desalination plant[4]:

- Automation of the operation of the plant completely;
- Replacement of alternating current (AC)-motors with direct current (DC)-motors, elimination of the present inverters. The changes had to result the increase of efficiency of the plant. A new kind of inverter, developed by the solar energy institute of the Fraunhofer-Gesellchaft was tested;
- Sterilisation and disinfection of the produced drinkable water using anodic oxidation, by eliminating any kind of chlorine products, which have caused a deep corrosion of the plant and the water pipe line;
- Increasing the seasonal water storage, the capacity of the batteries and the photovoltaic field to match the increased water demand fluctuation of the island.

The following project (JOUR0115) sought to employ the existing plant at Tremiti for the development of a new generation of PV desalination technology taking into consideration that it was of high interest for further application of photovoltaics to improve the desalination process and the plant performance[5].

R&D aims, which were set by the co-ordinator were the following:

- Inclusion of the latest membrane technology into the system;
- Energy recovery from the high-pressure fluid at the membrane outlet;

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4 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=318882&CFID=3638434&CFTOKEN=26586724

5 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=254495&CFID=3638434&CFTOKEN=26586724

- Improving power conditioning system and particular new inverters and converters;
- Modification of the battery system;
- Optimisation of the over all process and in particular the optimised feeding of the membrane system (optimised desalination pressure over time);
- Conditioning of the inlet water to avoid corrosion, improvement of the over all efficiency and elimination of the chemical treatment of water which complicates the process at present: temperature increase of the inlet water, electrical charging.

The third project (JOU20061) initiated a new desalination plant of 100 kWp. The assessment of the feasibility of such a desalination plant was made in the framework of the project[6].

Italenergie Spa was present since the beginning (1979) in developing and testing the reverse osmosis process energized by a photovoltaic current generator. Apart from reducing energy consumption in the reverse osmosis plant, there were found other possibilities to reduce energy consumption in solving other problems connected to the water pre-treatment steps. The acidification pre-treatment of the sea water involved the use of electrical motors to inject and dose the acids and a very short lifespan of all the components touched by the affected solutions, above all the high pressure pumps and membranes. As the main efforts of the producers of reverse osmosis plants were and are mainly in the pressure pumps and in the membrane development, Italenergie concentrated its efforts in the solution of the seawater pre-treatment and fresh water after-treatment, always with the aim to improve the water quality and to reduce the energy absorption. The experimental results had to be transferred in a new conceived plant near a new photovoltaic current generator of 100 kWp realized by the Commune of Tremiti Islands, which was supposed to work in parallel with the already existing 65 kWp. The reverse osmosis has a rate of 6 m^3/h of desalinated water. The input of seawater, considering a filtration efficiency of the membrane of 42%, was expected to be ~14 m^3/h.

[6] http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=261603&CFID=3638434&CFTOKEN=26586724

Note: As the projects were implemented long time ago, it was difficult to find any additional comments on the results of the projects described above.

Project title	Development of a stand-alone PV power system for remote villages, making use of pumped water energy storage: an intelligent integration of a PV power system in a remote village partial central and partial de-central PV power supply
Project acronym	-
Project Contract No.	JOU20155
Name of Programme	JOULE 2, 3 FWP
Contract type	Cost sharing
Year of development	1992-1996
Contractor / Responsible	Engineering and Computing Applications SA, Greece Spyros Kyritsis

Short description of the project

Photovoltaic power plants are an attractive option for supplying electrical power to remote areas, but require an energy storage system to cover nighttime, cloudy weather and peak time power demands. One storage system-micro PV-hydro technology - uses excess daytime-generated power to pump water uphill to reservoir tanks. Later requirements for electricity are met by piping the water back downhill through a turbine driven generator. Pumped water represents a simpler and more reliable means of storing energy than lead-acid batteries and has associated benefits.

The main objectives of the project were the following: to develop and install a stand-alone PV plant with an optimum combination of centralised and decentralised PV generator for energy supply in remote villages.

Innovative aspects and conclusions of the project

The system design and operation was optimised using a *plant energy management model*, which allows the simulation of the operation of all the constituent components and prediction of their combined performance.

Input data for the model take the form of local solar radiation and temperature statistics. The village electrical load profiles for winter and summer were also estimated. The regulator action of distributing DC power between PV array, batteries, and inverter was simulated, as was the performance of the inverter in converting DC to AC. The pump and turbine efficiency characteristics were allowed for in the energy management model; together with pipeline effects such as resistance to water flow. Use of this model at the design stage allowed the optimal sizing of components to ensure high system efficiency. Without the model, the system could only have been designed to the best efficiency point of individual components. This would not give the best overall system efficiency. The model, coupled with system monitoring, ensures that the plant consistently operates at the highest overall efficiency possible. Modeling can be applied to any location, given appropriate local data.

A computer model of a PV-hydro system has been developed to optimise the design and control of micro PV-hydro systems and it was used in the design and testing of two pilot systems, located on remote Cyclades islands (Greece).

Table 15 Main characteristics of PV-hydro system

The main components of a micro PV-hydro system	Details and providers of the components
PV panels	The PV array of 18kW peak is made up using 300 France PHOTON 60Wp PV panels
water pump (which also functions as a generator, running in reverse when stored water is released)	-
water turbine	-
power regulating equipment (to convert direct current (DC) from the PV panels and turbine to alternating current (AC) for the pump and village loads)	Siemens (Germany) supplied the 7.5kW DC generator for the water turbine
water storage reservoirs	Two 150m^3 water reservoirs, 100m apart in height
a *system logic controller*	Supplied by Siemens

Testing the pilot systems demonstrated their ability to meet the basic requirement of supplying electricity needs reliably, cleanly and at a realistic cost. The investment cost of the installed stand-alone system is considerably high. The expenditure rises due to the high cost of civil works (water reservoirs) and also due to lack of accessibility (need for road construction) and to high cost of materials transportation. On the other hand, the economical and social impacts derived from the installation of such stand-alone systems are of great importance (both electricity and water supply) because economical and social development is associated to the infrastructure. Under such circumstances the high investment cost is of minor importance.

Pic. 38 The water storage reservoir in the photovoltaic field at Donoussa Island

The installations made in the framework of JOULE project were used continuously to satisfy the demand for electricity and water supply in the islands. Later on the PV plant was renovated[7]: The battery storage was partially replaced by a micro-hydraulic system to increase the efficiency, minimise energy losses and decrease production costs.

6.1.1.2. Direct solar-powered plants

Many research projects were dedicated to the use of solar energy in desalination processes. It is one of the oldest technologies to desalinate water but one of the most complicated and the most expensive as the productivity depends on the area of solar collectors. Therefore the cost of collectors is very important, and many projects indicated this aim as one of the most important parts of their projects. For sure, the solutions varied a lot though most of them were trying to find new cost-effective plant components and equipment (SOLDES, EuroTrough, JOR3950003, etc.).

[7] D. Manolakos, G. Papadakis, D. Papantonis, S. Kyritsis. A stand-alone photovoltaic power system for remote villages using pumped water energy storage. Energy 29 (2004), pp. 57–69.

SOLDES project (IC18980265) developed polycarbonate plate with dark aluminium strips in order to reduce the costs. Although the costs were reduced, they came up with new proposal to use stone, aluminium strips and polycarbonate plates in order to reach higher savings in manufacturing the collectors. They refused to use steel as it has lower resistance against sea climate. Despite these innovations, their product still was not able to compete with the price of potable water desalinated using conventional fuel.

EuroTrough (JOR3980231) and EuroTrough 2 (ERK-CT-1999-00018) projects were focused on the developing of lightweight construction of the parabolic trough collector in desalination. It increased the temperature range of applications to 200-400^oC. The proposed solutions as well as simplification of design, improvement of the optical performance, etc. helped to reduce the costs of the collector and the final product - water.

Solar production of process heat in the temperature range of up to 150^oC holds a very high potential to substitute high amounts or fossil energy. The solar collectors suitable for the desired high temperatures are vacuum tube collectors. The next described project (JOR3980293) was aiming to reduce the cost via lower energy consumption. They tested vacuum vapor compression unit to operate the system, which achieves energy consumption less than 10 kWh/m^3. The design of the desalination plant was also orientated towards cost reduction.

However, there is a range of possibilities to improve the efficiency of flat plate collectors, avoiding the expensive vacuum technology: - concentration of the radiation using CPC mirrors - convection barriers - highly selective coatings - inert gas filling - low pressure filling.

First approximations show that a combination of these techniques yields efficiencies for non-vacuum solar collectors higher than 50% for temperatures up to 150^oC. In the proposed project (JOR3961005, JOR3977001), the effects of these improvements were evaluated.

SODESA project (JOR3980229) aimed to develop corrosion-free solar collectors for the desalination plant, which would be able to work 24 hours. The proposed zigzag reflector, polymer materials were used in order to reduce corrosion, corrosion-free absorbers, but the costs was high due to chosen expensive materials.

The following projects (AQUASOL and MEMDIS) were focused on solar multi-effect distillation and membrane distillation technologies, respectively. Apart from scientific innovations in increasing of current performance ratio via inclusion of a double heat pump and reduction of process discharge to zero (AQUASOL), the projects aimed to increase the efficiency of the processes and reduce the costs of produced water. MEMDIS project concerns with the development of two prototypes to test the operation of the hydrophobic membranes: a compact system (150 l/d) and a large system (2 m^3/d). The compact system is operating since December 2004 while the large system will start up in January 2006. Both installations will be installed at the ITC facilities.

Fraunhofer ISE, the main coordinator/project partner of AQUASOL and MEMDIS, continues the research (SMADES) in developing membrane distillation components and systems for small-scale, stand-alone desalination plants. MEMDIS and SMADES are still ongoing projects so final results cannot be provided.

Table 16 Direct solar projects

Title	Year	Reference No.	The basic features of the project
CPC collector for high temperatures	1996-1997	JOR3961005	*Type of RES:* Solar *Specific aims of the project:* to develop a high temperature solar collector that allows lower production costs than evacuated solar collectors
CPC-Collector for high temperatures	1998-2000	JOR3977001	*Type of RES:* Solar *Specific aims of the project:* to develop a high temperature solar collector that allows lower production costs than evacuated solar collectors
A novel high efficient solar collector for desiccative and evaporative cooling (CODEC)	1996-1998	JOR3950003	*Type of RES:* Solar *Specific aims of the project:* The development of a low-cost solar collector with new materials and a novel absorption method, also suitable for heat production for modular desalination and water purification plants *Test plant:* under Portuguese climate conditions
Solar thermal electricity in the Mediterranean: feasibility study for integrated solar	1995-1996	RENA940014	*Type of RES:* Solar *Specific aims of the project:* Improvement and the cost reduction of

combined cycle systems for electricity production with parabolic troughs in the Mediterranean area			Direct Solar Steam generation with large parabolic trough collector field *Test plant:* Plataforma Solar de Almeria, Spain
Development & optimization of a new process for desalination of sea water by means of solar energy (SOLDES)	1998-2003	IC18980265	*Type of RES:* Solar *Specific aims of the project:* The use of heating air flow for humidification of seawater *Test plant:* indoor test plant, Germany *Capacities:* 10 m^3/d *Cost*: 51.2 €/m^2 *Type:* stand-alone
Development of a low cost European desalination and process heat collector (EuroTrough)	1998-2001	JOR3980231	*Type of RES:* Solar *Specific aims of the project:* Developing of Solar Trough Collector for a wide applications in 200-400°C; Cost reduction *Test plant:* Plataforma Solar in Almeria, Spain *Capacities:* 549.000m^2, 50 W *Cost*: 200 €/m^2 *Type:* depends on a concrete plant
EuroTrough II – extention, test and qualification of a full scale loop of eurothrough collectors with direct steam generation (EuroTrough 2)	2000-2002	ERK-CT-1999-00018	*Type of RES:* Solar *Specific aims of the project:* Developing of Solar Trough Collector for a wide applications in 200-400°C; Cost reduction; Commercialisation *Test plant:* Plataforma Solar in Almeria, Spain *Capacities:* 549000m^2, 50 W *Cost*: 200 €/m^2 *Type:* depends on a concrete plant
Solar VVC desalination plant	1998-2001	JOR3980293	*Type of RES:* Solar *Specific aims of the project:* Prototype solar desalination plant which is competitive in the market; Commercialisation *Test plant:* n.a. *Capacities:* 750m^3/d *Cost*: 2$/$m^3$ *Type:* depends on a concrete plant
Solar-thermally driven desalination system with corrosion free collectors and 24-hours-per-day storage (SODESA)	1998-2001	JOR3980229	*Type of RES:* Solar *Specific aims of the project:* Corrosion free solar collectors *Test plant:* Fraunhofer ISE, Germany Pilot plant: Pozo Izquierdo, Gran Canaria Island, Spain *Capacities:* 600m^3/d *Cost*: 25€/m^3 *Type:* stand-alone
Enhanced zero discharge seawater desalination using hybrid solar	2002-2006	EVK1-CT-2001-00102	*Type of RES:* Solar *Specific aims of the project:* The development of a seawater desalination

technology (AQUASOL)			technology based on *multi-effect distillation* that is energy efficient, low-cost and has a zero discharge *Test plant:* Pozo Izquierdo. Gran Canaria Island, Spain *Capacities:* 7600m^3/d *Cost*: n.a. *Type:* stand-alone
Development of stand-alone, solar thermally driven and PV-supplied desalination system based on innovative membrane distillation (MEMDIS)	2003-2006	NNE5/819/2001	*Type of RES:* Solar-PV *Specific aims of the project:* The development of stand-alone desa-lination system which is based on highly innovative membrane distillation technology *Test plant:* Pozo Izquierdo. Gran Canaria Island, Spain *Capacities:* 0.15 m^3/d; collector 6m^2, PV 1m^2, *Cost*: n.a. *Type:* stand-alone
PV and thermally driven small-scale, stand alone desalination systems with very low maintenance needs (SMADES)	2003-2005	ICA3-CT-2002-10025	*RES:* Solar-PV *Specific aims of the project:* The development of stand-alone desalination system which is based on highly innovative membrane distillation technology *Test plant:* Several locations (Jordan, Egypt and Morocco) *Capacities:* ranging from 0.2 to 20 m^3/d *Cost*: n.a. *Type:* stand-alone

Note: The projects marked in bold are described below in more details

Project title	Development and optimisation of a new process for desalination of sea water by means of solar energy
Project acronym	SOLDES
Project Contract No.	IC18980265
Name of Programme	INCO, 4 FWP
Contract type	Cost sharing
Year of development	1998-2003
Contractor / Responsible	Ruhr-Universität Bochum, Germany / Efat Chafik

Short description of the project

The central idea of the project is to use the sun for heating and to humidify that hot air by contact with seawater. The main issue of the actual investigation is a new process of seawater desalination using solar energy and turning away from merely heating or evaporating of the seawater itself as the main idea for water separation is the stepwise loading of air by vapor. The process consists of several steps for air heating, each followed by a humidification stage. This manner of operating makes it possible to obtain high vapor concentration in the airflow, thus reducing the airflow rate through the plant.

Innovative aspects and conclusions of the project

The use of solar energy as an economic source for the realisation of large-scale industrial seawater desalination is still unattainable. One of the main problems is the need for expensive solar collectors to cover large areas to collect solar energy. This is a natural sequence of the limited solar insolation flux and the high heat amount needed to evaporate water.

This project presented a new way to solve this problem. It was an approach towards a seawater desalination method using simple and cost-effective plant components and equipment. A substantial investment reduction can be realised using air as a heat carrier and keeping the maximum air temperature less than 100°C. Following a humidifying step, the moderately heated air can be humidified by injecting seawater into the air stream. This process was previously published as a German patent.

A main point for developing the new process was to design equipment specifically needed for solar air heating, humidifying of heated air by contact with seawater and for extraction of desalted water from humid air.

In order to minimise the costs of the used collector, new type of solar collector was generated based on the following selection criteria:

- Minimum ratio of price to efficiency;
- Maximum life-time;
- Resistance against sea climate (no steel);
- Simple design to be manufactured in developing countries

New developed collector consisted of a polycarbonate plate with inserted dark aluminum strips. The end price of the collector could be about 51.2 €/m^2, which includes the connecting pipes and is about 50% of the comparable commercial collectors. But it was concluded that the price is still not competitive and new construction of the collector is proposed using stone, aluminum strips and polycarbonate plates. Using the solar collector, which was described above, the following research was concentrated on the use of the sun for heating airflow and to humidify hot air by contact with seawater. After loading the airflow by a large amount of vapor, the water content can be easily recovered by cooling the humid air in dehumidification equipment. A main feature of this desalination process is to conduct the heating/humidifying procedure in several stages in order to load the air with a high amount of humidity and to reduce the volume of circulating air.

Several pieces of equipment had to be developed in order to use this desalination process. Suitable and economic collectors, humidifiers and dehumidifiers were designed, manufactured and tested.

Based on the theoretical and experimental work that was carried out on the dehumidifier, the following criteria should be met for the heat recovery heat exchangers and the dehumidifier for air dehumidification in the new desalination process:

- The heat exchanger tubes, elbows and other parts coming in contact with seawater must be constructed of the proper material to withstand seawater corrosion, such as CuNi 90/10.
- Fins should be made of aluminum or copper.

- Frames and casing of the heat exchanger should be made of stainless steel 304L.
- The heat exchanger must be equipped with a condensate-collecting basin also made of stainless steel 304L.
- Special care should be given in the construction to avoid any non-condensed vapor leakage through the heat exchanger without passing through the finned coils.
- Any condensate leakage from the condensate-collecting basin is not allowed since it is a direct loss of product (water).

This new desalination process was developed and the investigation brought the following results: The applicability of the process could be verified and tested in an indoor pilot plant in Germany. There the process could be used and optimised under scientific conditions. Furthermore, an outdoor pilot plant could provide desalted water by running the new process under Mediterranean conditions.

All required equipment was developed, manufactured and tested in Greece and in Germany. The design, prediction and optimisation of collectors, humidifiers and dehumidification equipment could be worked out. Methods for process calculation and optimisation were developed and tested.

Methods for energy optimisation as well as the optimum economic conditions of the process could be developed and investigated.

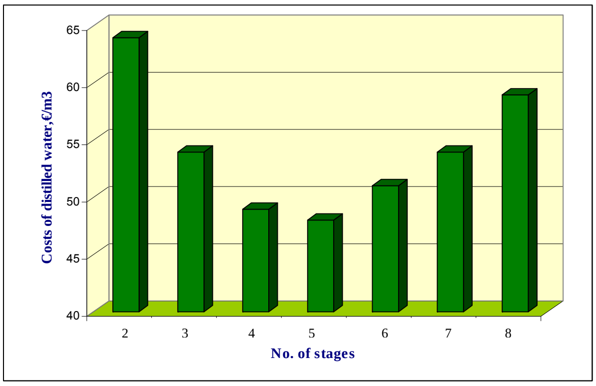

Fig. 37 Specific costs of distillate production under varying stage numbers with capacity around 10 m^3/d, A_K=5000m^2, Coll.No.5

Using the above-mentioned results, a complete process design and an engineering background could be provided to construct a desalination plant using the new process for production of 10 m^3/d potable water[8]. The results of that investigation provided a first approxima dependency of these costs on the number of stages is shown in figures.

[8] Chafik E. Design of plants for solar desalination using the multi-stage heating/humidifying technique. Desalination 168 (2004), pp. 55-71. / Chafik E. A new type of seawater desalination plants using solar energy. Desalination 156 (2003), pp. 333-348 / Chafik E. A new seawater desalination process using solar energy. Desalination 163 (2002), pp. 25-37.

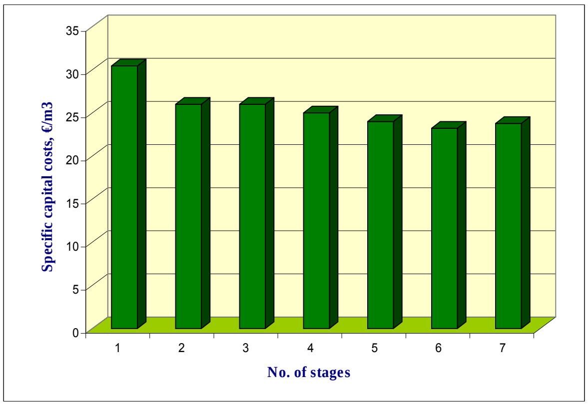

Fig. 38 Specific capital costs of distillate production under varying stage numbers with capacity around 10 m^3/d, A_K=5000m^2, Coll.No.5

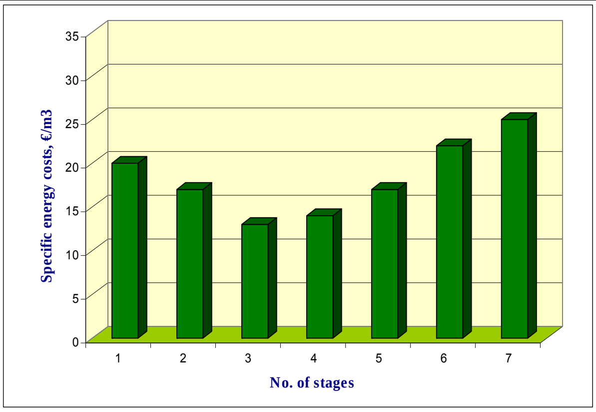

Fig. 39 Specific energy costs of distillate production under varying stage numbers with capacity around 10 m^3/d, A_K=5000m^2, Coll.No.5

The above shown water prices do not yet include any additional measures for enhancement of the plant's economy. However, the figures presented herein qualitatively present the influence of the number of heating/humidifying stages on specific costs. It can be seen that the specific capital costs are less dependent on the number of stages and that the specific energy cost is at a minimum with four or five stages. The process flow sheet of the plant producing 10m^3 is shown in Fig.40. These figures are the end result of the SOLDES project.

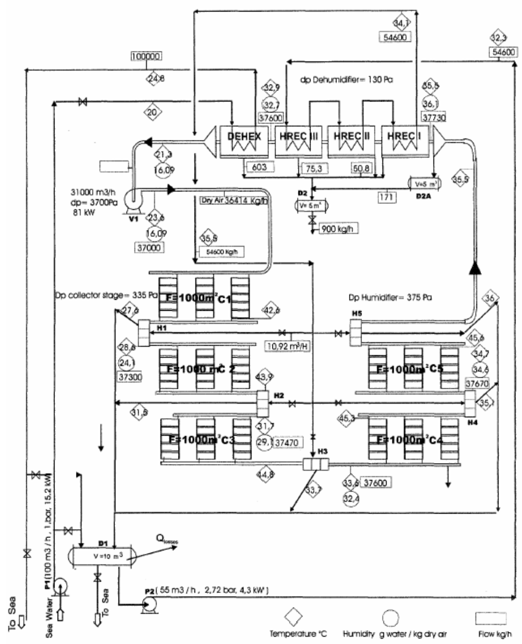

Fig. 40 Process flow sheet for a 10m^3 plant at 510 W/m^2 mean insolation value

Project title	Development of a low cost European desalination and process heat collector (1st stage) Eurotrough II – extension, test and qualification of a full scale loop of eurothrough collectors with direct steam generation (2nd stage)
Project acronym	EuroTrough EuroTrough II
Project Contract No.	JOR398023 ERK-CT-1999-00018
Name of Programme	NNE-JOULE C, 4 FWP EESD, 5 FWP
Contract type	Cost sharing Cost sharing
Year of development	1998-2001 2000-2002
Contractor / Responsible	Instalaciones Abengoa SA, Spain. Rafael Osuna Instalaciones Inabensa SA, Spain. Pedro Robles Sanchez

Short description of the project

The work targets collector development for a wide range of applications in the 200 - 400°C temperature range in solar fields up to the hundreds MW range. The works are mostly done within 2 main projects co-financed by the EU and some other ones (DISS I (JOR3CT950058 and DISS II (JOR3CT980277) which were focused on improvements of the collector more than on application of it in desalination plants.

The new EuroTrough design: -Incorporates newest features in lightweight construction, drive technology, control technology and concentrator technology with collector weights below 30kg/m²;

-Views the aspects of a mass manufacturing, transport and assembly concept, that allows the economic implementation of parabolic trough collectors for electricity generation, desalination and process heat applications;

-Will achieve the largest automation of operation;

-Enables for the minimization of operation and maintenance requirements;

-Reduces solar collector costs below 200 €/m².

Application of the parabolic trough collector in desalination is just one field of possible application of technology:

- Solar thermal electricity generation in co-generation plants
- Solar thermal process heat applications in a wide range of process steam

- Solar thermal seawater desalination in MED processes

Innovative aspects and conclusions of the projects

The high-performance EuroTrough parabolic trough collector models ET100 and ET150 have been developed for the utility scale generation of solar steam for process heat applications and solar power generation[9]. With corresponding receiver tubes they can be used in combination with various heat transfer fluids in large solar fields. With an optical concentration of 82:1 operating temperatures over 500°C may be reached. The ET100 and ET150 structure geometry has included wind channel and finite element method validation and is compatible with the standard receiver tubes and mirror panels of the market. The loop and field concept is also fully compatible with the proven solar field technology of the successful Solar Electric Generating Systems (SEGS) in California and can be integrated to field sizes for up to 200 MWel solar plants. The collector modules have been fully qualified in the years 2000 – 2002 with a synthetic heat transfer fluid for 395°C operation at the Plataforma Solar in Almeria (PSA) with independent performance test certificates from the research laboratories. 14% solar field cost reduction is anticipated due to weight reduction and collector extension to 150 meters. A 50 MW solar power plant with 549 000 m^2 of EuroTrough collectors and 9h-thermal storage is projected for South Spain. The EuroTrough collector behaviour for incident angles of more than 30° is more efficient than the LS-2 collector. This is due to the larger collector module, higher geometric precision of the parabola, and less shading due to improved absorber support design. The new model of absorber tube – the UVAC (Universal vacuum collector, SOLEL), has the same external size and shape as the previous model (HCE), but higher performance and better durability. More details of the achievements within the project are presented in the table below.

EuroTrough characteristics

Layout	parabolic trough collector
Support structure	steel frame work, pre-galvanized, three variants; light weight, low torsion
Collector length	12 m per element; 00 - 150 m collector length
Drive	hydraulic drive
Max. wind speed	operation: 14 m/s, stow: 40 m/s

[9] E. Lupfert et al. EUROTrough design issues and prototype testing at PSA. Proceedings of Solar Forum 2001. Solar Energy: The power to choose. April 21-25, 2001, Washington DC.

Tracking control	clock + sun sensor, <2 mrad
Parabola	$y = x^2/4f$ with f = 1.71 m
Aperture width	5.8 m
Reflector	4 glass facets
Absorber tube	evacuated glass envelope, UVAC® or other, application dependent
Fluid	oil, steam, application dependent
Cost	< 200 Euro/m^2

Pic 39 The EuroTrough collector prototype tested at PSA has currently four, later six - collector elements to one side of the hydraulic drive

The following *cost reduction potentials* were exploited[10]:

1. Cost reduction by simplification of the design: less different profiles, parts, better transportation; assembly concept; cost reduction by weight reduction of the structure; frame work structure, closed profiles, corrosion protection; finite element method for structural design calculations; wind analyses for proper definition of the load cases.
2. Cost reduction by improvement of the optical performance of the collector: rigid support structure; frame work torque box; manufacturing, assembly accuracy.
3. Cost reduction achieved in additional steps: possible tilt of the collector and extension of collector length per drive unit (ET150).

[10]Geyer M. et al. EuroTrough-parabolic Trough collector developed for cost efficient solar power generation. 11th Int. symposium on Concentrating solar power and chemical energy technologies, September 4-6, 2002 Zurich, Switzerland.

The anticipated overall cost reduction for the solar field was 14% for ET150 collectors. Additional reduction of solar electricity cost was achieved by the higher annual performance due to improved optical parameters.

Table 17 Basic features on the project plant

1. Detailed EuroTrough design including procurement specifications, manufacturing drawings, assembly drawings and operating instructions for the full size collector	Detailed technical description and specifications of all components of the new Solar Trough Collector Design; Detailed results of the structural behaviour of the new structure under all operation conditions by FEM calculations; Construction and workshop drawings of all collector parts; Design drawings of all required collector manufacturing jigs; Design drawings of the collector field assembling and erection jig as far as assembling procedures and required tools.
2. Full size prototype of half a 100m EuroTrough Collector Module.	Heat transfer loop with Thermal Oil Syltherm 800 (silicone oil) for operation up to 400°C; Plant components pump, cooler, expansion vessel; Measurement and control systems for temperature, volume flow, pressure, power, local controller; A parallel reference collector.
3. Solar Process Heat Market Assessment.	Industrial process heat is mainly used in the 80 – 150°C temperature range. There is another major use at temperature above 300°C, this is mainly in the metal sector. Collector performance mainly depends on how high the operating temperature is above ambient and the intensity of the incident radiation. Without concentration collector performance drops drastically for higher temperatures. For Industrial process heat application a concentrating collector like the Eurotrough is required.
4. Parabolic Metallic Reflector Design Concept.	Theoretical study of structural behaviour of small (1.2m aperture width) metallic collector with very thin metallic foil (<0.2mm thickness) under stress and non-stretched thin metallic sheet (0.5mm thickness); Two small prototypes: one with stretching technology (1.2 m aperture, 2.4m long) and other with non-stretching technology (1.2m aperture, 3.2m long); Optimised procedures in assembly processes for both technologies, assuring a good enough optical quality.
5. Tracking Control Concept.	Detailed tracking control design, with the optimisation in local control (electronic circuitry, communications, cost), optical encoder selection and solar vector mathematical algorithm; Construction of one tracking control unit and assembly in Euro trough loop at PSA; Detailed design of a structural testing device to evaluate collector twisting for different daytimes.

Implementation. The industrial EuroTrough partners are prepared to offer solar fields with the EuroTrough collectors ET100 and ET150 on a turn-key basis to utilities, IPP developers and process heat users; they have been prequalified with EuroTrough solar field offers for the Integrated Solar Combined Cycle projects in Mathania (India) and Kuraymat (Egypt). EuroTrough solar field cost depends on field size and specific site. For a first of ET150 solar field with at least 500 000 m^2 in Southern Spain, the EuroTrough partners count with solar field cost of 206 €/m² including HTF system and installation.

The project led to new contracts in Southern Spain. Applying all the achievements it was expected to reach Levelized Electricity Costs (according to the IEA method) of 0.15 €/kWh for this project. Series production cost of the total collector installation below 200 €/m^2 of aperture was anticipated.

The main challenges for the EuroTrough technology are electricity generation, and process heat in a wide temperature range, including desalination.

Project title	Solar VVC desalination plant
Project acronym	-
Project Contract No.	JOR3980293
Name of Programme	NNE-JOULE C, 4 FWP
Contract type	Cost sharing
Year of development	1998-2001
Contractor / Responsible	Solargen (Europe) Ltd, UK Jeffrey Kenna

Short description of the project

Many attempts have been made at developing commercial solar desalination systems but the project initiating group didn't see any of them being materialised. The reason for this is that while technical options have been demonstrated they are too complicated or too expensive to compete with fossil fuel systems.

The objective of this project is to design and build a prototype solar desalination plant that will be commercially viable and produce water at rather low costs[11].

11 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=3333703&CFID=3625287&CFTOKEN=64718024

The project tasks comprised:

- Modification and testing of vacuum vapor compression (VVC) unit to operate on steam.
- Design and testing of the heat transfer system (receiver, storage and boiler).
- System optimisation.
- Final design and construction.
- Commissioning and monitoring.
- Integration issues.

Innovative aspects and conclusions of the project

The technical approach taken was to use a desalination technology that has the lowest energy consumption and combine it with a solar thermal system that produces the least cost energy that is compatible with the desalination technology:

- a commercially available VVC desalination system which is normally electrically powered was converted to run on steam at 25 bar pressure. Mechanical energy consumption could then be reduced to below 10 kWh/m^3;
- a fixed mirror concentrator and a tracking receiver will provide thermal power for the desalination unit. An annual solar-steam energy efficiency of 43% was calculated.
- The system can operate in solar only or hybrid mode. The main characteristics of VVC desalination system are listed below:
- VVC desalination unit achieves energy consumption less than 10 kWh/m^3;
- Solar receiver achieves target efficiency of 65%;
- Prototype was completed and produces 750 m^3/day of clean water under solar only conditions;
- Prototype achieves an availability of 80%.

The approximate cost of fresh water is less than $2/m^3.

Project title	Solar-thermally driven desalination system with corrosion free collectors and 24-hours-per-day storage
Project acronym	SODESA

Project Contract No.	JOR3980229
Name of Programme	NNE-JOULE C, 4 FWP
Contract type	Cost sharing
Year of development	1998-2001
Contractor/ Responsible	Fraunhofer ISE, Germany / Matthias Rommel

Short description of the project

The project has set the following objectives[12]:

1. To design, set up, operate, evaluate and finally assess a solar thermally driven distillation system that works at 80°C. In the project a pilot system will be operated that has a capacity of 30 l/h. The system will be driven by thermal solar energy.
2. To develop, design, construct and operate corrosion-free solar collectors that are suitable and appropriate for the distillation system.
3. To develop and optimize a strategy for operating the solar driven systems for 24 hours-per-day by including a thermal heat storage into the system. The aim is to increase the daily-distilled water production from about 150 (without storage) to 600 litres per day.
4. To gather operation experiences and to fully assess the performance and cost results of this system. Additionally, a study will be elaborated to estimate application potentials and water production costs for the case that the distillation unit is driven by diesel waste heat instead of solar collectors. Finally the aim is to evaluate the possibilities for; the application and dissemination these systems, especially in the Mediterranean countries.

Innovative aspects and conclusions of the project

The project is based on experimental investigations and developments. The different tasks were shared between the project partners:

12 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=3332605&CFID=3752427&CFTOKEN=72277782

- The development of the collector with a non-corrosive absorber that is suitable to be operated with seawater at temperatures of 80°C and that is adopted to be used with the distillation unit.
- The development of the operation strategy to run the desalination system with a heat storage tank on a continuous 24-hours-per-day basis. The target is to reach a production rate of 600 m^3/d.
- The installation and monitoring of the pilot system at the test site 'Pozo Izquierdo' in Gran Canaria, Spain. The newly developed collector with non-corrosive absorber and the new operating strategy with storage tank were applied to the pilot system, which operated and was monitored for a full year (the monitoring data were not found).
- The investigations on the water treatment on the necessary installations for the seawater pre-treatment and the treatment of the distilled water to reach drinking water quality were conducted. The achievement is that not only the technical assessment of the desalination system but also a full economic assessment is possible.
- The full technical and economic assessment of the desalination system. The aim was to achieve distilled water costs of 25 ECU/m^3 for a system that uses the components and the operating strategy developed in the project.

Pic. 40 Water-PPS (pumping and purification system),
developed by Fraunhofer ISE

Hot seawater is extremely aggressive and can affect even materials such as stainless steel, especially if there is no continuous but intermittent flow as is the case in solar driven systems. Therefore the main challenge in the development of a collector with a corrosion-free absorber was to find appropriate absorber materials. An important requirement was the possibility of selectively coating the absorber because without a very good selective coating ($\varepsilon=5\%$), the collector efficiency would not be high enough at an operating temperature of 90°C. Due to this coating, the stagnation temperature is expected to rise up to about 200°C. At the beginning of the project, it was focused on polymer materials, since they seemed be a good choice concerning both the resistance against hot seawater and the possibility of applying a selective coating. The researchers had coated polymers successfully in earlier projects using the technology of sputtering. However, problems arose with the demand for temperature resistance: polymers, which can withstand 200°C are extremely expensive. Furthermore, semi-finished products such as tubes or plates and techniques for connecting them to construct fluid-guiding structures are not always available.

The next step was to make different absorber structures using epoxy sheets, fibreglass matting with epoxy resins and a special ceramic material. The main disadvantage of these constructions – besides technical problems, which could not be solved in the time available – was necessity for extensive manual work. New collectors with corrosion-free absorbers were developed based on glass tubes. They can withstand stagnation conditions and have a good efficiency at the operating temperatures of about 90°C required for thermal desalination systems. The seawater is directly heated up in the collector absorbers. No heat exchanger is needed between the collector and the desalination loop. This increases the collector system efficiency considerably. Investigations on materials, thermal and optical simulations, and indoor and outdoor collector tests, were carried out to develop the collector. The collectors were installed in the SODESA pilot plant, which was successfully taken into operation in May 2000. The first operating experience with the collector field is good. The evaluation of the data from the collector field shows good agreement between the efficiencies measured on the collector test facility of Fraunhofer ISE and the values determined during operation of the pilot plant in Pozo Izquierdo, Gran Canaria. The measurements also show that even under the dusty conditions prevailing at the test site, the collector with a zigzag reflector operates better than the collector with a diffuse reflector.

The new collectors with corrosion-free absorbers are in principle suitable for all thermally driven desalination techniques (multi-stage flash, multi-effect distillation, vapor compression, membrane distillation, multi-effect humidification). They may also be used in PV-driven RO systems to preheat feed water.

Note: After project's end, most of the equipment was dismantled. The heat storage tank and part of the piping will be reused in the MEMDIS project (large unit)

Project title	Enhanced zero discharge seawater desalination using hybrid solar technology
Project acronym	AQUASOL
Project Contract No.	EVK1-CT-2001-00102
Name of Programme	EESD, 5 FWP
Contract type	Cost sharing
Year of development	2002-2006
Contractor / Responsible	Centro de investigaciones energeticas, mediambientales y tecnologicas, Spain Felix Yndurain

Short description of the project

The main objective of this project is the development of a seawater desalination technology based on *multi-effect distillation* that is energy efficient, low-cost and has a zero discharge.

Scientific and technological developments will be focused in the increasing of current Performance Ratio of conventional MED desalination systems by the inclusion of a double heat pump to energy recovering from brine, the use of brine to the commercial production of salt, avoiding any discharge, and coupling a hybrid solar/gas-fired cost-efficient thermal energy system. Final developed system is expected to have remarkable environmental features, with relevant aspects in energy efficiency and water production cost, when compared with conventional MED systems.

Innovative aspects and conclusions of the project

Research activities in solar desalination at the Almeria PSA have three main innovations[13]:

1. The solar field is based on new static CPC type (Compound Parabolic Concentrator) solar collectors designed to supply medium temperature heat (60ºC-90ºC),
2. Development of a new double-effect absorption (LiBr-H2O) heat pump,
3. Reduction of process discharge to zero by recovering the salt from the brine in an accelerated process using advanced passive solar dryer techniques.

In the AQUASOL configuration proposed (see figure), water is the working fluid that transfers the thermal energy supplied by the solar field to the storage tank. A gas-fired backup system is necessary to guarantee minimum operating conditions (DEAHP requires steam at 180ºC) and permit 24-hour MED plant operation (to reduce the impact of capital costs). Although the system can operate in both solar-only mode and fossil-only mode, system efficiencies are different because the heat pump cannot operate with the contribution of the solar field alone. A third hybrid operation mode (solar-gas) would also be possible with the absorption heat pump operating at partial load, thus maximizing use of the solar resource. Plant configuration allows for multiple possibilities that can easily be adapted to the socio-economic circumstances of the location where the seawater desalination plant is to be installed.

In August 2004, the AQUASOL Project research phase was successfully concluded and all the subsystems have been designed and implemented for their evaluation during the demonstration phase. The desalination system developed combines the use of *solar static collectors* and the *absorption heat pump* technology, in order to increase the overall efficiency of the process.

Also the AQUASOL project will design and install a new first effect for the PSA MED plant which will be fed with hot water from the thermal storage tanks in nominal operating conditions as shown in Table. This addition is an innovation over conventional MED plants in which low-pressure saturated steam is used as the heat

[13] http://www.psa.es/webeng/aquasol/files/Congresos/ECCE4_3-1-0029_Aquasol.pdf

transfer fluid. The concept of DEAHP was fully demonstrated by previous PSA experience, being a clearly important contribution to water-cost reduction in Solar-MED processes.

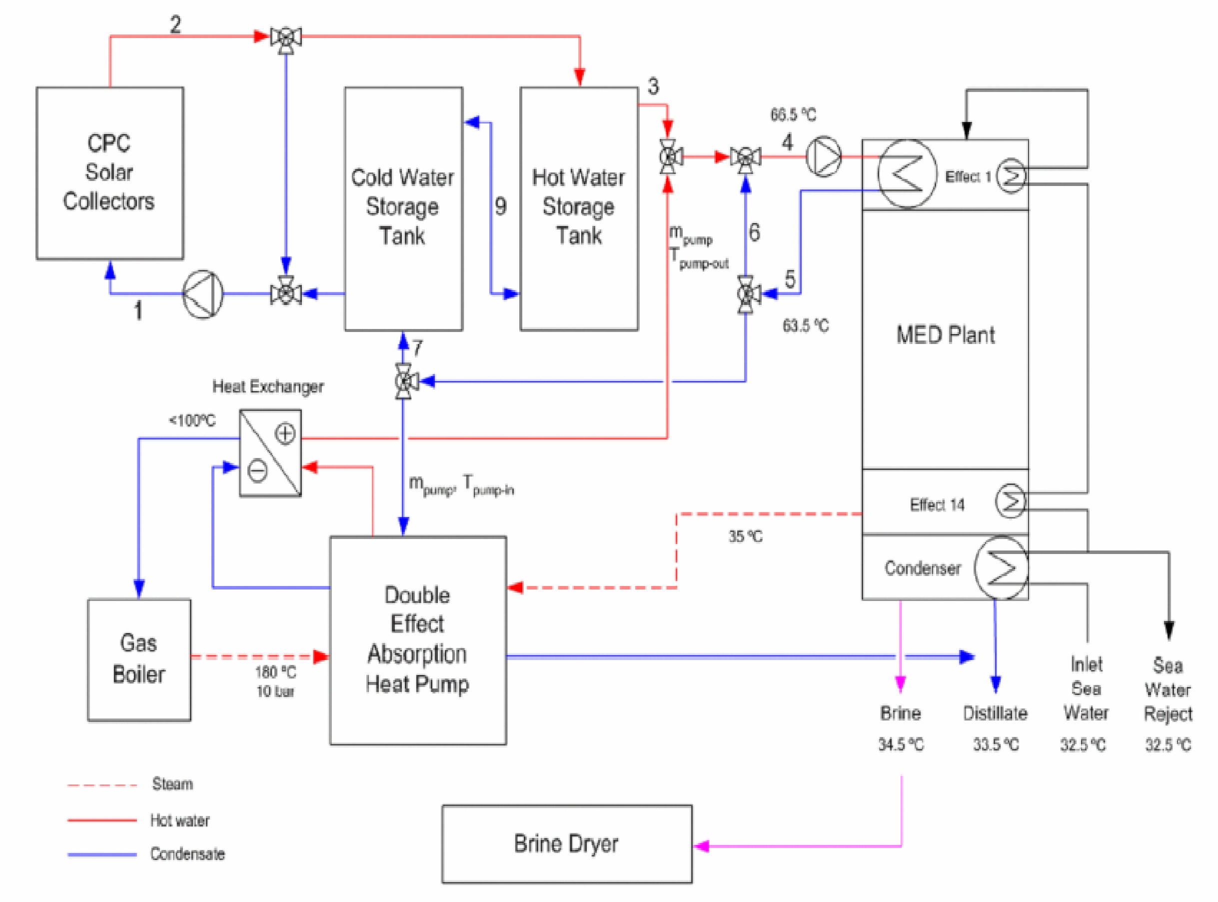

Fig. 41 Configuration proposed for AQUASOL Plant

Table 18 Estimated performance of the new first cell for PSA MED plant[14]

	Desalination driven by solar collector field	Desalination driven by double effect absorption heat pump (DEAMPH)
Power consumption	200 kW	150 kW
Inlet/outlet hot water temperature	75.0/71.0°C	66.5/63.5°C
Brine temperature	68 °C	62 °C
Hot water flow rate	12 kg/s	12 kg/s
Pressure drop	0.4 bar g	0.4 bar g

[14] J. Blanco; D. Alarcón. Innovative idea sto reduce current cost of solar seawater desalination based on MED technology. http://www.idswater.com/Common/Paper/Paper_46/blanco_desalination.htm

AQUASOL developments are expected to reduce the overall system investment cost as well as improve energy efficiency and process economics, making it competitive with conventional desalination techniques, even leaving aside environmental considerations. Cost estimation of desalted water using different technologies was made and it was concluded that a typical commercial MED should consider the following data: GOR = 7.5, production = 9600 m^3/day, 90% availability, 15 years system lifetime and 50% solar fraction. If a fuel cost of 4.5 €/GJ is considered, the needed cost of solar system to the achievement of the same economic competitiveness as conventional MED plant, is equivalent to around 125 €/m^2 of solar collector. The project is not finished yet and the final results cannot be evaluated.

Project title	Development of stand-alone, solar thermally driven and PV-supplied desalination system based on innovative membrane distillation
Project acronym	MEMDIS
Project Contract No.	NNE5/819/2001
Name of Programme	EESD, 5FWP
Contract type	N.A.
Year of development	2003-2006
Contractor / Responsible	Fraunhofer ISE, Germany Rudiger Dorner, M.Rommel

Short description of the project

The overall objective of the MEMDIS project is the development of stand-alone desalination systems, which are based on highly innovative membrane distillation (MD) technology. The systems integrate solar thermal and PV energy. The desalination energy is supplied entirely by solar thermal collectors and the electrical auxiliary energy (feed water pumping) is supplied by a PV system.

First stage of the project involves development of a MD-module with heat recovery function. The project includes two systems, the compact system, with a nominal production of 150 l/d, and the large system (2 m^3/d). The compact system was installed in Gran Canaria in December 2004 and it has been operating since January 2005; according to the schedule plan, the large system will be installed at the end of

2005, to be started up in January 2006. In the next stage the works will be focused on reducing energy consumption increasing the channel length in the module as well as improving the membrane distillation modules with heat recovery function.

Innovative aspects and conclusions of the project

The focus of development work since the project beginning in April 2003 is on the construction of the MD-module and the system design of small systems.

The module construction is a spiral wound one with integrated heat recovery function. A screening of materials as membranes, condenser foils, spacer materials and resins for the casing was carried out. A machine was constructed to wind the eight different layers, which form the evaporator, condenser and distillate channel to the spiral wound module form.

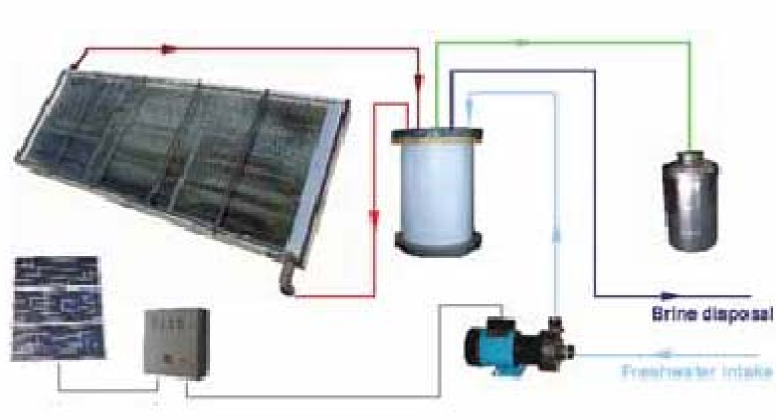

Fig. 42 Sketch of a simple MD-system with production capacity of about 150 l/day.

Pic. 41 MEMDIS compact system, installed at Fraunhofer ISE at the end of September, 2004[15]

[15] Third management report covering period from 1-04-2004 to 30-09-2004.

A system design for small systems with capacities between 100 and 500 lt per day without heat and electricity buffer was carried out. It only consists of corrosion free solar thermal collectors developed by Fraunhofer ISE in the SODESA project (JOR3-CT98-0229), one to four MD-modules and a PV-driven control and pump system. A sketch of a system for a production capacity of about 150 l/day is given in Figure 38. The collector area is about 6m^2, the membrane area of the module is about 7m^2, the PV-area is about 1m^2. Annual simulation calculations for that system were carried out with weather data sets for different potential installation locations[16].

The large system mainly consists of a collector field, a heat storage tank, a heat exchanger and a set of distillation membranes.

More information cannot be provided due confidentiality of the ongoing project.

Project title	PV and thermally driven small-scale, stand alone desalination systems with very low maintenance needs
Project acronym	SMADES
Project Contract No.	ICA3-CT-2002-10025
Name of Programme	INCO 2, 5 FWP
Contract type	Cost sharing
Year of development	2003-2006
Contractor / Responsible	Fraunhofer ISE, Germany Ruediger Dorner, Andreas Maurer, M. Rommel

Short description of the project

The overall objective of the project is the advancement of stand-alone desalination systems, which are based on the highly innovative membrane distillation technology. The objectives are:

- Evaluation of the present state-of-the-art for small-scale, stand-alone desalination systems with low maintenance needs.
- To conduct a socio-economic study to determine the specific needs and possibilities for the application of small-scale desalination systems.
- Development of appropriate small-scale, stand-alone desalination systems with low maintenance needs based on membrane distillation.

[16] European photovoltaics projects 1999-2002. European Commission. Directorate-General for research. 2003. pp. 180-181.

- Development and testing of the membrane distillation components and systems.
- Dissemination of results in workshops conducted in each of the participating countries.

Innovative aspects and conclusions of the project

Fraunhofer ISE is currently developing a solar thermally driven stand-alone desalination system. The aim is to develop systems for a capacity ranging from 0.2 to 20 m^3/d. Technical simplicity; long maintenance-free operation periods and high-quality potable water output are the very important aims which will enable successful application of the systems.

The separation technique on which the system is based is *membrane distillation (MD)*. For the design of a solar-powered desalination system, the question of energy efficiency is very important since the investment costs mainly depend on the area of solar collectors to be installed. The technical specifications of the MD module that is used for the current investigations are:

- hydrophobic PTFE membrane, mean pore size 0.2 μm,
- height 700 mm,
- diameter 460 mm,
- membrane area 8 m^2,
- feed temperature at evaporator inlet 60-85°C,
- specific thermal energy consumption 140-200 kWh/$m^3_{distillate}$ (GOR about 4-6),
- distillate output 20-30 l/h,
- all parts are made of polymer materials (PP, PTFE, synthetic resin).

The following MD module, a corrosion-free solar collector, a pump and a temperature hysteresis controller were installed on the outdoor small-scale test system. Laboratory tests under defined testing conditions of all components considered to be very important for the preparation of successful field tests under real conditions. Seawater, pump, performance tests showed that the handling of the system is quite easy, and long-term operation periods without maintenance are possible.

Simulation calculations for such systems with module characteristics derived from several experimental investigations were carried out for different potential installation locations. The simulation results for three different locations (Jordan, Morocco, Egypt) show that a very simple compact system with a collector area less than 6 m^2 and without heat storage can distil 120 to 160 lt of water during a day in the summer[17]. Experimental investigations on a testing system are currently being carried out at Fraunhofer ISE. New MD modules will be developed aiming at a higher GOR value and a lower pressure drop.

6.1.1.3. Wind-powered desalination plants

Wind energy based desalination projects differ from the previous ones as the innovation research is based on certain regions or places, moreover, some of them include wide analysis of water scarcity problems as well as climatic and economic conditions in the regions.

PRODESAL and MODESAL dedicated their research for the Mediterranean Sea region. PRODESAL project was one of the first ones, which coupled wind energy with reverse osmosis technology and applied it for a middle-scale stand-alone desalination plant. The project group was working on 4 new concepts of reverse osmosis aiming at an optimised efficiency and reduced water costs. The following MODESAL project tried to solve the problems, which were faced by the pilot plant in Tenerife with the special focus on the concept of a family of modular seawater desalination plants. The plants are able to work at autonomous or grid-connected or hybrid mode. High energy efficiency was achieved.

One of the projects (RENA 940055) reached innovations of the desalination systems due to specific conditions of the chosen place where the plant was installed: the seawater enters RO unit through a rock hole of around 18 meters depth.

[17] J. Koschikowski, M.Wieghaus, M.Rommel. Solar thermal-driven desalination plants based on membrane distillation. Desalination 156 (2003), pp. 295-304.

Table 19 Wind energy desalination projects

Title	Year	Reference No.	The basic features of the project
Prodesalination. Towards the large-scale development of decen-tralized water desali-nation. Detailed concept and pilot operation for a large-scale development of decentra-lized water desalination (PRODESAL)	1995-1996	RENA940018	*Type of RES:* Wind-RO *Specific aims of the project:* Development of modular concept of combined WEC (wind energy converter)-RO sea water desalination plant; Energy storage costs *Test plant:* Tenerife, Spain *Capacities:* 100-250 m^3/d, 200 kW *Cost*: n.a. *Type:* stand-alone
Development of water desalination plant through RO powered by wind energy in the island of Patmos (Gr)	1995-1996	RENA940029	*Type of RES:* Wind-RO *Specific aims of the project:* Assessment of water needs and RE potential in the Mediterranean islands; Commissioning of a desalination plant *Test plant:* Patmos, Greece *Capacities:*n.a. *Cost*: n.a. *Type:* stand-alone
Modular desalination: development and pilot-operation of a family of second generation mo-dular wind powered sea water desalination plants (MODESAL)	1996-1997	JOR3950018	*Type of RES:* Wind-RO *Specific aims of the project:* To develop general modular plant concept which combines wind energy and RO; concept of a family of a modular sea water desalination plant, Energy storage costs *Test plant 1:* Tenerife, Spain *Capacities:* 60-110 m^3/d, 200 kW *Type:* stand-alone *Test plant 2:* Syros, Greece *Capacities:* 60-900 m^3/d, 1600 kW *Type:* stand-alone
Wind powered desalina-tion for small coastal and island communities in Mediterranean regions	1995-1996	RENA940055	*Type of RES:* Wind-RO *Specific aims of the project:* The development of a robust system which would be able to operate at remote sites away from electricity grid *Test plant:* Therasia, Greece *Capacities:* 4.8 m^3/d, 15 kW *Type:* stand-alone
Autonomous wind-diesel	1997-	JOR3971010	*Type of RES:* Wind-diesel

hybrid generator with heat recovery for sea water desalination, telemonitored for supervision and data acquisition	1998		*Specific aims of the project:* Distillation under vacuum; Efficiency improvement *Test plant:* n.a. *Capacities:*n.a. *Type:* stand-alone

Note: The projects marked in bold are described below in more details

Project title	Prodesalination. Towards the large-scale development of decentralised water desalination. Detailed concept and pilot operation for a large-scale development of decentralised water desalination
Project acronym	PRODESAL
Project Contract No.	RENA940018
Name of Programme	RENA, 3 FWP
Contract type	Cost sharing
Year of development	1995-1996
Contractor / Responsible	Instituto Tecnologico y de Energias Renovables SA, Spain Manuel Cendagorta Galarza Lopez

Short description of the project

1. A network of excellence executing a concerted in-depth study of water demand and supply around the Mediterranean and in the Near East was set up (members: Italy, Spain, Greece, Morocco, Tunisia, Cyprus, Israel, Egypt and Bahrain). The goal of this network was to identify market potential, socio-economic benefits and cost considerations, and suggested locations.

2. A range of seawater desalination systems was defined and a reference Wind/RO plant was designed, set-up, and operated. This plant represents the innovative approach of combining wind converters, RO technology, power and operational control, as well as energy storage.

3. The dedicated development of four new concepts of reverse osmosis sea water desalination aiming at an optimised efficiency and reduced cost of water. These concepts cover a range of sizes from very small scale to medium size systems, all aiming at the decentralized approach. This co-ordinated parallel approach is canalised into the set-up of a large-scale

implementation scheme for decentralized renewable energy powered desalination systems in the Mediterranean area.

Innovative aspects and conclusions of the project

The plant was installed in Spain and consists of a 200kW WEC, the ENERCON E-30, and an RO unit with 3 identical RO blocks. The RO blocks are constructed according to a new, innovative design. This represents a completely new approach to the RO process and a milestone in seawater desalination technology as well as for wind energy application. The design of the RO blocks allows for operation at fluctuating feed water flow and pressure and facilitates them switching on and off while reducing the specific electricity consumption of the RO process.

In total three innovative, modular WEC-RO plants of different size have been designed, set up and operated. They allow for perfectly matching the drinking water production rate to the available wind power, thus permitting autonomous, grid-connected and hybrid operation. Through the implementation of a totally new, inherently energy saving RO concept a very high-energy efficiency of the entire RO unit could be achieved, even when including the energy consumption of peripheral components into the consideration[18].

Project title	Modular desalination: development and pilot-operation of a family of second generation modular wind powered sea water desalination plants
Project acronym	MODESAL
Project Contract No.	JOR3950018
Name of Programme	NNE-JOULE C, 4 FWP
Contract type	Cost sharing
Year of development	1996-1997
Contractor / Responsible	Wirtschaft und Infrastruktur GMBH & CO Planungs KG, Germany Heinz Ehmann

Short description of the project

[18] Helm, P., Ehmann H., etc. Wind powered reverse osmosis desalination for stand-alone island operation. http://www.insula.org/solar/grottke.html

The project continues the main principles of PRODESAL project and is aimed to fix the problems, which occurred in operation of the pilot plant in Spain.

The objective of the project was to develop a concept of a family of modular seawater desalination plants, adaptable to a broad variety of regions making use of locally available Wind Energy resources. The family concept is based on a limited number of standardized modules. These modules (advanced technology wind energy converter, hybrid power units, various size sea water desalination units, electric generator unit for off-grid or grid connected operation etc.) were interconnected using a highly flexible power conditioning and power management system. The concept includes the parallel production of water and electrical power according to the operator's needs. The modularity of the concept allows for the flexibility of adding/subtracting power and user modules during the operational phase. It thus enables the operator to develop the plant to changing operational needs or financial possibilities[19].

Innovative aspects and conclusions of the project

The project includes the conception of a family of Wind Energy Converter/Reverse Osmosis (WEC/RO) desalination plants. The project involved building two wind energy desalination plants of different sizes - one was located on Tenerife (Spain) and the other on Siros (Greece)[20]. Both pilot plants on Tenerife and Syros follow both the general modular plant concept, which combines WECs of various sizes with various numbers of RO blocks. The WEC are in all cases 3-blade, active pitch controlled, gear-less ENERCON machines. The lack of a gear-box and other fast rotating components reduces

- energy losses between rotor and generator,
- sound emissions,
- mechanical wear and tear,
- oil losses,
- mechanical friction losses,

and leads to low maintenance requirements.

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19 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=2360179&CFID=3842471&CFTOKEN=31534684

20 Helm, P., Ehmann H., etc. Wind powered reverse osmosis desalination for stand-alone island operation. http://www.insula.org/solar/grottke.html

Optionally an energy storage system is included which adapts the WEC output power to the power requirements of the load and includes a diesel generator, batteries and a flywheel generator. The output of the energy storage system is connected to the RO unit and to the electric grid if available. The connection to the electric grid can be interrupted if necessary. In addition, a secondary electricity source like a diesel generator might be included.

The RO unit is subdivided in a seawater pre-treatment section, a number of identical RO blocks and a drinking water storage section. The seawater storage section contains a tank, which acts as an energy buffer: the operation of the seawater pump can be restricted to periods of high wind power availability if required.

The number of RO blocks determines essentially the seawater desalination capacity of the plant. Each RO block incorporates an energy recovery system, which is based on the piston accumulator principle. A high-pressure pump is only required on the fresh water side of the RO process, thus reducing the high pressure water flow rate and the energy consumption. The use of a sea water resistant high-pressure pump is also advantageous, because it reduces the equipment costs. By varying the speed of the high-pressure pump, the desalination rate can be adapted to the available wind power and water demand. The produced drinking water is stored in a second storage tank, such providing a further energy buffer and the possibility to adapt the wind power availability to the actual water demand.

Table 20 Comparison of the characteristics of two plants

Plant	Tenerife, Spain	Syros, Greece
Installation place	Wind park of Granadilla	Syros
WEC characteristics	ENERCON E-12 with magnet synchronous generator, 30 kW nominal power and a passive yaw system	ENERCON E-40 with synchronous ring generator, 500 kW nominal power and a grid management system
Storage system	does not include the optional energy storage system	Energy storage system
No. of RO blocks	1	8
Max. power of RO unit	200 kW	200 kW*
Desalination capacity	60-110 m^3/d	60-900 m^3/d
Water storage	1 14m^3 tank for pre-filtered water 1 14m^3 tank for produced	

	drinking water	

**Since the maximum power consumption of the RO unit is only 200kW whereas the nominal power of the WEC in Syros is 500kW, a large fraction of the generated electricity is fed into the island's electric grid.*

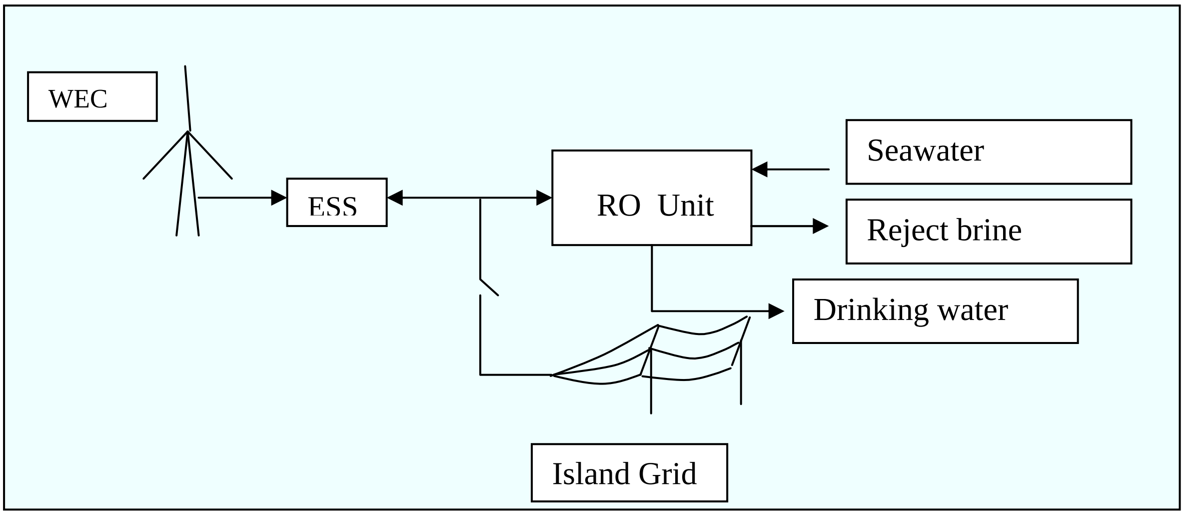
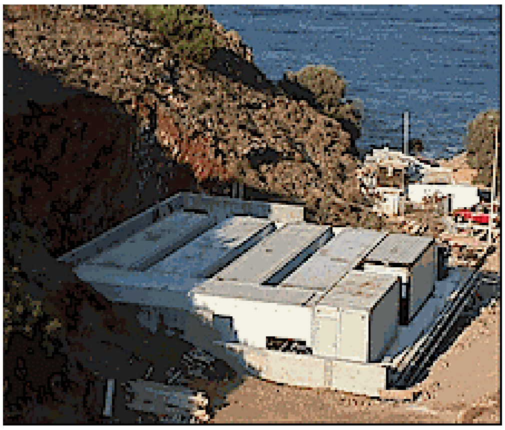


Fig. 43 General WEC –RO plant design

The long-term operation of the prototype and pilot plants has allowed verifying the following features:

- All plants produce high quality drinking water with a typical conductivity of 0.85mS/cm (sea water values are about 41mS/cm on Tenerife and 61mS/cm on Syros).
- The combined WEC-RO plants can operate in autonomous as well as grid-connected mode.
- In the autonomous mode, the RO unit follows perfectly the available wind power.
- Switching processes are managed correctly.
- The power consumption of the high pressure pump and as a consequence the water flow and pressure can vary over a wide range, e.g. 5.5 to 15.3kW on Tenerife.
- The energy efficiency is very high.



Pic. 42 View on RO unit on Syros

Pic 43 View on the RO unit of the WEC-RO pilot plant on Tenerife

A critical factor to the success of this project has been the fact that the company has developed in-house expertise in desalination. Most RE powered desalination plants have been collaborative efforts between an RE company and a desalination company. The operation of the plant at Syros has demonstrated that the novel concepts on energy recovery and energy management are soundly based. Energy consumption of the unit is believed to be around 3kWh/m^3, which is excellent.

While no water costs figures are available for this project, the scale of the project coupled with the fact that a very competitive wind turbine is being used suggest that water costs should be at the low end of the spectrum for this type of plant[21].

In total three (PRODESAL and 2xMODESAL) innovative, modular WEC-RO plants of different size have been designed, set up and operated. They allow for perfectly matching the drinking water production rate to the available wind power, thus permitting autonomous, grid-connected and hybrid operation. Through the implementation of a totally new, inherently energy saving RO concept a very high-energy efficiency of the entire RO unit could be achieved, even when including the energy consumption of peripheral components into the consideration.

The developed and pilot-operated technology is particularly suitable for remote areas with small and medium local water demand and can provide a contribution for

[21] United Nations Educational, Scientific and Cultural Organization. Renewable energy powered desalination systems in Mediterranean region. July, 1999.

combating up-coming serious water shortages in the Mediterranean area, including southern European countries, North Africa and the Middle East.

Project title	Wind powered desalination for small coastal and island communities in Mediterranean
Project acronym	-
Project Contract No.	RENA940055
Name of Programme	RENA, 3 FWP
Contract type	Cost sharing
Year of development	1995-1996
Contractor / Responsible	Vergnet SA, France Jerome Billerey

Short description of the project

The main objective of the project was the development of a robust system, which would be able to operate at remote sites away from electricity grid.

Innovative aspects and conclusions of the project

The research results were applied in a small wind powered autonomous desalination system, which was installed on the Therasia island. Therasia is a small island situated in the South Aegean and belongs to the Cyclades islands complex.

One of the innovations of the system is the way on how seawater enters the RO unit – through a rock hole of around 18 meters depth. This seawater intake system makes the pumping of seawater simpler and also acts as a natural pre-filter, reducing the pre-treatment requirements.

A submerged booster pump of 0.37 kW (220 VAC, 1 phase) drives the seawater from the well to the RO unit. The motorisation of the RO booster pump and the building electrification are on the AC current side, while the high-pressure pump of the RO unit as well as the control system is on the DC current side. By using a direct current motor, the losses due to the inverter are alleviated. This increases maintenance costs, for the replacement of the brushes of the direct current motor every 6 months. This is acceptable when the heavy cleaning requirements of the RO unit and membranes are taken into consideration[22]. The operation of the unit had some problems related to the water quality, membrane pressure with battery voltage, etc.

The use of 15 kW wind turbine to power a seawater desalination unit has been made possible combining good overall system efficiency and minimum electricity storage. The system works satisfactorily, although it can be improved. From short experience of the Therasia plant the following remarks can be made:

- The use of a battery system is necessary for an autonomous unit.
- In order to avoid the reduction of membrane efficiency due to clogging, the RO unit needs to be run a minimum of 30 minutes per 24 hours. This means that the system has to be sized with sufficient battery storage to account for low wind periods.
- To avoid losses due to voltage transformation, the battery voltage was chosen high (120 V).
- The losses due to the inverter have been avoided as this has been removed; since DC motor for the high-pressure pump is used.
- It was concluded that the development of a wind desalination system should be concentrated on small to medium scale systems. Larger desalination systems are connected to local electricity grids, in which case development work on interface between wind energy and desalination techniques is no longer relevant.

Further development must be on reliability and acceptable maintenance requirements, total system cost and appropriate wind power to desalination interfaces.

[22] European Commission. Desalination guide using renewable energies. The demonstration component of the Joule-Thermie programme. 1998. 95 p.

6.1.1.4. Projects dealing with hybrid RES or selection of suitable technologies

The projects described above were orientated to a particular source of renewable energy and its application in a desalination unit. The following projects focus on a broader overview of RES and desalination processes, aiming to find the best match of energy source and desalination process under particular climate, economic, social, etc., conditions of the region.

The REDDES project illustrates the typical aims of such kind of research: it produces software for choosing appropriate desalination and energy sources and capacities. Factors considered are analysis of information on RES, climate, social, economic, technical conditions of target areas. The tool is also able to calculate investments, costs, pay-back period and is flexible to apply. The software was tested on 8 Dodecanese islands selecting the best fitted technology and providing investment and costs calculations.

Another group of projects aimed to design a specific desalination plant after careful analysis of climatic data of location, trying to select the best fitted technology (OPRODES, ADIRA) or coupling one or more than one renewable energy sources to run the plant (OPRODES, SDAWES, RENA940030). Besides careful preparatory analysis, each project solved unique tasks. OPRODES which is a research project, intended to make a site-extrapolable optimisation of photovoltaics/wind/RO systems using commercial membranes. The proposed RO modifications involved changes in pre-treatment intakes, pressure tube, and cleaning tank. ADIRA project team applied the data analysis for 5 desalination plants (it is planned to built 2 plants, the project is ongoing) in different countries around the Mediterranean Sea (Morocco, Cyprus, Turkey, Egypt and Jordan).

Some projects were orientated to couple different kind of energies in the same desalination plant. As these projects are more complicated from the technical side of the implementation, the first step was development of software programmes to simplify the preparatory works.

SDAWES project had the very ambitious task to couple a stand-alone wind park (2 wind generators) with different desalination processes such as RO, vacuum vapor compression, electrodialysis in one desalination plant, which was built in Gran Canaria Island. Similar project (RENA940030) combined wind with PV only and reached the level of technology, which is suitable to run the plant 24 hours under sufficient climate conditions.

Table 21 Projects dealing with hybrid RES or selection of suitable technologies

Title	Year	Reference No.	The basic features of the project
Renewable energy driven desalination systems (REDDES)	2002-2003	4.1030/Z/01-081	*Type of RES:* Wind-solar-biomass-RO *Specific aims of the project:* The development of integrated management and design tool for the use of renewables in desalination: climate, economic, social, financial evaluation of the plant *Application region:* Dodecanese, Greece
Peace engineering. Key accessories for the Jordan Rift Valley desalination plant powered by renewable energy sources	1994-1995	JOU20383	*Type of RES:* RES-RO *Specific aims of the project:* Design of powerpack to drive RO process; Optimisation of efficiency of pumps *Application region:* Rift Valley, Jordan *Type:* stand-alone
Optimization of RO desalination systems powered by renewable energies (OPRODES)	1998-2001	JOR3980274	*Type of RES:* PV-Wind-RO *Specific aims of the project:* Intends to make a site-extrapolable optimisation of the design of photovoltaic/wind/RO systems using commercial reverse osmosis membranes *Test plant:* Gran Canaria, Spain *Capacities:* 326 m^3/d
A decision support system for the integration of Renewable Energy into water Desalination Systems (REDES)	1995-1996	RENA940038	*Type of RES:* all types *Specific aims of the project:* The development of a methodology and a tool followed by Decision Support System (DSS) for selection of the best technology for desalination plant *Application region:* Greece
Autonomous desalination system concepts for seawater and brackish water in rural areas with renewable energy potential, technology, field	2003-2007	ME8-AIDCO-2001-0515-59610	*Type of RES:* PV-Wind-RO *Specific aims of the project:* Development of optimum concepts to supply rural areas with fresh water taking into account not only technical, but also legal, social,

experience, socio-technical and socio-economic impacts (ADIRA)			economic, environmental and organisational issues *Plants:* Cyprus, Egypt, Jordan, Morocco, Turkey
Desalination of sea-water using renewable energy sources	1996-2000	IC18960039	*Type of RES:* all types *Specific aims of the project:* Analysis of 2 desalination methods: vapor compression method and multiple effect evaporation method; Application for 2 pilot plants; Cost and energy consumption improvements *Plants:* Greece, Jordan
Seawater desalination plants connected to an autonomous wind energy system (SDAWES)	1996-2000	JOR395077	*Type of RES:* Wind-PV-RO-VVC-ED *Specific aims of the project:* The determination of best fitted system (RO, VVC, ED) with wind energy *Test plant:* Gran Canaria, Spain *Capacities:* Wind: 2x230kW wind turbines RO plant: 8x25m^3/d, VVC unit: 50 m^3/d, ED unit: 190 m^3/d *Type:* stand-alone wind park
Hybrid renewable energy systems in Donoussa and La Graciosa Islands as prototype systems for applying desalination at small villages in Mediterranean Islands and coastal areas, by using local energy sources for electricity production	1995-1995	RENA940030	*Type of RES:* Wind-PV-RO *Specific aims of the project:* Combination of PV with wind energy to energise reverse osmosis reactions; Innovative PV-hydro plants *Test plants:* Donnousa, Greece, La Graciosa, Spain *Type: -*

Note: The projects marked in bold are described below in more details

Project title	Renewable energy driven desalination systems
Project acronym	REDDES
Project Contract No.	4.1030/Z/01-081
Name of Programme	ALTENER 2, ENG
Contract type	Cost sharing
Year of development	2002-2003
Contractor / Responsible	Regional energy agency of Dodecanese SA, Greece Savas Karayannis

Short description of the project

The objective of this project is the development and delivery of an integrated management and design tool for the use of renewable energies (wind, solar, geothermal) in the desalination of seawater that will be implemented in arid remote and isolated communities[23]. The tool was supposed to apply, as a pilot project, in the small Greek islands of the Dodecanese in the Southeastern Aegean.

The milestones to implement the project:

1. The collection of all techno-economical data concerning the RES desalination coupling technologies. The study is supposed to include data from operating systems from various locations, such as the Middle East, Spain and the USA. Technical and economical restriction parameters will be identified and will be considered in the modeling of RES desalination coupling solutions. The marketing research about desalination systems and all the mechanical equipment necessary for the operation of the plants.

2. The development of a multi criteria analysis (MCA) tool to simulate the cases with specific regional data (such as RES potential, fresh water demand and supply) in order to identify the optimum RES desalination solution for each region separately.

3. The implementation of the developed methodology in the arid Dodecanese islands via realised a Geographical Information System (GIS) database. The database is supposed to include the available RES potential (solar, biomass, wind and geothermal resources) for each island and water supply and demand data. During visiting the islands and contacting local authorities necessary information for inputs to the MCA tool should be collected in order to design an appropriate RES desalination system for each island.

4. The selection of the appropriate equipment for each island and calculations of the total cost of the plants and the operation cost per year.

23 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=6314210&CFID=3752427&CFTOKEN=72277782

5. The dissemination of the results should be based on the developed strategy to achieve the implementation of RES in a regional, national and European level.

Innovative aspects and conclusions of the project

The designed multi criteria analysis (MCA) systems have as a backbone the use of renewable energy sources with the aim to produce potable water to satisfy demand of fresh water at the lowest possible cost with environmentally friendly means.

MCA is able:

- *to evaluate the feasible RES-desalination capacity,*
- *to select the sites of the RES units,*
- *to estimate the economic efficiency of the plants.*

One of the strongest sides of the project is well-developed information dissemination strategy and the co-operation with the authorities of Dodecanese islands had to increase the confidence and the acceptance of the RES plants by the local communities. Product water quality depends on desalination process. The analysis showed that the most widely used technologies all over the world are MSF, followed by RO, VC and ED processes are implemented much less and MED could be named as the least implemented technology. In general, cost figures for desalination have always been difficult to obtain. Desalination costs are largely depended on the process, feed water type, product quality requirements, electricity price, etc. The total cost of water produced by a desalination plant includes the investment cost as well as operating and maintenance cost. In a comparison between seawater and brackish desalination the cost of the first is about 3 to 5 times the cost of the second one for the same plant size. The project partners indicated approximate costs (€/m^3 per day) for a typical plant size between 10.000-20.000 m^3/d (VC exists below 2500 m^3/d). (see Table 22).

Table 22 Approximate costs for a typical RES plant

Process	Investment	Energy	Consumable	Labour	Mainte-nance	Total costs, €/m^3
MSF	1000-2000	0.6-1.8	0.03-0.09	0.003-0.2	0.02-0.06	0.68-2.15
MED	900-1800	0.38-1.12	0.02-0.15	0.03-0.2	0.02-0.06	0.45-1.53
VC	900-2500	0.56-2.4	0.02-0.15	0.003-0.2	0.02-0.08	0.63-2.83
SWRO	800-1600	0.32-1.28	0.09-0.25	0.03-0.2	0.02-0.05	0.46-1.78
BWRO	200-500	0.04-0.4	0.05-0.13	0.003-0.2	0.004-0.02	0.12-0.75
ED	266-328	0.06-0.4	0.05-0.13	0.03-0.2	0.006-0.009	0.15-0.74

In terms of the time of construction, a thermal process requires more time than a membrane process. Later on evaluation of the various RES-desalination options was made simulating various combinations between renewable energy (PV, solar and wind) technologies and different processes, summarise of which is presented in the Chapter 1, Fig. 1. Based on previous analysis MCA tool was developed followed by its implementation and use for design of RES desalination schemes. MCA tool evaluates the feasible RES-desalination capacity, selects the sites of the RES units, and estimates the economic efficiency of the plants. The MCA tool takes into account specific regional data (such as RES potential, fresh water demand and supply) in order to identify the optimum RES desalination solution for each region separately[24]. The tool consists of a Geographical Information System (GIS) database and techno-economical analysis software. The main functions of the GIS database are: the determination of water shortage problem and geographical distribution of demand, the determination of the available sites for the RES and desalination plants and to provide data for the evaluation of site related costs. This data include heights, slopes, and distances from road network, electricity grid, the water distribution networks and the sea.

[24] mhtml:http://www.nad.gr/readsa/files/REDDES%20Overview.mht!REDDESOverview.files/frame.htm

The tool was applied, as a pilot project, to the islands in the Dodecanese region in Greece.

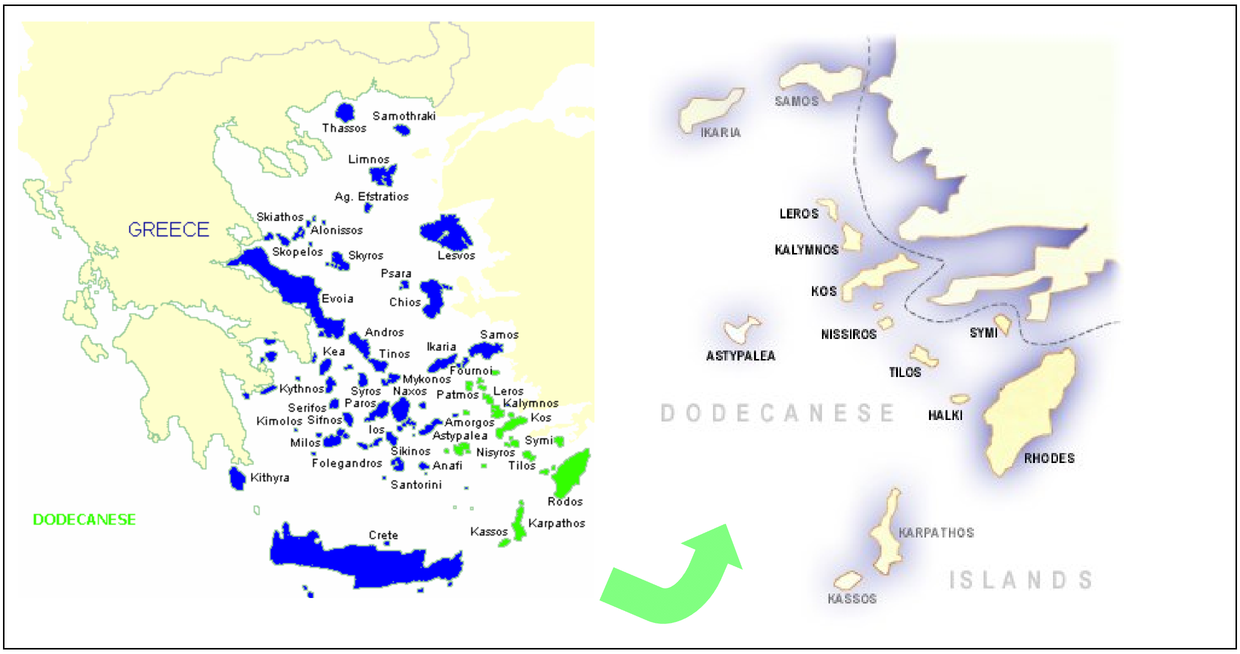


Fig. 44 Location of Dodecanese islands

The Water Needs Index was applied to 8 islands as well as technical-economic feasibility of REDDES desalination systems under investigation which are given below:

- 1 m^3 of RO desalinated water requires 8 kWh_{el} to produce water of 250-350 ppm quality.
- The cost of manufacturing, transportation, assembly and test operation of a RO-desalination unit is calculated at 1200-1500 €/m^3 installed, depending on the size of the unit.
- The cost of manufacturing, transportation, assembly and test operation of a wind generator is calculated at 800-1200 €/kW_{el} installed depending on the size of the unit.
- The cost of manufacturing, construction, assembly and test operation of a seawater intake network is calculated at 150-200 €/m^3 desalinated.
- 1 m^3 of MED desalinated water requires 1,5 kWh_{el} and 105 kW_{th} to produce water of 10-20 ppm quality.
- The cost of manufacturing, transportation, assembly and test operation of a MED desalination unit is estimated at 1.200-1.500 €/m^3 installed depending on the size of the unit.

- The cost of drilling and testing of a geothermal production well is estimated at 40-50 €/kW$_{th}$ installed (including geothermal network, heat exchange system and reinjection wells).
- The cost of manufacturing, transportation, assembly and test operation of the heat exchange system for waste heat utilisation is estimated at 20-25 €/kW$_{th}$ exchanged.
- Load factor of wind generator operation is 35% and that of the geothermal or waste heat system is 90%.

It has to be underlined, that in the present calculations no subsidies were envisaged and it is stressed that such subsidies would substantially improve the economic feasibility. For example in the case of Symi given that a subsidy of 40% on the initial investment is realistic, then the price of the desalinated water would fall from 1,91 €/m^3 to 1,56 €/m [25].

Table 23 Approximate costs to produce potable water on Dodecanese islands

Island	Applied technology	Cost of water per m^3, EUR	Cost of unit, EUR
Astypalaia	RO (350m^3/d) Wind (350kW)	2,03	900.000,0
Kassos	RO (100m^3/d) Wind (100kW)	2,03	900.000,0
Kasteloriso	RO (350m^3/d) Wind (350kW)	2,60	300.000,0
Leros	RO (700m^3/d) Wind (700kW)	1,87	1.7000.000,0
Nisyros	Geothermal (300m^3/d)MED (100m^3/h at 75^{o}C)	1,74	620.000,0
Patmos	RO (650m^3/d) Wind (700kW)	1,87	1.600.000,0
Symi	RO (600m^3/d) Wind (600kW)	1,91	1.500.000,0
	Waste heat MED	1,00	800.000,0
Telos	RO (200m^3/d) Wind (200kW)	2,10	510.000,0

The main advantage of the MCA tool is that it can be easily adapted to any site around the world if local databases are available. The tool can provide invaluable

[25] mhtml:http://www.nad.gr/readsa/files/REDDES%20Overview.mht!REDDESOverview.files/frame.htm

help to local authorities and also private investors for selecting the optimum RES driven water production schemes for a specific region.

Project title	Optimisation of RO desalination systems powered by renewable energies
Project acronym	OPRODES
Project Contract No.	JOR3980274
Name of Programme	NNE-JOULE C, 4FWP
Contract type	Cost sharing
Year of development	1998-2001
Contractor / Responsible	Universidad de las Palmas de Gran Canaria Antonio Gomez Gotor

Short description of the project

This project intended to make a site-extrapolable optimisation of the design of photovoltaic/wind/RO systems using commercial reverse osmosis membranes. Its objectives therefore include:

- The collection of solar radiation and wind velocity data for potential sites in various geographical locations.
- The simulation of solar photovoltaic/wind energy inputs into a pilot RO plant that makes to function under different modes of operation and under the climatic conditions particular to each of the potential sites.
- An assessment of the effect of the discontinuities and changes in the availability of solar and wind energies on pressure variations and, hence, on the flow, salt rejection and the useful life of the membranes.
- Extrapolable optimisation of the design of photovoltaic/wind/RO systems for a number of sites.

The milestones of the project[26] are as follows:

[26] http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=3755149&CFID=3752427&CFTOKEN=72277782

1. Collection of climatic data, i.e. wind, solar radiation and seawater temperature data, for each of the geographical areas under scrutiny. Simultaneously, a study of the specifications of commercial wind turbines and PV cells that are easily available on each of the chosen geographical areas was carried out.
2. Collection and analysis of the climatic data in order to determine the most suitable statistical analysis method. Taking into account the specifications of available PV cells and wind turbines, and options such as energy dissipation and storage, the power available to the RO plant as a function of time was calculated. A software package was designed in order to help translate the power availability calculations into real power availability to the plant.
3. A pilot RO plant, with flexibility of both component specifications and modes of operation and suitable for the study of commercial membrane performance and ageing under conditions imposed by the use of solar and wind energy, was designed and installed.
4. Data on parameters relevant to the ageing and performance of the membranes, such as pressure flow, pH, conductivity, salt concentration and temperature, has to be collected at the entrance and exit of the membranes. Additionally, the pH and conductivity will be measured for each membrane in order to assess the performance and ageing of each individual membrane in the tube.

Innovative aspects and conclusions of the project

The design of PV/wind/RO desalination systems was reviewed, taking the effects of the changes and discontinuities in the power availability into account. Appropriate changes in the system's configuration were suggested wherever the behavior of the membranes deviates from the optimum.

The *RO modifications* have been made[27]:

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[27] Ignacio de la Nuez Pestana, F.J.Garcia Latorre, Celso Argudo Espinoza, A. Gomez Gotor. Optimization of RO desalination systems powered by renewable energies. Part I: Wind energy. Desalination 160 (2004), pp. 293-299.

- *Pre-treatment intakes:* In order to study different pre-treatments, together or separately, there are three independent inputs for the addition of pre-treatment products.
- *Pressure tube:* The pressure tube will take two inputs of product water through both tube side ends. This system has been chosen to check the quality of the product water in the different membranes. The collector of product water will be covered inside the tube so that it collects the product water coming only from the first membrane, or of the first and second ones, and so on. With this system, we will be able to test, in a variable or invariable regime, whether it is necessary to use n-membranes.
- *Cleaning tank:* An automated cleaning tank has been installed since due to the automation of the plant, and the possibility to foresee shutdowns of long duration and outbursts, the cleaning will be carried out automatically, with the possibility of carrying it out manually in some cases.

A software package was elaborated, including the findings, to assist interested third parties in designing a PV/wind/RO desalination system suited to the climatological conditions of their proposed sites.

Pic. 44 The experimental RO plant[28]

[28] L. Segura, I. Nuez, A. Gómez. Integración directa de energías renovables en procesos de osmosis inverse. http://www.ja2005.ua.es/insc/conftool/uploads/3241-LSegura_ja05.pdf

The RO plant designed for this project retains the philosophy of a conventional desalination plant, but it includes a series of important modifications for the study of the membranes undergoing a variable regime due to wind and solar energy fluctuations. With this system the operation of the plant in variable regime and with stops and successive starts, depending on the availability of electric power in the system, is proved. The ways of operation obtained with ample file of data of the operational parameters were distinguished and direct influence in the life of membranes (pressure, volume, pH, conductivity, concentration of salts, temperature, conversion) was proved. The maximum flow in high-pressure pump (stainless steel piston pump in solid ceramics) is around 13 m^3/h with power ranges from 7-85 bar.

Since the RO plant has been built for research, it has many instruments and monitors with an adequate control system, which operates the rejection valve and a speed variator, simulating the different non-conventional energy power inputs[29].

[29] Ignacio de la Nuez Pestana, F.J.Garcia Latorre, Celso Argudo Espinoza, A. Gomez Gotor. Optimization of RO desalination systems powered by renewable energies. Part I: Wind energy. Desalination 160 (2004), pp. 293-299.

Project title	Autonomous desalination system concepts for seawater and brackish water in rural areas with renewable energy potential, technology, field experience, socio-technical and socio-economic impacts
Project acronym	ADIRA
Project Contract No.	ME8-AIDCO-2001-0515-59610
Name of Programme	N.A.
Contract type	N.A.
Year of development	2003-2007
Contractor / Responsible	Fraunhofer ISE, Germany

Short description of the project

The project focuses on field investigation of autonomous desalination system (ADS) concepts for fresh water supply in rural areas, making use of non-conventional water resources.

R&D objectives and the main principles are following:

1. Evaluation of possible and sustainable solutions for regions and countries targeted in this project (up to 15 pilot installations are planned).
2. The evaluation of technical, economical, environmental, legal and social aspects.
3. The elaboration of methodologies and tools (handbook, questionnaires, concepts) to assist stakeholders in the realisation of future in the realisation of future ADS projects.
4. Multidisciplinary, participative and integrated problem solving approach.
5. Top-down & bottom up approach.

The main milestones of the project:

- Identification and quantification of regions, where decentralised desalination units are a solution for the fresh water supply problem

- Generating information on market available desalination systems through a technical study and development of technical concepts for installing sustainable desalination units in certain areas
- Planning, implementation and monitoring of small-scale, stand-alone desalination systems in the field to achieve detailed results on technical viability, socio-technical and socio-economic concerns
- Gaining information about actors in the field of water and energy supply, possible investors and the political framework in order to be able to identify potentials and barriers to boost the implementation of decentralised desalination units.
- Preparation of tools, data bases, training and awareness raising materials for supporting the systems designers, installers, operators and final water users in the implementation and sustainable running of decentralised desalination units.
- Dissemination of the project results, the lessons learned and experiences at all levels in order to raise awareness among all relevant stakeholders at local, national and international level.

Innovative aspects and conclusions of the project

*Specific outcomes: h*andbook, decision support tool, database. Economical and legal master plans for target, training materials, dissemination material, workshops, active expert network[30,31].

Besides that, some specific achievements are already made in the reference to the plants, which are already built or the preparatory works are in the process. More detailed information and statistics are available in "installation details" and in ADIRA web database www.adira.gr. Despite the ambitious plans (up to 15 installations are planned), at the meantime 5 plants in 5 countries are confirmed.

Table 24 Design characteristics of ADIRA plants

[30] U.Seibert, G.Vogt. Potentials, technologies, fiels experience, socio-technical and socio-economic impacts. Presentation of the project.
[31] http://www.aua.gr/gr/dep/oik/lab/man/main%20page%20files/Research%20Programmes%20Files/ADS%20concepts-Seibert-Vogt%20etc.pdf

The plant	Water and energy data	
Cyprus-Nicosia *PV-RO*	Water source:	Sea
	Type of water:	Seawater
	PPM TDS:	N.A
	Water demand:	N.A
	Wind speed (m/s):	4.5
	Solar radiation (kWh/m2/d):	4.5
Egypt-i-Sinai *Wind&PV*	Water source:	Sea
	Type of water:	Seawater
	PPM TDS:	35000
	Waterdemand:	Drinking, irrigation
	Wind speed (m/s):	5-8
	Solar radiation (kWh/m2/d):	4-5
Jordan	Watersource:	Ground
	Type of water:	Brackish
	PPM TDS:	N.A
	Water demand:	N.A
	Wind speed (m/s):	N.A
	Solar radiation (kWh/m2/d):	N.A
Marocco-Tensift	Water source:	Sea & Ground
	Type of water:	Seawater and Brackish water
	PPM TDS:	35000 / 1500 - 6000
	Water demand:	domestic livestock
	Wind speed (m/s):	coast: High / island :Low
	Solar radiation (kWh/m2/d):	5

Turkey	Water source:	Ground & Surface
	Type of water:	Seawater
	PPM TDS:	N.A
	Water demand:	high in tourism and agriculture
	Wind speed (m/s):	1-16
	Solar radiation (kWh/m2/d):	N.A

ADS in _Nicosia, Cyprus_ is based on PV-RO desalination system. The initial design of the system concerns with a 10 kWp Photovoltaic array, 1900 Ah battery bank, a 10 kW inverter and an 2.1 m^3/h brackish water RO unit having an installed capacity of 5.5 kW. It has been calculated that autonomous system is more expensive that the one connected to the grid, leading to a unit water cost of 1.85 €/m^3 for the grid connected system and 0.76 €/m^3 for the autonomous system.

Egypt - i-Sinai data: ADS is developed to desalinate seawater using solar stills and PV and wind energy. The requirements for the capacity of the plant are: Drinking water ca.1 m^3/d, Irrigation water ca. 3 m^3/d, Salt and Electricity.

Pic 45 Egypt - Greenhouse with Built-in Roof Still

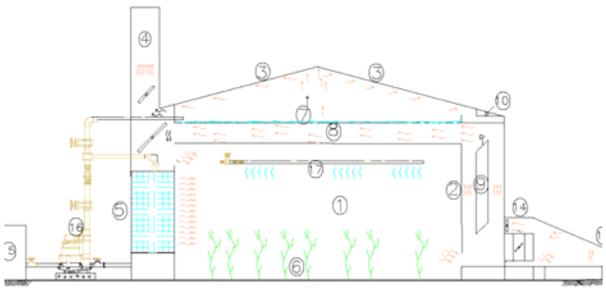

Fig. 45 Basic configuration of the Greenhouse

Note: As the project is still ongoing, final conclusions cannot be drawn.

p.s. the project also is co-financed by MERDC.

Project title	Desalination of sea-water using renewable energy sources
Project acronym	-
Project Contract No.	IC18960039
Name of Programme	INCO, 4 FWP
Contract type	Cost sharing
Year of development	1996-2000
Contractor / Responsible	Dimman Consulting Ltd. , Greece Dimitri Paschaloudis

Short description of the project

The main objectives are as follows:

- To accumulate meteorological data in the Mediterranean area for desalination purposes
- To design a desalination method using the *vapour compression method*, under low pressure where,
    a. the compressor is powered by wind energy and
    b. solar energy is used for heating the feed
- To design another desalination method using the multiple effect evaporation method, where the external heating in the top effect is achieved by solar trough collector
- To construct two pilot units using the two mentioned methods, and install them in two different countries (Greece and Jordan).
- To monitor the operation of the pilot units and measure the necessary parameters
- To make a feasibility study for future construction of larger units in various sites of the Mediterranean

Innovative aspects and conclusions of the project

The work focuses on 2 desalination methods: vapour compression method and multiple effect evaporation method. The methods are oriented to handle the draught problem in small and isolated communities, with no technological supporting and facilities.

The project team focuses on the desalination methods with low investment cost, no operational cost, and a minimum of maintenance cost, which seem to be very attractive in the remote areas.

The key activities envisaged are:

- Optimization of the operational parameters for the two methods (temperature, pressure, concentration ration etc.).
- Design of the key components for the two methods (evaporator/condenser, compressor, windmill, solar collectors, auxiliary heat exchangers). Three critical points will be taken under consideration: a) low construction cost, b) low maintenance cost, c) minimum control needs.
- Construction and installation of the two pilot units. The installation areas are in Macedonia, Northern Greece, and in Aqaba, Southern Jordan. These sites have been chosen due to good meteorological conditions and available facilities for experimental operation.
- Installation of a data acquisition system for monitoring the operation of the units. Development of the corresponding software.
- Presentation of the operation results. These will correlate the quality and quantity of the produced water with the operational parameters, and also include the financial analysis of the operation.
- Scale and site analysis for future industrial apply.

We could not find results for this project.

Project title	Seawater desalination plants connected to an autonomous wind energy system
Project acronym	SDAWES
Project Contract No.	JOR3950077
Name of Programme	NNE-JOULE III 4 FWP
Contract type	Cost sharing
Year of development	1996-2001
Contractor / Responsible	Instituto tecnologico de Canarias, Spain Mr. Gonzalo Piernavieja

Short description of the project

The SDAWES project was designed to make use of one of the natural renewable resources available in Gran Canaria (Spain), wind, to produce scarce resource-water. It consists in connecting a number of different desalination plants to a stand-alone wind farm in order to produce fresh water on a grand scale.

The main objectives of the project are the following:

- To identify the best desalination system to be connected to an off grid wind farm (reverse osmosis, distillation by vapour compression and electrodialysis were analysed).
- To assess the influence of the variations of the wind energy in the behaviour of the desalination plants elements and in the quality of the produced water.

This objective is developed in the following steps:

1. Design of a wind farm to be operated isolated from the grid.
2. Determination of the behaviour of each desalination system (RO, VVC, EDR) working under intermittent operation.
3. Design, installation and working of a RO system with several lines, making possible the connection and disconnection of each line as function of the instantaneous power.
4. Determination of the life of the membranes working under intermittent operation.
5. Determination of the water production quality in function of the variations of the wind.
6. Assessment of the advantages and disadvantages of each desalination system working in the isolated system: determination of the optimal design of each plant.
7. Adaptation of the VC and the EDR plants to work connected to an off grid wind farm: definition of the working conditions and limits.
8. Design, installation and assessment of a control system to make possible the automatic working of the system.

9. Preparation of the installation, operation and maintenance handbooks.

10. Preparation of an industrial package to make possible the transfer of the results to the industrial sector of the European Union.

Innovative aspects and conclusions of the project

Desalination processes themselves are steady-state processes, which imply that they require continuous supplies of energy. This means that a certain degree of adaptation and compromise has to take place to get them to operate in a satisfactory manner when coupled to variable energy input. This in essence is what SDAWES was designed to investigate[32].

This is one of the most ambitious projects to bring together three desalination processes and a renewable energy source. The site (Pozo Izquierdo[33], located in the southeast of Gran Canaria Island) now has the largest concentration of equipment and expertise in desalination and renewable energy of any site in Europe and will undoubtedly become the main focus for research in this area of technology. To date little has been achieved in terms of research. However the Centre has plans to carry out a major long-term research programme[34].

Major findings:

⇒ *Checking the stability of the system.* The stability is possible due to the double control: from the wind, by changing the blade angle in case of excess of wind; and from the control system, by reducing the power consumption in case of lack of wind.

⇒ *Determination of the pressure control in the RO feed pipe.* Depending on the number of the connected RO plants, the flow changes and varies the pressure; several tests were performed to determine the control of the pressure.

⇒ *Optimisation of the system (wind farm with RO).* A simulation model has been used to identify the optimal installation of RO plants connected to an off grid wind farm. It has been decided to use only RO plants because it is the most suitable desalination system for seawater with the smallest specific consumption.

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[32] United Nations Educational, Scientific and Cultural Organization. Renewable energy powered desalination systems in Mediterranean region. July, 1999.

[33] This site is very well known by the wind surfing professionals, due to the very good wind conditions and the celebration of the World Championship of this sports modality.

[34] V.J.Subiela, J.A.Carta, J.Gonzalez. The SDAWES project: lessons learnt from an innovative project. Desalination 168 (2004), pp. 39-47.

⇒ As a preliminary *economical analysis*, a simulation software has been programmed to know which is the optimal installation of desalination plants (only RO) connected to an off grid wind farm. The results showed it would be possible to produce water with a competitive cost (about 0.8 €/m^3).

Project title	Hybrid renewable energy systems in Donoussa and La Graciosa Islands as prototype systems for applying desalination at small villages in Mediterranean islands and coastal areas, by using local energy sources for electricity production
Project acronym	-
Project Contract No.	RENA940030
Name of Programme	RENA, 3 FWP
Contract type	Cost sharing
Year of development	1995
Contractor / Responsible	Agricultural University of Athens, Greece Spyros Kyritsis

Short description of the project

The project regards a study of innovative combination of PV with wind energy. The project partners were aiming to develop a hybrid system and the supply of electricity to energising reverse osmosis desalination plants in two villages on the Donoussa island (Greece) and La Graciosa island (Spain). The villages are not connected to the main electricity network.

The construction of desalination plants in the villages was made in the framework of the JOU20155 project. The present project refers to blue print planning for the extension of these installations to integrate photovoltaics and wind turbines for producing fresh water through reverse osmosis desalination of seawater.

Innovative aspects and conclusions of the project

In the context of the project a software tool was developed[35]. The programme has been applied for simulating a hybrid system PV-wind in order to cover the electricity

[35] Manolakos D., Papadakis G., Papantonis D., Kyritsis S. A simulation-optimisation programme for designing hybrid energy systems for supplying electricity and fresh water through desalination to remote areas. Case study: the Merssini village, Donoussa island, Aegean Sea, Greece. Energy 26 (2001), pp. 679-704.

and water needs of the Mersini village on the Donoussa Island in the Aegean Sea of Greece. Computer simulation programmes are valuable tools to determine the optimum combination of technologies to be integrated as well as to determine an optimum energy management of complex integrated systems, i.e. setting the priorities for energy production and energy storage for each system technology. A computer simulation of the solar, wind and desalination technologies has been developed. Several programme runs were elaborated in order to select the equipment best suited to the case of Donoussa Island. Total solar radiation, ambient temperature, PV array module simulator, pump and turbine simulator, wind generator simulator and others are among the simulation components, which were involved in the programme data.

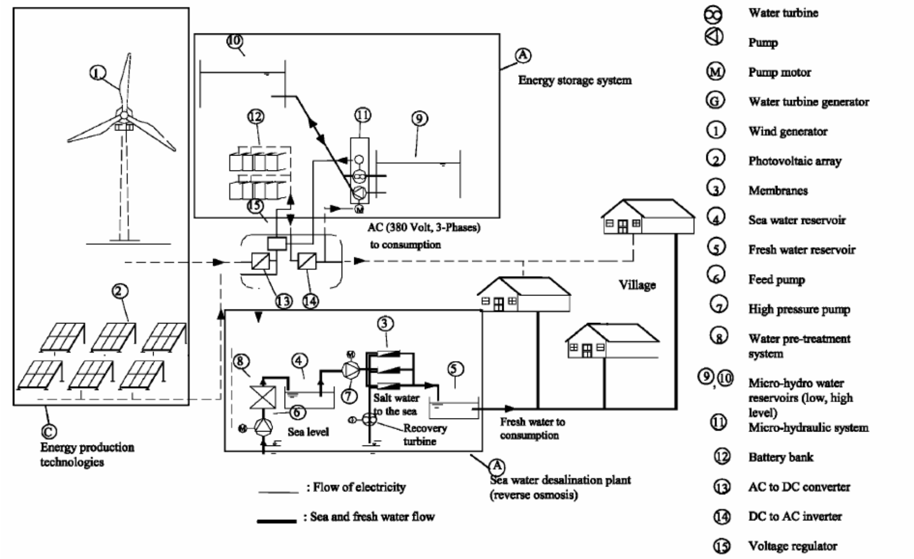


Fig. 46 Schematic diagram showing the integration of wind and solar technologies for supplying electricity and water

When there is sufficient wind energy production provide with the necessary quantities of fresh water, the batteries remain fully charged at that time. Under such circumstances, the system storage, consisting of batteries and micro-hydro, does not operate at all and the consumption is satisfied by the energy produced by PV and wind hybrid system.

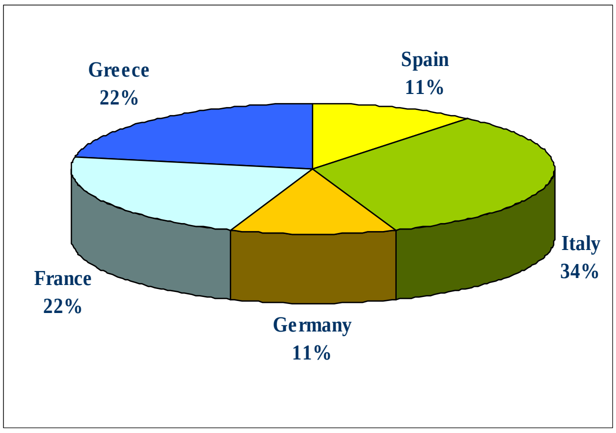
6.1.2. Demonstration projects

Today, seawater desalination plants are well developed on an industrial scale. Each day about 25 Mm^3 of world water demand is produced in desalination plants. These "water factories" have a capacity ranging up to 230.000 m^3/d and can provide large cities with drinkable water.

Small villages or settlements in rural remote areas without infrastructure do not profit from these techniques. The large plants use a complex technology and cannot easily be scaled down to very small systems and water demands. Furthermore, the lack of energy sources as well as a missing connection to the grid complicates the use of standard desalination techniques in these places and increases the costs. This is one of the reason why the European Union promotes special projects to demonstrate the advantages of RES based small scale desalination plants.

There were eighteen demonstration projects overviewed in total. Not all of them were implemented fully due to financial or technical problems of project partners. Nevertheless some basic features could be drawn:

- Demonstration plants were built in five countries: Italy, Greece, France, Germany and Spain (see Fig.47).
- We found no demonstration projects after 1997-2001 round of contracts.
- All three described technologies occupy similar share (see Fig. 48).
- Most of the demonstration projects were implemented on islands (77 %).
- Most of demonstration plants built are of small and medium scale. Wind-energy fed plants were bigger and also provided electricity to communities or buildings.
- The smaller desalination plants were designed to work in autonomous mode while basically wind energy based units are connected to the electricity grid (see Fig.49).
- Almost all demonstration projects used RO, usually coupled with PV and wind.
- Seawater is the main source to produce potable water in the described projects.



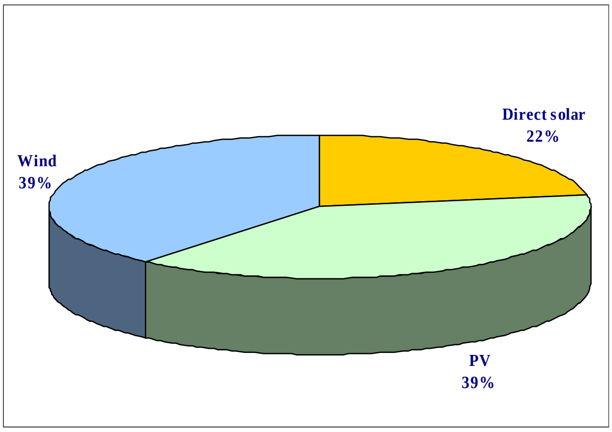


Fig. 47 Countries where demonstration plants were installed

Fig. 48 The share of RES in the projects

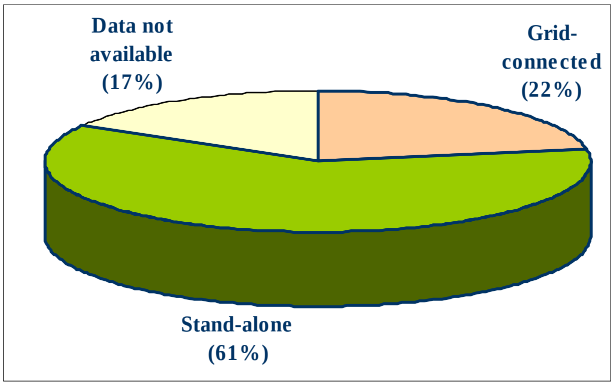


Fig. 49 The type of the demonstration plants

Below described projects are grouped according the source of renewables used in the plants.

6.1.2.1. Direct solar desalination plants

One of the main features of the desalination plant using solar energy is the size of collecting area. It determines the capacity of the plant and the amount of distilled potable water. We found four projects, which were aiming to demonstrate the use of solar energy to desalinate the seawater and to satisfy the demand for it in the remote areas.

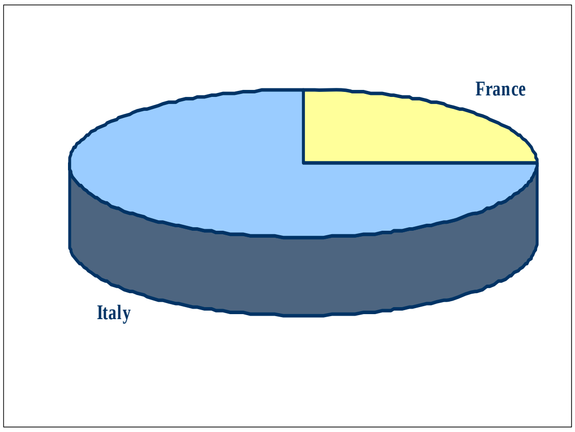


Fig. 50 The application countries of the demonstration plants using solar energy

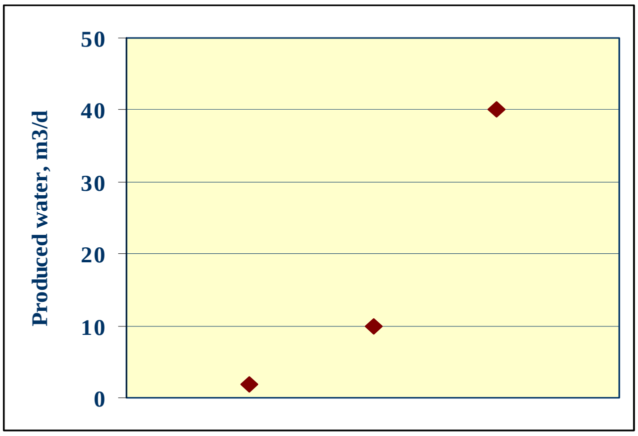


Fig. 51 The range of produced potable water by demonstration desalination plants

Although all the projects were dedicated to the use of solar energy for desalination processes, the main principles of the projects were rather different (see the summarising Table 25).

- The collectors' area varies from 408 m^2 to 25.000 m^2 and the produced potable water varies from 1.9 m^3/d to 40 m^3/d.
- Not all of the demonstration plants met the raised goals in terms of efficiency. One of the exceptions is the largest plant installed in Italy, which showed the productivity of 10 m^3/d using the solar ponds, which covered 25.000 m^2. It was concluded that with the same energy supply capacities 100 m^3/d of potable water could be reached.
- Most of the plants were constructed to work in a stand-alone mode and the produced energy was delivered to the desalination plants only.
- There were no data on the costs of produced water.
- Not all of the projects met their goals and expected results.

The latest demonstration project (SE./00303/94) was more experimental than demonstration one. It researched and applied the use of full titanium desalinator for better heat transmission in the plant.

The proposed solutions helped to reduce requirements of chemicals, decrease maintenance needs and to increase reliability as well as the lifetime of the plant.

Table 25 Solar energy based demonstration projects

Title	Year	Reference No.	Basic features of the project
Multi-stage-flash desalination plant with solar energy as the main energy source at Lampedusa island	1980-1983	SE./00009/79	*Type of RES:* Solar *Specific aims of the project:* To analyse the working conditions on concentrating and a multi-stage-flash (MSF) desalination *Plant:* Lampedusa, Italy *Capacities:* 1.9-2.9 m^3/d; 408 m^2 *Type:* stand-alone
A solar desalination plant in the Guade-loupe dependencies	1984-1987	SE./00790/83	*Type of RES:* Solar *Specific aims of the project:* Desalination using multiple effect evaporator; Reducing corrosion or blockage *Plant*: Guadeloupe, France *Capacities:* 40 m^3/d *Type:* stand-alone
Solar pond for desa-lination of sea water	1985-1988	SE./00457/84	*Type of RES:* Solar *Specific aims of the project:* Self gradient solar ponds; Economics of their application *Plant*: Italy *Capacities:* 10 m^3/d; 25.000 m^2 *Type:* -
Innovative desalination unit dedicated to solar ponds	1994-1998	SE./00303/94	Type of RES: Solar *Specific aims of the project:* First full-titanium desalinator; Maintenance of solar ponds, chemical requirements, reliability and overall costs *Plant:* Ancona, Italy *Capacities:* n.a. *Type:* -

Project title	Multi-stage-flash desalination plant with solar energy as the main energy source at Lampedusa island
Project acronym	-
Project Contract No.	SE./00009/79
Name of Programme	ENALT 1C, ENG
Contract type	Demonstration
Year of development	1985-1988
Contractor / Responsible	Agip Nucleare, Italy Benevolo

Short description of the project

The project's aim was to use solar energy for desalination of seawater. The project partners referred to the scarcity of fresh water in the isolated islands in the Mediterranean Sea, which is very often crucial for the inhabitants and their economic development. In meantime the desalination was based on oil as the energy source. The working conditions of concentrating collectors and of a multi-stage-flash (MSF) desalination unit were supposed to demonstrate in this project.

Lampedusa is an Italian island situated between Sicily and the Libyan coast. The solar conditions are very favourable for the proposed use. The island itself has no substantial water resources, of its own.

Innovative aspects and conclusions of the project

The project's aim was to use solar energy for desalination of seawater. Currently the desalination is based on oil as the energy source. The working conditions of concentrating collectors and a multi-stage-flash (MSF) desalination unit should be demonstrated in this project. Solar plant was designed with a total surface of 408 m^2. More information is given in Table 26.

Table 26 Comparison of the two collectors[36].

Characteristics of the solar fields	Belmar (Italy) collector	Contraves (Switzerland) collector
Type	concentrating linear parabolic	concentrating linear parabolic
Installation place	in the open air	inside a greenhouse
Number of collectors	96	16
Net collecting area	288 m^2	120 m^2
Orientation with respect to the horizon	35°	35°
Tracking system	E-W	E-W
Concentration ratio	13:1	6:1
Collectors steady yield	55%	45%
Reflectors	Polished inox steel 19/10 AISI 304 HA parabolic cylinders	anodized aluminium parabolic cylinders, glass covered

The projects partners very critically concluded that the *results* of the projects did not meet the expected output:

- The solar system consisting of concentrating collectors is not suitable for a site near the sea.
- The use of the uncovered BELMAR collectors was therefore interrupted due to continuous corrosion on the polished stainless steel mirrors. Apart from the problems with salt water the dust deposit lowered the performance to 40% of a clean collector.
- It was found to be not advisable to use two different collector types on one installation. The overall efficiency of the solar collectors was much lower than the individually tested collectors.
- The MSF desalinator worked poorly under partial load. The seawater used for the desalination had to be cut down to approx. 1000 l/h (50%). The production of distilled water was low 80-120 l/h instead of 300 l/h.

36 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=327753&CFID=3752427&CFTOKEN=72277782

Project title	A solar desalination plant in the Guadeloupe dependancies
Project acronym	-
Project Contract No.	SE./00790/83
Name of Programme	ENALT 2C, ENG
Contract type	Demonstration
Year of development	1984-1987
Contractor / Responsible	Entropie SA, France De Gunzbourg

Short description of the project

This project aims to demonstrate the feasibility of exploiting solar energy as the prime energy source for seawater desalination using a multiple effect evaporator. Successful implementation of this project could lead to it becoming a springboard for similar projects in areas of the Community or the World where there is abundant sunshine and saltwater but shortages of fresh water.

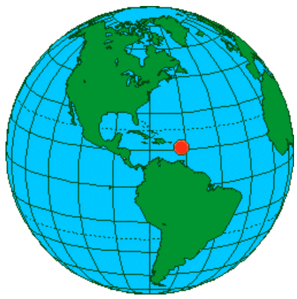


Fig. 52 Position of Guadeloupe in the world

The desalination plant consists of high-energy efficiency multiple effect evaporators operating at very low pressure, coupled by way of water storage and an automatic energy management system to a field of evacuated tube collectors. The distillation process uses heat supplied by the solar collectors and electricity for auxiliaries (pumps, controls, etc). All the heat is used at 70°C. In order to reduce the possibility of corrosion or blockage, the temperature of the seawater entering the evaporators never exceeds 70°C. This necessary operation under vacuum and therefore a vacuum pump is required upon start-up and during operation to compensate for air beaks. The aim is to reduce the costs of existing system[37].

Innovative aspects and conclusions of the project

The built unit comprises:

- a solar collector field (tubular type under vacuum),
- a hot water storage tank allowing for a regular operation of the desalination unit 24 hours a day and a very high efficiency multi-effect distillation unit[38].

The choice of the collector with tubular type under vacuum has been made after a comparative study with a flat plate, selective painted collectors with single and double glassing; the comparison has taken into account many parameters such as the required land area, the cost of earth work and civil works, the resistance to high speed winds, the comparative costs of collector fields, the transport, etc.

With the aim of limiting the build up of deposits in the system a dissolving agent is introduced by a measuring pump, along with the seawater. This should allow continuous production for 6 months to 1 year before cleaning is necessary. Several evaporation stages or effects are stacked inside a vertical cylindrical body. Heat is introduced into the highest effect by hot water coming from the solar water storage. This heat is released to the seawater across the walls of a horizontal exchanger. A fraction of seawater evaporates and the vapour thus produced condenses to fresh water, at a slightly lower temperature, on the exchanger in the next effect. The heat of condensation is then released to seawater. This process continues until the final effect where the temperature is close to that of the seawater feed which is pumped to the top of the evaporator. Pumps extract the salt and fresh water. Drinking water is produced by dosing the distilled water with minerals, increasing its pH and adding chlorine.

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37 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=365433&CFID=3635238&CFTOKEN=44070679

38 J. De Gunzbourg, T. Froment. Construction of a solar desalination plant (40 cum/day) for a French Caribbean island. Desalination, 67 (1987), pp. 53-58.

To maintain continual operation and to control the evaporator inlet temperature buffer storage of 100 m^3 is placed between the collectors and the evaporator unit. The whole system is controlled and monitored automatically.

The costs of equipment, transport, installation commissioning and training are about 7.5 MFF (ex taxes). Fresh water production is ca.12 000 m^3 per year or 40 m^3/day and the expected payback time is 7 years.

Project title	Solar pond for desalination of sea water
Project acronym	-
Project Contract No.	SE./00457/84
Name of Programme	ENALT 2C, ENG
Contract type	Demonstration
Year of development	1985-1988
Contractor / Responsible	ENI SpA – AGIP, Italy S. Folchitto

Short description of the project

Salt gradient solar ponds are those, which have been studied more than any other type of solar pond. Much of the large-scale experimental work has been carried out outside of Europe and because expected results are encouraging for particular applications, this project was chosen as the first such demonstration project of its kind[39].

In salt gradient solar ponds, three stratums may be distinguished:

- A shallow, layer on the surface with a low salt concentration. This layer is subject to vertical convection currents induced by the wind and evaporation.
- An intermediate layer with a gradually increasing concentration of salt with depth, thereby preventing vertical convection currents.
- A bottom layer, having a constant high salt concentration, accumulates heat and has convection currents. Therefore the pond contains a certain amount of

39 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=331117&CFID=3625287&CFTOKEN=64718024

salts whose concentration approaches the saturation at the depth of 3-4 metres. Total salt content is 15.000 tons.

Heat is absorbed and stored into the bottom layer, which is insulated by the intermediate stratum from the atmosphere. The site is most suitable because of availability of salt and water, high level of solar radiation and the flat nature of land. Frequently high wind speeds may induce on the pond surface waves that are suppressed by a buoyant net system. It was aimed to evaluate, using data collected from a relatively large sized solar pond, whether sufficient heat can be economically stored and subsequently used for moderate temperature end use applications.

Innovative aspects and conclusions of the project

The pond with a clay floor covered by an impermeable plastic liner and of a surface of 25000 m^2, has been linked to a desalination unit producing 10 m^3/day of fresh water. The desalination unit has been run, without any problem, starting from the end of May 1990 up to the end of November 1990. It has been demonstrated by experimental data, that a bigger unit up to 100 m^3/day may be ran by the pond of such size.

Heat is extracted by a heat exchanger fed with hot bittern pumped from the bottom of the pond; cooler bittern returns to the pond through a diffuser, installed on a platform in the middle of the basin. The diffuser allows returning the bittern at a determined level under the gradient layers, to avoid gradient perturbations. This technology may become susceptible to be widely adopted for certain application especially in southern Europe.

The demonstration project has allowed understanding the limits of the application from economic point of view, which are strictly related with the scale effect. The most economic size that has been envisaged for an industrial application will be about hundred thousands square meters.

Energy savings of 330 toe/year and a payback of 8 years are expected.

Project title	Innovative desalination unit dedicated to solar ponds
Project acronym	-
Project Contract No.	SE./00303/94
Name of Programme	THERMIE 1, ENG
Contract type	Demonstration
Year of development	1994-1998
Contractor / Responsible	Servizi di Ricerche e Sviluppo, Italy Caira Marco

Short description of the project

The project concerns the design, optimisation, construction, assembling, start-up and extensive monitoring of a full-titanium desalinator[40]. It is the first full-titanium desalinator in the world, with a meaningful size and fed by a high salinity heating fluid. The project has three main aims:

1. The improvement of the economics of solar desalination, namely desalination of water through operation of solar ponds.
2. The demonstration of thermal performance, maintenance and chemicals requirements, reliability and overall costs of a full-titanium desalinator, through operation of a plant of meaningful size, in order to disseminate the technology of full-titanium desalinators in the electric-energy production industry, for utilization in co-generation units.
3. The improvement of knowledge regarding the industrial-size utilisation of heat recovery from highly corrosive fluids.

Innovative aspects and conclusions of the project

The design, construction and installation phases have been completed and followed by experimental campaign and data analysis as well as by the activities for adaptation of the solar pond site for the monitoring of the desalination.

40 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=3389188&CFID=3625287&CFTOKEN=64718024

The operation tests took place at the site of the Solar Pond of Universtity of Ancona, Italy. Data collected during manufacturing tests and most of all during the start-up and the operation of the plant, under manufacturing tests and most of all during the start-up and the operation of the plant, under various conditions and alignments, will be useful for the improvement of the know-how on heat recovery with highly corrosive media, on co-generation plants aimed at producing electricity and fresh water, on desalination fed by solar energy.

A main output of the project is the assessment of data which allow to compare the additional cost of the full titanium desalinator with respect to a traditional technology one, with the benefits of :

- a better heat transmission through tube bundles, which means a better performance,
- a reduced requirement of chemicals and of maintenance activities,
- an improved plant reliability and duration.

A careful fluid dynamic analysis of the failing fluid on the tube bundles was performed during the first phase of the design activity, in order to maximise the improvement of heat transfer coefficient due to reduced fouling, and therefore the improvement of heat performance. Preliminary calculations and tests allowed to reach heat performance of 750 kjoule/kg of distillate, averaged during the operation of the plant, with a 3 stage full-titanium desalinator, to be compared with a standard technology desalinator with same number of stages and operating conditions. This means the possibility of reducing the overall tube bundle surface of the titanium desalinator by a factor 1.2 (=900/750), in order to obtain the same productivity of the 3-stage titanium desalinator with respect to a 3-stage traditional desalinator, and to use the 20% of margin by adding a new stage to the desalinator, which will be a 4-stage multiple effect desalinator. The heat performance of this desalinator is, as a consequence, 620 kJ/kg.

6.1.2.2. Desalination plants with PV collectors

Most of PV based desalination plants were coupled with reverse osmosis or electrodialysis technologies to desalinate sea water. The capacities varied from very small (1.4kW) to bigger ones (63kW) but all the plants are considered as small-scaled (up to 100 m^3/d).

Most of the projects were implemented in the remote areas (islands) in the southern Europe (see the graphs). Some of the projects were dedicated to satisfy the potable water and electricity needs of a certain building (hotel, lighthouse) while the others were orientated to the needs of community of the island or region. The ACCEPT project (SE./00124/90) differs from the others by the final use of distilled water: it was planned to use 24 m^3 of water produced daily for agriculture. Also, it was noticed that PV driven desalination plants were autonomous. It could be stated that PV as the source of energy was chosen because there was no central electricity grid in the target area and PV stays one of the most suitable technologies to overcome this problem.

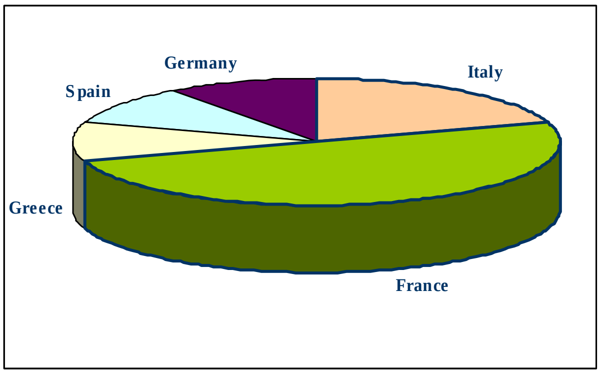


Fig. 53 The spread of demonstration desalination plants with PV

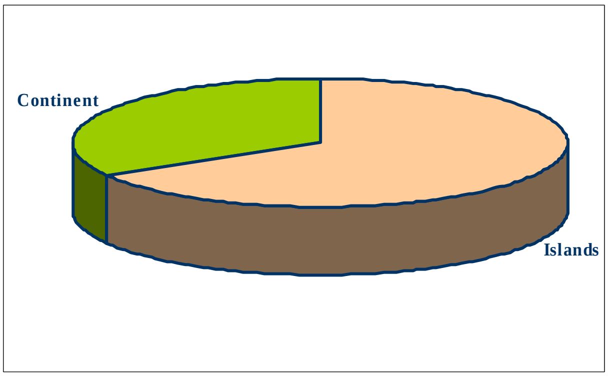


Fig. 54 Territorial distribution of the plants in the context of remoteness

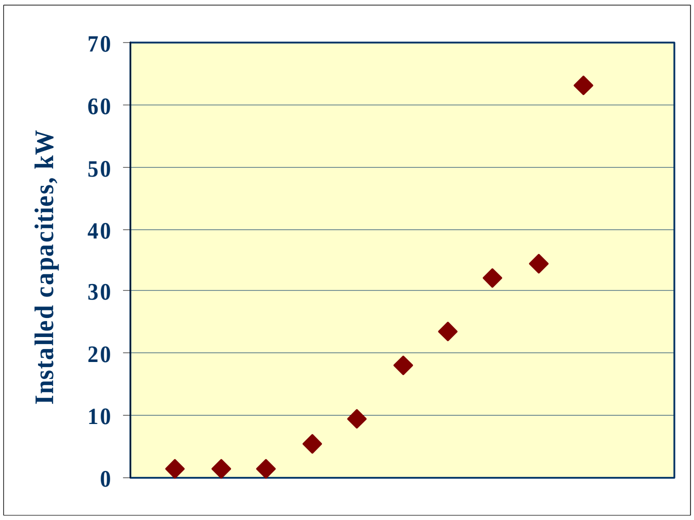


Fig. 55 The range of installed capacities within the projects

It could be concluded that PV based demonstration projects met the biggest difficulties to be implemented, and some of them were cancelled or not finished.

Table 27 PV collectors driven demonstration projects

Title	Year	Reference No.	Basic features of the project
Lipari island water desalina-tion plant	1987-1991	SE./00336/87	*Type of RES:* PV-RO *Specific aims of the project:* Sea water storage tank constructed to reduce the necessary electricity storage in the batteries, To analyse the working conditions on concentrating and a multi-stage-flash (MSF) desalination *Plant:* Lipari, Italy *Capacities:* 13.7 m^3/d; 63 kW *Type:* stand-alone
PV power supply for desalination, refrigeration and lighting	1987-1993	SE./00143/85	*Type of RES:* PV *Specific aims of the project:* The demonstration of the use of PV to provide drinking water and electricity to remote areas *Plant:* Milos, Greece *Capacities:* 34.3 kW in total, from which 13 kW for desalination *Type:* grid connected
Almeria solar powered reverse osmosis plant	1987-1995	SE./00233/86	*Type of RES:* PV-RO *Specific aims of the project:* Cost minimising via membranes, pumps modernisation *Plant:* Almeria, Spain *Capacities:* 23.5 kW *Type:* stand-alone
PV powered lighthouse and desalination plant (Punta Libeccio)	1988-1993	SE./00565/85	*Type of RES:*PV *Specific aims of the project:* To show how PV could supply energy to an isolated lighthouse, three keepers dwellings and a desalination plant *Plant:* Marrteimo, Italy *Capacities:* 18.2 kW *Type:* stand-alone
Electricity and water supplies for Glenan islands by PV generators	1991-1994	SE./00198/90	*Type of RES:* PV *Specific aims of the project:* electrification by PV of some islands, the energy also has to be provided to desalination units. Project was not finished. *Plant:* Glenan, France

			Capacities: 19 kW (5 units) *Type:* stand-alone
PV generators on islands of Brittany and Corsica	1991-1995	SE./00035/91	*Type of RES:* PV *Specific aims of the project:* To built 40 PV plants sites on small islands around the French coast in the framework of this project. Total module size is 38000 Wp. The units involved PV, wind, diesel, but the financing covered only PV plants *Plant:* Brittany, Corsica, France *Capacities:* 40units, installed 12, the project is cancelled *Type:* stand-alone
Advanced concept combined electrodialysis PV project (ACCEPT)	1992-1997	SE./00124/90	*Type of RES:* PV-RO *Specific aims of the project:* Coupling PV power to an electrodialysis water plant; Incorporation of intelligent system controller *Plant:* Germany *Capacities:* 24 m^3/d; 32 kW *Type:* stand-alone (?)

Project title	Lipari island water desalination plant
Project acronym	-
Project Contract No.	SE./00336/87
Name of Programme	ENDEMO C, ENG
Contract type	Demonstration
Year of development	1987-1991
Contractor / Responsible	Italenergie SpA, Italy Fonzi Fulvio

Short description of the project

The aim of the project was to install the desalination system, which would be able to produce 5000 m^3 of drinkable water per year with an improved technology in comparison with the Tremiti island plant. To demonstrate the economical supply of fresh water by desalination for the case of sites with long transportation as

well as to compare DC motor pumps with AC motor pumps for the purpose of the reverse osmosis desalination.

Innovative aspects and conclusions of the project

It was planned to incorporate PV energy for a seawater desalination plant with reverse osmosis system. (5000 m^3/year).

Table 28 General data of system

Nr. subsystems	1
Power subsystem	63 kWp
Total power	63 kWp
Backup	none
Nr. of modules	1440
Module description	ITALSOLAR, TYPE 36 MS/CE, 40 Wp, 36 five inch square mono-crystalline cells; (Voc : 21.5 V; Vmp : 17.5 V;) double glass with anodized aluminium frame, 420 x 940 mm, 7 kg
Connection	8 modules in series (172 Voc, 140 Vmp); 180 of these strings in parallel
Support	on racks, subfields, 1500 m^2; hot zinced steel structures, 30 deg. inclination
Max. power tracker	data not available
Charge controller	special design
Battery	Lead/acid in 4 groups, STECO LD-1800
Capacity (Ah)	750 kWh
Inverter	for half of the system, 110Vdc/380Vac, 3 phase
Load description	Three identical reverse osmosis systems, working in parallel.
Consumption of the reverse osmosis	6. 5 kWh/m^3 of fresh water.

Project title	PV power supply for desalination, refrigeration and lighting
Project acronym	-
Project Contract No.	SE./00143/85
Name of Programme	ENALT 2C, ENG
Contract type	Demonstration
Year of development	1987-1993
Contractor / Responsible	Petros Moschovitis Engineering, Greece

Short description of the project

One more project related to the demonstration of the use of PV to provide drinking water and electricity to remote areas. The project was carried out on the island of Milos, a touristic island in Greece.

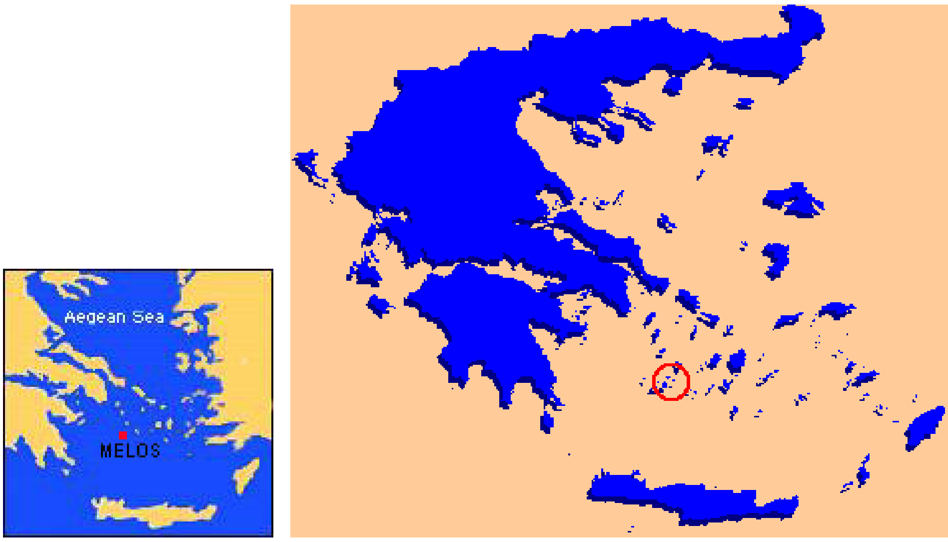


Fig. 56 Position of Milos island

Innovative aspects and conclusions of the project

The system layout to implement was fixed including the following data.

- 13 kWp for the desalination unit,
- 5 kWp for the restaurant,
- 5 kWp for a water -packing unit,
- 5 kWp for the goat farm,
- 13. 8 kWp for thirty houses, including 20 street lighting poles.
- Total: 34.3 kW.

Siemens modules SM 555 were foreseen.

There is no data on the implementation of the project.

Project title	Almeria solar powered reverse osmosis plant
Project acronym	-
Project Contract No.	SE./00233/86
Name of Programme	ENDEMO C, ENG
Contract type	Demonstration
Year of development	1987-1995
Contractor / Responsible	Deutche aerospace AG, Germany Maass Karl

Short description of the project

The purpose of the project was to demonstrate that small scale PV powered water desalination plants could be constructed in a compact and cost efficient way. This type of plant was urgently needed in Southern Europe and Developing Countries at meantime. It was expecting that the demonstration project served as an intensive publicity for commercialisation of the technology (100 systems potential market in Spain only).

Innovative aspects and conclusions of the project

On the site built at the ALMERIA University, brackish water is pumped from a well of 60m. Drinking water (about 8000 m^3/year) obtained by a reverse osmosis plant is stored for consumption. A 23.5 kWp PV generator supplies the required energy.

New type of PLATE MODULE system, with turbulent flow on the feed water side and hence less membrane scaling and fouling which leads to less maintenance. The pressure pump of the RO system works with 220 V DC motor, 6750 W, avoiding inverters. While the PV generator and the batteries worked without problems, the water pumps, the reverse osmosis plant, the inverter and the monitoring system had several, partly major, failures.

The Final Report on System Monitoring (June, 1995) analyses 32 month of operation and puts in evidence that the system is well designed for its task; however the frequent failures of some components decrease its effective utilisation. The plant was supposed to continue the operation after the end of the project with some improvements (new pumps, new membranes, etc.) to be made. The cost per unit of energy is calculated to be 4.1 ECU/kWh for the demonstration project and 1.2 ECU/kWh for a replication. For a replication these cost lead to 2 ECU/m^3 (for brackish water) and 11.8 Ecu/m^3 (for sea water).

Table 29 Details of the plant

Nominal PV power	23.5 kWp
Nr. of modules	816
Module description	612 AEG type PQ 10/20/01; (Typ I) + 306 AEG type PQ 10/40/01; (T.II) (I) : 20 10x10cm poly-cryst. cells, 6 V,16.5 W (II): 40 10x10cm poly-cryst. cells, 12 V,38.4 W Very high resistance glass; UV stabilized PVB; 6.7 kg; 0.25 or 0.5 sqm. Connections : type 20 : 36 series, 17 parall. : type 40 : 18 series, 17 parall.
Connection	2 in series, 24 V
Support	on racks
Max. power tracker	included in inverter
Chrg. controller	charge/discharge regulator: special design, microprocessor controlled
Battery	Spanish TUDOR, 110 cells
Capacity	2240 Ah.(at 100 h). {1650 Ah (10h}; type C 10
Inverter	AEG, Solarverter, type SV3 sinusoidal, transistor-pulse type, 3 kHz
Inv. in (V)	130 to 300 V DC in; max 16 A DC
Inv. out (V)	3.3 kVA; 13 to 127 V out; 3 phases; to 50/60 Hz
Load description	PLEUGER submersible pump NE612 for raw water pumping. (three phase, AC motor, hence inverter necessary). 4.2 cbm/h, header 30 m.
Monitoring	Weather station; Reading every 10 seconds six relevant plant data, averaging over ten minutes, storing on floppy. (DAM 800 data acquisition system by TELEFUNKEN). Stored data: (1) Insolation, array plane. (2) amb. temp. (3) module temp. (4) array output energy. (5) energy to and from battery. (6) inverter DC energy

Meantime there are more projects on the use of solar/PV/wind energy for desalination plant run in Almeria.

Project title	PV powered lighthouse and desalination plant (Punta Libeccio)
Project acronym	-
Project Contract No.	SE./00565/85
Name of Programme	ENALT 2C, ENG
Contract type	Demonstration
Year of development	1988-1993
Contractor / Responsible	Cesen SpA, Italy C. Maccio

Short description of the project

This project is one of the examples how PV could supply energy to an isolated lighthouse, three keepers dwellings and a desalination plant.

The Punta Libeccio lighthouse is situated on Marettimo Island, 40 km North West of Sicily. The lighthouse is manned continuously, and three lighthouse keepers and their families live in three dwellings near the lighthouse.

Table 30 General information about the plant

PV arrays	1) An 8.4 kWp PV array, 1300 Ah battery and regulator, provides DC power for a 1000 W lamp and rotation mechanism (25 W) at Punta Libeccio Lighthouse off Sicily. The lamp has a range of 32 nautical miles. The lamp is operational for 15 hours a day. The battery allows 10 days operation during periods of no sun. 2) A 9.8 kWp array with a 300 Ah battery, two 5 kVA inverters and a control system supplies AC power for a reverse osmosis seawater desalination plant. This subsystem also supplies lights, refrigerators, a washing machine and TV in three keepers dwellings near the lighthouse. The battery allows for 3 days operation during periods of no sun. Excess energy can be cross-fed between the two systems to minimise waste.
Back-up	30 kW diesel generator
Nr. of subsystems	2
Power of subsystems	18,2 kWp (8.4 + 9.8)
Number of modules	520
Module description	ANSALDO AP 35 HD, poly-crystalline, 35 Wp; 1380 x 340 mm
Connection	10 in series, 4 strings (of 10 series connected modules) in parallel; six (for lighthouse) and seven (for desalination and household appliances) of these sub-arrays parallel.

Support	on racks, 55 deg. inclination, (orientable)
Max power tracker	none
Charge controller	separate, for the two systems
Battery	FIAMM
Battery voltage	120 V
Battery capacity	1950 Ah (234 kWh) and 450 Ah (54 kWh)
Inverter	Two of type LAES
Inverter in	120 V DC
Inverter out	220 V AC
Inverter power	2 x 5 kW

No data about the results of the project were found.

Project title	Electricity and water supplies for Glenan islands by PV generators
Project acronym	-
Project Contract No.	SE./00124/90
Name of Programme	THERMIE 1, ENG
Contract type	Demonstration
Year of development	1991-1994
Contractor / Responsible	Municipalità de Fouesnant, France Gouriou Herve

Short description of the project

The main issue of the project is the electrification of some islands in the Bretagne, Glenan archipelago (France). The islands are tourist centres in summer and all (except St. Nicolas) are unoccupied in winter.

It was planned to install five PV systems totaling about 19 kWp to provide power for domestic use, water desalination and pumping on five small islands of the Glenan archipelago.

Innovative aspects and conclusions of the projects

All 5 PV systems totalling about 19 kWp were installed. The three originally foreseen systems at Penfret have been joined to make one big system (5500 Wp).

Table 31 Main characteristics of the plant

The unit	Drenec	Cigogne	Bananec	St. Nicolas	Penfret
Installation	August, 1991	August, 1991	December, 1992	March, 1992	December, 1992
Power subsystem	3 x 1472 Wp			9600 Wp	5500 Wp
Inverter/connection	220V AC			wind/diesel and wind systems, using the existing inverter and batteries	
Monitoring	Data logger SUNPAC with local data storage			Tele-monitoring by modem type TBC, made by NAPAC	
Module description	PHOTO-WATT BPX 47500 (46 Wp),	PHOTO-WATT BPX 47500 (46 Wp),	PHOTO-WATT PWX 500 (46 Wp) without frame	PHOTOWATT, 40 Wp modules. BPX 47500-old	PHOTOWATT BPX 47500 (46 Wp),
Connection	2 in series, 24 V, total 32 modules each.			9 strings of 26 in series, 312 V, total 234 modules. (+ 6 for aircraft safety signals on wind generator mast).	10 in series, 120 V, total 120 modules
Support	On roofs	On racks of the wall	On roofs	On racks	
Charge controller	P.watt 40M24		S.T.N.	S.T.N.	S.T.N.
Battery type	Oldham		CFEC-STECO	CEAC	CEAC
Battery voltage (V)	24			308	120
Battery capacity (Ah)	560			1500	560
Battery capacity (kWh)	134			510	67
Inverter type	Atlas	Vic-tron	Mobitro-nic	FAIVELEY	

Inverter in (V)	24			308	120
Inverter out (V)	220			380/220	220
Inverter power (kW)	2	1	1	10	5
General electricity supply	Electrification and pumping of drinking water			Electrification of houses and for and water desali-nation plan	

Monitoring was made fully on the islands of St. Nicolas and Penfret: all important parameters are measured, stored on site and also transmitted by MINITEL. For Drenec and Cigogne the AC consumption and the DC inverter input are measured. Due to financial difficulties of the second contractor no monitoring data could be collected and no final report could be written.

Project title	PV generators on islands of Brittany and Corsica
Project acronym	-
Project Contract No.	SE./00035/91
Name of Programme	THERMIE 1, ENG
Contract type	Demonstration
Year of development	1991-1995
Contractor / Responsible	Solaire Techniques Nouvelles (STN), France

Short description of the project

There was supposed to install 40 PV plants sites on small islands around the French coast in the framework of this project. The sites are small homes/farms, nature reserves and tourist centres. Total module size is 38000 Wp.

Innovative aspects and conclusions of the projects

The systems sizes range between 192 Wp (4 modules) and 3264 Wp (68 modules). Some systems provide 24 V DC and some provide both, 24 V DC and 220 V AC.

Applications include domestic lighting and power, water desalination and pumping, and communications.

Innovation is claimed for the variety of applications. Some systems include PV, wind and diesel generators but this project involves financing only PV systems.

Table 31 Main data of the PV system

Annual PV energy output	25000 kWh
Nr. of subsystems	42
Power subsys.	from 192 to 3264 Wp
Total power	38048 Wp
Backup	none, wind and Diesel
Nr. of modules	816
Module description	PHOTOWATT, 536 modules type BPX 47500 (12 V, 46 Wp), Multi-crystalline silicon, 36 cells, 1042 x 462 x 39 mm, bi-glass, 9.2 kg; and 280 modules type BPX 47451 (12 V, 44 Wp), multi-crystalline silicon, 36 cells, 1060 x485 x 65 mm, bi-glass, 8.9 kg.
Connection	2 in series, 24 V
Support	on the roofs and on racksy
Max. power tracker	none
Chrg. controller	STN, type PW R 40M, or PHOTOWATT 20C24 and others
Battery	Lead acid, OLDHAM, CFEC, STECO and others
Capacity	(C100)
Batt. (Ah)	from 105 to 800 Ah
Inverter	VICTRON, Mobitronic, STN and others
Inv. in (V)	24 V
Inv. out (V)	220 V, 50 Hz
Inv. power (kW)	0.6, 1.0, 1.2, 1.5, 2.0 kVA
Load description	Lighting and general electricity (pumps, low consumption refrigerators and deep-freezers (type TRS), circulators, desalination, etc.) for farmhouses.
Monitoring	Measurement of electricity consumption by conventional (Landis & Gyr) counters.

Twelve systems installed in 1991 continue to operate. In 1993 the system of "Ile-verte" was increased from 8 to 28 modules. Data logger systems (SUNPAC, with local data collection) have been installed on 9 of the operating systems. On the "Ile Saint Rion" system a TBC NAPAC system with data transmission by telephone modem has been installed. In 1994 due to financial difficulties of the contractor no further systems were installed, no monitoring data could be collected and final report was not written.

The project has been cancelled.

Project title	Advanced concept combined electrodialysis PV project
Project acronym	ACCEPT
Project Contract No.	SE./00124/90
Name of Programme	THERMIE 1, ENG
Contract type	Demonstration
Year of development	1992-1997
Contractor / Responsible	AMT Applied Membrane Technologies Consulting & Engineering GmbH, Germany H. Finken

Short description of the project

The demonstration type project had to demonstrate for the first time the coupling of PV power to an electrodialysis water desalination plant. The DC power of the PV generator drives directly the electrodialysis desalination apparatus.

Table 33 General data of system

Nr. subsystems	1
Power subsystem	32 kWp
Total power	32 kWp
Backup	none
Nr. of modules	608
Module description	DASA type MQ 36
Connection	16 modules in series (220 V dc); 38 strings in parallel
Support	on racks
Max. power tracker	data not available
Charge. controller	intelligent system controller with 5 switchable groups
Battery	FULMEN or TUDOR
Capacity (Ah)	500 Ah (110 kWh), for half day capacity
Inverter	none
Load description	220 V DC/50-100 V DC converter to produce 24 m^3/d desalted water
Monitoring	foreseen

A 32 kWp PV system with 500 Ah/220 V battery and intelligent system controller to power a water desalination plant of 24 m^3 per day output. The plant is operated only during day-time in order to minimize battery capacity. The treatment plant operates on the electodialysis principle, which is claimed to use one third of the power of a reverse osmosis plant for water of moderate salinity (around 3000 ppm). Estimated consumption: 3.6 kWh/m^3. The water will be utilized for agriculture (irrigation of fruit and vegetables). *There are no data on the implementation of the project.*

6.1.2.3. Wind energy desalination plants

Most of wind energy based desalination plants were coupled with reverse osmosis or electrodialysis technologies to desalinate seawater. The capacities varied from very small (10kW) to big ones (3000kW) and in contrary to other RES based desalination plants these demonstration projects vary a lot in terms of capacities and maximum powers. The next common feature of these projects is that wind energy is orientated to supply electricity (most of the plants are connected to the grid) and only smaller part of energy is transmitted to desalination process. All the projects were implemented and plants were built in small islands, mostly without electricity grids and this is the reason to explain the choice of bigger wind turbines and multifunction of the plants.

Some projects were devoted to built one more or less powerful wind turbine while other projects (mostly in Greece) were orientated in building smaller wind turbines but more (up to 10 in Crete).

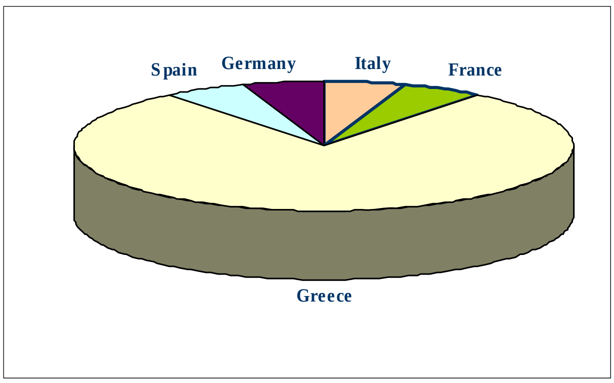


Fig. 57 The spread of demonstration desalination plants run by wind energy

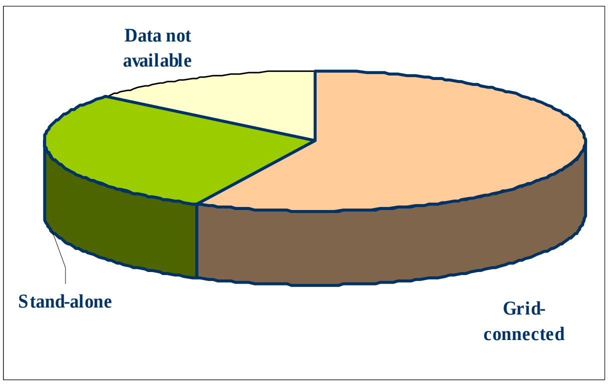


Fig. 58 The types of desalination plants referring to the ability to work autonomously

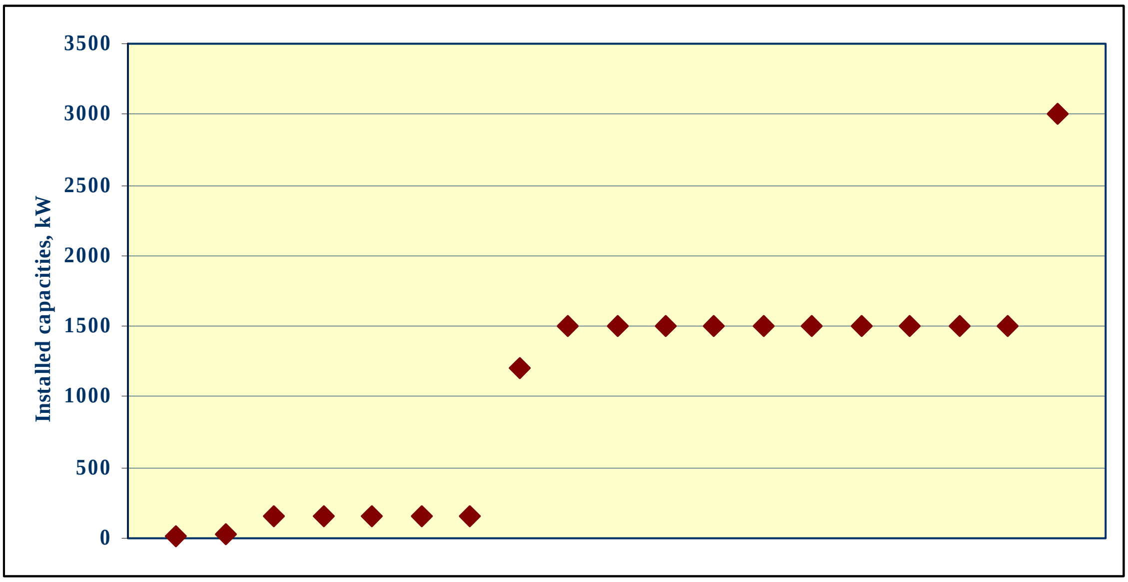


Fig. 59 The range of installed capacities within the projects

Table 34 Wind energy driven demonstration projects

Title	Year	Reference no.	The main idea
A 25 kW wind turbine for Giglio desalination plant	1983-1992	WE./00501/83	*Type of RES:* wind *Specific aims of the project:* To demonstrate that wind energy electricity generation can be used to powered thermic and electrical components in a desalination plant. *Plant:* Giglio, Italy *Capacities:*25 kW *Type:* -
1.2 MW wind turbine integrated in a total energy system for the island of Helgoland	1984-1993	WE./00323/83	*Type of RES:* wind *Specific aims of the project:* wind turbine with an estimated yearly output of 4.6 GWh integrated in a total energy system for the supply of electricity, heat and drinking water by desalination *Plant:* Helgoland, Germany *Capacities:* 1200 kW, 800 m^3/d *Type:* stand-alone (diesel back-up)
3 MW wind farm composed of 6 wind energy opti-mised for low wind speed on the island of	1984-1993	WE./00021/97	*Type of RES:* wind-RO *Specific aims of the project:* Part of the project involves the production of desalted water by means of a 300 kW asynchronic generator and a reverse osmosis drinking-water plant *Plant:* Menorca, Spain *Capacities:* 3000 kW, 700 m^3/d *Type:* stand-alone

Menorca			
Wind generator based electrifica-tion of communal premises in the island of Saint Nicolas– Commune de Fouesnant	1987-1989	WE./00154/86	*Type of RES:* wind *Specific aims of the project:* To provide the bulk of the electricity consumed by a planned aqua-culture installation with wind power. *Plant:* Saint Nicolas, France *Capacities:*10 kW *Type:* grid-connected
A wind energy/desalina-tion system for Syros	1991-1993	WE./00199/90	*Type of RES:* wind *Specific aims of the project:* To build 80+80 kW wind plants; To reduce the costs of water; To mage energy flows via control unit. *Plant:* Syros, Greece *Capacities:* 2x160 kW, 2x150 m^3/d *Type:* grid-connected
Three medium size wind turbines coupled to the desalina-tion plant of Mykonos	1991-1993	WE./00187/90	*Type of RES:* wind *Specific aims of the project:* To save energy for the operation of an existing desalination plant by installing three medium size wind turbines, directly connected to the desalination plant and parallel connected to the grid *Plant:* Ithaki, Greece *Capacities:* 3x150 kW *Type:* grid-connected
Combination of wind power units with a pimp storage power plant on Crete	1997-2001	WE./00009/97	*Type of RES:* wind *Specific aims of the project:* Integration of pump storage plant in the environment of arid islands by using a closed water circuit and desalination by reverse osmosis *Plant:* Crete, Greece *Capacities* 10x1500 kW *Type:* grid-connected

Project title	A 25 kW wind turbine for Giglio desalination plant
Project acronym	-
Project Contract No.	WE./00501/83
Name of Programme	ENALT 2C, ENG
Contract type	Demonstration
Year of development	1983-1992
Contractor / Responsible	Itin, Italy Brajon Alberto

Short description of the project

The aim of the project was to demonstrate that wind energy electricity generation could be used to powered thermic and electrical components in a desalination plant.

The system is energy self-sufficient and self-controlled in order to be installed especially in remote localization without technical supervision personal.

Innovative aspects and conclusions of the project

The plant has been designed in order to combine two different technologies: multi-effects process and steam compression through the use of an ejector.

Wind turbine electrical generator was directly connected to three electrodes in the desalination plant boiler. The control system changes the level of the process liquid in the boiler according to the wind speed so that the quantity of seawater to be desalinated in the plant is automatically modified. The wind turbine selected for the project is a AIT 03 by Aeritalia (today Alenia). It has an horizontal axis, two blades, 10 m diameter up-wind rotor connected to synchronous generators rated to 25 KW mounted on a 10 m high tower for wind speed in the range 5 and 18 m/s. The site originally selected to the demonstration project had an average speed of 5.5 m/s and the wind turbine was able to produce 25700 kWh per year.

Design, manufacturing and installation of all part of the plant has been carried out with many difficulties due to the bureaucracy rules and authorizations, so the project spread over many years.

Until today SASTIL never received authorization for regular operation with direct collection of seawater discharge of saline concentrated output into the sea.

Due to incorrect location and due to the low speed and direction variability of the wind was not possible to make significant demonstration testing phase and valid measurements data collection.

The data collected with a wind sensor sited near the wind turbine at 20m height, but later on it was verified that existed poor wind condition to guarantee regular plant operation.

Start up testing demonstrated that the rotor rarely shows required speed to operate the electrical generator.

Project title	1.2 MW wind turbine integrated in a total energy system for the island of Helgoland
Project acronym	-
Project Contract No.	WE./00323/83
Name of Programme	ENALT 2C, ENG
Contract type	Demonstration
Year of development	1984-1993
Contractor / Responsible	Gemeinde Helgoland, Germany Herzog

Short description of the project

The energy demand on Helgoland is characterised by the following figures: yearly electricity demand is 16.500.000 KWh (max power demand of 3.2 MW); yearly heat demand is 28.000.000 KWh (max power demand of 12 MW). Following by this, project aims to build 1,2 MW wind

turbine made mainly by MAN (as WEG 60) with an estimated yearly output of 4.6 GWh integrated in a total energy system for the supply of electricity, heat and drinking water by desalination for the Island of Helgoland.

Innovative aspects and conclusions of the project

Within this demonstration contract the wind turbine was constructed. The wind turbine and the 2 heavy fuel diesel engines produce the required electricity. The 5 small diesel engines act as a backup. The reverse osmosis plant will primarily be fed by excess electricity produced by the wind turbine.

The system consists of the following parts[41]:

- A wind turbine (1.2 MW),
- a combined heat/electricity system consisting of 2 diesel engines coupled to two electricity generators (2x1.2 MW)
- two heat pumps (2x1.2 MW heat output),
- diesel engines producing electricity (2x0.4 MW + 3x3.34 MW),
- heavy fuel boilers producing heat (2x5.5 MW),
- hot water storage (150 m^3),
- a sea water desalination plant (reverse osmosis), daily output 800m^3), and
- an exhaust purification plant.

In order to enable operation in a small local grid, a variable speed asynchronous generator with static frequency converter is used (AC-DC-AC link). It allows a speed variation of the rotor between 40-110% of the rated speed. Using a synchronous condenser compensates the reactive power demand.

The estimated cost per energy unit produced by the wind turbine is 0.40 DM while a conventional solution would lead to a cost of 0.21 DM.

The wind turbine was put into operation the February 1990 and was taken over by the user the March, 1991.

41 http://ica.cordis.lu/search/index.cfm?fuseaction=proj.simpledocument&PJ_RCN=330631&CFID=3815207&CFTOKEN=49445902

Up to date the wind turbine has been into operation and has produced about 1673 MWh, which corresponds to about 10% of the islands electricity needs.

Project title	3 MW wind farm composed of 6 wind energy optimised for low wind speed on the island de Menorca
Project acronym	-
Project Contract No.	WE./00021/97
Name of Programme	NNE-THERMIE C, 4 FWP
Contract type	Demonstration
Year of development	1984-1993
Contractor / Responsible	Gedisa, Spain Duran Vidal

Short description of the project

The following objectives of the project were set:

- To show the technical and economic feasibility of the installation of 500 kW aerogenerators, which are designed to provide an efficiency that is 20% greater than that of conventional generators for wind speeds that are below the nominal speed for the machine.

- To produce a significant amount of electricity - 3% - with a view to contributing to electricity demand of the island, by means of a system that does not cause contamination, thereby collaborating with the implementation of the objectives of Menorca, Reserva de la Biosfera (Menorca, Biosphere Reserve) in Spain.

- To turn a zone, which has been subjected to deterioration owing to the presence of a former rubbish dump, into a location, which is put to correct use, thereby collaborating with the implementation of the objectives of Minorca, Biosphere Reserve.

Innovative aspects and conclusions of the project

The installation consists of two distinct parts:

1. The aeolian part, consists of six 500 kW aerogenerators, designed and optimised for light winds, which is connected to a conventional electricity network on the island. The aerogenerators is located on a zone belonging to the Borough of Maó, exposed to the predominant winds of the first and third quadrant.

The installations are supposed to supplement with an electric power transformation plant, for connection to the 15000 V network run by the local electricity company.

The aerogenerators are of the fixed pitch type, the height of the propeller hubs being 45 m, the diameter of the blades also being 45m, and they will be equipped with disc brakes on the high-speed side and a triphasic asynchronic generator designed to operate at two different speeds, depending on the instantaneous output.

The existing building will be used, the environmental impact will be reduced to a minimum and the new electricity line will be buried underground.

2. The second part, not included in this proposal, involved the production of desalted water by means of a 300 kW asynchronic generator and a reverse osmosis drinking-water plant which is supposed provide 700m^3/day, using a control and regulation electrical system that will operate upon the two sub-systems. The system can work independently of the conventional electricity network, or using another type of support, such as diesel.

No results could be found for this project.

Project title	Wind generator based electrification of communal premises in the island of Saint Nicolas – Commune de Fouesnant
Project acronym	-
Project Contract No.	WE./00154/86
Name of Programme	ENDEMO C, ENG
Contract type	Demonstration
Year of development	1987-1989
Contractor / Responsible	Commune de Fouesnant, France

Short description of the project

The project was designed to provide the bulk of the electricity consumed by a planned aqua-culture installation and a municipal residence on the island of St-

Nicolas, in West France, with wind power. Projects innovation is the use of 270 V DC in the DC link of the installation together with battery storage as well as the use of the energy generated to supply the desalination plant.

Innovative aspects and conclusions of the project

<u>*Module description:*</u>

Wind turbine was installed in April 1988 and the desalination unit in August 1988.

Wind turbine has an AEROWATT of 10 kW, the diameter of wings is 7 m.

Wind turbine feeds a small battery supported grid through a rectifier and an inverter. The generated energy is used generated by a municipal residence of St. Nicolas Island and the desalination units of the aqua-culture plant. The estimated annual energy consumption is estimated at 43,1 kWh of which 11 kWh will be used by the residence and the rest by the aquaculture plan (20.1 kWh for the water exchange and 12 kWh for desalination). As at the site of the installation the annual mean wind speed is 7,6 m/s, it is expected that the wind turbine will cover the needs with the aid of the 154 unit battery storage system, while the existing diesel generator will be used as back-up.

The estimated payback time of the project is about 7 years.

The demonstration phase showed that the estimation concerning the performance of the wind turbine and the whole system was correct.

Project title	A wind energy / desalination system for Ano Syros
Project acronym	-
Project Contract No.	WE./00199/90
Name of Programme	THERMIE 1, ENG
Contract type	Demonstration
Year of development	1991-1993
Contractor / Responsible	Municipality of Ano Syros, Greece Beltsics

Short description of the project

The project was designed to reduce the operational cost of a desalination plant by using wind energy. This demonstrational project had to demonstrate that the direct connection of a wind turbine to a desalination plant is technically possible and economically viable.

Innovative aspects and conclusions of the projects

The desalination plant consists of two units with a total capacity of 160 kW. The main energy consumption comes from the pumps.

The plant has a nominal capacity of producing 2x150 m^3/day and is going to work on a 24-hour basis, 7 days a week, 10 months a year. Since the wind potential is very high (628.000 W/m2), a 200 kW wind turbine will be used in order to optimise energy management. In order to obtain the highest amount possible of energy savings, the W/T is going to be directly connected to the desalination plant and parallel connected to the grid. The two energy sources (W/T, grid) as well as the consumption (desalination plant) will be connected through a control unit, which will conduct the energy management.

There are no data about the status of the implementations of the project.

Project title	Three medium size wind turbines coupled to the desalination plant of Mykonos
Project acronym	-
Project Contract No.	WE./00187/90
Name of Programme	THERMIE 1, ENG
Contract type	Demonstration
Year of development	1991-1993
Contractor / Responsible	Municipal enterprise of Myconos, Greece C. Veronis

Short description of the project

Objective of the project was aimed to save energy for the operation of an existing desalination plant by installing three medium size wind turbines and to demonstrate that the wind turbines directly connected to the desalination plant and parallel connected to the grid (for back-up) is a mechanically and economically feasible system.

Innovative aspects and conclusions of the projects

The original project site was the island of Ithaki.

The works were carried out in the following phases:

1. The first works involved wind measurements. This work was necessary to make the numerical simulation of the region to design wind turbines, control system and data acquisition system.
2. Phase 2 consisted of the order planning and manufacturing of the wind turbines, the control system and the data acquisition system and the foyer control and connection.
3. Then civil works at the sites of installation of the W/T were carried out and transportation, installation and erection of the whole system were performed together with the power line from the W/T to the desalination plant.
4. Phase 4 included commissioning, measurements and evaluation, preliminary tests of short duration as well as measurement 10 parameters of the systems operation.

Only one of the 3x150 kW Nordtank wind turbines was supported by the Commission.

No more results are available.

Project title	Combination of wind power units with a pump storage power plant on Crete
Project acronym	-
Project Contract No.	WE./00009/97
Name of Programme	NNE-THERMIE C, 4 FWP
Contract type	Demonstration
Year of development	1997-2001
Contractor / Responsible	Hellenische energiekontor, Greece

Short description of the project

The Hellenic Energiekontor planned to build 10 units of 1,5 MW (in total 15 MW) wind farm at the Monastery Epanosifi on Crete. The mountain near the monastery has promising wind conditions, which allow low generation cost. The following objectives of the project were set:

- Reducing the production costs for wind energy through better performance of wind farm
- Demonstration and testing of wind power units in combination with a pump storage power plant
- Reducing the energy production costs for peak and intermediate load by substituting fossil power plants through hydroelectric and wind power
- Efficient energy storage of exceeding wind energy by a pump-storage unit
- Integration of renewable energies in weak islands grids
- Reducing of emissions (in particular CO_2) of fossil power plants by wind turbines and hydro-electrical power plants
- Integration of pump storage plant in the environment of arid islands by using a closed water circuit and desalination by reverse osmosis
- Avoiding stabilisation problems by wind power in weak island grids.

Innovative aspects and conclusions of the project

The latest technology with 1,5 MW machines was used to minimize investment and generation costs. Within this project the wind farm is combined with a pump storage power plant (5MW) with a closed water circuit. Losses due to evaporation should be replaced by desalinated seawater due to reverse osmosis. The reason for linking the wind power plant to the pump storage plant is the following:

During the night the base energy load of the grid has its minimum (about 100/140 MW) and is generated by steam units fuelled by heavy oil. The intermediate and the peak loads are generated by gas turbines. During the night time (about 8h) the wind units can not operate because of problems relating to the stability of the grid which make it necessary to turn off the wind power plant. This circumstance would cause a loss of 33% of the possible wind power production and consequently increasing costs for wind energy production. A pump storage power plant gives the possibilities to store the exceeding wind energy during the night and to supply power during daytime as intermediate or peak loads. The implemented innovations in wind farm allow:

- To increase performances of the wind farm,
- To lower energy production costs for wind farm and peak,
- To intermediate load and reduces emissions (CO_2) due to fossil power plants.

The whole concept of the combined wind park/pump storage unit is in so far innovating as it could open application in market, where the meteorological and geological conditions are suitable, but limited to where generated power exists. Potential areas could be islands of the Cyclades in Greece or the Canary islands. The development of standardised modules could also reach to the exploitation of smaller and bigger potentials.

The Hellenic Energiekontor planned a 15 MW windfarm (10 units of 1,5 MW) at the Monastery Epanosifi on Crete. The mountain near the monastery has promising wind conditions, which allow low generation cost[42].

The design phase began at the end of 1996. Co-contractors and manufacturers for the necessary equipment were contacted. Wind measurements at the site Epanosifi and a wind study were already finished in 1996. Further contracts with the landlords and municipality let to start the construction.

Concluding achievements of the project:

1. Energy production costs (ECU/kWh) of wind turbines in combination with pump storage power plant 20-30% lower than energy production costs for gas turbines.
2. Integration of renewable energies in weak island grids without stability problems for the grid.
3. Implementation of the experiences and the know-how in further projects in similar regions.

No further data are available.

[42] http://europa.eu.int/comm/energy/library/we97.pdf

Table 35 Cost sharing/research projects

No	Acronym	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
		Tremiti island desalination plant	1988-1989	1 FP ENNONUC 3C Cost-sharing contract	EN3S0132	Fonzi	Italsolar, Italy	*Type of RES:* PV-RO *Specific aims of the project:* Technological improvements; Water storage optimisation
		Improvement of the PV reverse osmosis desalination process	1991-1994	2 FP JOULE 1 Cost-sharing contract	JOUR0115	n.a.	Italenergie SpA, Italy	*Type of RES:* PV-RO *Specific aims of the project:* Modernising membranes-chemical pre-treatment; Optimisation of energy flows and savings
		A new photovoltaic desalination plant	1992-1994	3 FP JOULE 2 Cost-sharing contract	JOU20061	Fulvio Fonzi	Italenergie SpA, Italy Tel.: +39-864251107	*Type of RES:* PV-RO *Specific aims of the project:* PV-RO membrane efficiency
		Development of stand-alone PV power system for remote villages, making use of pumped water energy storage: an intelligent integration of a PV power system in a remote village with partial central and partial decentral PV power supply	1992-1996	3 FP JOULE 2 Cost-sharing contract	JOU20155	Spyros Kyritsis	Engineering and computing applications, SA, Greece +30-210-7754658	*Type of RES:* PV-RO *Specific aims of the project:* Coupling PV desalination plant with storage system in order to provide 24 h functioning

No	Acronym	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
		CPC collector for high temperatures	1996-1997	4 FP NNE-JOULE C Exploratory awards contract	JOR3961005	Grossauer	Kalkgruber Solar- und Umwelttechnik GmbH, Austria kaljgruber@kalkgruber.at Tel.: +437252439950	*Type of RES:* Solar *Specific aims of the project:* to develop a high temperature solar collector that allows lower production costs than evacuated solar collectors
		CPC-Collector for high temperatures	1998-2000	4 FP NNE-JOULE C Cooperative research contracts	JOR3977001	Ing. Johann	Kalkgruber Solar- und Umwelttechnik GmbH, Austria kaljgruber@kalkgruber.at Tel.: +437252439950	*Type of RES:* Solar *Specific aims of the project:* to develop a high temperature solar collector that allows lower production costs than evacuated solar collectors
	CODEC	A novel high efficient solar collector for desiccative and evaporative cooling	1996-1998	4 FP NNE-JOULE C Cost-sharing contract	JOR3950003	Christoph Schwarzler	Institut fuer luft- und kaeltetechnik gemeinnuetzige GmbH, Germany Tel.: +493514081700	*Type of RES:* Solar *Specific aims of the project:* The development of a low-cost solar collector with new materials and a novel absorption method, also suitable for heat production for modular desalination and water purification plants
		Solar thermal electricity in the Mediterranean: feasibility study for integrated solar combi-ned cycle systems for electricity production with parabolic troughs in the Mediterranean area	1995-1996	3 FP APAS RENA Cost-sharing contract	RENA940014	Jose Juan Villa	Union Electrica Fenosa SA, Spain	*Type of RES:* Solar *Specific aims of the project:* Improvement and the cost reduction of Direct Solar Steam generation with large parabolic trough collector field

No	Acronym	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	SOLDES	Development and optimization of a new process for desalination of sea water by means of solar energy	1998-2003	4 FP INCO Cost-sharing contract	IC18980265	Efat Chafik	Ruhr-Universitat Bochum, Germany chafik@alf.iws.ruhr-uni-bochum.de tel.: +492343226423	*Type of RES:* Solar *Specific aims of the project:* The use of heating air flow for humidification of seawater
	EuroTrough	Development of a low cost European desalination and process heat collector	1998-2001	4 FP NNE-JOULE C Cost-sharing contract	JOR3980231	Rafael Osuna	Instalaciones Abengoa SA, Spain rosuna@acpub.duke.edu	*Type of RES:* Solar *Specific aims of the project:* Developing of Solar Trough Collector for a wide applications in 200-400°C; Cost reduction
	EuroTrough 2	EuroTrough II – extention, test and qualification of a full scale loop of eurothrough collectors with direct steam generation	2000-2002	5 FP EESD Cost-sharing contract	ERK-CT-1999-00018	Pedro Robles Sanchez	Instalaciones Inabensa SA, Spain	*Type of RES:* Solar *Specific aims of the project:* Developing of Solar Trough Collector for a wide applications in 200-400°C; Cost reduction; Commercialisation
		Solar VVC desalination plant	1998-2001	4 FP NNE-JOULE C Cost-sharing contract	JOR3980293	Jeffrey Kenna	Solargen (Europe) Ltd, UK kenna@solargen.com Tel.: +44-1225-816807	*Type of RES:* Solar *Specific aims of the project:* Prototype solar desalination plant which is competitive in the market; Commercialisation

No	Acronym	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	SODESA	Solar-thermally driven desalination system with corrosion free collectors and 24-hours-per-day storage	1998-2001	4 FP NNE-JOULE C Cost-sharing contract	JOR3980229	Matthias Rommel	Fraunhofer-Gesellshaft zur foerderung der angewandten forschung E.V., Germany rommel@ise.fhg.de tel.: 49-7314588141	*Type of RES:* Solar *Specific aims of the project:* Corrosion free solar collectors
	AQUASOL	Enhanced zero discharge seawater desalination using hybrid solar technology	2002-2006	5 FWP EESD Cost-sharing contract	EVK1-CT-2001-00102	Felix Yndurain	Centro de investigaciones energeticas, mediambientales y tecnologicas, Spain	*Type of RES:* Solar *Specific aims of the project:* The development of a seawater desalination technology based on *multi-effect distillation* that is energy efficient, low-cost and has a zero discharge
	MEMDIS	**Development of stand-alone, solar thermally driven and PV-supplied desalination system based on innovative membrane distillation**	2003-2006	5 FP EESD	NNE5/819/2001	Matthias Rommel	Fraunhofer ISE, Germany dorner@zv.fhg.de Tel: +49-89-1205594	*Type of RES:* Solar-PV *Specific aims of the project:* The development of stand-alone desalination system which is based on highly innovative membrane distillation technology
	SMADES	PV and thermally driven small-scale, stand alone desalination systems with very low maintenance needs	2003-2005	5 FP INCO 2 Cost-sharing contract	ICA3-CT-2002-10025	Matthias Rommel Andreas	Fraunhofer ISE, Germany +49-89-1205594 dorner@zv.fhg.de	*RES:* Solar-PV *Specific aims of the project:* The development of stand-alone desalination system which is based on highly innovative membrane distillation technology

						Maurer	Fraunhofer ISE 49-76-145885138 andreas.maurer@ise.fhg.de	
	PRODESAL	Prodesalination. Towards the large scale development of decentralized water desalination. Detailed concept and pilot operation for a large-scale development of decentralized water desalination.	1995-1996	3 FP APAS Cost-sharing contract	RENA940018	Manuel Cendagorta Galarza Lopez	Instituto tecnologico y de energias renovables, Spain Tel. +34-922-391000 manu@iter.rcanaria.es iter@iter.es	*Type of RES:* Wind-RO *Specific aims of the project:* Development of modular concept of combined WEC (wind energy converter)-RO sea water desalination plant; Energy storage costs
		Development of water desalination plant through RO powered by wind energy in the island of Patmos (Gr)	1995-1996	3 FP APAS Cost-sharing contract	RENA940029	John Chadjivassiliadis	LDK consultants engineers and planners Ltd, Greece main@ldk.gr	*Type of RES:* Wind-RO *Specific aims of the project:* Assessment of water needs and RE potential in the Mediterranean islands; Commissioning of a desalination plant
	MODESAL	Modular desalination: development and pilot-operation of a family of second generation modular wind powered sea water desalination plants	1996-1997	4 FP NNE-JOULE C Cost-sharing contract	JOR3950018	Heinz Ehmann	Wirtschaft und infrastruktur GmbH & CO Planungs KG, Germany +49-89-7201232	*Type of RES:* Wind-RO *Specific aims of the project:* To develop general modular plant concept which combines wind energy and RO; concept of a family of a modular sea water desalination plant, Energy storage costs

No	Acronym	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
		Wind powered desalination for small coastal and island communities in Mediterranean regions	1995-1996	3 FWP APAS RENA Cost-sharing contract	RENA940055	Jerome Billerey	Vergnet SA, France	*Type of RES:* Wind-RO *Specific aims of the project:* The development of a robust system which would be able to operate at remote sites away from electricity grid
		Autonomous wind-diesel hybrid generator with heat recovery for sea water desalination, telemonitored for supervision and data acquisition	1997-1998	4 FP NNE-JOULE C Exploratory contract	JOR3971010	Paul Timmermans	Turbowinds NV, Belgium Tel.: +32-2-6892292	*Type of RES:* Wind-diesel *Specific aims of the project:* Distillation under vacuum; Efficiency improvement
	REDDES	Renewable energy driven desalination systems	2002-2003	Energy programmes ALTENER 2 Cost-sharing contract	4.1030/Z/01-081	Savvas Karayannis	Regional energy agency of Dodecanese S.A., Greece nom@nad.gr Tel.: +30-241046503	*Type of RES:* Wind-solar-biomas-RO *Specific aims of the project:* The development of integrated management and design tool for the use of renewables in desalination: climate, economic, social, financial evaluation of the plant
		Peace engineering. Key accessories for the Jordan Rift Valley desalination plant powered by renewable energy sources	1994-1995	3 FP JOULE 2 Cost-sharing contract	JOU20383	Norbert Kaiser	Kaiser Bautechnik Ingenieurgesellschaft, Germany norbert.kaiser@fh-ansbach.de Tel.: +49-203-3062900	*Type of RES:* RES-RO *Specific aims of the project:* Design of powerpack to drive RO process; Optimisation of efficiency of pumps

No	Acronym	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	OPRODES	**Optimization of RO desalination systems powered by renewable energies**	1998-2001	4 FP NNE-JOULE C Cost-sharing contract	JOR3980274	Antonio G OMEZ GOTOR	Universidad de Las Palmas de Gran Canaria, Spain aggotor@ulpgc.es Tel: +34-92-8355789	*Type of RES:* PV-Wind-RO *Specific aims of the project:* Intends to make a site-extrapolable optimisation of the design of photovoltaic/wind/RO systems using commercial reverse osmosis membranes
	REDES	**A decision support system for the integration of Renewable Energy into water Desalination Systems**	1995-1996	3 FP APAS RENA Cost-sharing contract	RENA940038	Stella ALEXOPOULOU	Strategic Planning, Effective Engineering and Development Ltd., Greece	*Type of RES:* all types *Specific aims of the project:* The development of a methodology and a tool followed by Decision Support System (DSS) for selection of the best technology for desalination plant
	ADIRA	Autonomous desalination system concepts for seawater and brackish water in rural areas with renewable energy potential, technology, field experience, socio-technical and socio-economic impacts	n.a.	n.a.	ME8-AIDCO-2001-0515-59610	n.a.	Fraunhofer institute foor solar energy systems, Germany www.adira.info www.adira.gr	*Type of RES:* PV-Wind-RO *Specific aims of the project:* Development of optimum concepts to supply rural areas with fresh water taking into account not only technical, but also legal, social, economic, environmental and organisational issues
		Desalination of sea-water using renewable energy sources	1996-2000	4 FWP INCO Cost sharing	IC18960039	Dimitri Paschaloudis	Dimman Consulting Ltd. , Greece	*Type of RES:* all types *Specific aims of the project:* Analysis of 2 desalination methods: vapour compression method and multiple effect evaporation method;

				contract				Application for 2 pilot plants; Cost and energy consumption improvements
	SDAWES	Seawater desalination plants connected to an autonomous wind energy system	1996-2000	4 FP NNE-JOULE C Cost-sharing contract	JOR395077	Gonzalo Piernavieja	Instituto tecnologico de Canarias, Spain +34-28452020	*Type of RES:* Wind-PV-RO-VVC-ED *Specific aims of the project:* The determination of best fitted system (RO, VVC, ED) with wind energy
		Hybrid renewable energy systems in Donoussa and La Graciosa Islands as prototype systems for applying desalination at small villages in Mediterranean Islands and coastal areas, by using local energy sources for electricity production	1995-1995	3 FP APAS RENA Cost-sharing contract	RENA9400 30	Spyros Kyritsis	Agricultural university of Athens, Greece skin@aua.gr	*Type of RES:* Wind-PV-RO *Specific aims of the project:* Combination of PV with wind energy to energise reverse osmosis reactions; Innovative PV-hydro plants

Table 35 Demonstration projects

No	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	Multi-stage-flash desalination plant with solar energy as the main energy source at Lampedusa island	1980-1983	Energy programmes ENALT 1C Demonstration contract	SE./00009/79	Benevolo	Agip Nucleare SpA, Italy	*Type of RES:* Solar *Specific aims of the project:* To analyse the working conditions on concentrating and a multi-stage-flash (MSF) desalination *Plant:* Lampedusa, Italy
	A solar desalination plant in the Guadeloupe dependencies	1984-1987	Energy programmes ENALT 2C Demonstration contract	SE./00790/83	DE Gunzbourg	Entropie SA, France Tel.: +33-30610550	*Type of RES:* Solar *Specific aims of the project:* Desalination using multiple effect evaporator; Reducing corrosion or blockage *Plant*: Guadeloupe, France
	Solar pond for desalination of sea water	1985-1988	Energy programmes ENALT 2C Demonstration contract	SE./00457/84	S. Folchitto	ENI SpA-AGIP, Italy Tel.: +39252061208	*Type of RES:* Solar *Specific aims of the project: S*elf gradient solar ponds; Economics of their application *Plant*: Italy
	Innovative desalination unit dedicated to solar ponds	1994-1998	Energy programmes THERMIE 1 Demonstration contract	SE./00303/94	Caira Marco	Servizi di Ricerche e Sviluppo, Italy Tel.: +39-0668300047	Type of RES: Solar *Specific aims of the project:* First full-titanium desalinator; Maintenance of solar ponds, chemical requirements, reliability and overall costs *Plant:* Ancona, Italy

No	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	Lipari island water desalination plant	1987-1991	Energy programmes ENDEMO C Demonstration contract	SE./00336/87	Fonzi Fulvio	Italenergie SpA, Italy	*Type of RES:* PV-RO *Specific aims of the project:* Sea water storage tank constructed to reduce the necessary electricity storage in the batteries, To analyse the working conditions on concentrating and a multi-stage-flash (MSF) desalination *Plant:* Lipari, Italy
	PV power supply for desalination, refrigeration and lighting	1987-1993	Energy Programmes ENALT 2C Demonstration contract	SE./00143/85	n.a.	Petros Moschovitis Engineering, Greece Tel: +30-210-8231138	*Type of RES:*PV *Specific aims of the project:* The demonstration of the use of PV to provide drinking water and electricity to remote areas *Plant:* Melos, Greece
	Almeria solar powered reverse osmosis plant	1987-1995	Energy programmes ENDEMO C Demonstration contract	SE./00233/86	Maass Karl	Deutsche aerospace AG, germany Tel. +49-4103603734	*Type of RES:*PV-RO *Specific aims of the project:* Cost minimising via membranes, pumps modernisation *Plant:* Almeria, Spain
	PV powered lighthouse and desalination plant (Punta Libeccio)	1988-1993	Energy Programmes ENALT 2C Demonstration contract	SE./00565/85	C. Maccio	Cesen SpA, Italy Tel: +39-105501	*Type of RES:*PV *Specific aims of the project:* To show how PV could supply energy to an isolated lighthouse, three keepers dwellings and a desalination plant *Plant:* Marretimo, Italy

No	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	Electricity and water supplies for Glenan islands by PV generators	1991-1994	Energy Programmes THERMIE 1 Demonstration contract	SE./00198/90	Gouriou Herve	Municipalità de Fouesnant, France Tel: +33-98560018	*Type of RES:*PV *Specific aims of the project:* electrification by PV of some islands, the energy also has to be provided to desalination units. Project was not finished. *Plant:* Glenan, France
	PV generators on islands of Brittany and Corsica	1991-1995	Energy Programmes THERMIE 1 Demonstration contract	SE./00035/91		Solaire Techniques Nouvelles (STN), France Tel: +33-98977272	*Type of RES:*PV *Specific aims of the project:* To built 40 PV plants sites on small islands around the French coast in the framework of this project. Total module size is 38000 Wp. The units involved PV, wind, diesel, but the financing covered only PV plants *Plant:* Brittany, Corsica, France
	Advanced concept combined electrodialysis PV project (ACCEPT)	1992-1997	Energy programmes THERMIE 1 Demonstration contract	SE./00124/90	H. Finken	AMT applied membrane technologies consultino & engineering GmbH, Germany Tel. +49-407212073	*Type of RES:*PV-RO *Specific aims of the project:* Coupling PV power to an electrodialysis water plant; Incorporation of intelligent system controller *Plant:* Germany
	A 25 kW wind turbine for Giglio desalination plant	1983-1992	Energy Programmes ENALT 2C Demonstration contract	WE./00501/83	Brajon Alberto	Itin, Italy Tel: +39-64402941	*Type of RES:* wind *Specific aims of the project:* To demonstrate that wind energy electricity generation can be used to powered thermic and electrical components in a desalination plant. *Plant:* Giglio, Italy

No	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	1.2 MW wind turbine integrated in a total energy system for the island of Helgoland	1984-1993	Energy programmes ENALT 2C Demonstration contract	WE./00323/83	Herzog	Gemeinde Helgoland, Germany +49-43312012334	*Type of RES:* wind *Specific aims of the project:* wind turbine with an estimated yearly output of 4.6 GWh integrated in a total energy system for the supply of electricity, heat and drinking water by desalination *Plant:* Helgoland, Germany
	3 MW wind farm composed of 6 wind energy optimised for low wind speed on the island of Menorca		4FP NNE-THERMIE C Demonstration contract	WE./00021/97	Duran Vidal	GEDISA, Spain Tel: +34-971467711 Fax: +34-971461622	*Type of RES:* wind-RO *Specific aims of the project:* Part of the project involves the production of desalted water by means of a 300 kW asynchronic generator and a reverse osmosis drinking-water plant *Plant:* Menorca, Spain
	Wind generator based electrification of communal premises in the island of Saint Nicolas – Commune de Fouesnant	1987-1989	Energy Programmes ENDEMO C Demonstration contract	WE./00154/86		Commune de Fouesnant, France Tel: +33-98560018	*Type of RES:* wind *Specific aims of the project:* To provide the bulk of the electricity consumed by a planned aqua-culture installation with wind power. *Plant:* Saint Nicolas, France
	A wind energy/desalination system for Syros	1991-1993	Energy programmes THERMIE 1 Demonstration contract	WE./00199/90	Beltsics	Municipality of Ano Syros, Greece Tel.: +30-2281027213	*Type of RES:* wind *Specific aims of the project:* To build 80+80 kW wind plants; To reduce the costs of water; To mage energy flows via control unit. *Plant:* Syros, Greece

No	Title	Year	Programme Contract type	Reference No.	Responsible person	Contacts	The main idea
	Three medium size wind turbines coupled to the desalination plant of Mykonos	1991-1993	Energy Programmes THERMIE 1 Demonstration contract	WE./00187/90	C. Veronis	Municipal enterprise of Myconos, Greece Tel: +30-22890-23990	*Type of RES:* wind *Specific aims of the project:* To save energy for the operation of an existing desalination plant by installing three medium size wind turbines and to demonstrate that the wind turbines directly connected to the desalination plant and parallel connected to the grid (for back-up) is a mechanically and economically feasible system. *Plant:* Ithaki, Greece
	Combination of wind power units with a pimp storage power plant on Crete	1997-2001	4FP NNE-THERMIE C Demonstration contract	WE./00009/97		Hellenische Energiekontor, Greece Fax: +357-2494953	*Type of RES:* wind *Specific aims of the project:* Integration of pump storage plant in the environment of arid islands by using a closed water circuit and desalination by reverse osmosis *Plant:* Crete, Greece

6.1.3 Conclusions

Solar thermal:

The large size of the plant means it is important to minimise construction costs.

There are often few cheap construction materials, which withstand hot seawater. Suitable plastics are too expensive and cheap metals corrode. Successful materials were glass and titanium. Recent projects concentrated on hybrid systems combining solar thermal desalination with PV or wind power.

PV-powered RO:

PV modules were generally the most reliable part of the system.

Many early demonstration projects failed due to financial problems.

Wind-powered RO:

Improvement tools for siting prevented the failure of more recent projects.

There are several software tools available to help wind-driven RO systems, which seem to overlap: a survey of which tools are best suited to different tasks would be useful.

The trend is towards larger wind turbines, which provide electricity also for the local community.

Reverse osmosis (general):

The most frequently mentioned problem was corrosion, especially in early projects.

Water chemistry should be controlled to avoid fouling and scaling. Corrosion of the metallic components comes from the low quality of the metal elements and leakages of salty water on them. Corrosion is particularly strong in the seawater plants.

Therefore many projects mentioned improvements in automated pre-treatment of seawater, or promoting continuous operations by energy storage, variable power consumption and back-up systems. Another approach to make operation more continuous is to combine wind and PV power.

6.2 MERDC projects

Middle East Desalination Research Centre (MEDRC) was set up to conduct, facilitate, promote, co-ordinate and support basic and applied research in water Desalination technology and supporting fields as well as to raise the standard of living in the Middle East and Northern Africa (MENA) region by cost reduction and quality improvement in the technical processes of water desalination.

Besides the main mission, MEDRC set the following objectives:

- To conduct, facilitate, promote, co-ordinate and support;
- Basic and applied research in the field of water desalination and related technical areas with the aim of discovering, developing and improving methods of water desalination which are financially and technically feasible;
- Desalination training programs, which develop technical expertise and scientific skills throughout the Middle East;
- Information exchange, including electronic networking to ensure global technical information dissemination concerning water desalination methods and research.
- Establish relations with other states, organizations, as will foster progress in the development, improvement and use of water desalination in the Middle East and elsewhere.

MEDRC RESEARCH PROGRAM - Decrease the cost of desalination - Develop productive partnerships and cooperation - Develop sustainable desalination technologies - Improve communications in the desalination community - Develop human resources for application of desalination and foster international cooperation in research activities, particularly among regional experts - Utilize limited regional and international research resources - Maximize technology transfer		
Thermal desalination	Intakes and Outfalls	Environment Issues

Membrane desalination	RESEARCH TOPIC AREAS	Hybridized Systems
Non-Traditional or Alterna-tive Desalination		Certification Programmes
Operation and Maintena-nce	Energy Issues ∗	Assessment Studies

Fig. 55 R&D areas in the field of desalination, supported by MEDRC.

∗ Research under this topic is focused on reduction in energy consumption and the use of cheap **alternative energy sources.**

The promotion of the use of Renewable energy sources (RES) in desalination processes is implemented in the Energy Issues research topic area; nevertheless it has to be noted that RES based technologies might be supported in the context of other fields as well.

Research is focused on their applications to special conditions of the Middle East and North Africa (MENA) countries. MENA is an economically diverse region that includes both the oil-rich economies in the Gulf and countries that are resource-scarce in relation to population. Total population of MENA is about 300 million people. MENA countries suffer from a shortage of drinking water, especially in the remote areas where water transportation is extremely expensive.

The MENA region includes 21 countries: Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, West Bank and Gaza, Yemen (see the map).

In total, eight MEDRC R&D projects based on the application of RES in desalination were described. In contrast to the EU co-financed projects, MEDRC projects were dedicated to a broader analysis of RES application in MENA region, rather than to the development of innovative technologies. Only three pilot plants were built in the framework of the projects (1xMorocco, 2xJordan). Nevertheless, the studies could be applied in all the countries to simplify the choice of desalination technologies and processes, and the design of desalination plants as well as to calculate the necessary investments and other operation and maintenance costs under particular social, economic, climate conditions of particular

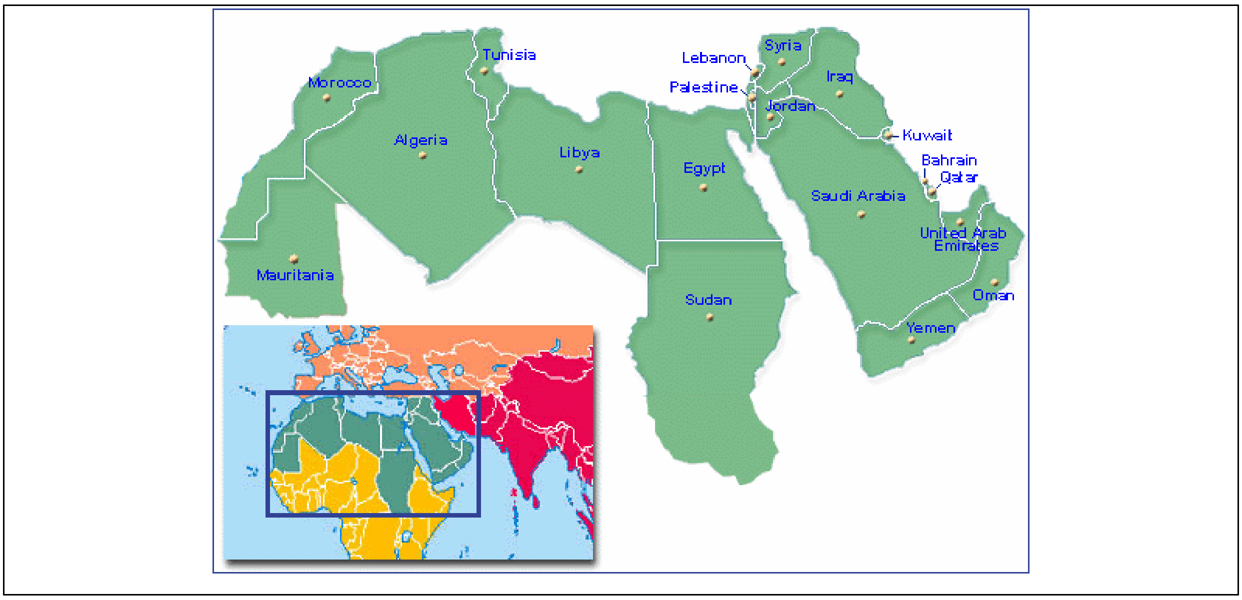


Fig. 59 Middle East and North Africa (MENA) countries

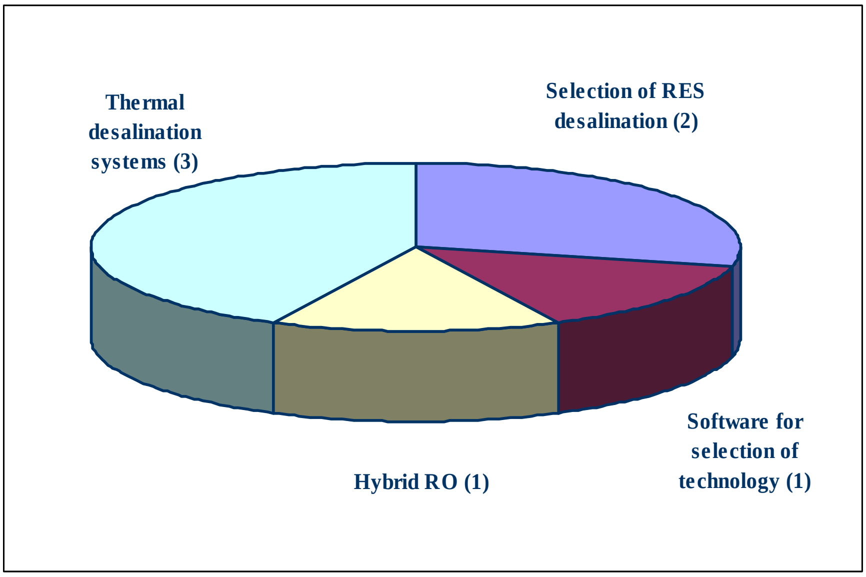


Fig. 60 The research areas of MEDRC desalination projects

The first two projects described below give general conclusions about selection of RES desalination systems while the third project is a software tool for selection. Then there is one project on hybrid RO and three on thermal desalination systems (see Fig. 60)

Table 36 MEDRC desalination RES projects

No	Title	Year	Reference No.	Responsible person	Contacts	The main idea
	PV powered desalination	1998-2003	98-BS-033	Karsten Burges	Ecofys BV, Netherlands	Analysis of possible desalination processes without applying the solutions to a certain desalination plant or region
	VARI-RO solar-powered desalting	1997-2000	97-AS-005a	W.D. Childs A. E. Dabiri	Vari-Power Company Encinitas, California, USA Science Applications International Corporation San Diego, California, USA	Analysis of new technologies coupled with solar power desalting processes
	Matching renewable energy with desalination plants	1997-2001	97-AS-006a	Rolf Oldach	IT Poer Ltd The Manor House, Chineham Court, Lutyens Close Chineham, Hampshire,UK	To analyse which renewable energy sources are the most suitable to use for powering small-scale desalination plants
	Matching renewable energy with small unit desalination plants: development of a pc-based decision support system	1997-2002	97-AS-006b	Th. Melin, L.Eilers	Institut fuer Verfahrenstechnik der RWTH Aachen, Germany	The development of DSS for selection of desalination plant powered by RES (continuation of the project No. 97-AS-006a)
	Development of a Logistic Model for the design of autonomous desalination systems	2000-2002	00-AS-014	E. Tzen	Center for Renewable Energy Resources Greece	Development of a stand-alone desalination system driven by a hybrid power supply system

	with renewable energy sources					
	Hybrid fossil/solar heated multi-effect-still	1997-2002	97-BS-016	Jürgen Rheinländer	Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) Germany	Development of a small-scale thermal desalination system powered by solar energy or fossil heat, suitable for Morocco
	Small scale thermal water desalination system using solar energy or waste heat	1997-2001	97-AS-024b	H. Müller-Holst	Bayerisches Zentrum für angewandte Energieforschung e.V. ZAE Bayern Munich, Germany	The design of small scale water desalination system driven by solar energy or waste heat working on humidification and dehumidification of air by natural convention (designed for building in Oman)
	The small solar med-desalination plant	1998-2004	98-AS-024a	L.B. Begrambekov	Lidasa Ltd Russia	Design of a solar powered small-scale desalination plant based on multi-effect distillation principle (with the application for pilot plant in Oman)

Project title	PV powered desalination
Project Contract No.	98-BS-033
Year of the final report	2003
Principal investigator	Karsten Burges Ecofys BV, The Netherlands
Type of application	Analysis of possible desalination processes without applying the solutions to a certain desalination plant or region.

Short description of the project

The objectives of this study:

- To perform a technical and economic analysis and comparative study of reverse osmosis and electrodialysis processes powered with photovoltaic energy
- To develop guidelines for selection and design of plants involving these processes
- To contribute to identification of feasible applications and, hence, accelerated opening of priority markets integrating suitable technology options
- To stimulate technology development and creation of tools for design and manufacturing of promising technologies

The project aims to analyse the possible desalination processes without applying the solutions to a certain desalination plants or regions.

Innovative aspects and conclusions of the project

The main technical finding in the study is that reverse osmosis is the only realistic choice in case seawater as the water source. If low salinity water is used as feed, in general, electrodialysis is slightly preferable.

With respect to markets, PV powered desalination systems for dwellings are considered to be a priority market. This major conclusion is based on some findings of the analysis[43]:

⇒ From a technical point of view, RO as well as ED in combination with a PV power supply are options for desalination at remote sites. Technology selection and

[43] PV powered desalination. Final report of MERDC project 98-BS-033. http://www.medrc.org/dwnftp/default.htm

combination depends on site conditions, user requirements as well as application framework conditions. From that point of view, it is hardly possible to define a favourable system topology for universal application.

⇒ ED shows slightly better characteristics considering intermittent or fluctuating flux as a consequence of changes in solar resource. ED – more than RO – allows use of effective chemicals for anti-fouling.

⇒ When salinity of the feed water is higher than the range of 1200 ppm – 2000 ppm TDS, RO is superior because of higher energy efficiency. This concentration level is the ‘rule of thumb’ for systems powered by utility grids with respective specific electricity costs. In the case of a stand-alone power supply, the level may be different, probably lower, due to the higher costs of electricity from PV systems.

⇒ In case of RO, requirements of feed water quality are higher. As a consequence, pre-treatment often is more complex.

⇒ As ED only removes ions from the water, for production of drinking water quality, additional measures may be required (disinfection, removal of particles etc.).

⇒ For remote application simple, robust concepts are preferable for the power supply system as well as for the water processing plant.

⇒ Batteries may increase the performance ratio of the PV system and, hence, overall productivity. However, they require careful maintenance otherwise battery life will be reduced dramatically. In particular, adequate management of larger storage batteries (10 kWh and above) at remote sites proved to be difficult.

⇒ Auxiliary generators and hybrid systems are increasing system productivity but are vulnerable. They require careful maintenance and, hence, higher skills. Consequently they are more promising for systems with larger capacity.

⇒ In general, in combination with PV, intermittent operation of the water processing plant will be most promising. This requires modification of common design rules for the water processing part. In general, storage for product water will be required. Its size will depend on the correlation of resource and demand patterns. Attention has to be paid to product water quality in storage, especially in regions with higher temperatures (MENA region).

⇒ A promising battery-less system concept for PV powered RO has been identified. It uses electronic speed control for the pumps and a Clark pump for energy recovery. Practical results still have to be reported. In particular, susceptibility for fouling and scaling has to be evaluated. Observation of further progress is recommended.

Costs vary from 1.24$/m^3 for seawater desalination, 0.59 – brackish water, 0.35 – LPRO-MS. The details of investments for all the kinds of water desalination treating reverse osmosis are presented by project partners below:

Table 37 Total and specific costs for RO and ED desalination[44]

Process	Investment (€m^3/day)	Energy (€m^3)	Cosum. (€m^3)	Labour (€m^3)	Maintenance (€m^3)	Total costs (€m^3)
SWRO	800-1600	0.32-1.28	0.09-0.25	0.03-0.2	0.020-0.05	0.460-1.78
BWRO	200-500	0.04-0.4	0.05-0.13	0.03-0.2	0.004-0.02	0.124-0.75
ED	266-328	0.06-0.4	0.05-0.13	0.03-0.2	0.006-0.009	0.146-0.739

**BW salt content 2000-10.000 ppm, SW salt content 30.000-50.000 ppm.*

The values given are based on larger plants producing between 10,000 and 20,000 m^3/day.

For small plants specific product costs are significantly higher. Common figures for brackish water desalination are about 5 €/m^3.

Following the overview and analysis of different sources, the project partners developed the match options of desalination processes and power supply systems.

Table 38 Match options of desalination processes and power supply systems

	PV battery	PV only	PV auxiliary	PV hybrid
Brackish water <-2 m^3/day				
ED	Technical: 0 Economical: + Human res.: -	Technical: ++ Economical: ++ Human res.: +	Technical: + Economical: 0 Human res.: -	Technical: +/- Economical: - Human res.: --
RO	Technical: 0	Technical: +	Technical: 0	Technical: -

44 European Commission DG XVII, (1998), "Desalination guide using renewable energies"

	Economical: + Human res.: -	Economical: ++ Human res.: 0	Economical: -- Human res.: -	Economical: +/- Human res.: --
Brackish water >5 m^3/day and up				
ED	Technical: 0 Economical: 0 Human res.: -	Technical: + Economical: 0 Human res.: +	Technical: + Economical: 0 Human res.: 0	Technical: - Economical: +/- Human res.: -
RO	Technical: 0 Economical: 0 Human res.: -	Technical: 0 Economical: + Human res.: +	Technical: 0 Economical: 0 Human res.: -	Technical: - Economical: +/- Human res.: -
Sea water <-2 m^3/day				
ED	Technical: 0 Economical: -- Human res.: 0	Technical: + Economical: -- Human res.: +	Technical: 0 Economical: -- Human res.: -	Technical: - Economical: +/- Human res.: --
RO	Technical: 0 Economical: + Human res.: -	Technical: + Economical: + Human res.: 0	Technical: - Economical: - Human res.: -	Technical: - Economical: +/- Human res.: --
Sea water >5 m^3/day and up				
ED	Technical: - Economical: -- Human res.: +	Technical: + Economical: -- Human res.: +	Technical: + Economical: -- Human res.: 0	Technical: +/- Economical: - Human res.: -
RO	Technical: - Economical: 0 Human res.: --	Technical: 0 Economical: - Human res.: -	Technical: 0 Economical: - Human res.: -	Technical: +/- Economical: +/- Human res.: -

**cell shading indicates unattractive options*

Legend:

++	very good match
+	matching
0	not relevant
-	not matching

--	strong mismatch
+/-	very diverse, no general score

Project title	VARI-RO solar powered desalting study
Project Contract No.	97-AS-005a
Year of the final report	2000
Principal investigator	Willard D. Childs Vari-Power Company, Encinitas, California, USA Ali E. Dabiri Science Applications International Corporation, San Diego, California, USA
Type of application	Analysis of new technologies coupled with solar power desalting processes

Short description of the project

The aim of the study was to determine the potential of new approaches to improve solar-powered desalting. These approaches include combining modern solar power conversion technology with newly developed, hydraulic-driven, pumping and energy recovery technology for brackish water and seawater reverse osmosis (BWRO or SWRO) desalting.

The study includes

- a literature search of existing methods,
- preliminary modelling and assessment,
- technical analysis,
- comparisons of water produced per quantity of solar energy insolation for various models.

Innovative aspects and conclusions of the project

The primary focus of this study was directed toward determining the technical viability and potential to improve solar-powered desalination using new approaches. Projections were made to show the water production that could be obtained with these new approaches. These water production projections were then compared to the existing methods that were found by SQU in their literature search.

Four new combinations of solar energy conversion and SWRO desalting systems were evaluated for comparison to existing methods, as follows:

- System A: Solar photovoltaic – electric module with the VARI-RO EMD (electric motor drive) version.
- System B: Solar dish collector – Stirling engine electric module with the VARI-RO EMD (electric motor drive) version.
- System C: Solar trough collector – thermal energy module with the VARI-RO DDE (direct drive engine) version.
- System D: Solar dish collector – thermal energy module with the VARI-RO DDE (direct drive engine) version.

During the literature search it was found that current desalted water production per unit of surface area of the solar energy collector is quite low. The large surface area required per unit quantity of water produced results in high total water cost – primarily because of the high costs of the solar energy collector, maintenance of the collector surface, and land surface area.

For comparison, the results of the study indicated that it was feasible to increase water production in the range of 200 to 1200 l/m^2 per ay using the RO process. The highest production capability resulted from the new advanced methods for solar energy conversion and RO pumping and energy recovery. Using the most advanced solar-powered RO desalting system in the study, it was found that about 300 times the water could be produced as compared to the simple solar stills, and 30 times as compared to the other distillation methods.

It was also found that the use of thermal storage techniques, to allow 24 hour operation, would reduce the capacity requirement of the desalting system – and hence provide another possibility to reduce the total water cost.

Previous limitations of solar-powered desalting have been due to the huge solar energy collector surface areas that are needed per unit of water produced. These surface areas not only have high capital cost, and take up a lot of land area, they also require substantial maintenance.

This MEDRC-sponsored study has shown that, by using the advanced methods outlined, the required solar collector surface area can be dramatically reduced. This alone will provide a significant reduction in fresh water cost. Combining these technological advancements with a suitable manufacturing program – to produce modular units on a mass production basis –can further reduce these costs.

The study has shown that the cost of solar-powered desalination technology can be substantially reduced. The VARI-RO technology *(the hydraulic-driven pumping and energy recovery system is known as the VARI-RO system (patents issued and pending))* can provide a substantial breakthrough in the art of solar-powered desalting of seawater. It is recommended that a program can be initiated that will show that the following benefits for solar-powered desalting can be achieved:

- A modular system can be developed, which will not restrict the scale of the solar powered seawater desalting facility but will lower the cost through mass production.
- Very high fresh water production rates can be obtained for stand alone solar powered desalting facilities, as compared to rates for other solar conversion methods.
- Where it is appropriate, advanced systems can be devised for fossil fuel backup and/or augmentation, with thermal energy storage systems, which can help reduce the overall cost of solar-powered water desalting.

Project title	Matching renewable energy with desalination plants: literature review and analysis of the state of the art of renewable energy and desalination systems
Project Contract No.	97-AS-006a
Year of the final report	2001
Principal investigator	Rolf Oldach Senior Engineer, IT Power Ltd The Manor House, Chineham Court, Lutyens Close Chineham, Hampshire RG24 8AG, UK
Type of application	To analyse which renewable energy sources are the most suitable to use for powering small-scale desalination plants

Short description of the project

The project group tried to describe the state of the art of renewable energies suitable for powering small-scale desalination plants following these steps:

- The renewable energy technologies considered in detail are solar thermal energy, photovoltaics and wind energy, as these are the most relevant for desalination applications.
- The analysis of the following desalination technologies is presented:
    - distillation processes (multistage flash distillation, multiple effect distillation, vapour compression),
    - crystallisation processes and membrane processes (reverse osmosis, electrodialysis, ion exchange).
- The analysis of typical combinations of renewable energies and desalination plants.

Innovative aspects and conclusions of the project

The first part of the report presents the state of the art of renewable energy technologies. After a description of the technology, the following factors are assessed for each technology:

- suitability for providing power to specific desalination technologies;
- technical maturity;
- complexity and flexibility of operation,
- availability of equipment;
- energy requirements,
- product water quality,
- site requirements and resource availability;
- economic aspects.

Conclusions are summarised in the following Table 39.

Table 39 Recommended renewable energy-desalination combinations

Feed water available	Product water	RES available	System size, m^3/d			Suitable RE-desalination combination
			Small (1-50)	Medium (50-250)	Large (>250)	
Brackish water	distillate	solar	✓			Solar distillation
	potable	solar	✓			PV-RO

	potable	solar	✓			PV-ED
	potable	wind	✓	✓		Wind-RO
	potable	wind	✓	✓		Wind-ED
Sea water	distillate	solar	✓			Solar distillation
	distillate	solar		✓	✓	Solar thermal-MED
	distillate	solar			✓	Solar thermal-MSF
	potable	solar	✓			PV-RO
	potable	solar	✓			PV-ED
	potable	wind	✓	✓		Wind-RO
	potable	wind	✓	✓		Wind-ED
	potable	wind		✓	✓	Wind-VC
	potable	geothermal		✓	✓	Geothermal-MED
	potable	geothermal			✓	Geothermal-MSF

As part of the project, a review of papers and reports on matching renewable energies with desalination units was carried out. Papers were classified and have been listed by technology.

Project title	Matching renewable energy with small unit desalination plants: development of PC-based decision support system
Project Contract No.	97-AS-006b
Year of the final report	2002
Principal investigator	Prof. Th. Melin, Mr. L. Eilers Institut fuer Verfahrenstechnik der RWTH Aachen, Germany
Type of application	The development of DSS for selection of desalination plant powered by RES (continuation of the project No. 97-AS-006a)

Short description of the project

The objective of this project was to develop a computer-based Decision Support System (DSS), DesalSolar, useful for

- Selecting the best desalination and renewable energy technology combination from the reported combinations in the literature based on the site parameters and the requirements of the customer;
- Calculations of rough design parameters of desalination plant and renewable energy supply systems;
- Estimations of the specific water costs for each combination of desalination process and energy source;
- Comparison of different process combinations in economic terms.

Innovative aspects and conclusions of the project

The problem analysis for the users with regard to the decision attributes of the decision-making process is modelled by a Fuzzy system. The basic design parameters are evaluated using simple procedures and the data collected from the plant suppliers. Empirical correlations are developed for specific water cost estimation using the data of the existing plants.

The DSS allows the user to perform the following tasks:

To evaluate different desalination processes (reverse osmosis, electro dialysis, multiple-effect distillation, multiple-stage-flash evaporation, mechanical vapour compression, solar stills) for given local conditions.

- To evaluate different renewable energy power supply systems (photovoltaics, flat plate collectors, linear focusing collectors) for given local conditions.
- To develop feasible combinations of desalination and renewable energy technologies for stand-alone desalination application of sea or brackish water (< 5,000 mg/L TDS).
- To design desalination plant and renewable energy supply systems for the desired water demand, local climatic and economic conditions.
- To calculate the specific water cost.
- To present the relevant information of the designed desalination plant and renewable energy system.

The user has to provide the following information:

- land cost and the availability of land for the construction of a desalination plant,

- the necessity for mobility of a desalination plant,
- the necessity to adapt the plant's capacity for a future increase in drinking water demand,
- the necessity to operate the plant with little additives,
- the availability of skilled operators,
- the plant's robustness towards incorrect operation by the operators.

The following parameters are calculated by the DSS:

- Size of a renewable energy system;
- Size of a desalination unit;
- Specific drinking water costs.

Fig. 58 Main frame of "DesalSolar"

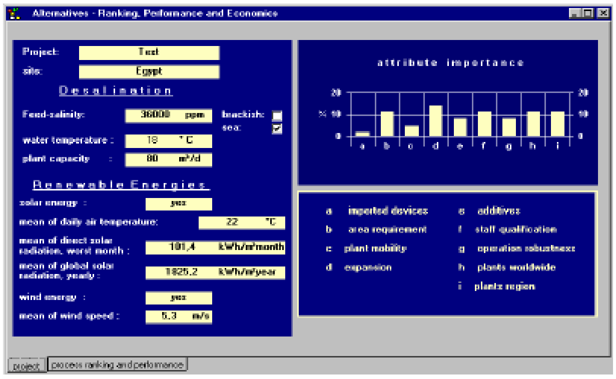


Fig. 59 Project overview frame

The DSS can run on any PC having a CD drive and Windows98 operating system.

Project title	Development of a Logistic Model for the Design of Autonomous Desalination Systems with Renewable Energy Sources
Project Contract No.	00-AS-014
Year of the final report	2002
Principal investigator	E. Tzen Centre for Renewable Energy Resources, Greece
Type of application	Development of a stand-alone desalination system driven by a hybrid power supply system

Short description of the project

A RO desalination unit powered autonomously by a wind generator and/or photovoltaics is considered today as one of the most promising configurations in view of the power matching of desalination and renewable-energy technologies. The objective of the project was the developing of a desalination system driven by a hybrid power supply system consisting of renewable energy power generation systems coupled to conventional power generation systems.

Innovative aspects and conclusions of the project

The HybridRO simulation software has been developed based on logistic approach, for the design of an autonomous hybrid power supply system to drive an RO unit for the desalination of brackish and seawater. It has been developed on the basis of accurate theoretical information collected by conducting a detailed literature survey. It simulates the performance of energy supply systems and provides results in terms of power production, capacity ratios, energy and fuel savings and component wear, which can be used as inputs to an economic analysis model for predicting unit water cost. It can assist a designer in sizing hybrid power supply hardware and in selecting appropriate operating options on the basis of overall system performance and cost for specific weather conditions and load profiles. It uses a time-series approach for long-term predictions.

HybridRO is user-friendly simulation software, operating in the MS Windows environment. The main components of this software are the power production unit, the power consumption source, the storage units and the economic analysis module. The software has around 20 projections/windows. The power supply unit comprises of wind generators, photovoltaics and diesel generators. The selection of the power supply system mainly depends on the potential of each renewable power source (wind, solar potential). The power required to drive the RO unit, as well as several auxiliary loads, is the power consumption source. The storage units are the battery storage system and the water reservoir for storing the water produced. An additional important component of HybridRO is the economic analysis module, which estimates the unit cost of the water produced based on the life-cycle cost method. The software also has features for viewing the simulation results in graphical form.

The model developed is principally for calculation of the power produced by all the power generators, the fuel consumption of the diesel generator, the energy required to drive the desalination unit and battery the performance of the batteries on a scale with an adjustable time step. Furthermore, it allows a wide choice of system components and of configurations and operating strategies in order to achieve the highest usage of renewable energy in order to reduce the use of the diesel unit and provide the least cost-option for unit water production.

Project title	Hybrid fossil / solar heated multi-effect-still
Project Contract No.	97-BS-016
Year of the final report	2002
Principal investigator	Dr.-Ing. Jürgen Rheinländer Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), Germany
Type of application	Development of a small-scale thermal desalination system powered by solar energy or fossil heat, suitable for Morocco

Short description of the project

The main objective of the project was the technical development of a small-scale thermal desalination system, suitable for de-central hybrid operation from solar and fossil heat sources.

The main tasks of the work programme were:

- Design, construction and testing of a four-effect thermal desalination system based on the principle of humidification and de-humidification of air.
- Preparation of the technology transfer and study of the technical and economic potential for application and local manufacturing of the technology in Morocco.

The work programme comprised the following tasks:

1. Detailed design for a prototype MES unit with 4 cells.
2. Construction of the prototype MES and fitting for measurements.
3. Laboratory-Test of the full process in the prototype MES unit at ZSW.
4. Set up of the infrastructure for field tests with (a copy of) the prototype MES at CNR (Morocco).
5. Study on the potential for local manufacturing of the system in Morocco.

6. Evaluation of economics of de-central water production by the system in Morocco.

Innovative aspects and conclusions of the project

The research and development was aimed at a system with the following main advantages:

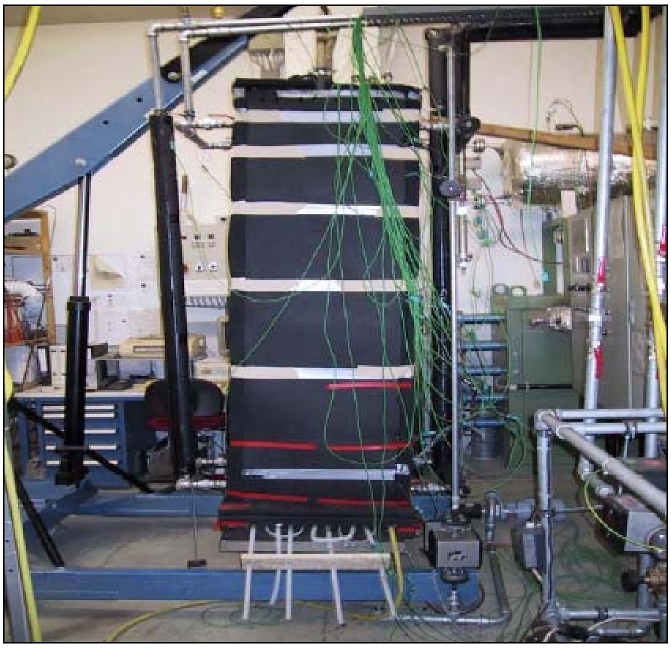
- Suitable for production capacities of a few m^3 per day;
- Simple modular design and construction from materials available in most developing countries;
- Easy operation and maintenance;
- Easy repair with technical know-how available in most developing countries;
- Economically competitive with conventional solutions for water supplies to small customer groups at isolated sites.

In the Thermal Process Laboratory of ZSW, a prototype MES unit was constructed. The 4-effect-distillation unit consists of four stages (effects) made from the heating and cooling plates and three intermediate plates. The MES unit is tilted by approximately 3° - 5° from the vertical, so that the evaporation paper (wick) will sit close to the surface of the evaporation plate and guarantee good heat transfer. The brine is supplied to each stage *via* a rectangular perforated tube and is distributed over the whole width of the evaporation surface. The distillate and concentrate mass flows are collected in troughs at the bottom of the evaporation and condensation sides and lead into the heat recovery system.

Most of the components are bolted together in order to achieve simple assembly and disassembly of the laboratory test facility. In future, an easier construction without bolts may be possible. The four effects are sealed to prevent the leakage of water vapour. The material is EPDM (degree of hardness: 50° shore A, dimension: 30mm x 5mm and 20mm x 5mm).

The evaporation paper (ARMORIB-L, Daramic®), was selected in an earlier investigation of different wick types. It possesses good heat conductivity characteristics (temperature losses within the fleece are approx. 1K) due to its thickness (s = 0.6 mm).

The evaporation paper reduces the velocity of brine flow, enlarges the evaporation surface and retains the calcium carbonate $CaCO_3$ and magnesium hydroxide $Mg(OH)_2$ at higher temperatures from the brine. The easy and cheap replacement of the evaporation paper reduces the need for mechanical or chemical cleaning of the evaporation surfaces.



Pic. 46 The 4-effect distillation unit in the Thermal Process Laboratory of ZSW

The MES was investigated under different experimental conditions and operating modes, which are typical operating conditions for the real performance. The main results from the measurements are:

- For all operation modes, the distillate output of the MES process is a strong function of the temperature level of the heat input. The heat supply should be as close to 100°C as possible. Low cooling temperature level is helpful but not as decisive as the heating temperature level.
- Re-circulation of hot brine increases specific output of the apparatus but not the GOR.
- Heat recovery from distillate and excess brine for pre-heating of feed increases GOR.
- Screens in effects do not increase GOR very noticeably.
- The combination of heat recovery with screens and forced convection by blowers yields the best GOR values.

- The maximum GOR achieved using the four effects was, 2.4 at 96°C heating fluid inlet temperature.

An MS-EXCEL tool for technical and economic comparison of different small size desalination technologies (typically for 10 m^3/day), including thermal and membrane systems, was developed and applied for the study on the potential of application in Morocco:

- a tourist hotel near Laayoune on the Atlantic coast requiring desalination of sea water for up to 150 guests and other services;
- a cattle breeder village in the inland near the southern border to Algeria requiring desalination of brackish water for 50 families and the animals.

As a suitable technology for the hotel, RO was identified; MES could not compete with RO, as easy access to an electric power supply from grid or diesel engine was assumed.

Project title	Small scale thermal water desalination system using solar energy or waste heat
Project Contract No.	97-AS-024b
Year of the final report	2001
Principal investigator	H. Müller-Holst Bayerisches Zentrum für angewandte Energieforschung e.V., ZAE Bayern (Bavarian Center for Applied Energy Research), Munich, Germany
Type of application	The design of small scale water desalination system driven by solar energy or waste heat working on humidification and dehumidification of air by natural convention (designed for building in Oman)

Short description of the project

A desalination system based on the principle of humidification and dehumidification of air by natural convection and using solar energy or waste heat as a source of energy was investigated in this project. Evaporation of seawater and condensation of water vapour from humid air take place in a single chamber at ambient pressure and at temperatures between 40 and 85°C. The main task and essential objective of the present project were verification and optimization of a simulation model for this solar thermal seawater desalination system by comparison of simulation and measured results obtained when performing the following steps:

1. Design and calculation of a demonstration system based on the meteorological data of the Sultanate of Oman, using an existing simulation program. This will allow calculation of the optimum component sizes for the collector field, storage tank and distillation unit.
2. Construction of the unit in Europe and shipment to Oman.
3. Commission and operation of the unit under the actual meteorological and seawater conditions of Oman.
4. Utilization of the collected data in updating the simulation program to optimize future design of commercial units.
5. Introduction of the desalination process in the Middle East/North Africa region.

Innovative aspects and conclusions of the project

Based on the Multi Effect Humidification (MEH) model of the distillation unit, a TRNSYS component for the unit was developed. This component consists of three counter-flow heat exchangers with temperature dependent heat transfer coefficients. The heat conductivity of each of the three heat exchangers is calculated from the mean values of the two inlet temperatures of the heat exchangers. The component 'desalination unit' has architecture as shown in Fig. 61. The unit model is implemented in a program code written for the simulation environment, TRNSYS 14.2. The program consists of the description and components of the planned architecture of the whole desalination system.

Following the results of the simulations, a 42m^2 solar collector field and a 3.5 m^3 thermal water storage tank appeared to be the ideal configuration to enable the optimum operation of the system within the limits of the boundary conditions. This design will enable 24 hours per day operation time at a load flow for the distillation unit of 700 l/h on 250 days of the year. The operation of the system under those ambient conditions relating to the simulation calculation will allow an average daily distillate production of 865 litres with a maximum daily production of 1048 litres.

Deviating slightly from the optimal configuration, 40 m^2 of collector area and a storage tank of 3.2 m^3 have been applied in the realized set-up. This is not a significant deviation from the optimum operation point – performance will only decrease by 5% from the values predicted above.

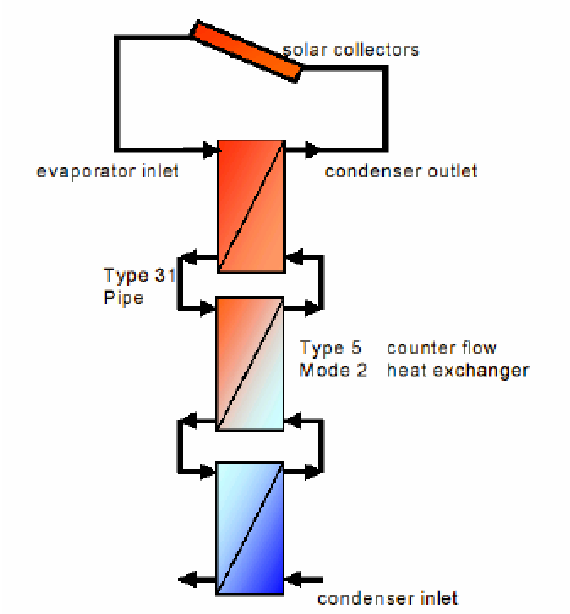


Fig. 61 Three serial heat exchangers each with a temperature-dependent heat exchange coefficient are identified with the seawater desalination unit

After one year of measuring time, the performance of the distillation unit (measured in terms of specific energy consumption, distillate production ratio and distillate conductivity) has not decreased. During the maintenance in November 2000 no inappropriate scaling on the evaporation surfaces or elsewhere in the system was discovered. The Gulf water appears to be well suited for this desalination process even when running the process at inlet temperatures of 80°C in the evaporator. To demonstrate the long-term reliability of the process, the operation should be continued for several more years.

The main results and findings of the project are as follow:

⇒ The model parameters for the distillation unit obtained from steady-state investigations provide useable correlation with the measured data (<5% deviation in simulated and measured values for daily distillate output).

⇒ The model parameters for the other components (storage tank, collector field, heat exchanger) were refined by the discussed procedure and predict output values corresponding to the measured values with accuracy better than 7 %.

⇒ The applied MEH-distillation process is suitable for the local conditions in Oman and worked reliably for a period of one year without a need for major maintenance.

⇒ The raw water quality of the beach well of the test site Al-Hail in Seeb/Oman is perfect for use with the present distillation process; additional water pre-treatment is not needed. This indicates that problems with raw water supply should not be encountered in applications using similar raw water conditions within the Gulf region.

⇒ The solar collectors used (ThermoSolar Heliostar 400V-A evacuated flat plate collector) are suitable to deliver sufficient heat for the desalination process, if an additional insulation is used on the reverse side and vacuum leakages are avoided in future installations.

The results of the presented project are considered to be a further step towards successful commercialisation of the MEH-desalination system. In general, the project provides a simulation code that includes evaluated parameters and describes the components of this type of solar thermal desalination system. In principle, the tool can also be used to design different types or larger sizes of thermal desalination plant by adapting the system components. Last but not least, the high-resolution meteorological data for wind speed, solar irradiation and ambient temperature deliver the basis for further simulations within this region.

Project title	The small solar MED-desalination plant
Project Contract No.	98-AS-024a
Year of the final report	2004
Principal investigator	L.B. Begrambekov Lidasa Ltd, Russia
Type of application	Design of a solar powered small-scale desalination plant based on multi-effect distillation principle (with the application for pilot plant in Oman)

Short description of the project

For successful operation in remote and rural locations the small-scale desalination plants, in particular, the solar powered desalination plants should satisfy a number of specific requirements. The capacity of these plants should be in the range of few hundred litres to some tens tons per day and require no qualified operators. They have to work in autonomous or quasi-autonomous mode. Recovery should be high and the consumption of water for supplementary needs (cooling, cleaning) should be small. The plant should be environmental friendly. The use of chemicals should be avoided and waste production should be small.

In this project a solar energy powered desalination technology suitable for small-scale remote location application based on Multi-effect distillation principle is developed.

Innovative aspects and conclusions of the project

The work includes calculation, computer simulation, design, fabrication and testing of the solar desalination plant. Calculation and computer simulation of main parts and systems of the plant as well as their experimental investigation were made. Energy and material balances of main processes and systems were performed. In particular, quasi-closed collectors loop, effects, pre-heaters, air-steam condenser, vacuum system, solar tracking system, brain discharge and distillate discharge systems were analyzed. The special techniques and devices including scale-preventing coating, device for water softening were elaborated. All of them were tested separately and then during indoors and outdoors experiments with the pilot plant.

Two different MEH units were tested. The first one ("SODESA system", which was developed in the framework of SODESA project co-financed by the EU and described in the previous section) consisted of a thermal storage tank at ambient pressure and a collector field. The feed water was heated by direct circulation through the collector. The system efficiency was high due to elimination of heat exchangers, but costly materials to resist seawater corrosion at 100ºC were required for the collector and the heat storage tank.

The second unit tested in Oman consisted of a standard evacuated flat plate collectors and a pressurized storage tank with a closed fresh water loop at 2.5 bar for heat supply. The storage tank was made with mild steel and all piping with standard copper. The feed was heated by a titanium heat exchanger. The required electrical power was supplied by PV-cells. Table 40 compares the designed parameters of two systems. Daily production rates of these two are 11.7 to 18 l/m^2d and 16.3 to 22.5 l/m^2d.

Table 40 Comparison of "Sodesa System" and "Oman System"

	SODESA System	Oman System
Characteristic	Completely seawater filled system: Everywhere corrosion resistant components needed. No heat exchangers required	Divided System: Heat Supply contains fresh water: standard collector / storage technique. Titan Heat exchanger separates heat supply and distillation unit
Collectors	Seawater proof special collectors made from silicon / glass pipes (ISE Freiburg scg)	Standard Evacuated Flat Plate Collector thermoSolar 400 V
Collector Aperture Area	47.2 m^2	40 m^2
Max. Storage Temperature	99°C	120°C
Storage Tank Size	6,3 m^3 (Ambient Pressure)	3,2 m^3 (Pressurized)
Designed Productivity	550 – 850 l/d	650 - 900 l/d

The efficiency of the modern MEH-system is much higher than that of the conventional simple solar still. However, they retain some weak points of the solar stills such as the usage of relatively high quantity of feed water.

The main features and advantages of the developed plant are as follows:

- The desalination plant has capacity 1000 l/d.
- Main elements of the solar collecting system of the plant are the tubular vacuum collectors and mirror concentrators. They installed in sixteen modules operating in the solar tracking mode. Solar collectors are filled with distilled water and produce steam, which provides operation of desalination system.
- Desalination system includes twelve connected in series condensers/evaporators (effects) and last condenser cooled with feed water and electric fans. The range of the working temperatures is expanded up to 100ºC.

- Softening of feed water and anti-scale coating of the heat exchange surfaces are used for prevention of the scale formation.

The experimental plant was designed and fabricated as a stand-alone unit for testing the elements of the pilot plant, particularly, desalination sub-unit.

The plant operates autonomously. It produces drinking water of the best quality independently on salinity and the temperature of feed water and on variations of ambient conditions. The electricity demand of the plant is satisfied with 2 m^2 PV-cells. Special water for cooling of the last condenser is not used.

The plant operates with 70-85% water recovery depending on salinity of feed water. Chemicals are not used for water disinfection and for anti-scale treatment. Full drying of brine and salt production as a by-product are foreseen. The long term testing run of the plant in natural conditions of Sultanate of Oman proved that presented solar powered desalination plant can serve as an autonomous source of drinking water for a small community in a remote location without any external thermal and electrical power supply and any additional cooling water.

6.3. Other projects

There are many other projects, which were not described in the previous sections due other sources of financing. In these projects the main donors are national governments, local communities, and research centres or universities in some cases. Some of the projects were already described in the Chapter 4. Below some projects are overviewed in more details.

Project title	Windgenerator with mechanical coupling to a desalination plant
Project acronym	AERODESA I
Funding	Government of the Canary Islands. The project has been carried out by ITC (Instituto Tecnologico de canarias).
Year of development	N.A.
Type of project	Wind+RO

Short description of the project

The aim of the project was to develop low-tech wind generator with a rated power of 15 kW, specially designed to be coupled to a seawater RO desalination plant (with a capacity of 10 m^3/d) with a mechanical coupling system and seawater as a control fluid.

Innovative aspects and conclusions of the project

The unit has been designed for both ordinary and low maintenance conditions, which is essential in isolated areas or developing countries.

Technical Description

The rotor is made up by three 4.5 meter long blades, built with fibber-glass in polyester in the traditional way. The blades have been built in Gran Canaria (Canary Islands). The driving gear consists of a main low rotation shaft in the wind turbine nacelle, a first multiplication for bevel gear, a vertical prop shaft made of different units elastically attached, and, finally, a multiplication for the desalination pump.

The desalination module is made up by four osmotic membranes, set in series, with a low recovery rate, according to the operation requirements of the system. The control system, supported by a pressure accumulator, uses seawater as a control fluid.

The desalination plant works under variable regimen, according to the technical limits established by the membrane's manufacture (from 45 to 70 bars). This variable regimen is regulated by the seawater valves system, which acts as a control system.

Application area

The project can be installed in any part of the world with a medium wind speed. Nevertheless, the unit has been designed for both ordinary and low maintenance conditions, which is essential in isolated areas or developing countries, so that these kind of areas seem to be its natural market

Some interesting data

- Relation surface/water production: 59 m^2/m^3-d (m^3 means 1 m^3 of desalted water per day)
- Water cost m3 (prototype): 3.78 €/m3
- Water cost m3 (fabrication cost): 1.89 €/m3

Project title	Wind generator with hydraulic coupling to a desalination plant
Project acronym	AERODESA II
Funding	Government of the Canary Islands. The project has been carried out by ITC (Instituto Tecnologico de Canarias).
Year of development	N.A.
Type of project	Wind+RO

Short description of the project

This project was continuation of the previous one with the special focus on automation of the system.

The main objective of the project was construction of the wind generator with a rated power of 15 kW, specially designed to be coupled to a seawater RO desalination plant of two modules (with a rated capacity of 15 m^3/d) with a oil-hydraulic mechanical coupling system, thus allowing a high automation of the system.

Innovative aspects and conclusions of the project

Technical Description

It is a horizontal axis wind turbine with a passive downwind orientation system and two hinged blades. It has also an overspeed brake system and a hydraulic power transmission system by means of a set turbine and a displacement oil pump.

The oil-hydraulic system, which acts as a control system, allows the desalination plant to work under nominal conditions.

Application area

The project can be installed in any part of the world with a medium wind speed. Nevertheless, the unit has been designed for both ordinary and low maintenance conditions, which is essential in isolated areas or developing countries, so that these kind of areas seem to be its natural market

Some interesting data

- Relation surface/water production: 55 m^2/m^3-d (m^3 means 1 m^3 of desalted water per day)
- Water cost m^3 (prototype): 4.2 €/m^3
- Water cost m^3 (fabrication cost): 2.03 €/m^3

Project title	Windturbine electrical coupled to a desalination plant
Project acronym	AEROGEDESA
Funding	Government of the Canary Islands. The project has been carried out by ITC (Instituto Tecnologico de Canarias).
Year of development	N.A.
Type of project	Wind+RO

Short description of the project

The main idea of the project was electrical coupling from a 15 kW commercial wind turbine to a Reverse Osmosis desalination plant (with a desalination capacity of 18m^3/d), operating under a constant regime and managing the storage and available wind energy use through a battery bank. The battery bank guarantees that the washing system is filled with seawater, thus guaranteeing a longer working life of the membranes. The whole system is fully automated.

Innovative aspects and conclusions of the project

Technical Description

Wind turbine with a rated power of 15 kW, a three-phase self exciting induction generator for a static condenser battery, a charger and a three-phase sine-wave inverter, both micro-processed. A Reverse Osmosis desalination plant of $18m^3/d$ adapted to a frequent start/stop configuration is coupled to the system.

The whole system is fully automated. The control and data acquisition systems are made up by a Programmable Logic Controller (PLC) receiving all the signs from the sensors in the plant and making decisions in relation to the start/stop configuration in the installation. It will also monitor the safety devices by using two microprocessors exclusively used to control and manage the available energy in the electric system.

Application area

The project can be installed in any part of the world with an average wind speed and no grid connection because of economic reasons.

Some interesting data

- Relation surface/water production: $41.26m^2/m^3$-d
- Water cost m3 (prototype): 3.11 €/m^3
- Water cost m3 (fabrication cost): 1.91 €/m^3
- Water cost m3 (optimised system with energy recover and bigger desalination plant about 300 m^3): 1.12 €/m^3

Project title	Desalination plant coupled to a solar photovoltaic field
Project acronym	DESSOL
Funding	ITC and AG-SOLAR (Germany) The project has been carried out by ITC and REWET (Germany)
Year of development	N.A.
Type of project	PV+RO

Short description of the project

The project consists of the design, installation estimation and optimization of a drinking water production system in coastal areas isolated from the electricity grid. It is made up by a Reverse Osmosis desalination plant (rated capacity: 3 m^3/d, for a daily operation of 8 hours) driven by an isolated photovoltaic array (peak capacity: 4.8 kW).

Innovative aspects and conclusions of the project

Technical description

The desalination plant has been specifically designed to work isolated from the electrical grid and the system is fully automated. The desalination plant works for a daily period whose duration is determined both by the state of charge of the batteries in the photovoltaic array and the available solar radiation. The system has been designed to produce a minimum of 800l/d under normal conditions of solar radiation in subtropical areas.

Some data of interest

- Surface-production relation: 75m^2/m^3

Project title	Reverse Osmosis Sea Water Desalination by Renewable Energy Sources
Project acronym	SWRO + RES
Funding	GECOL General Electric Company (Libya)
Contacts	Ras Ejder, Libya
Year of development	2001-2002
Type of project	RES+SWRO

Short description of the project

As at the most parts of the North African shore sweet water is not available in the ground (at acceptable depths), it needs to be transported by pipelines or generated by seawater desalination. For small towns far away from bigger cities the construction of pipelines is economically not justified, and hence seawater desalination is the only remaining solution. Conventionally powered desalination plants depend on fuel or electricity supply from more urbanised areas. If this energy supply is not available at very remote sites, the utilisation of renewable energies can be the solution. This project, financed by Libian General Electric Company, is demonstration project to show how it is possible to apply RES for water desalination.

Innovative aspects and conclusions of the project

The SWRO + RES project is located at the town Ras Ejder, near the border to Tunisia. GECOL wanted to investigate and demonstrate the feasibility of RES utilisation for SWRO systems under real conditions. Therefore, the capacity of the system has been selected rather big for a pre-commercial application.

The German ZSW, the prime contractor of GECOL, was responsible for the overall system design and for the design of the Photovoltaic (PV) power system. LI has been selected as the consultant for the desalination system and interface components because of its experience in this technology field.

Some data of interest

- Capacity RO plant: 300 m^3 / day
- Capacity of PV system: 100 kWp
- Capacity of wind power: 200 kWp
- Capacity of diesel generator: 70 kW
- Battery storage capacity: 70 kWh

Services:

- RO system design
- RO equipment specification, tendering and procurement supervision
- Supervision of RO equipment implementation and commissioning
- Analysis of RO system performance monitoring, technical and economical analysis
- Interface specification
- Training of local personnel

Project title	Wind-diesel system for water and electricity supply in the island of Fuerteventura
Project acronym	PUNTA JANDÍA
Funding	ITC and AG-SOLAR (Germany) The project has been carried out by ITC and REWET (Germany)
Year of development	N.A.
Type of project	Wind – diesel RO

Short description of the project

This project is focused on the basic elements for living in a community, which are the following:

- water
- energy
- improvement of the economic infrastructure of the population

The difficulties of a fishermen's community, without power mains (the electricity grid ends 20 km before the village), have turned, by means of this project, into an increase of the living standards through a full self-supply of:

- Drinkable water through RO plant powered by wind energy, with the possibility of water processing.
- Energy self-supply through a wind-diesel system isolated from the grid.
- Improvement of the economic conditions of the fishermen with an ice generation plant and a cold-storage plant to freeze fish. These plants are also powered by a wind-diesel system.

Innovative aspects and conclusions of the project

<u>*Innovative aspects of the project*</u>

Arrangement and renewal the original village (houses, streets and sidewalks), providing it with all the necessary infrastructures (street and home lighting, drinkable water and sewers) with the maximum respect to the original situation (unpaved sand streets and hidden services network).

Outside the village, in an architectonic setting in keeping with the environment, a group of highly technical installations have been developed to meet all the requirements of the village: one wind turbine to transform wind energy to electric power, diesel equipment (when the wind lacks), sea water desalination plant, cold-storage room for fish, ice generation plant, hauling capstan and sewage treatment plant.

The power supply concept is a hybrid (wind-diesel) system and a synchronous machine coupled to a flywheel. Starting up is provided by a tank of compressed air, which starts to move the flywheel. The control of supplied power to the stand alone grid is achieved by dump loads.

Technical data of installations

- *Planned drinkable water supply*: 60 litres/day (with low consumption toilets)
- *Power supply (Kph/person/year)*: unlimited
- *Desalination capacity:* 56 m3 per day (higher than necessary, but the desalination plant will only work with wind and never with fuel: all the water will be produced by the wind)
- *Water storage tank*: 2 x 500 m 3.
- *Cold-storage room for*: 1200 Kg of fish at 0^oC
- *Ice production*: 500 kg/day
- *Peak power demand*: 100 KW
- *Wind turbine*: Vestas, V27, 225 KW
- *Diesel equipment*: 2 x 60 KW
- *Control system*: flywheel, dump loads and PC with AT Bus.

Application area

This project has been tested to spread it out with improvements and adjustments for The project has been co-financed with the European Commission through the VALOREN Program; Town council of Pájara (Fuerteventura), Fuerteventura Water Association, Industry Council (Government of the Canary Islands) and the Institute of Renewable Energies (IERCIEMAT). The partners involved were the University of Las Palmas de Gran Canaria (ULPGC) and the Institute of Renewable Energies (IER-CIEMAT). Nowadays ITC is managing the project.

7. DESALINATION RES MODELS

In recent times several simulation software packages have been developed in the field of Renewable Energy Sources (RES) and Desalination (DES).

A RES simulation program generally predicts the performance of a system, which may be a single system or combination of more than one system, comprising of photovoltaics, wind turbines, diesel generator, battery storage, etc. The analysis of the simulation results provides an understanding of the most appropriate technology to meet the load and optimally utilize the RES resource of a particular site.

The selection of the power supply system is based on firstly the type of energy sources available, followed by the size and operation control of the system components and their cost effectiveness.

There are some software packages that are reported in the literature which are useful to simulate only specific type power supply system. Examples of such packages are; PV stand-alone and grid connected systems by PVFORM (Menicucci, 1988) and ASHLING (Keating, 1991), or wind-hybrid systems by Hybrid1 (Manwell, 1992). Some of them have a primary purpose of investigating the performance of a particular system component, such as lead/acid batteries in PV plants and accessing their suitability and their optimal operation within the system (Zmood, 1988).

Different types of simulation packages vary in their complexities to serve various purposes are reported in the literature. Some of them comprise of simple linear model (Lorenz 1988, Lilienthal et al., 1995) and others are complex model having provisions for varying the design randomly within a chosen range of component sizes (van Dijk et al., 1991). Seeling-Hochmuth (1995) developed a hybrid system, which is a non-linear hybrid model with complex interdependence of operating strategy and sizing. Marrisson and Seeling-Hochmuth (1997) included an appropriate cost/benefit function for the optimization of hybrid systems. Manwell (1995) presented an updated model, the HYBRID2, which simulates a hybrid power systems consisting of wind, diesel, PVs as well as battery storage employing a combined time series and statistical approach methodology.

Generally, one can classify these simulation models into two broad categories:

- Logistic

- Dynamic
- Logistic models are primarily used for
- long-term performance predictions
- system design and component sizing
- studies of system operation
- providing data for economic analyses

Models of this type are based on the energy balance between the energy supply sources and the energy demand system during each time step (typically 10 minutes). They are capable of examining system behavior on a yearly basis with reasonable simulation time.

Dynamic models are generally used for

- component design
- assessment of system stability
- determination of power quality

Dynamic models are generally used for hybrid power supply systems without storage capability or systems with minimal storage, such as flywheel.

Regarding DES modeling, several software packages have been developed for the design and performance evaluation of the desalination units. In addition, some of these software packages include plant cost estimation module.

RO membrane manufacturers have accomplished a lot of work in this area. RO software packages from membrane manufacturers are available on the following web sites.

ROSA by DOW/FilmTec	(www.dow.com)
Rodesign, Rodata by Hydranautics,	(www.membranes.com)
WinFlows by Osmonics Desal	(www.osmonics.com)
ROPRO 6.1, Costpro by Fluid Systems	(www.kochmembrane.com)
WinCarol 1, 2p flows by Toray, Ropur, Trisep	(www.ropur.com)

The above software packages have different levels of sophistication and different input and output formats. For instance, in ROSA Software of DOW company, the user provides as input data: the amount of the required produced water, the recovery ratio, analysis of the feed water (brackish or seawater), and the temperature of operation. Additionally, the user selects the type of the membrane depending on the application (a list with several types and sizes of membranes is provided). The user also specifies the number of pressure vessels as well as the number of membranes in each pressure vessel. The software provides a summary of important parameters of the system under consideration, such as pressure of operation, quantity and concentration of the produced water, reject brine and feed water, the osmotic pressure as well as corrections and/or suggestions for the selected system (i.e. addition of chemicals, change of recovery ratio etc.).

Furthermore, several other tools have been developed regarding the performance and optimization of the several desalination technologies, such as the model proposed by Green and Belfort for membranes fouling, the measurement and control model of RO by Mindler and Epstein, etc.

Concerning RES-DES modeling, not much work is reported in the literature.

A statistic model developed by the NTUA examines the use of wind or PV power supply systems to drive desalination units (electrodialysis, reverse osmosis or vapor compression). CRES and NTUA have developed a probabilistic model, WINDISP for the investigation of the performance of combined Wind/Diesel Desalination systems. It calculates the annual energy production of both wind and diesel generators along with the water production and the fuel savings for each entered scenario. The model is focused mostly on the maximum use of wind energy in an autonomous power supply system. In general, probabilistic models require long-term load and resource data (i.e. hourly, monthly or seasonal) as input. They are useful for the estimation of the overall system performance on a yearly basis. They are less time consuming than time-series models, but they give little information about the time system conditions.

Additionally CRES has developed a logistic programme suitable for the examination of several types of autonomous power supply systems for supplying power to RO units for the desalination of brackish or seawater. The Institute fuer Verfahrenstechnik der RWTH has developed a computer based decision support system useful for the selecting of the best RES desalination combination while the

Agricultural Univ. of Athens has developed a software tool for designing hybrid renewable systems.

SOLDESS is a computer program developed to simulate the operation of a solar thermal desalination unit, based on the existing Solar MED plant in Abu Dhabi. Finally, ZSW and SimTech develop IPSEpro and RESYSpro tools for the prediction of technical economic and ecological performance of water and power point systems including desalination and water treatment (membrane and thermal processes), renewable energy sources for power (e.g. wind and PV power) and conventional power generator (diesel).

Following a more detailed description of the existing RES desalination models is presented[45].

[45] The following data is a literature review of the existing models and not a recommendation of use.

RES Desalination Models

ID Number	1
Name of Programme	INCO-DC, EU/DG XII
Project Title	"Mediterranean co-operation for water desalination policies in the perspective of a sustainable development"
Project Contract No	IC897042
Year of development	1997-2000
Contractor/Responsible	National Technical Univ. of Athens, Greece D. Assimakopoulos

Work description

A unified approach for the evaluation of alternative RE powered desalination systems (wind energy and solar energy by means of photovoltaics) and their comparison on the basis of the economics of the associated investments is presented. The proposed method works out a preliminary plant design, evaluates the energy flows and calculates the water cost and the expected water-selling price. The energy needs of the desalination processes (Electrodialysis, Reverse Osmosis and Mechanical Vapor Compression) and the energy production by the RE technologies (wind turbines and photovoltaics) are estimated using simplified models. The size and type of the back up power units (energy storage, grid connection or diesel generators) are identified. The expected unit water-selling price is estimated, taking into account the water production cost and the investment profitability index. The computer-aided design tool proposes technology combinations that guarantee the desalination energy needs and provides the means to compare the alternative options on the basis of economic indicators.

Design Approach

Step 1 - Definition of a list of alternative technology arrangements, which can satisfy the targeted water demand.

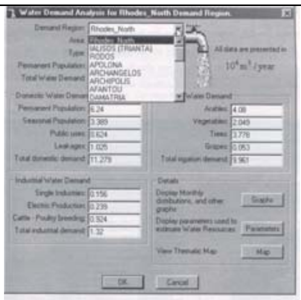
Step 2 – Detail design of each candidate option is made to determine the plant capacity, the structure of the power unit and the operational characteristics.

Step 3 – Financial analysis of the investment associated with the selected RES desalination combination. The investment and operational costs are analytically estimated and the expected water-selling price is evaluated on the basis of the overall discounted water cost.

Software Implementation

The user defines different RES desalination combinations by selecting the desired desalination process and the RE source that will be used. Moreover, the grid connection and the use of diesel generators or storage units can be determined in order to generate a series of alternative RES desalination plant structures. In the initial form the user defines the costs for all the desalination and RES technologies as well as the financial parameters of the investment. The second step presents the energy requirements of the selected desalination process and provides the option to the user to alter the specific energy demand or re-estimate the energy requirements using different design variables. The third step presents the capacity and structure of the energy production unit and the user can alter the capacity of the RES unit and estimate the new energy production. The final step presents the design results of the selected RES desalination combination. Presents the plant characteristics, the cost analysis and the investment appraisal results.

References	
1. Desalination 133 (2001), pp. 175-198	"A tool for the design of desalination plant powered by renewable energies"
2. RES-Powered Desalination Systems in the Mediterranean Region: From Identification to Project Implementation, Conf. Proceed. Sept 1-2, 2000, Limassol, Cyprus	"A Decision-Making tool for water demand and availability analysis and advanced desalination systems", pp. 135-156



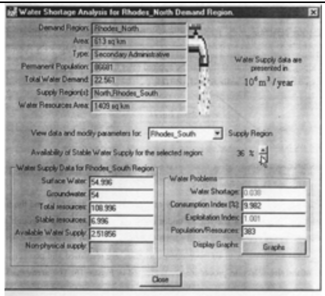
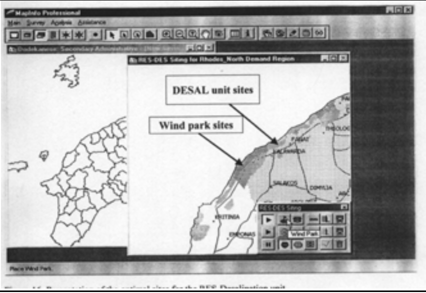


Fig. 1, 2 Windows for the water demand estimation and analysis



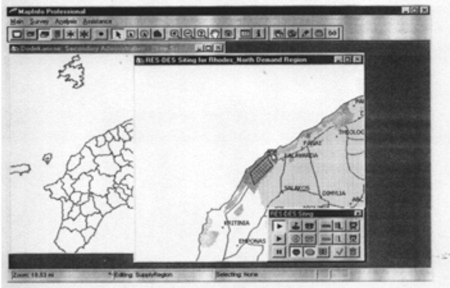
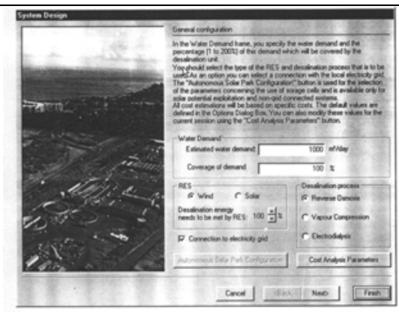


Fig. 3, 4 Windows for the site selection of the RES Desalination unit



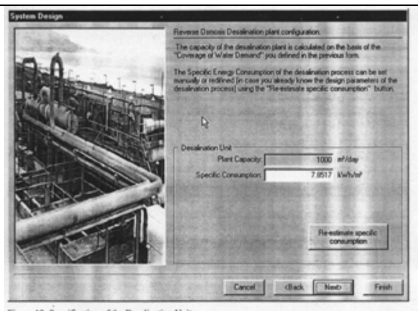
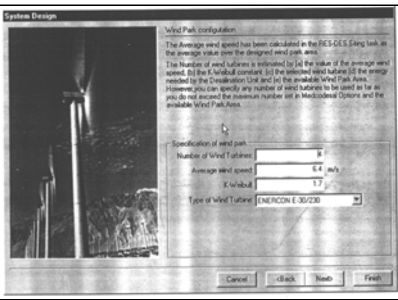


Fig. 5, 6 Windows for the RES-Desalination system's configuration



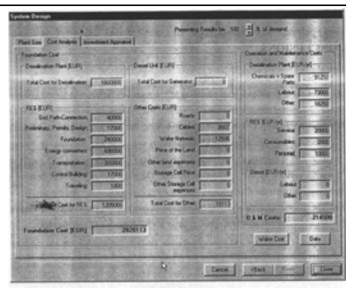


Fig. 7, 8 Windows for the wind park configuration and economic analysis

ID Number	2
Name of Programme	Middle East Desalination Research Center series R&D Projects
Project Title	Development of a Logistic Model for the Design of Autonomous Desalination Systems with Renewable Energy Sources
Project Contract No	00-AS-014
Year of development	2001-2002
Contractor/Responsible	Centre for Renewable Energy Sources, Greece, E.Tzen
Work description	

The simulation model HybridRO is a logistic program suitable for the examination of several types of autonomous hybrid power supply systems for supplying power to Reverse osmosis units for the desalination of sea or brackish water. HybridRO provides the designer to examine several scenarios with different power supply systems, such as Wind/PV/diesel – RO, Wind/diesel-RO, Wind/PV-RO, etc. The "best" scenario should serve the water needs of the location under study with lowest unit water cost and a satisfactory performance of system's entire life. The provision of a validate and users friendly software package to assist engineers for the design of hybrid systems to drive Reverse Osmosis desalination systems, is an important tool for the coupling of the two technologies which is not very applicable and market available.

Design Approach

The HybridRO model consists of two basic components the power supply system and the load.

The renewable energy sources, wind and/or photovoltaics provide power to the load and to the battery system. The Hybrid design used called battery storage/cycle charge. The diesel generator is used only to charge the batteries. When it operates, it runs near rated power and for substantial period of time. Its fuel efficiency and wear rate are therefore kept near to the optimum. However, for the proper operation of the Reverse Osmosis (RO) unit constant power input is required from the renewable energy sources. Thus, batteries in such systems are required at least for power stabilization. More analytically the power supply area is comprised the following components:

Wind Turbines (WT): The tool is able to examine the behavior of numerous WTs which could be either identical or with different characteristics. The produced power estimation is based on the wind data and the power curve of the WT, which is provided by the manufacturer. The major inputs for the estimation of the produced wind power are as follows:

Average wind speed (usually 10min step time series, for one year duration at least)

Standard deviation of wind speed (optional)

The power curve of the WT provided by the manufacturer. Alternatively, measured WT power curve could be examined

Cut-in & cut-out wind speed

WTs nominal power

Photovoltaics (PVs): Various types of PV modules implemented and the tool calculate according to the solar data the total output power. The model considers the total installed solar power to consist of a number of PV arrays, each one consisting of a number of PV modules. Solar power calculations follow the steps listed below:

Estimation of the solar time

Estimation of the radiation on a horizontal surface in the absence of the atmosphere

Estimation of the beam and diffuse radiation

Estimation of the radiation on each PV module

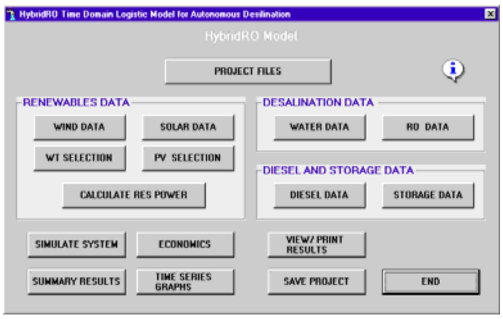
Estimation of the power output from each PV module and array

Estimation of the efficiency of the module

Diesel Generator (DG): Various types of DGs accomplished and the tool calculates the output

power as well as the fuel consumption. Also, several operational strategies such as maximum and minimum running time, minimum allowed power production are considered. Energy Storage System (batteries): the tool examines various types of batteries and their performance according to the power requirements. Battery storage is required to stabilize the power from the RES to the RO unit (constant power required). Also, the battery system can be chosen to provide some days of autonomy to the RO unit. The HybridRO is based on the power flow in and out of each battery bank and the state of charge (SOC). The model parameters are as follows: Nominal Capacity (kWh) Self-discharge rate (% per week) Charging efficiency versus SOC curve Discharging efficiency versus SOC curve Depth of discharge versus cycles to failure curve The use of the inverters, AC to DC or DC to AC, is taken into account in the form of losses from the battery bank to the loads. The main load is the Reverse Osmosis desalination systems - energy required to drive the booster water pump (BP) and the high-pressure pump (HPP). Energy required for its operation is calculated with the provision of several parameters such as daily water demand, water type (seawater or brackish water), unit's recovery ratio, pressure of operation, etc. Also, the possibility to use energy recovery system to reduce the energy consumed by the high-pressure pump of the RO unit is also provided. Several auxiliary loads, for instance dosing pumps for the RO unit and room lights, could also included. The total demand power is the summation of the two loads, the RO unit and the auxiliary load. Generally, several scenarios concerning the power supply systems could be examined depending on the availability of RE source at each location. Priority is given to the renewable energy sources whereas DG(s) is mostly considered as back-up system(s). The economic section of the HybridRO model is based on the use of conventional life cycle costing economics. Life cycle cost analysis appears as the most complete method for cost evaluation since both, the initial cost and the future costs for the entire operational lifetime of the system are considered. The methodology can be used to identify the power supply system, which has the lowest life cycle cost and hence will provide the lowest unit water cost. The following parts comprise the economic analysis area: Economic characteristics of each component of the hybrid desalination system. The current financial indices (inflation rate, interest rate, taxes, discount rate, etc) The investment results will be calculated by means of Internal Rate of Return (IRR), Net Present Value (NPV) and Payback Period of each investment.

References	
1. 2001 European Wind Energy Conference & Exhibition, 2-6 July, Copenhagen, Denmark, pp 948-951 2. MEDRC Report, www.medrcorg.om	"Development of a logistic model for the design of Autonomous Desalination system with RES"



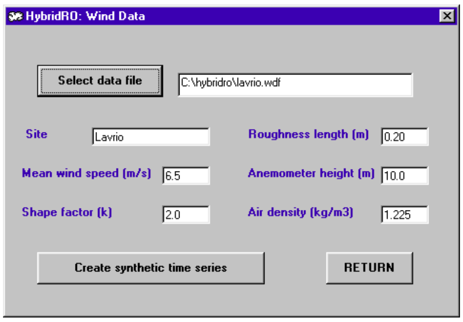
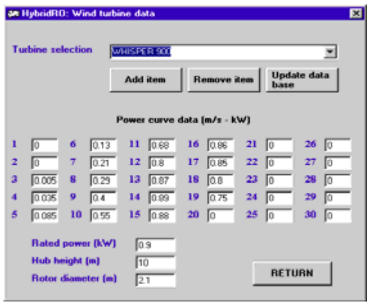


Fig. 1, 2 Start up screen and RES potential data



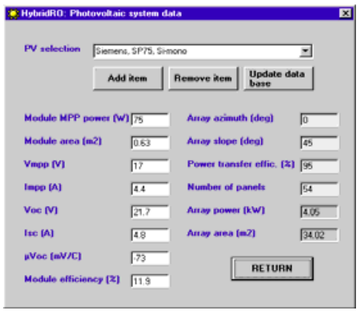
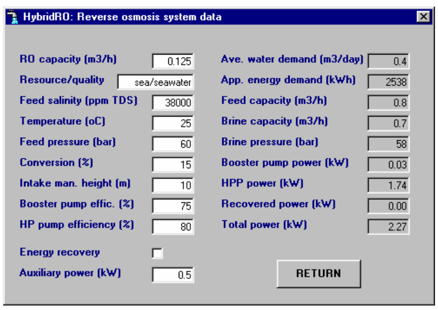


Fig. 3, 4 Windows for the W/T and PV data



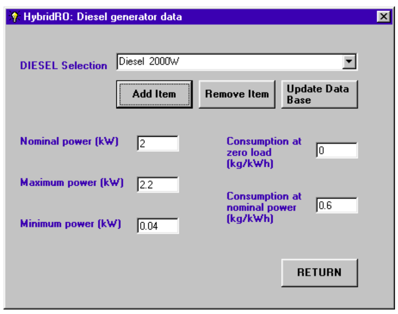
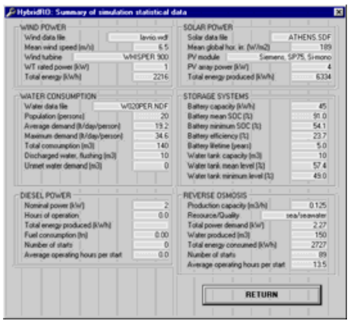


Fig. 5, 6 Windows for the RO design and diesel backup consideration



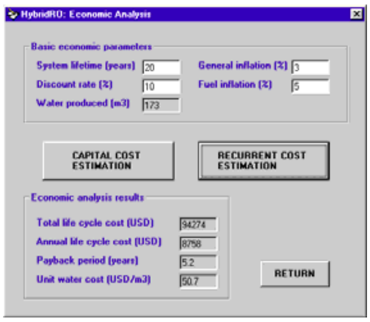


Fig. 7, 8 Windows for the presentation of the design and economic results

ID Number	**3**
Name of Programme	Middle East Desalination Research Center series R&D Projects
Project Title	Matching RE with Small Unit Desalination Plants: Development of a PC-Based Decision Support System
Project Contract No	97-AS-006b
Year of development	2002
Contractor/Responsible	Intitut fuer Verfahrenstechnik der RWTH Aachen (IV), Germany

Work description

The project concerns with the development of a computer based Decision Support System (DSS), DesalSolar, useful for selecting the best desalination and renewable energy technology combination, from the literature reported combinations, based on the site parameters of desalination plant and renewable energy supply system. It then estimates the specific water costs for each combination of desalination process and energy source, which will provide economic basis for comparison of different technology combinations. The problem analysis for the users with regard to the decision attributes of the decision making process is modeled by a Fuzzy system. The basic design parameters are evaluated using simple procedures and the data collected from the plat suppliers. Empirical correlations are developed for specific water cost estimation using the data of the existing plants.

Design Approach

The model is an easy-to-use decision support system (DSS) allowing the user to evaluate the application of a solar/wind powered renewable energy systems to drive small-scale desalination plant as an alternative to fossil fuel energy driven units. The term small-scale desalination plant represents desalination plants of up to 100 m3/day for sea and brackish water desalination. The DSS allows the user to perform the following tasks:

To evaluate different desalination processes (Reverse Osmosis, Electrodialysis, Multiple Effect Distillation, Multi-Stage Flash Evaporation, Mechanical Vapor Compression, Solar Stills) for given local conditions.

To evaluate different RE power supply systems (photovoltaics, flat-plate collectors, linear focusing collectors) for given local conditions.

To develop feasible combinations of desalination and RE technologies for stand-alone applications for seawater or brackish water desalination (<5000 mg/lt).

To design desalination plant and RE supply system for desired water demand and local climatic and economic conditions.

To calculate the specific water cost

To present the relevant information of the designed desalination plant and RE energy system

The main input parameters for the DSS are as follows: Feed water quality (TDS ppm) Drinking water demand Geographical location of the plant Additionally, the user has to provide the following information: Land cost and the availability of land for the construction of the desalination plant The necessity for mobility of desalination plants The necessity to adapt the plant's capacity for future increase in drinking water demand The necessity to operate the plant with little additives The availability of skilled operators and The plant's robustness towards incorrect operation by the operators. The outputs of the DSS are as follows: Size of the renewable energy system Size of the desalination unit Specific drinking water costs The DSS runs on any PC having a CD drive and Windows 98 operating system.	
References	
MEDRC Series of R&D Reports, www.medrcorg.om, October 2002	Matching RE with Small Unit Desalination Plants: Development of a PC-Based Decision Support System

ID Number	4
Name of Programme	APAS Programme
Project Title	Hybrid Renewable Energy Systems in Donousa and La Graciosa islands, as prototype systems for applying desalination to small villages in Mediterranean islands and isolated coastal areas, by using local energy sources for electricity production
Project Contract No	RENA-CT94-0030
Year of development	1994
Contractor/Responsible	Agricultural Univ. of Athens; National Technical Univ. of Athens, Greece, S. Kyritsis
Work description	
The work concerns the development of a software tool for designing hybrid renewable energy systems. The hybrid system consists of a wind generator and photovoltaics. The electricity consumption consists of the household and desalination unit consumption. The system is supplemented with batteries and a micro hydraulic plant for energy storage. The simulation programme is used to optimize the design of the system as well as to manage the energy supply and energy storage. The results prove that this simulation programme constitutes a valuable tool for the determination not only of the optimum combination of technologies, but also the optimum energy management of complex hybrid systems. The computer simulation of the solar, wind and desalination technologies includes the following components: total solar radiation mean ambient temperature PV array module simulator	

lead-acid battery storage model regulator/inverter component pump and turbine simulator pipeline simulator wind generator simulator Reverse Osmosis desalination plant component Software Implementation The programme for the simulation-optimization of the solar, wind and hydro power plant has the following structure: Step 1 - Input of several parameters and constants (PV panel characteristics, initial no of panels, wind generator curve, etc.) Step 2 - For a predefined cycle of days, the hourly variation of the following variables is calculated (in case where are not known): total solar radiation intensity on inclined surface and air temperature. Step 3 - Two typical profiles of electrical and drinkable water consumption are introduced (winter, summer). Step 4 - For a given number of PV panels, a certain wind generator, pump, turbine and desalination plant the followings are calculating: power produced from PVs and the wind generator total power consumption (household needs plus desalination) Based on the above results several strategies concerning the operation of the desalination plant are considered.

References	
Energy 26 (2001), pp. 679-704	"A simulation-optimization programme for designing hybrid energy systems for supplying electricity and fresh water through desalination to remote areas"

ID Number	5
Name of Programme	JOULE PROGRAMME
Project Title	Modular Desalination – Development and Pilot Operation of a Family of Modular Wind Powered Water Desalination Plants
Project Contract No	JOR3-CT95-0018
Year of development	1995
Contractor/Responsible	WIP, Germany, M. Stohr, H. Ehmann
Work description	
A tool for the assessment and optimization of the economic performance of wind powered water desalination plants for various design options and under various operation conditions. The tool is conceived for evaluating and optimizing the economic performance of such plants at specific sites, thus supporting decision making of investors and operators as well as banks and financing institutions. It helps to investigate whether the operation of such a plant is a cost effective business, determines the economic plant performance and supports the economic optimization of the plant design and of operation strategies. The investigated wind powered desalination plant can be either autonomous, grid-connected or a hybrid plant.	
References	
www.cordis.lu	

ID Number	6
Name of Programme	ALTENER 2
Project Title	Renewable Energy Driven Desalination Systems, “REDDES”
Project Contract No	4.1030/Z/01-081
Year of development	2002-2003
Contractor/Responsible	Regional Energy Agency of Dodecanese S.A., Greece, S.Karayiannis Gerling Sustainable Development Project Gmbh, Germany G. Radoglou
Work description	
The project concerns with the development of an integrated management and design tool for the use of RE (wind, solar, geothermal energy) for the desalination of seawater that will be implemented in arid, remote and isolated communities. The tool will be applied, as a pilot project, in the small Greek islands. The tool is based on multi-criteria analysis (MCA) and it is able to evaluate the feasible RES-Desalination capacity, select the sites of the RES units, and estimate the economic efficiency of the plants. The MCA tool takes in account specific regional data such as RES potential, fresh water demand and supply, in order to identify the optimum RES desalination coupling. A Geographical Information System (GIS) data has been developed in order to provide the RES potential, solar, biomass, wind and geothermal resources, as well as water supply and demand in each site. The tool is focused on four desalination technologies, Reverse Osmosis, Multi Effect Distillation, Multi Stage Flush and Vapor Compression with wind or solar energy. Technical and economical restriction parameters are identified and considered in the modeling of RES desalination coupling solutions. Data sources include relative literature, results from EU programmes and previous experience gained from existing RES desalination units. The production of a tool in a user-friendly form, providing the methodology to be applied for carrying out similar projects throughout Europe, and will be valuable to many interested local and regional Authorities. In this way, the interdisciplinary problem of choosing, dimensioning and evaluating RES desalination schemes that will cover water demands of remote communities will become easier to deal with.	
References	
www.cordis.lu	

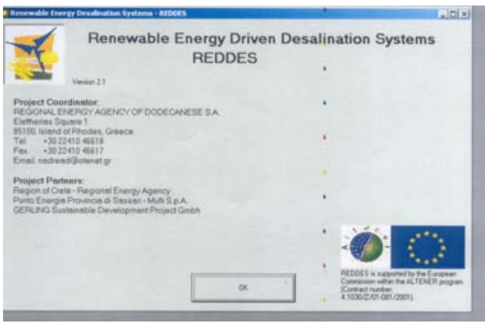
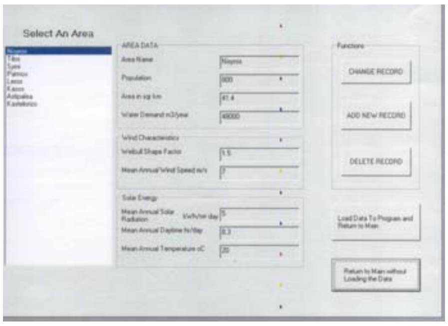


Fig. 1 Start up screen



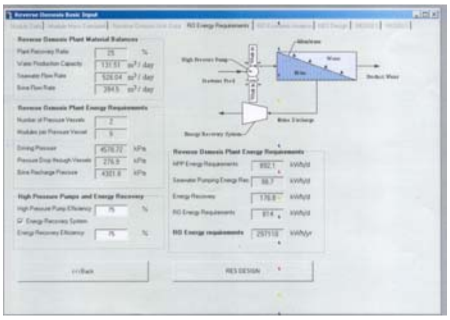
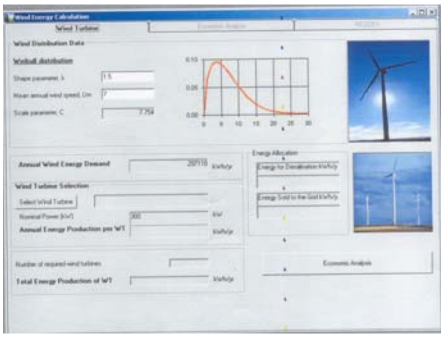


Fig. 2, 3 Windows for the site selection and desalination unit design



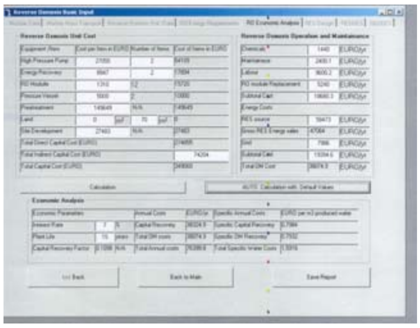


Fig. 4, 5 Windows for the RE technology design and economic evaluations

ID Number	7
Name of Programme	APAS RENA Programme
Project Title	A Probabilistic Model for Feasibility Studies on Wind Diesel Desalination Systems, WINDISP
Project Contract No	APAS RENA-CT94-0006
Year of development	1996
Contractor/Responsible	National Technical Univ. of Athens, Centre for Renewable Energy Sources, Greece

Work description

WinDiSP is a probabilistic model developed for the investigation of the performance of combined Wind—diesel desalination systems. The model calculates the annual energy production of both wind and diesel generators along with the water production and the fuel savings for each entered scenario.

WinDiSP is a computer program developed on a spreadsheet environment and operates under Windows 3.1x or Windows 95. The user is able to introduce data and perform calculations through a friendly to use menu. The program can be easily adapted to different autonomous power systems and various scenarios can be simulated. A Wind Energy Converters (WEC) database is incorporated. Probabilistic techniques are used for simulating the system operation.

Design Approach

The advantage of the methodology is that there is no need for long data sets, typically of wind speed, load and water demand. Those data are required for the use of time-series models and are usually difficult to be obtained. The main inputs of the model are:

The load demand duration curve

The wind speed duration curve

The WEC's power curve

The ADS-Diesel sets characteristics

The desalination plant configuration

A list of diesel units is included with data relating to the power output and minimum accepted loading. The fuel consumption of each diesel is calculated using a polynomial function. The water desalination plant is modeled considering the type of the plant- thermal or electric - the daily water production capacity and the energy consumption of the desalination unit.

The model calculates, on a yearly basis, the energy production of the WEC's and the diesel units, the load factor of the machines, the wind penetration, the dissipated wind energy, the annual water production and the fuel savings.

The probability distribution of the ADS load is calculated and compared for the diesels operation with and without WEC's. By comparing those curves conclusions can be made for the impact of the desalination plant and the wind energy integration in the existing power system. Moreover, the Internal Rate of Return as well as the Net Present Value of the investment is calculated using the discounted cash-flow method.

References	
Proc. of Mediterranean Conf. on Renewable Energy Sources for Water Production, 10-12 June, 1996, Santorini, Greece	A Probabilistic Model for Feasibility Studies on Wind Diesel Desalination Systems, pp. 100-104

ID Number	8
Name of Programme	-
Project Title	"SOLDES"
Project Contract No	-
Year of development	-
Contractor/Responsible	Ali M. El Nashar

Work description
SOLDES is a computer program developed to simulate the operation of solar desalination plants, which utilize evacuated tube collectors, heat accumulators and Multiple-effect distillation (MED) systems. The heat accumulator used is of the thermally stratified type using pure water as the storage fluid. Design Approach The procedure was written in Fortran language and consists of a main program, 22 sub-programs, two sets of system data files and four meteorological data files. The absorber area of the solar collector field can be varied between 500 m2 and 20,000 m2, the storage capacity per unit collector area of the heat accumulator can vary between 0.05 and 1.00m3/m2, the capacity of the evaporator can be varied between 100 m3/d to 2,000 m3/d the heat collecting system uses a bypass circuit to allow the heat collecting fluid (pure water) to recirculate back to the solar collector field when the outlet temperature from the collector field is below a set-point. When the collector outlet temperature rises above the set point, operation is switched over to the accumulator side. A solar-cell-type controller is used to start and stop the water-circulating pump of the collector field. The operation of the MED is controlled by the state-of-charge of the heat accumulator by the use of set-point switches, which allow the evaporator to start up when the accumulator water temperature is above a set point and to shut down if the water temperature drop below the set point. The program can also be used in optimizing the operation of existing plants or in the design of new plants. The tool is used at the solar MED plant in Abu-Dhabi.

References	
1.Desalination, Vol.130, (2000), pp 235-253	'Validating the performance simulation program «SOLDES» using data from an operating solar desalination plant »

ID Number	9
Name of Programme	The work mainly performed within a scientific consultancy project for the General Electricity Company of Libya
Project Title	IPSEpro, RESYSpro
Project Contract No	-
Year of development	-
Contractor/Responsible	Center for Solar Energy & Hydrogen Research, ZSW, Germany; J. Rheinlaender SimTech Simulation Technolgy, Graz, Austria; Lahmeyer International GmbH, Germany

Work description
IPSEpro and RESYSpro tools are developed for the prediction of technical, economic and ecological performance of water and power point systems including desalination and water treatment (membrane and thermal processes), renewable energy sources for power (e.g.

wind and PV power) and conventional power generator (diesel). IPSEpro is the heart of the tool. It is a flexible process-modeling package that allows the user to define new component models. This makes it possible to use IPSEpro for modeling any process that can be described by algebraic equations. The core of IPSEpro is a powerful equation solver, which is well suited to master the implicit equations that are very often required by thermodynamic process models. Via IPSEpro module PSExcel, which allows the use of IPSEpro model's inside Microsoft's spreadsheet programme MS-Excel, the process simulation is linked to time-dependent energy balancing (e.g. annual performance evaluation) and the code for economic systems analysis included in RESYSpro. A standard model library for IPSEpro comprising models for a wide range of conventional power plant and thermal process components has been extended with units for all sorts of desalination equipment and systems for utilization of renewable energy sources. Tables for economic analysis of the integrated water and power system extend the spreadsheet for the energy performance balancing in RESYSpro. The IPSEpro component models include parameters and functions for unit and O&M costs as functions of type and size. All cost data are entered into the economics spreadsheet, and the computation for specified projects (component) life, discount rate, local fuel and other local economy boundary conditions, the computation yields: Investment cost Annual O&M cost and cost of consumables Life-cycle cost and present value of the project Levelised electricity cost Levelised water cost Note: RESYSpro is ZSW's extension of IPSEpro with mathematical models for desalination processes and conversion of renewable energy. IPSEpro is a commercial Process Simulation Environment available through license from SIM Tech. The Middle East Desalination Research Center recently partially financed the integration and update of the tool within 2003 Announcement for projects funding.

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Desalination 157, (2003), pp 57-64	"Performance simulation of integrated water and power systems-software tools IPSEpro and RESYSpro for technical, economic and ecological analysis"

ID Number	10
Name of Programme	APAS Programme
Project Title	A Decision Support System for the Integration of RES into Water Desalination Systems - REDES
Project Contract No	RENA-CT94-0038
Year of development	1995-1996
Contractor/Responsible	SPEED Ltd, Greece, S. Alexopoulou
Work description	
Development of a Geographical Information System (GIS)/Decision Support System (DSS), for screening of the alternatives and the selection of the best design scheme concerning renewables and desalination. Information such as water needs, available water and resources are incorporated into an integrated GIS. The system combined the geographical representation of the various elements (position of the RES, area with water shortage) with a powerful database that hosts all the quantitave and descriptive information, which accurately	

define them. The data can be easily processed within the same system to produce either quantitative or qualitative results. Combining the various info "layers" to produce thematic maps or define their topological intersections using criteria, it is a straightforward procedure, while data processing results are also addressed. The system permits and facilitates the direct appraisal of the possibilities to combine RE with desalination processes to supply fresh water in every distinct area of the country to meet the needs of the various users, through multi-criteria methods. The DSS has been constructed for the selection of the best appropriate scheme of RES desalination method providing water for various uses.	
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APPENDIX

A1. LIST OF RES-DESALINATION APPLICATIONS

RES-Distillation Applications ≤ 50 m^3/day

Plant Type & Information Source	Solar MSF Sea Water Desalination		
Location	La Paz, Mexico		
Capacity	10 m^3/d		
Desalination Technology	Multi-Stage Flashing		
Energy System Type	352 m^2 Solar Collectors		
Year Commissioned	1980		
Manufacturing Company/Responsible Organisation	Dornier GmbH, Germany		
Note:		Plant No **1**	REF No [1]

Plant Type & Information Source	Sea Water Desalination		
Location	0.1 - 0.35 m^3/h		
Capacity	Area of Hzag, Tunisia		
Desalination Technology	Distillation		
Energy System Type	Solar Collectors		
Year Commissioned	1980-1983 decommission		
Manufacturing Company/Responsible Organisation	Dornier Gmbh, Germany		
Note:		Plant No **2**	REF No [1]

Plant Type & Information Source	Sea Water Desalination		
Location	7.2 m^3/d		
Capacity	Island of Lampedusa, Italy		
Desalination Technology	Multi-Stage Flashing		
Energy System Type	408 m^2 Solar Collectors		
Year Commissioned	1983		
Manufacturing Company/Responsible Organisation	Belmar, Italy, Contraves, Switzerland (collectors) AGIP Nucleare, Italy		
Note:	ENALT 1C Programme, SE./00009/79	Plant No **3**	REF No [2]

Plant Type & Information Source	Sea Water Desalination
Location	10 m^3/d
Capacity	Safat, Kuwait
Desalination Technology	Multi-Stage Flashing
Energy System Type	220 m^2 Solar Collectors
Year Commissioned	possible around 1983-84
Manufacturing Company/Responsible Organisation	Kuwait Institute for Scientific Research
Note:	Plant No **4** — REF No [25],[26]

Plant Type & Information Source	Brackish Water Desalination
Location	19 m^3/d
Capacity	El Paso, Texas, U.S.
Desalination Technology	Multi-Stage Flashing
Energy System Type	3,355 m^2 Solar Pond
Year Commissioned	1987
Manufacturing Company/Responsible Organisation	University of Texas
Note:	Plant No **5** — REF No [4]

Plant Type & Information Source	Sea Water Desalination [6]
Location	48 m^3/d
Capacity	Borkum Island - North Sea, Germany
Desalination Technology	Mechanical Vapour Compression
Energy System Type	45 kW Wind Energy Converter
Year Commissioned	1993
Manufacturing Company/Responsible Organisation	SEP:Gesellshaft fur Technische Studien Entwicklung Planung mbH, Germany
Note:	Plant No **6** — REF No [6]

Plant Type & Information Source	Solar MED seawater desalination plant
Location	Takashima island, Japan
Capacity	10 m^3/day
Desalination Technology	Multi-effect distillation
Energy System Type	Solar energy
Year Commissioned	1981
Manufacturing Company/Responsible Organisation	SASAKURA, Japan
Note:	Plant No **7** — REF No [31]

Plant Type & Information Source	Solar MED seawater desalination plant
Location	Black Sea, Bulgaria
Capacity	2 m^3/d
Desalination Technology	Multi-effect distillation
Energy System Type	Solar energy
Year Commissioned	1981
Manufacturing Company/Responsible Organisation	-
Note:	Plant No **8** — REF No [31]

Plant Type & Information Source	Solar MED seawater desalination plant
Location	Japan
Capacity	2 m^3/day
Desalination Technology	Multi-effect distillation
Energy System Type	Solar energy
Year Commissioned	1980
Manufacturing Company/Responsible Organisation	-
Note:	Plant No **9** — REF No [31]

Plant Type & Information Source	Solar MSF seawater desalination plant
Location	Bari, Italy
Capacity	5 m^3/day
Desalination Technology	Multi stage flash
Energy System Type	Solar energy
Year Commissioned	1974
Manufacturing Company/Responsible Organisation	ATLANTIS CH
Note:	Plant No **10** — REF No [31]

Plant Type & Information Source	Solar MSF seawater desalination plant
Location	Las Barrancas, Mexico
Capacity	24 m^3/day
Desalination Technology	Multi stage flash
Energy System Type	Solar energy, Parabolic collectors
Year Commissioned	1982
Manufacturing Company/Responsible Organisation	SEDUE, D
Note:	Plant No **11** — REF No [31]

Plant Type & Information Source	Solar MSF seawater desalination plant
Location	Kuwait

Capacity	22 m^3/day
Desalination Technology	Multi stage flash
Energy System Type	Solar energy
Year Commissioned	1984
Manufacturing Company/Responsible Organisation	ATLANTIS CH
Note:	Plant No **12** REF No [31]

Plant Type & Information Source	Solar ME seawater desalination plant
Location	Takima island, Japan
Capacity	16 m3/dayMulti effect distillation HTE
Desalination Technology	Multi effect distillation HTE
Energy System Type	Solar energy, collectors
Year Commissioned	1984
Manufacturing Company/Responsible Organisation	SASAKURA, Japan
Note:	Plant No **13** REF No [31]

Plant Type & Information Source	Solar MSF seawater desalination plant
Location	Qatar, UMM Said
Capacity	20 m^3/day
Desalination Technology	Multi stage flash
Energy System Type	Solar energy, Collectors
Year Commissioned	1986
Manufacturing Company/Responsible Organisation	Central Salt & Marine Chemical Research Institute
Note:	Plant No **14** REF No [31]

Plant Type & Information Source	Solar MED seawater desalination plant
Location	Almeria, Spain
Capacity	3 m^3/hour
Desalination Technology	Multi effects distillation, 14 effects
Energy System Type	Solar energy, Solar parabolic collectors
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	CIEMAT, Spain, DLR, Univ. Of Munich
Note:	Plant No **15** REF No [5],[31],[39]

Plant Type & Information Source	PV solar MSF seawater desalination plant
Location	Guadeloupe Dependancies, Island of La Desirade
Capacity	40 m^3/day

Desalination Technology	Multi effect distillation, 14 effects
Energy System Type	Solar energy, PV, Collectors: 670 m^2
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	ENTROPIE S.A.
Note:	Plant No **16** REF No [2]

Plant Type & Information Source	Solar MED distillation plant
Location	Yanbu, Saudi Arabia
Capacity	14 m^3/day
Desalination Technology	Multi effect distillation
Energy System Type	Solar energy
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	-
Note:	Plant No **17** REF No [31]

Plant Type & Information Source	Solar pond VC, MED seawater desalination plant
Location	Margherita de Savoia, Italy
Capacity	10 m^3/day
Desalination Technology	Vapour compression, Multi effect distillation
Energy System Type	Solar pond, 25.000 m^2
Year Commissioned	1989
Manufacturing Company/Responsible Organisation	AGIP Petroli, Univ. of Rome, Italy
Note:	Plant No **18** REF No [32]

Plant Type & Information Source	Wind evaporation seawater desalination plant
Location	Layang layang island, Malaysia
Capacity	7 m^3/day
Desalination Technology	Evaporation
Energy System Type	Wind energy, WEC:150 kW, Diesel:150 kW
Year Commissioned	1995
Manufacturing Company/Responsible Organisation	NORDTANK, DANVEST Energy
Note:	Plant No **19** REF No [37]

Plant Type & Information Source	Wind energy VC sea water desalination plants
Location	Pozo Izquierdo, Gran Canaria Island
Capacity	50 m^3/day
Desalination Technology	Vapour compression
Energy System Type	Wind energy, WEC
Year Commissioned	1999

Manufacturing Company/Responsible Organisation	ALFA LAVAL, Denmark; Canary Islands Institute of Technology, ITC, Spain
Note: SDAWES Project – JOULE III	Plant No **20** — REF No [31],[52]

Plant Type & Information Source	Solar evaporation brackish water desalination plant
Location	Hazeg, Sfax, Tunisia
Capacity	400-500 lt/day
Desalination Technology	Evaporation, Single effect process
Energy System Type	Solar energy, Solar collectors: 80 m^2
Year Commissioned	1986
Manufacturing Company/Responsible Organisation	DORNIER, Germany, National institute for Research on Rural Engineering Water and Forestry (INRGREF) Tunisia
Note:	Plant No **21** — REF No [17]

Plant Type & Information Source	Solar evaporation brackish water desalination plant
Location	Sfax, Tunisia
Capacity	250-300 lt/day
Desalination Technology	Multi effect Evaporation and condensation cycle process with flat plate solar collectors
Energy System Type	Solar energy, Solar collectors: 56 m^2
Year Commissioned	1998
Manufacturing Company/Responsible Organisation	AQUASOLAR, Germany ;Univ de Sfax, Tunisia
Note:	Plant No **22** — REF No [17]

Plant Type & Information Source	Solar pond ME-TC seawater desalination plant
Location	Univ. of Ancona, Ancona, Italy
Capacity	30 m^3/day
Desalination Technology	Multi effect distillation, Thermal compression
Energy System Type	Solar pond
Year Commissioned	1998-1999
Manufacturing Company/Responsible Organisation	Univ. of Rome “La Sapienza”, Rome
Note: THERMIE 1, SE./00303/94	Plant No **23** — REF No [2], [7]

Plant Type & Information Source	Hybrid fossil solar heated seawater desalination plant
Location	ZSW, Germany
Capacity	-

Desalination Technology	Multi effect distillation, Solar still
Energy System Type	Solar collector
Year Commissioned	1999
Manufacturing Company/Responsible Organisation	ZSW, Germany MEDRC Project, 97-BS-016
Note:	Plant No **24** — REF No [3]

Plant Type & Information Source	Solar MED seawater desalination plant
Location	Pozo Izquierdo, Gran Canaria, Spain
Capacity	600 lt/day
Desalination Technology	Multi effect Distillation
Energy System Type	Corrosion free Solar collectors
Year Commissioned	2000
Manufacturing Company/Responsible Organisation	SODESA project; Fraunhofer Institute for Solar Energy Systems, ISE Germany; Technological Institute of the Canary islands, ITC,Spain
Note:	Plant No **25** — REF No [8]

Plant Type & Information Source	Solar distillation seawater desalination plant
Location	Muscat, Sultanate of Oman
Capacity	1 m^3/day
Desalination Technology	Distillation, 12 effects
Energy System Type	Solar energy, collectors, 2 m^2 PVs, 50 m^2 solar pond
Year Commissioned	2001
Manufacturing Company/Responsible Organisation	MEDRC project, Oman, Project no: 98-AS-24A
Note:	Plant No **26** — REF No [2]

Plant Type & Information Source	Solar distillation seawater desalination plant
Location	Al-Hail, Seeb, Oman
Capacity	0,5-10 m^3/day
Desalination Technology	Distillation
Energy System Type	Solar energy, Flat plate collectors
Year Commissioned	2000
Manufacturing Company/Responsible Organisation	MEDRC project, Oman, Project no: 98-AS-024b
Note:	Plant No **27** — REF No [2]

Plant Type & Information Source	Solar thermal seawater distillation plant
Location	Beni Khiar - Tunisia
Capacity	1 m^3/day

Desalination Technology	Multi-Effect Distillation
Energy System Type	Solar energy, solar collectors 120 m^2
Year Commissioned	April 2003
Manufacturing Company/Responsible Organisation	Warmepumpen und Solartechnik Service Gbr (WpSOL),,Germany/ Agence Nationale des Energies Renouvelables (ANER) , Tunisia
Note:		Plant No **28**	REF No [9]

Plant Type & Information Source	Solar MED desalination plant
Location	Al Azhar Univ., Gaza
Capacity	200 lt/day
Desalination Technology	Multi effect distillation
Energy System Type	Solar energy, collectors
Year Commissioned	2000 (?)
Manufacturing Company/Responsible Organisation	-
Note:		Plant No **29**	REF No [24]

Plant Type & Information Source	Wind VC seawater desalination plan under fluctuating conditions
Location	Valbonne, France
Capacity	42 lt/hour
Desalination Technology	Vapour Compression
Energy System Type	Wind generator
Year Commissioned	~ 1985
Manufacturing Company/Responsible Organisation	Laboratoire CNRS, France
Note:	P. Reneaud, A.Jaffrin, “Wind and Solar Powered Vapor Compression Desalination Unit Operating Under Fluctuating Conditions”	Plant No **30**	REF No [29]

Plant Type & Information Source	Solar greenhouse seawater desalination plant
Location	Pozo Izquierdo, Santa Lucia, Las Palmas-Spain
Capacity	500 lt/hour
Desalination Technology	Solar Distillation, 1 effect
Energy System Type	Solar greenhouse
Year Commissioned	2003
Manufacturing Company/Responsible Organisation	SOLAR DEW (Holland)
Note:		Plant No **31**	REF No [50]

Plant Type & Information Source	Sea Water Desalination
Location	6 - 9 m^3/d
Capacity	Island of Suderoog at the German Coast of the N. Sea
Desalination Technology	Reverse Osmosis
Energy System Type	6 kW Wind Energy Converter
Year Commissioned	1980
Manufacturing Company/Responsible Organisation	Allgaier/ Hutter and GKSS
Note:	Plant No **1** REF No [10]

Plant Type & Information Source	Sea Water Desalination
Location	3.25 m^3/d
Capacity	Jeddah, Saudi Arabia, near the Red Sea
Desalination Technology	Reverse Osmosis
Energy System Type	8 kWp Photovoltaic Generator
Year Commissioned	1981
Manufacturing Company/Responsible Organisation	Mobil Solar Energy Corp.
Note:	Plant No **2** REF No [25],[27]

Plant Type & Information Source	Sea / Brackish Water Desalination
Location	0.5 m^3/h
Capacity	Ile du Planier (near Marseilles), France Pacific islands
Desalination Technology	Reverse Osmosis
Energy System Type	4 kW Wind Energy Converter
Year Commissioned	1982 experiment performed at Ile du Planier, 1983 experiment performed at Pacific islands
Manufacturing Company/Responsible Organisation	Cadarache Centre, France
Note:	Plant No **3** REF No [13]

Plant Type & Information Source	Brackish Water Desalination
Location	1.5 m^3/h
Capacity	Cituis West Jawa, Indonesia
Desalination Technology	Reverse Osmosis
Energy System Type	25 kWp Photovoltaic Generator
Year Commissioned	1982

Manufacturing Company/Responsible Organisation			AEG Telefunken (PVs), Federal Republic of Germany, Republik of Indonesia
Note:		Plant No **4**	REF No [12]

Plant Type & Information Source			Brackish Water Desalination
Location			0.5-0.1 m^3/h
Capacity			Perth, Australia
Desalination Technology			Reverse Osmosis
Energy System Type			1.2 kWp Photovoltaic Generator
Year Commissioned			1982
Manufacturing Company/Responsible Organisation			Mobil Solar Energy Corp. Solar Energy Research Institute of W. Australia
Note:		Plant No **5**	REF No [25],[27]

Plant Type & Information Source			Brackish Water Desalination
Location			no info available
Capacity			Wanoo Roadhouse, Australia
Desalination Technology			Reverse Osmosis
Energy System Type			6 kWp Photovoltaic Generator
Year Commissioned			1982-83
Manufacturing Company/Responsible Organisation			Mobil Solar Energy Corp. Solar Energy Research Institute of W. Australia
Note:		Plant No **6**	REF No [25],[27]

Plant Type & Information Source			Sea Water Desalination
Location			0.5-1 m^3/d
Capacity			Vancouver, Canada
Desalination Technology			Reverse Osmosis
Energy System Type			4.8 kWp Photovoltaic Generator
Year Commissioned			around 1983-84
Manufacturing Company/Responsible Organisation			Highquest Eng.Inc., Seagold Industries Corp.
Note:		Plant No **7**	REF No [25],[28]

Plant Type & Information Source	Sea Water Desalination
Location	5.7 m^3/d
Capacity	Doha, Qatar
Desalination Technology	Reverse Osmosis
Energy System Type	11.2 kWp Photovoltaic Generator
Year Commissioned	possible around 1984
Manufacturing Company/Responsible Organisation	Mobil Solar Energy Corp.
Note:	Plant No **8** — REF No [25],[27]

Plant Type & Information Source	Brackish Water Desalination
Location	1-2 m^3/d
Capacity	Tanote in Thar desert, Rajasthan state, India
Desalination Technology	Electrodialysis
Energy System Type	0.45 kWp Photovoltaic Generator, Diesel Generator
Year Commissioned	1986
Manufacturing Company/Responsible Organisation	Central Salt & Marine Chemicals Research Institute
Note:	Plant No **9** — REF No [14]

Plant Type & Information Source	Sea Water Desalination
Location	10 m^3/d
Capacity	Ohsima island, Funke City, Nagasaki
Desalination Technology	Electrodialysis
Energy System Type	25 kWp Photovoltaic Generator
Year Commissioned	1986
Manufacturing Company/Responsible Organisation	Hitachi Ltd. and Babcock-Hitachi Ltd., Nar Energy Development Organisation (NEDO)
Note:	Plant No **10** — REF No [15]

Plant Type & Information Source	Brackish Water Desalination
Location	0.95 m^3/h
Capacity	Hassi-Khebi, Algeria
Desalination Technology	Reverse Osmosis

Energy System Type	2.59 kWp Photovoltaic Generator
Year Commissioned	1987-1988
Manufacturing Company/Responsible Organisation	Algerian Renewable Energy Development Centre; Cadarache Centre, France, AEG (PVs)
Note:	Plant No **11** · REF No [13]

Plant Type & Information Source	Wind Desalination plant
Location	Island of St.Nicolas, West France
Capacity	Reverse Osmosis
Desalination Technology	10 kW Wind Energy Converter, Diesel Generator
Energy System Type	1988
Year Commissioned	no information available
Manufacturing Company/Responsible Organisation	Desalination [2]
Note:	Plant No **12** · REF No [2]

Plant Type & Information Source	Brackish Water Desalination
Location	2.5 m^3/h
Capacity	University of Almeria, Spain
Desalination Technology	Reverse Osmosis
Energy System Type	23.5 kWp Photovoltaic Generator
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	Junta de Andalucia; Diputacion de Almeria; ROCHEN (desalinator), GOMAR SCL, Spain; AEG, Germany (PVs)
Note:	Plant No **13** · REF No [16]

Plant Type & Information Source	Sea Water Desalination
Location	Island of Drenec, France
Capacity	Reverse Osmosis
Desalination Technology	10 kW Wind Energy Converter
Energy System Type	1990
Year Commissioned	no information available
Manufacturing Company/Responsible Organisation	Sea Water Desalination [16]
Note:	Plant No **14** · REF No [16]

Plant Type & Information Source	Sea Water Desalination		
Location	2 m^3/h		
Capacity	Lipari Island, Italy		
Desalination Technology	Reverse Osmosis		
Energy System Type	63 kWp Photovoltaic Generator		
Year Commissioned	1991		
Manufacturing Company/Responsible Organisation	ITALSOLAR, Italy (PV modules), ITALENERGIE SPA, L’ Aquila, Italy		
Note:		Plant No **15**	REF No [2]

Plant Type & Information Source	Sea Water Desalination]		
Location	Punta Libeccio, Marettimo Island, (north west of Sicily), Italy		
Capacity	Reverse Osmosis		
Desalination Technology	9.8 kWp Photovoltaic Generator, 30 kW Diesel Generator		
Energy System Type	1993		
Year Commissioned	installed but never operated		
Manufacturing Company/Responsible Organisation	Sea Water Desalination [2]		
Note:		Plant No **16**	REF No [2]

Plant Type & Information Source	Sea Water Desalination		
Location	0.6 (2× 0.3) m^3/d		
Capacity	Florida St. Lucie Inlet State Park, U.S.A.		
Desalination Technology	Reverse Osmosis		
Energy System Type	2.7 kWp Photovoltaic Generator, Diesel Generator		
Year Commissioned	1995		
Manufacturing Company/Responsible Organisation	Florida Solar Energy Center, Siemens (PVs), Recovery Engineering (R.O.), USA		
Note:		Plant No **17**	REF No [19]

Plant Type & Information Source	PV EDR brackish water Desalination
Location	Colorado, USA
Capacity	2.8 m^3/d
Desalination Technology	Reversal Electrodialysis
Energy System Type	2.3 kWp Photovoltaics
Year Commissioned	1995

Manufacturing Company/Responsible Organisation	Bureau of Reclamation, Colorado, USA
Note:	Plant No **18** — REF No [20]

Plant Type & Information Source	Sea Water Desalination
Location	0.2 m^3/h
Capacity	Therasia island, Greece
Desalination Technology	Reverse Osmosis
Energy System Type	15 kW Wind Energy Converter
Year Commissioned	1997
Manufacturing Company/Responsible Organisation	Vergnet, Aqua-Set, France, Helliodynami, Greece, Loughborough Univ., UK; Centro Marino Internationale, Italy; Commissariat u l' Energie Atomique, France
Note:	Plant No **19** — REF No [21]

Plant Type & Information Source	Wind RO seawater desalination plant
Location	Canada
Capacity	10 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	Wind energy, WEC
Year Commissioned	1974
Manufacturing Company/Responsible Organisation	-
Note:	Plant No **20** — REF No [31]

Plant Type & Information Source	PV RO brackish water desalination plant
Location	Conception del Ore, Mexico
Capacity	0.71 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	2.5 kWp Photovoltaics
Year Commissioned	1978
Manufacturing Company/Responsible Organisation	DIGASEES
Note:	Plant No **21** — REF No [31]

	PV ED brackish water desalination plant
Plant Type & Information Source	
Location	La Luz, Mexico
Capacity	15 m^3/day

Desalination Technology	Electrodialysis
Energy System Type	5 kWp Photovoltaics
Year Commissioned	1979
Manufacturing Company/Responsible Organisation	IONICS
Note:	Plant No **22** REF No [44]

Plant Type & Information Source	PV RO brackish water desalination plant
Location	Giza, Egypt
Capacity	5-7 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	7 kWp Photovoltaics
Year Commissioned	1980
Manufacturing Company/Responsible Organisation	NREA, Egypt
Note:	Plant No **23** REF No [33]

Plant Type & Information Source	Solar RO seawater desalination plant
Location	Okikawa, Japan
Capacity	15 m^3/day
Desalination Technology	Reverse osmosis
Energy System Type	Solar energy
Year Commissioned	1982
Manufacturing Company/Responsible Organisation	HITACHI, Japan
Note:	Plant No **24** REF No [31]

Plant Type & Information Source	Solar RO seawater desalination plant
Location	Las Barrancas, Mexico
Capacity	24 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	Solar energy
Year Commissioned	1982
Manufacturing Company/Responsible Organisation	SEDUE
Note:	Plant No **25** REF No [31]

Plant Type & Information Source	PV RO seawater desalination plant	
Location	Qatar	
Capacity	24 m^3/day	
Desalination Technology	Reverse Osmosis	
Energy System Type	Photovoltaics	
Year Commissioned	1982	
Manufacturing Company/Responsible Organisation	WSA, USA	
Note:	Plant No **26**	REF No [31]

Plant Type & Information Source	Solar RO brackish water desalination plant	
Location	Del Ore, Mexico	
Capacity	2 m^3/day	
Desalination Technology	Reverse osmosis	
Energy System Type	Photovoltaics	
Year Commissioned	1984	
Manufacturing Company/Responsible Organisation	DKSS D	
Note:	Plant No **27**	REF No [31]

Plant Type & Information Source	PV RO seawater desalination plant	
Location	Sant Nicola, Italy	
Capacity	12 m^3/day	
Desalination Technology	Reverse Osmosis	
Energy System Type	Photovoltaics	
Year Commissioned	1984	
Manufacturing Company/Responsible Organisation	ANSALDO, Italy	
Note:	Plant No **28**	REF No [31]

Plant Type & Information Source	PV RO seawater desalination plant	
Location	Canada	
Capacity	2 m^3/day	
Desalination Technology	Reverse osmosis	
Energy System Type	Photovoltaics	
Year Commissioned	1984	
Manufacturing Company/Responsible Organisation	HIGHQUEST CDN	
Note:	Plant No **29**	REF No [31]

Plant Type & Information Source	PV RO seawater desalination plant		
Location	Canada		
Capacity	3 m^3/day		
Desalination Technology	Reverse osmosis		
Energy System Type	Photovoltaics		
Year Commissioned	1984		
Manufacturing Company/Responsible Organisation	HIGHQUEST CDN		
Note:		Plant No **30**	REF No [31]

Plant Type & Information Source	Wind RO seawater desalination plant		
Location	Marsa Matrouh, Egypt		
Capacity	25 m^3/day		
Desalination Technology	Reverse Osmosis		
Energy System Type	Wind energy, WEC		
Year Commissioned	1987		
Manufacturing Company/Responsible Organisation	NREA, Egypt		
Note:		Plant No **31**	REF No [31]

Plant Type & Information Source	Solar energy RO seawater desalination plant		
Location	Hirosima, Japan		
Capacity	20 m^3/day		
Desalination Technology	Reverse osmosis		
Energy System Type	Solar energy		
Year Commissioned	1987		
Manufacturing Company/Responsible Organisation	HITACHI		
Note:		Plant No **32**	REF No [31]

Plant Type & Information Source	Solar energy RO seawater desalination plant		
Location	Brounsville, Texas, USA		
Capacity	36 m^3/day		
Desalination Technology	Reverse Osmosis		
Energy System Type	Solar energy, Fresnel lenses		
Year Commissioned	1987		
Manufacturing Company/Responsible Organisation	-		
Note:		Plant No **33**	REF No [31]

Plant Type & Information Source	Solar RO seawater desalination plant
Location	Yanbu, Saudi Arabia
Capacity	20 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	Solar energy
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	-
Note:	Plant No **34** REF No [31]

Plant Type & Information Source	Solar RO brackish water desalination
Location	Sulaibiya
Capacity	45 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	Solar energy
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	-
Note:	Plant No **35** REF No [31]

Plant Type & Information Source	Solar RO seawater desalination plant
Location	Marett island, Italy
Capacity	5 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	Solar energy
Year Commissioned	1989
Manufacturing Company/Responsible Organisation	MEMBRANE I, FILMTEC, USA
Note:	Plant No **36** REF No [31]

Plant Type & Information Source	Wind RO brackish water desalination plant
Location	Perth, Australia
Capacity	0.15-0.3 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	Wind energy, WEC
Year Commissioned	1990
Manufacturing Company/Responsible Organisation	Murdoch Univ., Australia
Note:	Plant No **37** REF No

			[30],[25],[27]

Plant Type & Information Source	PV RO brackish water desalination plant
Location	Sadous Riyadh Region, Saudi Arabia
Capacity	600 lt/hour
Desalination Technology	Reverse osmosis
Energy System Type	10.89 kWp Photovoltaics
Year Commissioned	1994
Manufacturing Company/Responsible Organisation	KACST, Saudi Arabia, NREL, USA

Note:		Plant No **38**	REF No [38]

Plant Type & Information Source	PV RO brackish water desalination plant
Location	Gillen Bore, Australia
Capacity	1.2 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	4.16 kWp Photovoltaics
Year Commissioned	1996
Manufacturing Company/Responsible Organisation	CAT

Note:		Plant No **39**	REF No [40]

Plant Type & Information Source	PV RO brackish water desalination plant
Location	Hamam Lif, Tunisia
Capacity	50 lt/day
Desalination Technology	Reverse Osmosis
Energy System Type	590 Wp Photovoltaics
Year Commissioned	-
Manufacturing Company/Responsible Org.	INRST

Note:		Plant No **41**	REF No [42]

Plant Type & Information Source	PV RO seawater desalination plant
Location	Pozo Izquierdo, Gran Canaria island
Capacity	3 - 4 m^3/day
Desalination Technology	Reverse Osmosis
Energy System Type	4.8 kWp Photovoltaics
Year Commissioned	1998 (1st version) 2000 (2st version)

Manufacturing Company/Responsible Organisation	Canary Islands Institute of Technology, ITC, Spain Spain		
Note:		Plant No **42**	REF No [51]

Plant Type & Information Source	Solar thermal membrane distillation for seawater desalination		
Location	Germany		
Capacity	0.2-20 m^3/day		
Desalination Technology	Membrane distillation		
Energy System Type	Solar collectors, PV for pumping needs		
Year Commissioned	1999		
Manufacturing Company/Responsible Organisation	Fraunhofer Institute, ISE, Germany		
Note:		Plant No **43**	REF No [18]

Plant Type & Information Source	Wind mill RO brackish water desalination		
Location	Coconut island, Hawai		
Capacity	0.78 m^3/hour		
Desalination Technology	Reverse osmosis		
Energy System Type	Wind mill		
Year Commissioned	-		
Manufacturing Company/Responsible Organisation	Univ. of Hawai		
Note:		Plant No **44**	REF No [34]

Plant Type & Information Source	PV RO brackish water desalination plant		
Location	INETI Portugal		
Capacity	100-500 lt/day		
Desalination Technology	Reverse osmosis		
Energy System Type	50-100 Wp Photovoltaics		
Year Commissioned	2000		
Manufacturing Company/Responsible Organisation	INETI, Portugal		
Note:		Plant No **45**	REF No [35]

Plant Type & Information Source	PV RO brackish water desalination plant
Location	Sadous Village, Saudi Arabia
Capacity	600 lt/hour

Desalination Technology	Reverse osmosis
Energy System Type	10.08 kWp Photovoltaics
Year Commissioned	2001
Manufacturing Company/Responsible Organisation	MEDRC Project, Oman
Note:	Plant No **46** REF No [3]

Plant Type & Information Source	Wind RO seawater plant
Location	Gran Canaria , Spain
Capacity	43-113 m^3/hour
Desalination Technology	Reverse osmosis
Energy System Type	Wind energy, WEC
Year Commissioned	2001
Manufacturing Company/Responsible Organisation	Univ. of Las Palmas
Note: OPRODES, JOULE PROGRAMME	Plant No **47** REF No [36]

Plant Type & Information Source	Wind RO seawater plant without batteries
Location	U.K.
Capacity	10 m^3/day
Desalination Technology	Reverse osmosis
Energy System Type	Wind energy, WEC 2 kW
Year Commissioned	2001-2002
Manufacturing Company/Responsible Organisation	CREST, UK
Note:	Plant No **48** REF No [41]

Plant Type & Information Source	PV RO seawater plant without batteries
Location	U.K.
Capacity	3 m^3/day
Desalination Technology	Reverse osmosis
Energy System Type	2.4 kWp Photovoltaics
Year Commissioned	2001-2002
Manufacturing Company/Responsible Organisation	CREST, UK
Note:	Plant No **49** REF No [43]

Plant Type & Information Source	PV ED brackish water desalination plant
Location	Bahrain
Capacity	50-300 gal/day

Desalination Technology	Electrodialysis
Energy System Type	1.32 kWp Photovoltaics
Year Commissioned	2002
Manufacturing Company/Responsible Organisation	Univ. of Bahrain
Note:	Plant No **50** REF No [45]

Plant Type & Information Source	PV RO brackish water desalination
Location	White Cliffs, New South Wales, Australia
Capacity	500 lt/day
Desalination Technology	Reverse Osmosis
Energy System Type	150 Wp Photovoltaics
Year Commissioned	2003
Manufacturing Company/Responsible Organisation	Centre for PV Engineering, Australia
Note:	Plant No **51** REF No [46]

Plant Type & Information Source	Wind seawater desalination plant
Location	Pozo Izquierdo, Gran Cnaria island
Capacity	15 m^3/d
Desalination Technology	REVERSE OSMOSIS
Energy System Type	Wind energy, Vergnet, 15 kW
Year Commissioned	1999
Manufacturing Company/Responsible Organisation	Canary Islands Institute of Technology, ITC, Spain
Note:	ITC pilot plant — Plant No **52** REF No [50]

Plant Type & Information Source	PV RO seawater desalination plant
Location	Punta Libeccio, Italy
Capacity	-
Desalination Technology	Reverse Osmosis
Energy System Type	9.8 kWp Photovoltaics, Diesel
Year Commissioned	1993
Manufacturing Company/Responsible Organisation	CESEN SPA, Italy
Note:	Plant No **53** REF No [2]

Plant Type & Information Source	Wind RO seawater desalination plant
Location	Gran Canaria

Capacity	10 m3/day
Desalination Technology	Reverse Osmosis
Energy System Type	15 Kw Wind Generator, mechanical coupling to RO
Year Commissioned	
Manufacturing Company/Responsible Organisation	ITC , Government of Canary islands, Spain,

Note:	AERODESA I Project The unit has been dismantled from 1998	Plant No **54**	REF No [61]

Plant Type & Information Source	Wind RO seawater desalination plant
Location	Gran Canaria
Capacity	15 m3/day
Desalination Technology	Reverse Osmosis
Energy System Type	15 Kw Wind Generator, hydraulic coupling to RO
Year Commissioned	
Manufacturing Company/Responsible Organisation	ITC , Government of Canary islands, Spain,

Note:	AERODESA II Project The unit has been dismantled from 1998	Plant No **55**	REF No [61]

Plant Type & Information Source	PV RO brackish desalination plant
Location	Coite-Pedreiras, Brazil
Capacity	250 lt/hour
Desalination Technology	Reverse Osmosis
Energy System Type	1.1 kWp Photovoltaics, Diesel
Year Commissioned	2000
Manufacturing Company/Responsible Organisation	DEE-UFC, ARCE, CEFET, Brazil

Note:		Plant No **56**	REF No [54]

Plant Type & Information Source	PV RO brackish desalination plant, without battery bank
Location	Mesquite, Nevada
Capacity	136 lt/hr
Desalination Technology	Reverse Osmosis
Energy System Type	~ 400Wp Photovoltaics
Year Commissioned	2003
Manufacturing Company/Responsible Organisation	ITN Energy Systems, Denver

Note:		Plant No **57**	REF No [74]

Plant Type & Information Source	Brackish Water Desalination
Location	~ 0.2 m^3/d
Capacity	Western Australia
Desalination Technology	Reverse Osmosis
Energy System Type	Wind Energy Converter, 42 kW PV, Diesel
Year Commissioned	1988
Manufacturing Company/Responsible Organisation	Murdoch Univ., Solarex
Note:	Plant No **1**	REF No 30

Plant Type & Information Source	Brackish Water Desalination
Location	0.4 m^3/h
Capacity	Maagan Michael, South of Haifa, Israel
Desalination Technology	Reverse Osmosis
Energy System Type	0.6 kW Wind Energy Converter, 3.5 kW Photovoltaic Generator, 3 kW Diesel Generator
Year Commissioned	1997
Manufacturing Company/Responsible Organisation	The Israel Electric Corporation Ltd. SIEMENS (PVs), World Power Technologies Inc. (WEC)
Note:	Plant No **2**	REF No 23

Plant Type & Information Source	Hybrid PV - Wind seawater desalination plant
Location	Lavrio, Attiki, Greece
Capacity	130-150 lt/hour
Desalination Technology	Reverse Osmosis
Energy System Type	3.96 PV, 1 kW WEC
Year Commissioned	2001
Manufacturing Company/Responsible Organisation	PHOTOVOLTAIC, TEMAK, CRES
Note:	Plant No **3**	REF No

Plant Type & Information Source	Hybrid PV - Wind seawater desalination plant
Location	Agricultural Univ. of Athens (AUA), Greece
Capacity	1.5-3 m3/dayr
Desalination Technology	Reverse Osmosis
Energy System Type	850 W PV, 1 kW WEC

Year Commissioned	2001
Manufacturing Company/Responsible Organisation	TEMAK, AUA

Note:		Plant No **4**	REF N 69

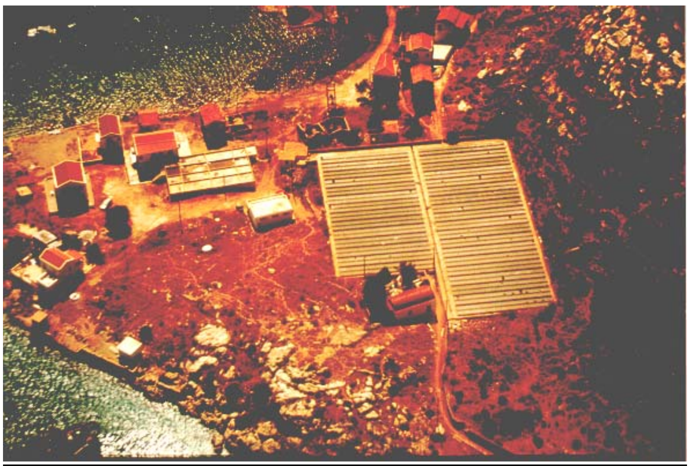
A2. OTHER RES - DESALINATION TECHNOLOGIES

Solar Distillation

Solar distillation has been used for many years, usually for comparatively small plants outputs. It is a very old process which in now days is more attractive in areas where the land cost is cheap. The solar still is basically a low "greenhouse" providing ideally, simplicity of construction and maintenance.

The principle of operation is simple, based on the fact that glass and other transparent materials have the property of transmitting incident short-wave solar radiation. Thus this "visible" radiation passes through the glass into the still and heats the water.

A great number of installations exist around the world in Australia, Haiti, Spain, India, USA, Mexico, Greece, etc. However, most of them are not in operation today. Several of the old plants plagued by storm damage, structure failure, sealing problems, and leakage.



Pic 1 View of the solar distillation plant in Kastelorizo island, Greece

One of the biggest plants was installed in 1967 in Patmos island in Greece. The solar still had an area of 8,640 m^2 and a product water capacity of 26 m^3/day from seawater. In such systems energy is required only to power the circulating water pumps. The main disadvantage of this technology is that almost all costs of the plant are associated with the still itself, meaning land purchase, ground preparation, still construction, cover, etc. Well-designed units can produce around 2.5 l/m^2 per day with a thermal efficiency of 50%. Since the mid-1960's long lasting solar stills have been built, at current prices, for a unit cost of US$50-$150/m^2. If the cost were kept down towards the lower range of $50/$m^2$, including materials and labor, then typical yields would have produced water at a cost of about US$4-$5.50/m^3, assuming low cost of the required land area. In 1996 the estimated costs for solar stills were $21 to $32/$m^3$.

Solar Membrane Distillation

Membrane distillation is the youngest of the membrane separation processes that can be used to desalinate water. It was introduced commercially on a small-scale in the 1980s. The process combines both the use of distillation and membranes. In the process, saline water is warmed to enhance vapor production, and this vapor is exposed to a membrane that can pass vapor but not water. After the vapor passes through the membrane, it is condensed on a cooler surface to produce fresh water. In the liquid form, the fresh water cannot pass back through the membrane, so it is trapped and collected as the output of the plant.

Thus far, the process has been used only in a few areas. Compared to the more commercially successful processes, membrane distillation requires more space and may use considerably pumping energy per unit of production. Being essentially a distillation process, it is subject to some of the same performance limitations as are experienced with that process.

The main advantages of membrane distillation lie in its simplicity and the need for only small temperature differentials to operate. Membrane distillation probably has its best application in desalting saline water where inexpensive low-grade thermal energy is available, such as from industries or solar collectors. The presented technology is able to supply clean water with plant capacities up to 20 m^3/d by avoiding the mentioned disadvantages of conventional technologies.

The membrane distillation (MD)-plant can be driven by solar heat and is therefore ideal to deliver water at remote areas with poor infrastructure. Typical characteristics of the process are as follows:

- efficient and compact spiral-wound membrane distillation modules
- recovery of the heat of condensation is integrated in the module design
- chemical pretreatment of feed water is not required
- low system pressure
- insensitive to dry-running and fouling
- negligible scaling problems due to process temperatures below 80°C

The operational efficiency and the long-term behavior of the process for the seawater desalination have been proven in pilot installations on the Canary islands and on the island of Ibiza, [70]. In order to test the module performance and to optimize the operation under real conditions a prototype plant has been tested on the island of Ibiza/Spain since May 1993. Additionally, within an INCO project, ICA3-CT-2002-0025, with the acronym **SMADES** and entitled "PV and thermally driven small-scale, stand-alone desalination systems with very low maintenance needs", 4 small compact systems installed with a capacity of 80-140 lt/day. The systems installed in Gran Canaria, Jordan, Morocco and Egypt.

A similar project with Ref Number ICA3-2002-10061 also concerns with the installation of 3 membrane distillation small systems (<2 m^3/day) in Jordan, Egypt and Morocco and one of around 2 m^3/day in Jordan.

Additionally, a very interesting project on solar thermal membrane distillation is the project entitled “Development of stand-alone, solar thermally driven and PV-supplied desalination systems based on innovative membrane distillation”, which runs within **MEMDIS** European project, Ref. No FP5 N° NNE5/2001/819. The objective of this project was the installation of 2 desalination plants of 900 lt/day and 1500lt/day. The partners of this project are ISE Fraunhofer, European Solar Engineering (ESE), GEP Umwelttechnik GmbH and ITC.

More analytically the 2 projects, SMADES and MEMDIS (also mentioned in Chapter 6) respectively, are presented below.

SMADES PROJECT [77]

1. Introduction

The overall objective of the project was the development of stand-alone desalination systems, which are based on the highly innovative membrane distillation technology. The systems integrate solar thermal and PV energy. The desalination energy is supplied entirely by solar thermal solar collectors and the electrical auxiliary energy is supplied by a PV system. Within this project four compact systems with a capacity of 80 -140 l/d have been installed in Gran Canaria (Spain), Irbid (Jordan), in Alexandria (Egypt) and in Khouimat Ej-Bail (Morocco). The fifth system has been installed at the Fraunhofer ISE, Freiburg (Germany). While the units in Jordan, Egypt and Germany are operated with artificial seawater the unit in Gran Canaria is operation with seawater from a bank filtration and the system in Morocco with brackish water. All systems have been installed between December 2004 and September 2005 and are still in operation.

2. System Description

Membrane distillation is a separation technique, which joints a thermally driven distillation process with a membrane separation process. The thermal energy is used for phase changing of liquid water into vapour while the membrane is only permeable for the vapour phase and separates the pure distillate from the retained solution. MD offers important advantages for the construction of solar- or waste heat driven, stand-alone desalination systems. The most important advantages are:

The operating temperature of the MD process is in the range of 60 to 85 °C. This is a temperature range where solar thermal flat plate collectors have a sufficient efficiency or waste heat from co- generation plants is available.

The Fraunhofer Institute for Solar Energy Systems (Germany) developed improved spiral wounded MD-Modules with an internal heat-recovery function, where the feed water is used as the coolant for the condenser channel.

The technical specifications of the MD module are:

- hydrophobic PTFE membrane, mean pore size 0.2 μmeter
- height 450 - 800 mm
- diameter 300 - 400 mm

- membrane area 6 m² - 12m²
- feed temperature at evaporator inlet 60 - 85 °C
- specific thermal energy consumption 100 - 200 $kWh/m^3_{distillate}$ (GOR about 3 to 6)
- distillate output 10-30 l/h
- all components are made of polymer materials (PVC, PE, PTFE, synthetic resin)

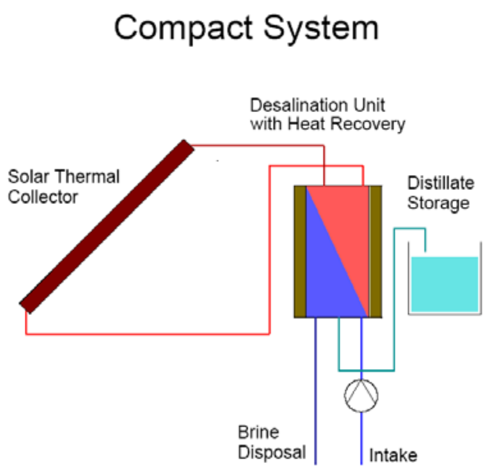


Fig. 1. Principle set up of the compact system

The five compact systems, a principle set up is shown in Fig. 1, mainly consist of 6-7m² solar thermal flat plate collectors, a membrane pump directly driven by a 75Wp PV-Module, a MD-Module with a membrane area between 6.2 and 9.7m² and a 500 lt feed storage tank. Four of the five units are also equipped with an additional 1m³ feed storage tank, while one unit is directly connected to a sea. The daily capacity of the systems ranges between 70 and 150 lt.

The system-operation follows the strategy of a batch process, which increases the system heat-recovery and the system recovery rate. Simultaneously the brine discharge rate is reduced. The refilling of the system is guaranteed by an additional refilling pump connected to a well (e.g. the system in Morocco) or to a storage.

The desalination units only have a typical pretreatment fleece and/or coarse filter-element.

Since the solar thermal collectors are directly connected to the salty water the riser and header tubes within the collectors are made of sea water resistant CuNi10. The units themselves are in autonomous operation and controlled by an internal control strategy.

Pic 2 Compact System in Egypt, Jordan and Morocco (from right to left)

While the feed storage is mounted above the collectors, most of the hydraulic components are installed in a closed housing covered by the back site of the collectors. The feed water is pumped from the feed storage into the MD-module. The distillate flows to a fresh water tank. The brine rejected from the evaporator outlet of the MD module is recirculated to the feed storage. So the salt concentration of feed water in the feed storage increases while the content of water decreases due to distillate production. The feed storage is refilled automatically when a trash hold is reached.

All compact systems excepting the one in Morocco are fully equipped with sensors for data acquisition. All relevant temperatures, volume flows and ambient conditions as well as the insolation in the collector plain are measured.

Long-term measurements with a “first generation” module were carried out (and are still in process) in Gran Canaria to investigate the aging behaviour and the long term resistant of the module and all system components. Within the scope of the project a new MD module was developed with an increased membrane exchange area, an increased heat recovery and an adapted spacer geometry. A module of the “new generation” type was installed in a compact system in Freiburg Germany and investigations with artificial seawater were carried out during spring and summer 2006.

3. Experiences and Lessons learned

The first unit was installed in Gran Canaria (Spain) and is in operation since December 2004. In June 2005 a replacement of the module was necessary since the

pressure loss of the 7m² collector-field and the connections between was higher than expected. The consequences of lower feed volume flows and therefore higher operation temperatures caused the damage of the MD – module. Since this failure the replaced MD-Module is in daily operation (until now for almost 17 months). As can be seen from one-year measurements there is no decrease of specific energy demand during the observed period. Moreover the temperature resistance of the MD-Modules could be increased by using more resistant polymers.
All systems are still in operation. The unit in Gran Canaria (Spain), consisting one of the first developed MD-Modules with 6.2 m² membrane area, produces between 60 and 80 liter per day. The system in Jordan, consisting a MD-Module with 8 m² membrane area, produces up to 120 l/d, while the system in Germany, consisting one of the newest MD-Modules with 9.7m² membrane area, has a capacity of 150 liter per day. The salinity of the product, measured in a daily average, is between 70 and 520ppm.

4. Cost Data
According to a cost analysis for an operation time of 20 years and depending on maintenance need the cost of the distillate water produced are between 8.66€/m³ and 21.51€/m³.

MEMDIS PROJECT [77]

1. Introduction
Within this project 2 two-loop systems with a capacity of 900 and 1500 l/d have been installed in Aqaba (Jordan) in December 2005 and in Gran Canaria (Spain) in February 2006. Both systems are connected directly to the sea. Both systems are in operation.

2. System Description
The Fraunhofer Institute for Solar Energy Systems (Germany) developed improved spiral wounded MD-Modules with an internal heat-recovery function, where the feed water is used as the coolant for the condenser channel. The technical specifications of the MD module are:

- hydrophobic PTFE membrane, mean pore size 0.2µm
- height 450 - 800 mm
- diameter 300 - 400 mm
- membrane area 6 m² - 12m²
- feed temperature at evaporator inlet 60 - 85 °C
- specific thermal energy consumption 100 - 200 kWh/$m^3_{distillate}$ (GOR about 3 to 6)
- distillate output 10-30 l/h
- all components are made of polymer materials (PVC, PE, PTFE, synthetic resin)

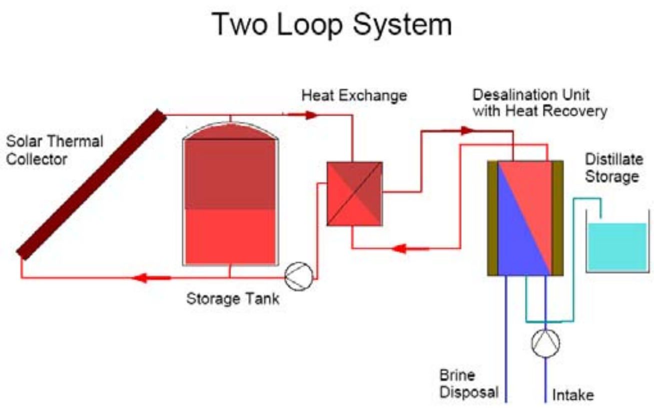


Fig. 2. Principle set up of the two-loop system

The 2 two-loop systems, a principle set up is shown in Figure 2, keep four main differences compared to the compact systems:

- A thermal storage tank is used to enable an extended operation time of the MD-modules even after sun-set →More distillate production per MD-module →Decreasing specific module costs
- The system consists of two loops. The desalination loop is operated with sea water and is separated from the collector loop which is operated with tab water by a corrosion resistant heat exchanger →The thermal storage and the collectors do not have to be sea water resistant → Cheaper standard components can be used
- There are five MD-modules operated in parallel in the desalination loop. The MD-modules are exactly the same as in the compact systems.
- A control unit is used to control the operation of the system. At low irradiation times the desalination unit is operated with heat directly from the collector field. If

enough insulation is available the surplus energy can be stored in the storage tank and after sun-set the desalination process can be continued with heat from the tank →The operation conditions can be adjusted to the optimal performance conditions for the MD module

The two loop systems are also completely supplied by solar thermal energy and PV. No additional energy supply is necessary.

Simulation computations were carried out for the system design and the development of an adapted control strategy for two different pilot plants.

The key data for the system in Aqaba are: 72m² standard flat plate collectors, 3m³ capacity heat storage, 4 MD-Modules (each 9.8m² membrane surface) and 1.44kWp PV. While the key data for the system in Gran Canaria are: 90m² double-glassed anti-reflective-coated flat plate collectors, 4m³ capacity heat storage, 5 MD-Modules (each 9,8m² membrane surface) and 1.92kWp PV.

The two “two loop” systems were installed as designed by the simulation computation in Aqaba in December 2005 and in Gran Canaria in February 2006. Picture 2 shows the collector field of the Aqaba system and the desalination unit installed in the building below the collectors.

Both two-loop systems are fully equipped with sensors connected with a data acquisition system. Daily data are saved on a computer and provided to the project partners via internet.

Pic 2 Collector field (left) and desalination unit with solar loop components (right) in Aqaba, Jordan

A plot of the operation performance of the two-loop system in Gran Canaria is presented in Figure 3 for a fine day in March 2006.

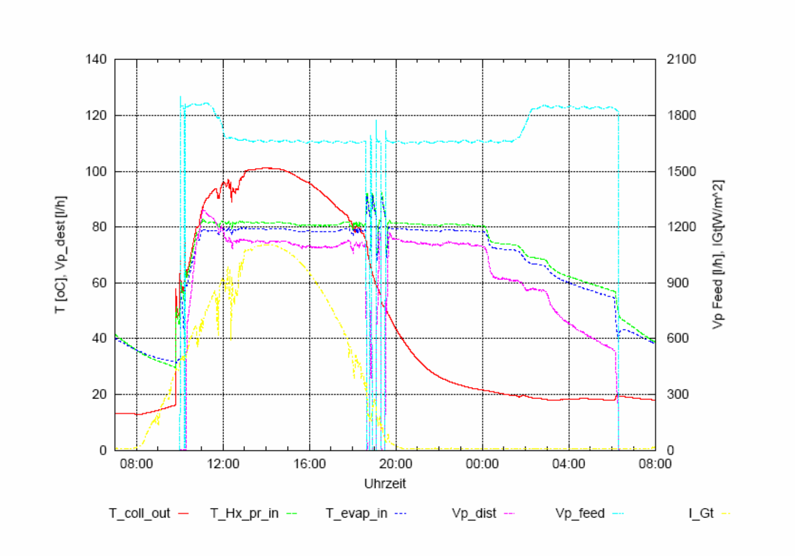


Figure 3. 24 hour measurement on the two loop system in Gran Canaria in March 2006

The yellow graph represents the global radiation on the tilted collector surface. The red graph is the collector outlet temperature and the green line represents the heat exchanger inlet temperature as adapted by the control unit. As can be seen the collector outlet temperature and the heat exchanger inlet are rising comparably until 11:00am (IG=450W/m²) when the set value at the heat exchanger inlet is reached. Then the collector outlet temperature continues rising while the heat exchanger inlet is set to 81°C. The evaporator inlet temperature of the MD modules is slightly below (~79°C, purple graph) due to heat losses of the heat exchanger. From 6:30pm to 7:30pm the controller switches to storage discharge. As can be seen the temperatures are fluctuating and cannot be controlled to the set value. The reason can be found in the slow reaction time of the control unit respectively the slow movement of the Valve. From 7:30pm to 0:10am (next day) the temperature control operates successfully again and the evaporator inlet temperature is set again to 79°C until the storage top temperature decreases below that value. The system is operated with a decreasing evaporator inlet temperature and distillate flow until 6:15am, March 24. Then the switch of temperature of 58°C at the heat exchanger inlet is reached. The distillate volume flow during operation on the set point temperature is about 75 and 80 kg/h. The cumulated distillate gain from the operation period between 10:00am March 23 and 6:15am March 24 is 1240kg. The collector field efficiency is between 0.61 and 0.5.

3. Experiences and Lessons learned

Two systems with a two loop set up and a heat storage were developed and installed in Aqaba and in Gran Canaria. The Aqaba system consists of a collector area of about 72m² and is producing about 600 to 700 litre distillate per day. That is about 200 litre less than expected. Main reason can be found in the very low performance of the heat exchanger. The heat loss between primary and secondary loop is about 10 K. The two- loop system in Gran Canaria consists of a collector area of 90m² and has a product capacity of more than 1300 l/day. That fulfils the expected results. The heat exchanger performs much well than in Aqaba. As can be seen from the comparison of the collector efficiency measurements the double glassed collectors in Gran Canaria show in average a 21% higher efficiency than the collector field in Aqaba where the efficiency is between 0.47 and 0.42. Since the technical and electrotechnical complexity in the two-loop system is in general higher, compared to the compact system based on membrane distillation, two loop systems will be favourably for daily capacities higher than 2000 litre.

4. Cost Data

The concept of the “two loop “system is different from the compact system and will be favourably from the economical point of view for daily capacities higher than 2000 lt.

Concluding, the process of the membrane distillation allows the effective use of low temperature heat sources like solar energy or waste energy from engines for small to medium scale desalination.

Although the process of membrane distillation is known since over 30 years cost-effective desalination modules have not been available so far.

Solar Humidification-Dehumidification (HD)

Solar desalination with humidification-dehumidification processes has proven to be an efficient means of production of fresh water in remote and sunny regions.

Numerous solar desalination installations concerned with small and medium production have been developed and studied. From the literature has been considered that systems based on the humidification-dehumidification principle produce fresh water at rates higher than those obtained from single solar stills under similar solar radiation.

The principle of the HD process is based on the fact that air can be mixed with large quantities of water vapor. The vapor carrying capability of air increases with temperature: 1 kg of dry air can carry 0.5 kg of vapor and about 670 kcal when its temperature increases from 30^o to 80^oC. When flowing air is in contact with salt water, a certain quantity of vapor is extracted by air, which provokes cooling. Distilled water, on the other hand, may be recovered by bringing the humid air in contact with a cooled surface, which causes the condensation of part of the vapor in the air. HD process is especially suited for seawater desalination when the demand for water is decentralized. In the case of solar HD air is heated and humidified by the hot water received from a solar collector.

Several studies and few installations have been done on the solar HD. Recently within the INCO-DC project IC18-CT98-0265 [2], [48,] a new seawater process using solar energy has been developed. The central idea of the new process is to use the sun for heating up of airflow and to humidify that hot air contact with seawater. After loading of the airflow by a large amount of vapor, the water content can be easily recovered by cooling of the humid air in dehumidification equipment.

A main feature of this desalination process is to conduct the heating/humidifying procedure in several stages in order to load the air with a high amount of humidity and to reduce the volume of circulating air.

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