ADIRA HANDBOOK

Autonomous Desalination system concepts for seawater and brackish water In Rural Areas with renewable energies – Potential, Technologies, Field Experience, Socio-technical and Socio-economic impacts

ADIRA HANDBOOK

A guide to autonomous desalination system concepts

MEDA Water

Co-funded by the European Union

Preface

Many regions of the world are facing severe water shortage problems. Often people must walk long distances just to obtain sufficient water to sustain life. Desalination of seawater or brackish water has become one of the most important “non-conventional” growing sources of drinking water in many parts of the world, and plays already an important role in solving problems of fresh water scarcity in areas where other water supply alternatives are not available.

Brackish and especially sea water desalination demands large amounts of energy. Therefore, the future of desalination is linked to the problem of energy source availability. Renewable energy resources have been utilised basically as an alternative answer to petroleum depletion and its contaminant power. In the regions that suffer from water shortage the renewable energy potential is usually high and allows for the efficient use of renewable energy such as wind and solar energy. Therefore the combination of renewable energy technologies for powering desalination technologies is a reasonable option in these areas. The present document, the **ADIRA HANDBOOK,** intends to facilitate the introduction of renewable energy powered desalination systems where needed and especially in remote areas far from the electricity grid.

The **ADIRA HANDBOOK**, **“A guide to autonomous desalination concepts”** was developed within the **ADIRA project**. The **ADIRA project** is one of the **MEDA projects** financially supported by the European Union (EU) for the development of the water sector in the Middle Eastern and North African (MENA) countries. The **MEDA programme** intends to improve local water management conditions through co-operation of non-profit organisations from EU countries and non-profit organisations in the MENA countries, focusing on capacity building, construction and demonstration plants, technology transfer and creation of awareness.

The **ADIRA project** seeks to demonstrate the feasibility of water desalination in areas around Mediterranean which are in need of fresh water. ADIRA has installed a number of **Autonomous Desalination Systems (ADS) powered by Renewable Energy Technologies.** That is, ADS independent of conventional energy sources which are able to turn brackish or sea water into useful potable water for the needs of the local communities. Eleven (11) such systems have been installed (a few pending at the time of writing) in Mediterranean countries, namely Cyprus, Egypt, Jordan, Morocco and Turkey. All ADS utilise Renewable Energies for fresh water production. The capacities of the installed ADS are in the range of 1 to 10 cubic meters of fresh water per day, while the cost of the produced water is in the range of 5 to 20 EUROS per cubic meter depending on the type of the technology used, the water salinity and climatic conditions. Master Plans have been prepared for each of the installations and methods of viability and sustainability of the systems have been studied and evaluated.

The **ADIRA HANDBOOK, “A guide to autonomous desalination concepts”** was another major objective of the ADIRA project. The handbook intends to guide decision makers, project developers and interested end users in the implementation of renewable energy driven desalination systems. It has been particularly designed for the non-specialist / non-engineer and its texts are systematically avoiding all technical material which is usually appearing in such manuals. The **ADIRA HANDBOOK** includes brief discussion on all the basic topics that need to be considered in ADS implementation covering the theory, fundamentals, operation principles, technical facts, socio-economic factors, administrative and legislative aspects. It also provides instructions for planning, installing and maintaining such Autonomous Desalination Systems, as well as readymade material for training local users. The information presented in this handbook will enable the reader to develop a general knowledge about ADS and their implementation.

Besides the **HANDBOOK**, the project team has developed a simplified ADS size-optimisation and cost analysis **Decision Support Tool** codenamed **"AUDESSY"** (AUtonomous DESalination SYstems). **AUDESSY** requires minimal, easy to find information, draws data from several built-in economic and engineering databases and (i) estimates the optimal size of ADS and Renewable Energy Systems combination to satisfy the existing water demand and (ii) analyses investment and running costs of the whole system and calculates the cost of each cubic meter of fresh water produced. The **AUDESSY CD** is offered with the **ADIRA HANDBOOK** in a pair that provides a sound starting point for everyone interested in Autonomous Water Desalination Systems implementation.

We wish this **HANDBOOK** and the associated **Decision Support Tool** to be useful to all those interested in providing fresh and clean water to regions that are in need but do not have the means, protecting at the same time the environment with the use of renewable energies.

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List of Abbreviations

ADIRA	Autonomous Desalination System Concepts for Sea Water and Brackish Water in Rural Areas with Renewable Energies – Potential, Technologies, Field Experience, Socio-Technical and Socio-Economic Impacts
ADS	Autonomous Desalination System
AC	Alternating Current
BW	Brackish Water
DC	Direct Current
DST	Decision Support Tool
ED	Electrodialysis
GOR	Gain Output Ratio
HD	Humidification-Dehumidification
HAWT	Horizontal Axis Wind Turbines
MD	Membrane Distillation
MED	Multi Effect Distillation
MEH	Multi Effect Humidity
MENA	Middle Eastern and North African
MSF	Multi Stage Flash
NGO	Non Governmental Organisations
OTE	Ocean Thermal Energy
O&M	Operation and Maintenance
PV	Photovoltaic
RES	Renewable Energy Systems
RO	Reverse Osmosis
R&D	Research and Development
SD	Solar Distillation
SW	Sea Water
TDS	Total Dissolved Solids
VAT	Value Added Tax
VAWT	Vertical Axis Wind Turbines
VC	Vapour Compression
WHO	World Health Organisation
Wh	Watt hour
Wp	Watt peak

Executive Summary

Desalination is the process of removing dissolved salts from saline or brackish water to make it fit for human consumption, home uses, irrigation, etc. Today many technologies developed based on desalination are very well established and considered as an important alternative for the supply of fresh water, especially in water scarce regions. New approaches in desalination technology are rapidly advancing parallel to the fresh water needs of users in remote areas as well as in cities and towns.

The Autonomous Desalination System (ADS) concept was introduced as an alternative solution to the problem of fresh water supply. ADS refer to desalination practices coupled with appropriate Renewable Energy Systems (RES). ADS units offer a viable and promising option for remote arid sites where there is no connection to the electricity grid or a grid connection is not feasible. Remote arid areas are characterised by dry climate, lack of fresh water and abundance of brackish or sea water resources. Isolated population residents, in general, suffer from shortage of skilled labour and are often unable to attract and sustain trained skills. In some remote areas around the world, people are accustomed to drink slightly brackish water which causes irritation of the digestive tract and skin diseases. Middle Eastern and North African (MENA) countries around the Mediterranean region are considered as good candidates to benefit from ADS applications owing to the availability of abundant renewable energy resources, particularly solar, coinciding with the fresh water demand that cannot be met with conventional sources.

The ADIRA[1] project is carried out within the framework of the Euro-Mediterranean Water Programme (MEDA WATER) - Euro-Mediterranean Regional Programme for Local Water Management. It intends to contribute to the improvement of technical, social and economic framework conditions in targeted countries mainly through the installation of a number of desalination pilot plants powered by renewable energy. This Handbook has been produced based on the work implemented within the framework of the ADIRA project.

An introduction to the ADS concept is provided to the reader in Chapter 1. Basic operation principles and main components of major desalination techniques and RES are described briefly.

Current desalination practice is presented by describing the two most popular methods being adopted today: (a) thermal and (b) membrane desalination technologies. Major thermal desalination techniques described include Multi Stage Flash (MSF), Multi Effect Distillation (MED) and Vapour Compression (VC), whereas most commonly used membrane desalination techniques are presented as Reverse Osmosis (RO) and Electrodialysis (ED) processes. Energy requirements for both methods are also estimated showing that thermal processes require higher energy input than membrane processes for similar water salinities.

RES are classified in six broad categories: Hydro-electric, solar, wind, biomass, geothermal and ocean energy. The most commonly used RES in ADS are solar and wind energy applications. Apart

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[1] Autonomous Desalination System Concepts for Sea Water and Brackish Water in Rural Areas with Renewable Energies – Potential, Technologies, Field Experience, Socio-Technical and Socio-Economic Impacts) project supported by the European Commission (EC) under the Euro-Mediterranean Water Programme (MEDA WATER)

from providing thermal energy, solar radiation is also converted into electrical energy using Photovoltaic (PV) cells. Wind is used to generate electric power through wind turbines which drive the desalination systems. Besides, more site specific geothermal energy is also claimed to be a useful source for desalination.

Today, overall capacity of worldwide renewable energy desalination installations accounts for less than 1% of the total capacity of conventional desalination plants, mainly due to the high capital cost of RES. Most ADS are using RO technologies (62 %). Thermal desalination processes are the second most popular, i.e. MED, MSF and solar PV technologies are followed by systems powered by solar thermal and wind energy. Some investment and operational cost figures are also presented for major desalination and RES applications.

Chapter 2 of the handbook describes methods for choosing the geographic and site where an ADS unit can be installed. It is important to select the most favourable site, in order to assure the competitive advantages of the process in that particular site which depends on several factors. This chapter intends to present a methodology to identify and select the most favourable regions and sites to install ADS units.

The first task in selecting the candidate region is information gathering, which requires a large variety of data to be collected from various sources of information such as ministries, existing utilities, research reports and feasibility studies.

Collection of data is proposed to be carried out in two stages; in the first stage, primary factors (macro-data) for the selection of favourable regions. In the second stage, the specific factors to be considered to select the favourable sites are examined. Then a set of screening criteria will have to be set to identify the potential regions. It is advised to employ (a) a comparative approach and (b) a weighted score analysis to select the most appropriate site. The chapter includes proposed criteria and methodology for developing and weighting the important factors.

In Chapter 3 the reader is informed about the arguments in favour of the use of ADS and reasons for their low capacity. The chapter also describes general concepts of ADS through an overview of the most common desalination and RES combinations. Emphasis is paid to systems with higher prospects on a research and technological basis. Evidently, these systems comprise the most promising practical solutions in the medium-term. Some indicative information is also presented concerning the market situation of ADS.

Concerning seawater desalination, the majority of the existing installations consists mainly of large centralised or dual-purpose desalination plants, as being more economic and suitable for large density population areas, ignoring the use of ADS in small poor communities. On the other hand, increasing concern for environmental pollution has stimulated interest for the use of renewable energy in water desalination.

Major limitations on the implementation of ADS seem to be the temporal and site dependent character of the resources and the high investment costs of renewable energy facilities.

Main criteria for the selection of ADS/RES combinations are presented, proposed and examined with reference to the potential technological solutions.

The suitability of RES for desalination are discussed through several aspects such as; availability of energy resources, climatic reasons, fluctuation in water demand, self-sufficiency of these systems, local support and diversification of energy resources.

The reasons for the present limited use of ADS, which represent only about 0.02% of total desalination capacity, are claimed to be related to several aspects which are addressed as: the technological challenges, costs for such projects (capital-intensive), availability (limitations in max exploitation of RE resources) and suitability (advanced desalination technology does not match with poor level of infrastructure).

Chapter 3 also briefly describes the factors affecting the selection of the best (optimum) desalination technology, which include: feed water quality, availability, salinity, product water quantity and quality, energy requirement, desalination technology, RE source availability, and other factors such as capital and running costs, operation and maintenance (O&M) expertise, and brine disposal.

Some market observations are presented for the reader through a detailed examination of current ADS technologies, concentrating to more technologically mature products. The ones presented are solar stills, humidification-dehumidification plants, MED system with thermal solar collectors, membrane distillation with thermal solar collectors, PV driven RO, and wind and PV driven RO.

Chapter 4 provides an overview of the institutional and policy conditions in targeted Mediterranean countries, namely Morocco, Turkey, Jordan and Egypt, and analyses how these conditions can affect both the promotion and implementation of ADS. The analysis of these representative countries applies to any country, especially in the Mediterranean region.

Before engaging in the ADS installation process in a country, the project developers have to examine various institutional and policy issues in that particular country. Information presented in this chapter guides the reader to evaluate the framework conditions and assists him to make an assessment of the administrative difficulties that will be faced during planning, constructing and operating ADS. It focuses on four areas, which are; governmental policy and programmes, legislation and administrative issues, water prices, and institutional framework conditions.

The water sector in a typical Mediterranean country involves many actors that can be viewed at three levels which are; decision making, executive and user-levels. It is noted that, as new challenges appear, the structure of water sector is directed towards decentralisation and privatisation, especially in the last decade.

Governmental policies and programmes play an important role in implementation of ADS. It is observed that ADS are not treated as a separate approach nor paid a sufficient attention in water policies in the countries studied, although the policies mostly recognise the importance of integrated water management and exploitation of non-conventional resources. Some governments have set up programmes to support rural communities in developing water and energy infrastructures and there are also examples of political support for the use of renewable energy.

The legal framework and administrative issues differ in many countries and are often not designed particularly for ADS. Hence required licenses and procedures are key factors for ADS project developers, which include: withdrawal/utilisation of seawater and brackish water, brine disposal, construction in coastal zones, drinking water quality, renewable energy installations, import taxes and VAT. The negative impacts of ADS implementation usually result from improper coordination of state departments involved in the required procedures, whereas the positive aspect is that legislation in all studied countries provides some incentives regarding small-scale applications and off-grid RES applications as well as some reductions of VAT and import taxes.

The subsidised municipal and rural water tariffs commonly observed in Mediterranean countries are addressed as factors that distort the market function and are not in favour of the development of ADS as an alternative. These result from facts such as the low income, limited financial resources of the rural communities and high initial investment costs of ADS. Instead, water tariffs based on cost recovery principle are advised together with developing suitable support schemes.

The chapter also provides recommendations on conditions to consider, procedures and rules to follow and criteria to use for the evaluation of the potential of ADS in any particular country.

Planning of ADS installations especially for remote communities requires careful analysis of the technical, financial and social aspects that prevail in the area of interest. Chapter 5 aims to present some other crucial aspects in planning and implementing ADS, which inevitably requires site-specific cost analysis and careful selection of financial implementation models. The social impacts, social sustainability and actors participation, which should be considered before the system is introduced to the community, play important roles in the successful implementation of such systems. Key points in purchasing ADS equipment, installation, operation and maintenance are also presented in this chapter.

Cost analysis for a given desalination technology is site-specific and is one of the most important steps in ADS planning as it is strongly related to the sustainability of the unit. The product cost is observed to be affected by unit capacity, quality of feed water, cost of energy, type of technology, site conditions, costs of land and labour and additional costs such as taxes, permits, fees, brine disposal, etc. Cost of water produced from ADS may easily be competitive in remote areas far from conventional energy sources compared to water produced from plants that run on grid electricity or oil. However it is expected that desalinated water will soon become economically viable as the number of ADS increases, allowing some economies of scale.

Chapter 5 also discusses a Decision Support Tool (DST) developed within the ADIRA project[2], which aids the process of cost calculation for various desalination technologies and situations. The DST cost categories include; feed water pre-treatment, desalination unit, renewable energy conversion and storage, brine disposal and other costs. Three examples of typical ADIRA installations are included in the accompanying CD.

The possible financing mechanisms listed for ADS investors include: personal savings / private funds, subsidies or grants to support technological innovations, loans from international funding agencies (e.g. World Bank Group, Global Environment Facility, Regional Multilateral Development Banks), national funding agencies, NGOs, European Commission Programmes (Europe Aid, etc.), combined projects with strong financial partners - private sector investment, and financing with limited guarantees over anticipated future cash flows.

A good implementation model is another requirement for ADS projects as they require high initial costs. The possible models are presented to the reader as; cash sales, consumer credits, credit institutions, lease, and fee for service. Selection of the proper model depends on the specific needs of the project.

Social aspects play an important role in sustainable operation of ADS, although they receive less consideration than techno-economic aspects. Social sustainability relies basically on the condition where the technology introduced is accepted by the community, meet their water needs and is within their capacity to operate and maintain. The applied social methodology either follows the case study approach which includes interviews and site visits or the feedback from people relating to ADS with the use of questionnaires. It is noted that the social aspects of desalination technologies should ideally be considered before they are brought to the communities.

The key actors (Stakeholders) are individuals or institutions that may (directly or indirectly, positively or negatively) affect or be affected by the outcomes of the ADS project. Hence a careful stakeholder analysis is required to identify them and their influence on the project. The chapter provides a step-by-step stakeholder analysis scheme for the reader.

Chapter 5 provides a general presentation of the ADS installation and operation plan which include selection of suppliers, bid finalisation and contracting, local actions, ADS installation and commissioning (transport and local delivery, preparation of ADS set-up), ADS operation, ADS maintenance, and O&M staff training.

Continuous evaluation and supervision are also crucial for sustainability of ADS. Monitoring is another important issue in ADS operation and requires regular examination of measuring data. Common data to be recorded are temperatures, pressures, flows, local conditions (ambient temperature, wind speed, solar irradiation), conductivities and power. Proper maintenance and care guarantees satisfactory performance of the ADS unit. Types of maintenance include preventive, predictive and corrective maintenance.

Training of the staff responsible for the operation of the ADS aims to ensure long lasting operation of the ADS, increase user satisfaction, prevent or minimise problems arising from inappropriate use and excessive expectations, and guarantee proper reaction to arising problems. The design of the training process consists of: 1. Situation analysis, 2. Assessment of the training needs for each group of trainees, 3. Planning of the training programme for each group of trainees, 4. Implementation, and 5. Evaluation of the training programme. A check list and an example of training activities for end users are also provided.

The ADIRA Handbook intends to guide decision makers, project developers and interested end users to the study and implementation of RES powered water desalination projects (ADS). The contents of the Handbook include a brief presentation of all the basic topics that need to be considered in proper ADS implementation starting from the theory, fundamentals, operation principles, technical facts, socio-economic factors, administrative and legislative aspects, and finally giving tips on planning, installation, O&M of such systems and training. The situation may differ from country to country due to various local conditions; still, the information presented in this Handbook will enable the reader to develop a general knowledge of ADS systems and their implementation.

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[2] AUDESSY: (AUtonomous DESalination SYstems) is the cost calculation software companion package offered together with the Handbook on CD.

1

Conceptual Framework of ADS and RES

S. Sözen and S. Teksoy

1.1 INTRODUCTION

Desalination is commonly defined as the process of removing dissolved salts from saline or brackish water to make it fit for human consumption i.e. domestic, agricultural and industrial purposes. It is considered as an important alternative for the supply of fresh water, especially in water scarce regions. Desalination of seawater and brackish groundwater is an established and rapidly advancing technology, which already provides fresh water to many towns and cities worldwide through large-scale applications as well as from well-established small-scale applications for ships, yachts, etc.

The concept of Autonomous Desalination Systems (ADS), which refers to desalination coupled with appropriate Renewable Energy Systems (RES), offers a viable and promising option for the arid regions suffering from water scarcity where there is no connection to the electricity grid or a grid connection is not feasible. In particular, the Middle East and North African (MENA) countries around the Mediterranean are believed to be good candidates to benefit from such applications owing to the availability of abundant renewable energy resources coinciding with the fresh water scarcity. The following section intends to provide general information on desalination techniques and renewable energy resources including the general technical and economic aspects. Further details on ADS concepts and choosing of best pairs are presented in Chapter 3.

1.2 THEORETICAL BACKGROUND ON TECHNICAL MATTERS

The multi-lateral ADS concept may be best reviewed by handling the desalination and the renewable energy technologies separately. The following sections provide some technical information about the major desalination practices and renewable energy systems that drive these systems.

1.2.1 Major Desalination Technologies

The desalination technologies may be subcategorized as membrane and thermal distillation processes (Table 1.1). The most commonly used technologies in large-scale applications are thermal distillation and reverse-osmosis (RO) filtration processes. The following part provides brief information on common desalination techniques.

The dominant desalination processes; Multi Stage Flash (MSF) and RO constitute 44 % and 42 % of the worldwide capacity, respectively. The MSF process represents more than 93 % of the thermal process applications, whereas the RO process represents more than 88 % of the membrane applications [1].

Table 1.1 Classification of Major Desalination Technologies

Thermal Technologies	Membrane Technologies
Multi Stage Flash (MSF)	Reverse Osmosis (RO)
Multi Effect Distillation (MED)	Electrodialysis (ED)
Vapour Compression (VC)	

Further information on desalination technologies related to the process descriptions, technology development, manufacturing and economics can be found in Annex 1.1.

1.2.1.1 Thermal desalination technologies

Thermal desalination technologies rely on the distillation processes to remove fresh water from salty water. Saline feed water is heated to vaporize, causing fresh water to evaporate as steam leaving behind a highly saline solution namely, the brine. The heat energy required is the latent heat of evaporation, which is around 627 kWh/m^3, plus losses. Cooling the vapor causes it to condense as freshwater. The brine solution produced as waste or by-product, requires appropriate disposal. The major thermal desalination technologies are *Multi-Effect Distillation* (MED), *Multi-Stage Flash* (MSF), and *Vapor Compression* (VC).

MED process proceeds in a chain reaction form in which the vapor resulting from each stage is condensed in the following stage, where it can be used as a thermal source for evaporation to be used to heat a second tank held at a lower pressure. Practical distillation systems often have many tanks at many pressure stages, known as effects.

The MSF technology is one of most popular systems in the Gulf countries, of which the existing installed capacity is about 8 million m^3/day. MSF is based on passing the saline water into a container and heating it to high temperatures, causing it to boil and the pressure in the container to decrease. A part of the water flashes to a vapor stage, while the rest of the hot water continues flowing through a series of chambers or stages. These chambers exhibit gradually-decreasing temperatures and pressures, leading to the transformation of the water into vapor (the pressure in each chamber is maintained at values less than the level of saturated vapor pressure). With this procedure, water loses some of its salt in each stage, and the salt remains with the residuals. The vapor is then condensed, transforming it into liquid freshwater. . MSF has a high recovery rate in producing freshwater (less than 25 mg/l). The required temperatures range between 90 and 110 ^{o}C.

A feature of the MSF technology is that it can utilize excess thermal energy. Thus, it is possible to combine the production of large amounts of power and water in one station, thereby satisfying the demand for both of them. More attention is given to the distillation system, especially because of its high durability under various conditions and its ease in treating raw water (usually seawater), compared to the reverse osmosis method used in the rest of the world.

In MSF distillation, the water is heated under pressure, which prevents it from vaporizing while being heated. It then passes into a separate chamber held at lower pressure, which allows it to vaporize, but well away from the heating pipes, thus preventing them from becoming scaled. Like MED, practical flash-distillation systems are divided into sections, but this time known as *stages*, hence the term *Multi-Stage Flash* (MSF). When first introduced in the 1960’s, MSF offered slightly lower energy efficiency than MED, but this was outweighed by scaling considerations and MSF became the industry standard.

VC process relies on raising the temperature of water vapor by compressing it, rather than direct heating, which allows it to be used as a heat source for the same tank of water that produced it. There may be thermal (for medium-scale) (TVC) or mechanical vapor compression (MVC) where the compressor may be driven by steam or a diesel/electric motor, respectively. This type of desalination station has a capacity less than 100 m^3/day, and is usually used on the level of industrial facilities.

1.2.1.2 Membrane based desalination technologies

Membrane based desalination technologies that do not involve phase changes but use exclusion membranes to separate fresh water (containing low salt levels) from saline waters. Feed water is brought to the surface of a membrane, which selectively passes water but excludes salts. The most common membrane based desalination processes are *Reverse Osmosis* (RO) and *Electrodialysis* (ED). The technology is relatively young compared with thermal technologies with the first plants coming into operation during the early 1960's (using the electrodialysis method) and early 1970's (using the reverse osmosis process).

RO is a membrane filtration process which is much more energy efficient compared to the distillation processes. RO technology uses pressure to separate the salt from the water and is capable of reducing water salinity from 40 000 to 400 mg/l. In the RO process, the seawater pressure is increased above the osmotic pressure, which allows the desalinated water to pass through semi permeable membranes, and collected as permeate stream, but retains the solid salt particles left as brine stream. There are several types of membranes, including cylindrical or tubular, flat plastic layers, very thin flat membranes and smooth clay fiber (known as the hollow fine fiber), and those with spiral forms (known as the spiral wound). The most commonly-used membrane is the spiral wound membrane.

The ratio of product flow to that of the feed is known as the *recovery ratio*. With seawater RO, a recovery ratio of 30% is typical, meaning that the remaining 70% appears as concentrate, which is returned to the sea.

The main components of RO plants are:

- initial treatment units, which remove the large dissolved solids from the feedwater, prior to flowing through the membranes. This is done to protect the membranes and to reduce salt deposits that can diminish the efficiency;
- high pressure pumps, which increase the feed water pressure on the membrane to the point that it exceeds the osmotic pressure, thereby providing enough energy to move the water in the opposite direction to the osmotic pressure;
- membranes;
- energy recovery units, recovering energy from the high pressure brine (for sea water feed)
- final treatment units, in which the acidity of the water is neutralized and chlorine added to disinfect it.

The ED process uses membranes as well, but unlike RO, the salt ions are deliberately carried through the membranes, leaving behind the freshwater. Two types of membranes are required: one that lets anions through but not cations, and the other that does the opposite. These membranes are stacked alternately and held apart by spacers. The saltwater is fed into the spacer layers on one side of the stack, and a DC voltage is applied to the stack as a whole. The salt ions are attracted through one membrane or the other depending on their polarity, and by the time the water comes out of the other side of the stack, it is alternately freshwater and concentrate in the spacer layers. Reversing the polarity of the applied voltage reverses the freshwater and concentrate layers, and this can be done periodically (several times per hour) in order to reduce fouling, and is termed Electrodialysis Reversal (EDR).

ED was commercialized during the 1960's and is widely used today for desalinating brackish water. The energy consumption depends very much on the concentration of the feed water and so ED is rarely used for seawater desalination.

Table 1.2 Summary of Available Desalination Technologies

Desalination Technology	Features	Pre-treatment	Typical Operating Temperature (^{0}C)	Typical Water Recovery (%)	Permeate Salinity (TDS[1])
Thermal	Requires heat source, usually oil fired High energy requirement High capital & operating cost Long history of dependable performance	Almost no pre-treatment	60 – 110	10 - 20	< 25 mg/l
Membrane	Electrical energy required Low energy requirement Low capital & operating cost Small footprint compared to thermal Nearly 20 years of proven performance	Filtration Anti-scalants	Ambient	30 - 60	350 - 1000 mg/l

[1]: Total Dissolved Solids

Table 1.2 provides an overview of the existing desalination technologies, listing their key features, and describing their pre-treatment requirements, typical operating conditions and water recoveries and permeates salinities achieved.

1.2.1.3 Energy considerations

Desalination is a process which intrinsically consumes a lot of energy. In membrane desalination, energy consumption is solely in the form of electrical energy and varies depending on the influent character i.e. brackish or sea water. There is no thermal energy consumption in membrane processes. Thermal desalination technologies require higher energy than membrane processes and consume energy both in the form of electrical and thermal energies.

The energy requirements (kWh/m^3) for the membrane and thermal desalination technologies are summarized in Table 1.3.

Table 1.3 Energy Consumption for Membrane Technology versus Thermal Technology (kWh/m^3)

Energy Consumption (kWh/m^3)	Membrane Technology	Thermal Technology
Electrical Consumption	1 – 2.5 (RO BW[1])	1.5 – 3 (Distillation)
	1 – 3 (RO SW[2])	8 – 14 (TVC[5])
	1 (ED, 1500 mg/L TDS[3])	
Thermal Consumption	N/A[4]	6 – 21 (Distillation)
		N/A (MVC[6])
Total Consumption	1 – 2.5 (RO BW)	7.5 – 24 (Distillation)
	4 – 7 (RO SW)	8 – 14 (VC)
	1 (ED, 1500 mg/L TDS)	

[1]: Brackish Water [3]: Total Dissolved Solids [5]: Thermal Vapour Compression
[2]: Sea Water [4]: Not Applicable [6]: Mechanical Vapour Compression

Energy requirement of a particular desalination process is also one of the major factors affecting its cost. Therefore project developers pay attention to the energy consumption while assessing the sustainability of ADS.

1.2.2 Renewable Energy Systems (RES)

RES convert renewable sources of energy to useful energy vectors or carriers, such as heat, electricity, mechanical power or fuels (gaseous or liquid) which provide an alternative solution to the decreasing reserves of fossil fuels. The common renewable energy resources include hydro-electric, solar, wind, geothermal, biomass and ocean energy which are also termed as ‘Green power technologies’ (Fig. 1.1). RES are able to provide reliable electrical power within a short and flexible time frame. In contrast, most fossil fuel plants, large hydro dams, or nuclear plants take several years to develop from the planning to implementation stages.

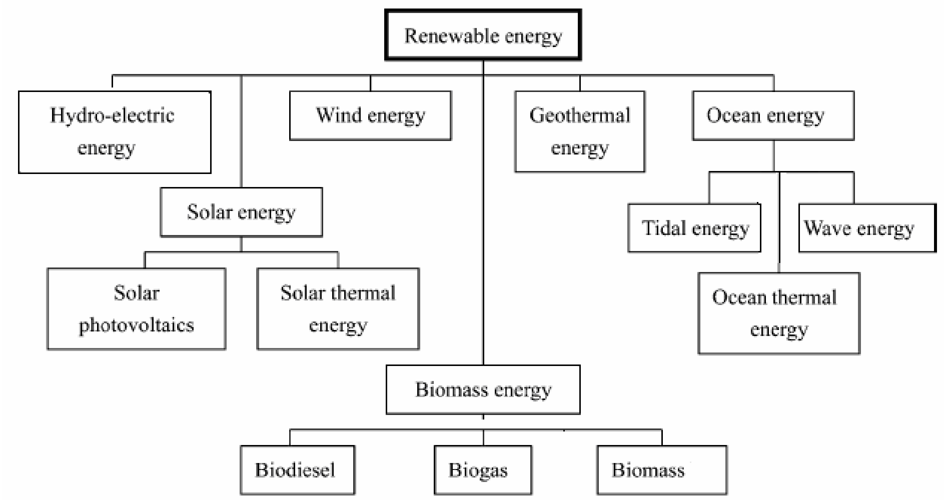

Figure 1.1 Renewable Energy Resources

The most common RE technology is the *wind energy*. The generation of electricity from the wind power is attained by the kinetic energy of wind. As wind passes through wind turbine blades, it turns a shaft coupled with a generator for the production of electricity. Currently, there are two categories of modern wind turbines, namely Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT), which are used mainly for electricity generation and water pumping. For the HAWT machines, the axis of rotation of the blades is horizontal, and for the VAWT, the axis of rotation is vertical. HAWT are the most common turbine configuration used today.

Photovoltaic (*PV)* systems use semi-conductor materials, usually made of silicon to convert sunlight into electricity. Although many semiconductor materials are available, single-crystal silicon is presently the most popular option for commercial cells. Several other important PV materials can be listed as polycrystalline silicon, amorphous silicon, copper indium dieseline, cadmium telluride, and gallium arsenide. Sunlight is converted to electricity using photovoltaic or solar cells. The energy of the absorbed light is transferred to electrons in the atoms of the PV cell. With the newfound energy, these electrons escape from their normal positions in the atoms of the semiconductor PV material and become part of the electrical flow, or current, in an electrical circuit. The special electrical property of the PV cell ‘built-in electric field’ provides the force, or voltage, required to drive the current through an external load. PV cells produce electricity as long as light shines on them. A PV or solar cell is the basic building block of a PV system and typically is able to produce 1 or 2 watts of power. To boost the power output of PV cells, they are connected together to form modules or arrays.

PV modules generate direct current (DC), the kind of electricity produced by batteries. Although incandescent lights can operate on DC, most electric devices require 120/220-volt alternating current (AC) as supplied by utilities. A device known as an inverter converts DC to AC current. Inverters vary in size and in the quality of electricity they supply. PV systems can be classified into two general categories: flat-plate systems or concentrator systems. Flat-plate collectors typically use large numbers or areas of cells that are mounted on a rigid, flat surface. These cells are encapsulated with a transparent cover that lets in the sunlight and protects them from the environment.

Currently, *PV* modules generate electricity for homes, cottages, utility grids and traffic signals, and are effective and price competitive in meeting power needs in remote locations and as an alternative to grid-extension or conventional stand-alone power systems i.e. diesel generators.

Geothermal energy is the heat of the earth; originating from Greek words *geo* (earth) and *therme* (heat). It may be classified in terms of the measured temperature as low (<100 ^{o}C), medium (100–150 ^{o}C) and high temperature (>150 ^{o}C). The thermal gradient in the Earth varies between 15 and 75 ^{o}C per km depth. There are also local centers of heat between 6 and 10 km deep due to disintegration of radioactive elements. Low temperature geothermal waters in the upper 100 m was claimed to be a reasonable energy source for desalination [2].

Biomass technologies use renewable biomass resources to produce an array of energy related products including electricity, liquid, solid, and gaseous fuels, heat, chemicals, and other materials to provide heat, make fuels, chemicals and other products, and generate electricity. The most common types of biomass include wood, plants, residue from agriculture or forestry, and the organic component of municipal and industrial wastes other than wood as known to be the largest source of bioenergy for thousands of years. Developments indicate that future biomass resources may be replenished through the cultivation of energy crops, such as fast-growing trees and grasses, called biomass feedstocks.

The two most common *biofuels* are ethanol and biodiesel. Ethanol, an alcohol, is made by fermenting any biomass high in carbohydrates, like corn, through a process similar to brewing beer. It is mostly used as a fuel additive to cut down a vehicle's carbon monoxide and other smog-causing emissions. Biodiesel, an ester, is made using vegetable oils, animal fats, algae, or even recycled cooking greases. It can be used as a diesel additive to reduce vehicle emissions or in its pure form to fuel a vehicle.

Biomass can be chemically converted into a fuel oil by heat, and can be burned like petroleum to generate electricity. *Biogas* energy can be produced in chambers with no oxygen through the phenomenon of anaerobic digestion. Biogas is a mixture of hydrogen, carbon monoxide, and methane and can drive turbines like a jet engine. It is commonly generated from biomass waste products at sewage treatment plants, solid waste landfills, through forest sector activities, and agricultural operations. The methane gas produced in the landfills as a result of decay of biomass can also be burned in a boiler to produce steam for electricity generation or for industrial processes.

The RES from the ocean include the conversion of ocean thermal energy (OTEC), as well as the wave and tidal energies. OTEC produces electricity from the natural thermal gradient of the ocean, using the heat stored in warm surface water to create steam to drive a turbine, while pumping cold, deep water to the surface to recondense the steam. Wave energy is one of the most dependable RES available up to 90 % of the time at a given site. There are floats or pitching devices which generate electricity from the bobbing or pitching action of a floating object, which generate electricity from the wave-driven rise and fall of water in a cylindrical shaft and Wave Surge or Focusing Devices also called "tapered channel" or "tapchan" systems, which rely on a shore-mounted structure to channel and concentrate the waves, driving them into an elevated reservoir where the water flow out of this reservoir is used to generate electricity, using standard hydropower technologies. The availability of tidal energy is very site specific, where tidal range is amplified by factors such as shelving of the sea bottom and funneling in estuaries, reflections by large peninsulas, and resonance effects and it is highly predictable, compared to solar, wind, and wave energy owing to the regularity of the tides. The recent innovations in wave energy include tidal fences and tidal turbines, which take advantage of the currents, set up by tidal flows. Tidal fences consist of turbines stretching entirely across a channel where tidal flow sets up relatively fast currents. The turbines are designed to allow the passage of fish, water and sediment through the channel. Tidal turbines, also installed in channels with tidal currents, resemble underwater wind turbines and require current speeds of 2–3 m/s; at lower velocities, harnessing energy from the current is uneconomic, while higher velocities can damage the turbines [3].

The general use of RES is likely to become more and more feasible in the near future [4, 5].

1.2.3 Desalination Powered by RES

RES are offering a sustainable energy resource to drive the desalination systems installed especially in remote areas. However, total worldwide renewable energy desalination installations amount to capacities less than 1% of that of conventional fossil fuel desalination plants. This is mainly due to the high capital and maintenance costs required by RES, disabling ADS to compete with the conventional fuel desalination plants.

According to the distribution of desalination technologies which are driven by RES, it may be observed that the major share is governed by the RO process (62 %), which is followed by thermal desalination processes i.e. MED and MSF. The distribution of RES utilized to drive the desalination plants indicate that solar PV technology is the most commonly practiced one having a 43 % share among the other RES, which is followed by the solar thermal and wind energy [6].

The most common and feasible ADS practices are known to be the solar thermal and/or geothermal energy coupled with thermal desalination as well as the PV and wind driven membrane desalination practices (Table 1.4).

Table 1.4 RES Coupled with Desalination Technology [6]

RES Technology	Feed water	Desalination Technology
Solar energy		
Solar thermal	SW[1]	MED
	SW	MSF
Photovoltaics	SW	RO
	BW[2]	
	BW	ED
Wind energy	SW	RO
	BW	
	SW	VC
Geothermal	SW	MED

[1]: Sea Water [2]: Brackish Water

1.3 THEORETICAL BACKGROUND ON ECONOMIC MATTERS

It is widely accepted that desalination will play an increasing role in meeting worldwide water needs, but is limited by its cost, which is largely dominated by the energy costs. The ADS with renewable energy systems are often considered cost competitive in cases of rural applications without connection to the local electricity grids. The major economic aspects of the ADS are summarized in this section for both the desalination technologies and the renewable energy supply systems.

Desalination technologies represent significant capital investment, with high on-going operation and maintenance costs. However, the cost of desalination processes have fallen considerably over the last years and in many instances the cost of desalination has fallen below conventional treatment processes.

When assessing the economic feasibility of a desalination system it is important to consider the following site specific costs:

- transporting the feed water to the desalination facility and permeate to the end users;
- pre-treatment costs (depends on desalination technology selected and feed water quality);
- post-treatment costs (depends on end-user expectations);

- supplying power to the site, as desalination technologies are large consumers of energy;
- availability of skilled personnel to operate the facilities;
- brine disposal costs;
- site specific environmental considerations.

The above mentioned costs represent only the desalination equipment costs and site specific costs such as establishment of feed water extraction sites, delivery of feed water to the plant, delivery of treated water from the plant to the community, provision of energy and process control, more complex pre-treatment steps, brine and backwash disposal need to be individually estimated for each site and added to the above costs.

The investment and operational costs of most common desalination and renewable energy equipment are presented in Table 1.5 including breakdown of consumables, labor and maintenance.

Table 1.5 Investment and Operational Costs for Major Desalination and RE Practices [7]

Desalination Process	Initial investment (€/m^3)	Consumables (€/m^3)	Labor (€/m^3)	Maintenance (€/m^3)
RO	1,600	0.25	0.2	0.05
VC	2,500	0.15	0.2	0.08
ED (BW[1])	328	0.13	0.2	0.01
RES	Equipment (€/kW)	Installation (€/kW)		Maintenance (€/kW)
W/T[2]	750	500		32
PV	4,000	153		10
Wave	10 cents	-		-

[1]: Brackish Water [2]: Wind Turbine

Costs of typical ADS units such as solar stills, MED, PV-RO, wind-RO systems are discussed in detail in Chapter 3.

1.4 REFERENCES

[1] El-Dessouky, H., Ettouney, H. (2000) MSF development may reduce desalination costs, Water and Wastewater International, p. 20–21.

[2] Rodriguez-Girones, Rodriguez, M., Perez, J., Veza, J., (1996) A systematic approach to desalination powered by solar, wind and geothermal energy sources, In: Proceedings of the Mediterranean Conference on Renewable Energy Sources for Water Production, European Commission, EURORED Network, CRES, EDS, Santorini, Greece, 10–12 June 1996, p. 20–25.

[3] Pelc, R., Fujita, R. M. (2002) Renewable energy from the ocean, Marine Policy, 26, 471 -479.

[4] WEC, World Energy Council (1994) New renewable energy sources; A Guide to Future, Kogan Press Ltd., London, p. 391.

[5] Tsai, W.T., Chou, Y.H. (2005) Overview of environmental impacts, prospects and policies for renewable energy in Taiwan, Renewable and Sustainable Energy Reviews, 9, p. 119–147.

[6] Desalination Guide Using Renewable Energies (1998) THERMIE Programme, CRES, Greece, ISBN 960-90557-5-3.

[7] Voivontas, D., Misirlis, K., Manoli, E., Arampatzis, G., Assimacopoulos, D., Zervos A. (2001) A tool for the design of desalination plants powered by renewable energies, Desalination, 133, p. 175-198.

2

Region Identification and Site Selection

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2.1 INTRODUCTION

The geographic location of a site where an ADS unit can be installed has a strong influence on the success of the project. If the desalination unit is not located in the most favourable position, the competitive advantages of the process can be wiped out. Considerable care must be exercised in selecting the installation site, and many different factors must be considered.

The first task in selecting the candidate region is information gathering; which requires a large variety of data to be collected. This includes identification, collection and analysis of data from the favourable regions within a country (areas of territory) and sites within the selected regions (possible locations of installations) in order to obtain helpful information about where to install ADS units. At this stage, various sources of information can be used, such as ministries, existing utilities, research reports and feasibility studies.

The candidate regions are then screened based on the collected data and the adopted criteria. Within the most favourable region, various sites are evaluated based on site-specific data and the corresponding criteria. Factors that generally apply to the ADS site location are classified into two major groups. The primary factors (macro data), which apply to the selection of the favourable regions, and the specific factors, which are considered for choosing an exact site location within the region. Although all factors are important in making a site location selection, subjectivity cannot be avoided, since some parameters are not measurable or not accurately measurable and thus, several choices are left to the experience of team experts. This chapter includes the criteria and methodology for developing and weighting the elements of a matrix which is designed to include all factors required for site selection.

2.2 DESCRIPTION OF THE PROCESS

Data identification, data collection and data evaluation are the essential steps to be taken for selecting the final site location. Preferred site identification is a multi-step process consisting of data gathering, screening potential regions and potential sites, followed by subsequent ranking of those sites. Data gathering includes qualitative and site-specific data useful in developing the screening and ranking criteria. The purpose of this section is to establish the basic information needed to be collected to identify candidate regions, and candidate sites within a selected region. Data identification takes into account the following aspects which are; environment, available infrastructures, socio-economic situation, and water and energy resources.

Considering the identification of data for the sites, two basic documents can be recommended: a data matrix with the list and description of the proposed data to be collected, and an indices matrix, a set of data derived (calculated) from the data included in the data matrix. Indices matrix is thought as a first analysis data tool, which could give useful figures to understand local reality.

Data collection can be obtained through filling the questionnaires described in Annex 2.1 and Annex 2.2. Two specific tools to collect data are designed: a basic questionnaire to collect data from regions, and a detailed questionnaire, to collect data from sites. The detailed questionnaire is the base to develop a database to enter data of sites. The data gathered consists of qualitative data as well as site-specific data. Qualitative data is the data used to help in making decisions for screening of the potential sites. Site-specific data consists of site characteristics used for screening and ranking of alternatives.

Since there are many regions in each country and many possible sites in each region to address the questionnaires, a selection process should be applied to reduce the amount of information to be analysed. The selection is made by a set of criteria which are used to identify the favourable regions and sites from the total possible regions / sites.

A preliminary (macro-level) screening measure is developed for the identification of the favourable regions in countries where ADS units will be installed. The macro screening criteria enables evaluation of region features needed for selection of site of ADS units. Application of the macro criteria enables establishing a list of favourable regions that may be suitable for the location of ADS units.

The selection of the favourable sites is performed with another set of criteria (micro-level). A matrix can be used to select the favourable sites. A matrix to screen and rank potential sites within the regions is developed and presented in this chapter (section 2.5). The ranking of the sites represents the second step in the screening process. The ranking matrix can be applied to the screened sites to establish a list of preferred sites for ADS units. Site identification and site selection to install an ADS unit is a very important and challenging task as various engineering, environmental as well as political-social-human factors are involved. The criteria provide a rational way to perform screening of regions and sites for further consideration for a potential site of an ADS unit.

Data evaluation is the final process in which the collected data is analysed to extract the relevant conclusions about, for example, where the most interesting sites to install the units are, which regions need fresh water the most, or where renewable resources are more abundant. The data collected establish the basis for the site characteristics criteria used in this chapter.

Identification of favourable sites for the installation of ADS units is a multi-step processes consisting of data collection, followed by the macro screening of regions, micro-screening of sites, and ranking matrix for the selection of the best viable site. The whole process of site selection is illustrated in Fig 2.1.

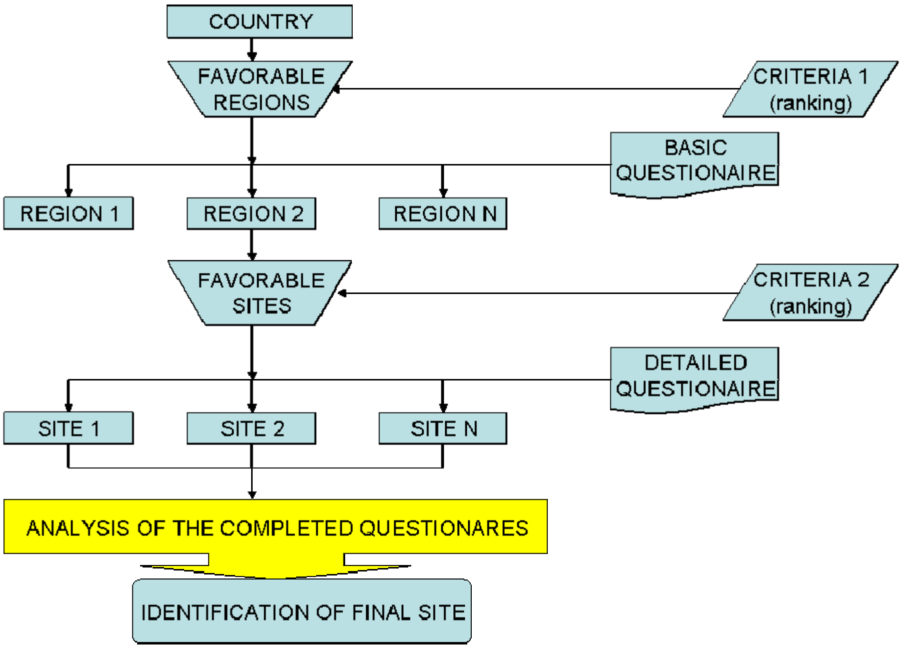

Figure 2.1. Basic Methodology in Site Selection

2.3 IDENTIFICATION OF THE REGIONS

2.3.1 Methodology

The collection of data may be carried out in two stages: in the first stage primary factors (macro-data) can be considered in order to perform the favourable regions selection, whereas in the second stage the specific factors can be considered to select the favourable sites (Fig. 2.1). This section presents the screening criteria for the primary factors (macro-data). Application of the criteria can be used to screen and identify the potential sites for ADS installation. A summary of the screening criteria is listed below:

1. Presence of a serious problem of fresh water supply
2. Availability of data (to identify, at least, the water, energy and socio-economic situations)
3. Availability of sufficient resources of feed water (brackish water or seawater)
4. Existence of important renewable energy resources: wind / solar / biomass / others
5. State of the electricity supply (insufficient or not existent, at least in some areas of the region)
6. Political interest and will (Is the region a strategic area?)

2.3.2 Developed Tools

The developed tool to collect data is a questionnaire (MS WORD format) to be directly filled in (Annex 2.1). The questionnaire contains the basic information from the studied region concerning the energy, water, social, infrastructures, economic and environmental aspects.

2.4 IDENTIFICATION OF THE SITES

2.4.1 Methodology

Similar to the criteria developed above to identify favourable regions another list is developed to identify the favourable sites within the candidate regions. The criterion developed to select favourable sites represents an expansion of the macro-screening criteria plus additional secondary site-specific criteria. These criteria are not limitations but recommended or desirable values for an optimum location of a system.

The technical, economic, social and other basic information are gathered from each candidate site. There might also be other factors, not included in the list, but may have an important influence on final evaluation of the site, or might even suddenly become crucial for its selection or rejection.

The site-specific data collection shall take into consideration the following recommended items:

Specific Factors

1. Availability of data is good (to identify, at least, the water, energy and socio-economic situations)
2. Population <= 2,500. This value is just an orientation, a proposed limit; which is a top value for most of the villages at rural areas of the Mediterranean countries. On the other hand, the concept of the ADS systems means small sizes, prepared to supply water for small populations.
3. Fresh water demand >= 1,000 l/day. Similarly to the previous point, this is a proposed minimum value. There has to be a minimum demand to justify the installation of an ADS system.

Technical Factors

1. Existence of renewable energy potential

   The generally recommended minimum values for energy potential are the following:

   a. Case of wind energy: Annual average speed >= 6.5 m/s
   b. Case of solar energy: daily average global solar radiation > 4,500 Wh/m^2 or the number of sunny days per year > 200

2. Availability and quality of feed water
   a. Minimum quantity > Four (4) times than the planned product water flow. This value has to be checked in relation to the desalination process. This minimum is an approximation. For example, normal operation of a RO small unit requires a feed water flow three times higher than produced water flow.
   b. Sea or brackish feed water is available. Seasonal variations in temperatures, quality as well as quantity of available feed water are important factors for site selection.
3. Basic water infrastructures
   a. Existence of wells
   b. In case of wells, depth of the water level is less than 50 m. [1]
   c. Absence or bad state of a water distribution system (mains) [2]
4. Land and building infrastructures
   a. Existence of a minimum flat area to install the equipment of the ADS units (PV panels, wind turbine, desalination plant…)
   b. Existence of some type of roofing building / house where to install the equipment that must be protected from rain, dust, wind, desalination unit, batteries, electric panels, PLC and so on. In case of absence of such buildings, sensitive equipment will have to be installed in appropriate containers.
5. Environmental aspects (related with brine treatment):

A major requirement for installing a successful and long lasting ADS unit is the ability to dispose of the brine in an environmentally acceptable manner.

   a. In inland areas:
      i. Reuse brine for salt production
      ii. Pour to saline wetlands
      iii. Pipe to a safe place, e.g. a deep well without environmental impacts (no leakages)
   b. In coastal areas: Pour into the sea (no local impact to marine life).

6. Electricity infrastructures
   a. No access to electricity for most of population (>75%), because:
      iv. High price for electricity
      v. Lack or bad state of electricity grid
   b. Existence of a rural electrification programme based on renewable energies
7. Accessibility of the site (state of roads and tracks is OK)

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[1] The less depth, the less size and power for the feed water pump. 50 m is a suggested top value.

[2] It is considered that a bad state or inexistence of water mains makes a site more interesting / favourable according to the idea of thinking first in the most in need people

Social and Economic Factors

1. Willingness of local population to participate
    a. There is a good relationship with the leader (person or group) of the community
    b. The local population does not only accept the project but also there is interest for taking part in it
    c. There are technicians (in the site or not very far from there) with the basic abilities to carry out the operation and maintenance (O&M) activities (at least, able to learn how to make the O&M)
2. Social benefits

To what extent will it improve people's life standards and change their lives? How drastic this change will be?

3. Water selling price

Can the users pay for water, how much and on what conditions?

4. Rules and regulations
    a. Environmental constraints imposed by both local and national regulations
    b. Need for permissions for digging wells or disposing brine
    c. Possibility of obtaining subsidies due to governmental programs.

2.4.2 Developed Tools

The developed tool to collect data is a questionnaire (MS EXCEL format) to be directly filled in (see Annex 2.2. It is elaborated from the data matrix and maintains the same basic structure of parameters grouped by the different aspects of the reality. The questionnaire improves the data matrix format and includes additional useful data.

A software tool is developed to store the data collected through the questionnaires, or it can be considered as an online questionnaire to be filled directly via Internet; it is a database system, DAT (Data Acquisition Tool) developed in MS ACCESS 2000.

2.5 DECISION MAKING FOR THE SELECTION OF FAVOURABLE REGIONS AND SITES

Decision making process continues with picking possible site areas within the geographical regions which look plausible and screen them. Generally, there are two theoretical approaches to select the most appropriate site [1,2,3,4]:

1. Comparative approach: All potential sites are compared to a reference site which can be either a site of an existing and well functioning unit, or a model, being a list of acceptable criteria
2. Numerical classification approach (weighted-score analysis): the various desalination sites are compared to each other in a numerical manner using marks, or relevance weight factors. This is a more systematic and transparent approach. It also leaves less room for subjectivity and personal judgment.

In practice, the site selection process requires the combination of the two approaches. Factors to be considered in the weighted-score analysis of various regions and sites are outlined in section 2.3 and 2.4 of this chapter. The ranking of the initial list of sites is based on a combination of weighting and scoring of specific criterion. The sum of the weighted criteria scores makes up the total score for a particular region or site. The higher the cumulative score, the higher the region or site will be ranked.

The criteria are also assigned a weight (percent based) on their level of importance. The establishment of criterion scores is dependent upon importance and significance of each criterion. The weights in the table below are principally set for illustration of the weighted-score method. The scoring and weighting is subjective, based upon the experience of the working team.

The ranking matrix establishes a *score* or numeric value representative of the presence of preferred site features. Table 2.1 presents a summary of the criteria and weighting factors to be applied to each of the screened regions. To illustrate the method, two fictitious site areas are presented for the reader; X and Y. These sites are assumed to satisfy all of the macro-screening criteria as potential locations for ADS units. These macro-screened sites are further examined in the ranking process for specific preferred site features. The macro-screen criteria meet the minimum requirements for site selection of an ADS unit.

A summary of the results from the macro-level screening of the two sites is shown in Table 2.1. The weighted-score analysis shows that region X has a higher score than region Y. Thus it should be further explored. The ranking of the sites represents the second step in the screening process. A ranking matrix is applied to the macro-screened region to select the most favourable site for an ADS unit. Table 2.2 leads to the candidate site selection within that region. Although the two fictitious sites (W and Z) meet the micro-screening criteria, site W has a higher score than site Z. Thus the key factors are in favor of site W.

Table 2.1 Candidate Regions Selection for Rural Areas with Renewable Energy

Factor	Weight %	Region location	
		Region X	Region Y
Scarcity of fresh water supply	30	25	20
Availability of data	10	7	7
Availability of brackish or seawater	20	15	12
Availability of renewable energy resources	20	18	18
Bad state or absence of the local electrical grid	10	5	2
Political interest	10	8	8
Total score	*100*	*78*	*67*

Table 2.2 Candidate Sites Selection for Rural Areas with Renewable Energy

Factor	Weight %	Site location	
		Site Z	Site W
Availability of data	5	3	3
Population	10	8	8
Fresh water demand	15	10	14
Renewable energy resources	15	13	13
Participation of local population	5	3	2
Availability of feed water	15	12	14
Basic water infrastructures	5	4	5
Buildings infrastructures	5	3	3
Environmental aspects	10	8	9
Accessibility of the site	10	6	10
Bad state or absence of the local electrical grid	5		
Total score	*100*	*70*	*81*

As summarised above site selection is one of the most important decisions to be taken for the installation of ADS units. Collection of the basic data and evaluation are the essential steps for the identification of regions and sites. The potential regions and the favourable sites can be screened based on the criteria developed in this work for the purpose of selecting the best apparent site. Scoring of the various criteria, when combined with the weighting system, establishes an overall ranked score for each site. Although most parameters in the selection criteria are measurable, some others are not. Therefore, there is a room for subjectivity in the decision process that requires highly experienced professionals. It should be noted that a great deal of experience and knowledge is required to make a realistic site selection of an ADS unit.

2.6 REFERENCES

[1] Sanver, A. and May, S.C. (2000) Site selection, Encyclopedia of Desalination and Water Resources, EOLSS Publishers CO. Ltd.

[2] Andrianne, J. and Alardin, F. (2004) Desalination site selection on North-African coasts, Desalination, 165, p. 231-239.

[3] Mahji, P. (2001) Developing environmentally acceptable desalination projects, Desalination, 138, p. 167-172.

[4] Andrianne J. and Alardin, F. (2002) Thermal and membrane processes economics: Optimised selection for seawater desalination, Desalination, 153, p. 305-311.

3

ADS Concepts, Choice of Pairs and Market Information

E. Mathioulakis and H. Fath

3.1 INTRODUCTION

In seawater desalination, most refer mainly to large, centralised or dual-purpose desalination plants, as being more economic and suitable for large density population areas, ignoring through this practice small and poor communities. However, numerous low-density population areas lack not only fresh water but, in most the cases, electrical power grid connections as well. For these regions renewable energy desalination is the only solution.

Furthermore, the increasing concern for environmental pollution has stimulated interest for the use of renewable energies in water desalination. Naturally, the existing main limitations, related to the temporal and site dependent character of these resources, the high land requirements and investment costs of renewable energy facilities has to be considered.

Apart from the above reasonable arguments for the use of RES in the face of the emerging and stressing energy problems, there is a number of reasons related to the more specific issue, this of the suitability of RES for seawater/brackish water desalination:

- Arid regions are often remote, coastal areas or little islands where renewable energy sources are available and conventional energy supply is not always possible or at least easy to have. In these cases RES represent the best energy supply option for autonomous desalination systems (ADS).
- Climatic reasons lead to remarkable coincidence on a time-basis, of the availability of RES, (especially when referring to solar energy), and the intensive demand for water. Furthermore, often freshwater demand increases due to incoming tourism, which is normally peaking at times when renewable energy availability is high.
- Both renewable energy systems and desalination refer to self-sufficiency and local support. The operation and maintenance of related systems in remote areas are often easier/cheaper than conventional energy ones. Furthermore, the implementation of RES driven desalination systems enforces sustainable socio-economic development by using local resources.
- Renewable energies allow diversification of energy resources and help to avoid external dependency on energy supply. This has to be seen through the prospect of the developing countries, where major water shortage problems exist, considering as well the fact that seawater desalination is a high energy consuming method.

However, the present situation does not reflect the obvious advantages of the use or RES in water desalination. More specifically, RES driven desalination systems are scarce, with usually small capacity. In effect, they only represent about 0.02% of total desalination capacity [1]. The reasons for this are related to various, often correlated, aspects:

- *Technology*: The use of alternative energy sources in desalination systems requires the coexistence of two separate and different technologies: the energy conversion and the desalination. Both are considered mature to a lesser or greater degree, even through there are still significant margins of efficiency and volume increase or lowering of costs. A real challenge for these technologies would be the optimum technological design of combined plants through a system-oriented approach.
- *Cost*: Utilisation of RES and development of desalination plants represent capital-intensive projects. Until today, renewable energy technologies are not considered totally mature and the various system components are still expensive. Even though prices decrease continuously, in many cases they are still prohibiting wider commercialisation.
- *Availability*: Renewable energies are unlimited, but transient, thus presenting intermittent character, leading to limitations concerning the maximum exploitation capacities per time unit. Furthermore, due to the geographical distribution of RES, renewable energy intensity and potential does not always coinside with the water demand intensity at local level.
- *Sustainability*: In most of the cases, the maturity of the associated technologies does not match to the low level of infrastructures which often characterise places with severe water shortages. Experience has shown that several attempts to integrate advanced desalination solutions in isolated areas failed due to lack of reliable technical support.

The following analysis presents the potential of RES driven desalination systems. Emphasis is paid to the systems with the higher prospects on a research and technological basis. Evidently, these systems comprise the most promising practical solutions in the medium-term.

The discussion presents the main aspects involved to the ADS/RES combination selection. Selection criteria are proposed and examined with reference to the potential technological solutions. Finally, some indicative information is presented concerning the market situation of ADS.

3.2 TYPICAL RES-DRIVEN DESALINATION CONCEPTS - AN OVERVIEW

3.2.1 Thermal Driven Desalination

3.2.1.1 Desalination powered by thermal solar energy

Thermal solar energy is considered to be one of the most promising applications of renewable energies for seawater desalination, as it is suitable for arid and sunny regions. A thermal solar distillation system usually consists of two main parts, the collecting device and the distiller. Solar thermal desalination processes are characterised as “direct processes” when all parts are integrated into one system, while the case of “indirect processes” refers to the heat coming from a separate solar collecting device, usually solar collectors or solar ponds.

Solar stills belong to the case of direct processes and due to the interest they present; they will be discussed thoroughly below. The low efficiency of the still, mainly due to the high heat loss from its glass cover, has led many researchers to examine the design concepts that would reduce the loss of latent heat of condensation at the glass cover or that would partly recover this energy. Thus, the idea of utilising latent heat of condensation via multi-effect solar stills has emerged. Actually, direct processes utilising humidification-dehumidification techniques should be mentioned through a broad area of design solutions [2, 3], leading eventually to significantly improved performance, in comparison to simple solar stills.

The indirect-type stills are based on the fact that heat is provided only at the first stage of such a multi-effect unit, thus the use of external heat source is possible. Conventional solar thermal collectors, corrosion-free collectors developed for the specific application [4] or even evacuated tube collectors have been used as the external heat source.

Installations based on conventional thermal desalination technology such as; MED and MSF are also included under the category of indirect processes. For reasons related to the complexity and the cost of desalination units, these plants are usually of larger size, although examples of smaller size are also referred (Fig. 3.1) [5]. Even though, lately, the development of such installations has been effectively abandoned, several MED and MSF pilot plants have been designed and tested during the past, especially at late 90s. These installations have been driven by flat plate, parabolic trough or vacuum solar collectors [6]. The evaluation of these plants has shown that MED has greater potential than MSF for designs with high performance ratio and, moreover, MED processes appear to be less sensitive to corrosion and scaling than the MSF processes [7].

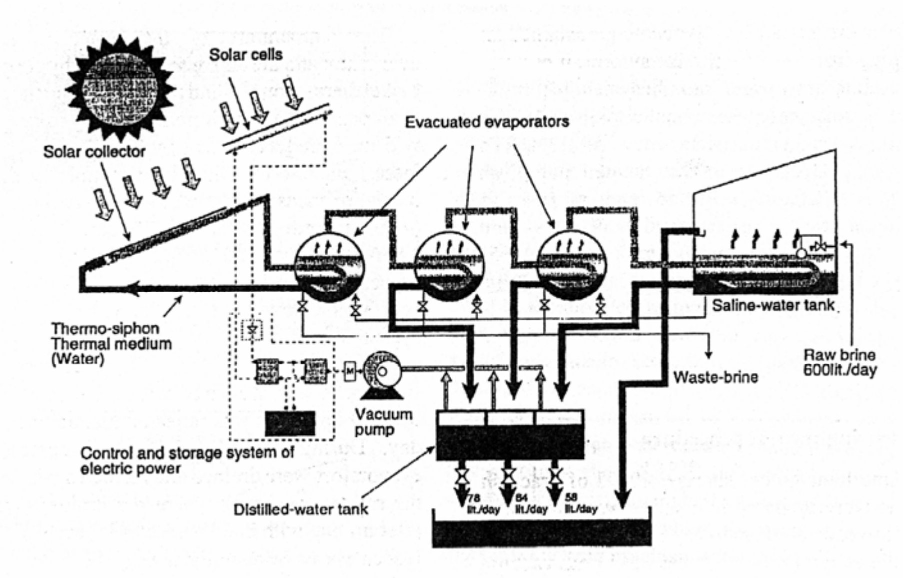

Figure 3.1 Three-effect Small Scale Solar Desalination Plant [5]

Solar thermal energy can be used, in principle, for the production of electricity or mechanical energy. Evidently, the process of thermal energy conversion is accompanied by decreased efficiency. During the past, only isolated attempts were reported, as was the case of a solar-assisted freezing plant powered by a point-focusing solar collector field, a cogeneration hybrid MSF-RO system driven by a dual purpose solar plant, and an RO plant powered by flat-plate collectors with freon as the working fluid [8].

Finally, special attention has to be given to the solar pond-powered desalination plants, identified by some authors as amongst the most cost-effective systems [9]. With relevance to this concept, different plants were implemented coupling a solar pond to an MSF process [10].

Solar stills

There is very rich bibliography on solar distillation, describing all possible configurations of solar stills, including theories, models and experimental results. Usually it is limited to each special still design, while part of it consists of comprehensive reviews and cost analyses [12, 13]. Most of the studies examine increases in efficiency by using latent heat of condensation or coils to preheat the feed water and increase vapour condensation, separated evaporation and condensing zones, capillary film techniques. Others try to increase feeding water temperature with various techniques, such as connection with solar collectors, use of intermediate storage in connection to collectors, or integration of solar still in a multi-source, multi-use environment [14, 15].

Conventional simple greenhouse-type solar distillation plants (Fig. 3.2) present specific disadvantages, such as low efficiency, high initial capital cost (counterbalanced in part by lower operational cost), large installation surface areas, vulnerability to extreme weather conditions (especially plastic covered stills), risk of formation of algae and scale on the black surface and need for special care to avoid problems related to dust deposition on the transparency of the cover.

At present, only few small solar distillation plants exist world wide, while a good number of them is in India. Despite the considerable number of plants constructed in the past, including several that still operate, there is not available, (at least published), analytical information about real operation conditions, cost of produced water, cost of installation, operation and maintenance or any other existing problems, i.e. pieces of information that could be very important for the optimum design of new installations [15].

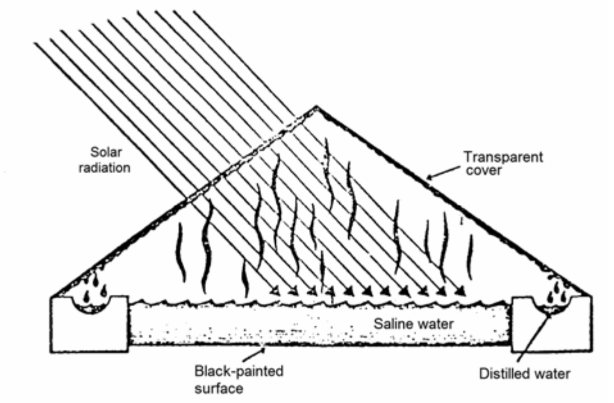

Figure 3.2 Conventional (one-stage) Solar Still [1]

Solar distillation plants are not commercialised yet, except for few individual units. In fact, in many cases, one may use the term of semi-empirical devices, thus characterising the design level. Constructions are made with locally available materials resulting to economic figures variation from region to region. On the other hand, the over all economics and operation conditions are of major importance for future applications and should be made to be known.

Humidification - Dehumidification

As it has already been mentioned, the humidification-dehumidification (HD) principle has been developed while trying to solve the major problem of solar stills, the energy loss in the form of latent heat of condensation. Solar desalination based on the HD principle results to an increase in the overall efficiency of the desalination plant and therefore appears to be the best method of water desalination with solar energy. At present, the HD desalination process is considered to be a promising technique for small capacity, solar driven desalination plants. Through this approach, relevant significant bibliography should be checked, as well as the facts and figures of various experimental units based on the principle of solar powered HD being constructed in different parts of the world (for an comprehensive review see reference [16]).

The process presents, indeed, several attractive features, including operation at low temperature, ability to combine with renewable energy sources (i.e. solar, geothermal), modest level of technology employed, simplicity of design and ability to be manufactured locally. Furthermore, it has the advantage of separating the heating surface from the evaporation zone, therefore, the heating surface is relatively protected from corrosion or scale deposits [2].

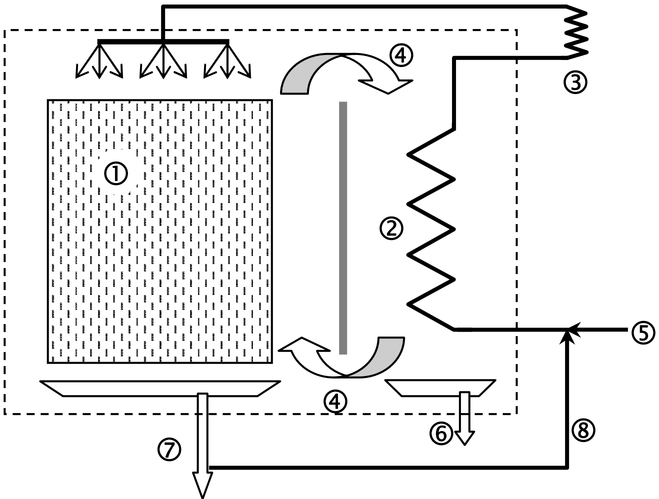

Figure 3.3 General layout of a HD unit: ① evaporation area, ② condensation area, ③ heat source, ④ air circulation, ⑤ feed saline water, ⑥ distillate, ⑦ brine, ⑧ brine recirculation reflux [2]

The basic operation principle of HD process is the evaporation of seawater and condensation of water vapour from the humid air taking place inside the unit at ambient pressure, while there is continuous humid air flow from the evaporator to the condenser including recovery of latent heat of condensation for the preheating of the feed water (Fig. 3.3). More thoroughly, when circulating air comes in contact with hot saline water in the evaporator, a certain quantity of vapour is extracted by the air. A part of the vapour mixed with air may be recovered as condensate, by bringing the humid air in contact with a cooling surface in another exchanger, in which saline feed water is preheated by the latent heat of condensation. On the basis of this principle, there have been proposed several configurations, differing through in the following points: the overall arrangement of the main unit (open-air closed-water cycle and open-water closed-air cycle), the circulation of the humid air between the evaporator and the condenser (natural or forced), the packing material placed in the evaporator (Raschig rings, tissues, fleece, stems) and the way to bring the heat to the unit (heating of the feed water or heating of the circulating air).

Although the first specific reference to the HD desalination process appeared in 1966 ("Humidification Cycle Distillation"), during the early 1960's, the Multi-Effect Humidity approach (MEH) was already introduced, describing the distillation by natural or forced circulation of an air loop saturated with water vapour. It has to be noted that the term "multiple effect" does not necessary refer to well distinguished stages, but to the fact that evaporation and condensation happen continuously over the whole temperature range between the condenser inlet and evaporator outlet.

Since its introduction, the MEH process has been evolved and various configurations have been investigated in different countries. The performance of the process has been improved over the years and an average daily production of 11.8 $l/m^2/day$ has been obtained from the systems, on an average gain output ratio (GOR) between 3 and 4.5 [17].

Membrane Distillation

Membrane Distillation (MD) is a thermally driven, membrane-based process. It first appeared in the end of the 60s, and it constitutes the most recent development in the field of thermal desalination processes. The process takes advantage of the temperature difference between a supply solution, coming in contact with the surface, on one side, of the readily selected micro-porous membrane, and the space, on the other side of the membrane (Fig. 3.4). This temperature difference results to a vapour pressure difference, leading to the transfer of the produced vapour, through the membrane, to the condensation surface. The overall process is based on the use of hydrophobic membranes, permeable by vapour only, thus excluding transition of liquid phase and potential dissolved particles.

Despite the fact that the process has been known for a considerable number of years, and the existing interest for commercial exploitation in desalination applications, the high cost and the problems associated with the use of membranes, have prohibited the development of commercial applications. On the other hand, during the last years, there has been carried out considerable research activity, as revealed by the existing relevant bibliography.

Within the field of desalination processes, it should be pointed out that the MD process takes place in atmospheric pressure, and temperatures not exceeding 80°C, requiring energy that can be provided by thermal energy systems. For this reason, MD is a process with several advantages, when regarded for the integration into solar, thermally driven, desalination systems. In addition, integrating membrane distillation with other distillation processes seems to be promising. For example, by using MD as a bottoming process for MSF or MED, the hot reject brine from MSF or MED could operate as the feed solution for the MD plant [18].

MD desalination seems to be a highly promising process, especially for situations where low-temperature solar, waste or other heat is available. When operating between the same top and bottom temperatures as MSF plants, MD with heat recovery can operate at Performance Ratios about the same as the commercial MSF plants. MD systems are very compact, similar to RO units, and at least 40 times more compact than other distillation desalination systems (such as MSF). It is obvious though that a more intensive research and development effort is needed, both in experimentation and in modelling, focused on key issues such as long-term liquid/vapour selectivity, membrane aging and fouling, feed-water contamination and heat recovery optimisation. Scale-up studies and realistic assessment of the basic working parameters on real pilot plants, including cost and long-term stability are also considered to be necessary.

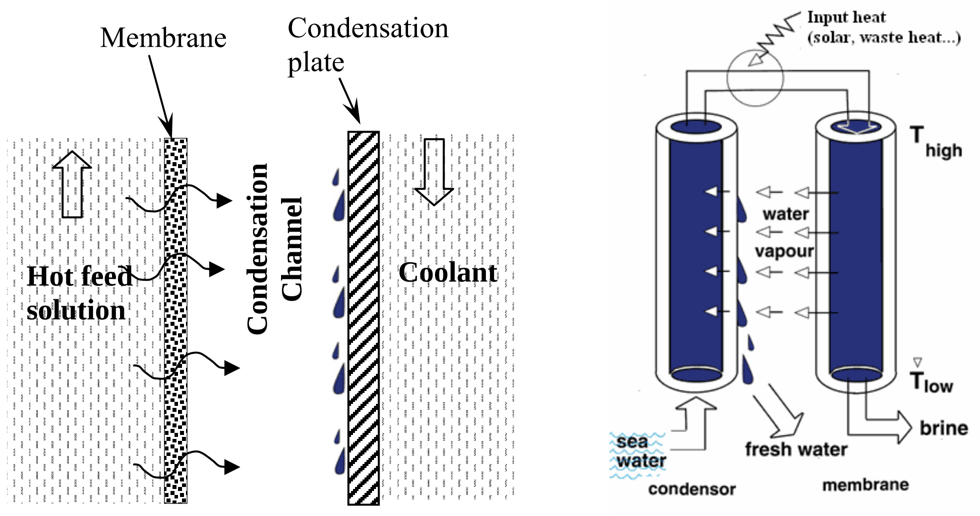

Figure 3.4.Principle of MD Process (left) and Schematic Diagram of a Typical MD System (right) [15]

3.2.1.2 Desalination powered by geothermal energy

Even though geothermal energy is not as common as solar (PV or solar thermal collectors) or wind energy in water desalination, it presents a mature technology, which can be used to provide energy for desalination at a competitive cost. Furthermore, and in comparison to other RES technologies, the main advantage of geothermal energy is that the thermal storage is unnecessary, since it is both continuous and predictable [19]. A high-pressure geothermal source allows the direct use of shaft power on mechanically driven desalination, while high temperature geothermal fluids can be used to power electricity driven RO or ED plants. However, the most interesting option seems to be the direct use of geothermal fluid of sufficiently high temperature in connection to thermal desalination technologies [7].

3.2.2 Electromechanical Processes

3.2.2.1 PV driven RO and ED process

There are mainly two PV driven membrane processes, reverse osmosis (RO) and electrodialysis (ED). The operational principles of RO and ED processes are described in Chapter 1. Comparing RO and ED, it may be concluded that in RO, water is transported through the membrane and the electrolytes are retained, while in ED the electrolytes are transported through the membrane and water is more or less retained [20].

Today, from a technical point of view, PV as well as RO and ED are mature and commercially available technologies. Besides, RO represents 42% of worldwide desalination capacity and more than 88% of membrane processes production. The feasibility of PV powered RO or ED systems, as valid options for desalination at remote sites, have also been proven [21]. Indeed, there are already commercially available, stand alone, PV powered desalination systems. The main problem of these technologies is the high cost and, for the time being, the availability (and resulting cost) of PV cells.

With regard to the process selection, the choice of the most relevant technology mostly depends on the feed water quality, level of technical infrastructure, (availability of skilled operators and of chemicals and membrane supplies) and user requirements.

Both RO and ED can be used for brackish water desalination, but RO constitutes a more realistic choice for seawater desalination, since it presents higher energy efficiency than ED when feed water salinity is higher than, for example, 2000 mg/l. ED is preferable for desalination of slightly brackish water, due to its relatively higher efficiency and robustness [20].

Considering feed water quality, pre-treatment is often more strict in the case of RO, since RO membranes are very susceptible to fouling. On the other hand, as ED only removes ions from the water, additional measures may be required (disinfection, removal of particles etc.).

With regard to the energy supply, RO presents lower energy consumption but ED shows better behaviour considering intermittent or fluctuating electrical power, as a consequence of changes in solar resource intensity.

Several RO or ED desalination systems driven by PV have been installed throughout the world in the last decades, most of them being built as experimental or demonstration plants. The challenge for the near future seems to be the development of small, autonomous, modular, flexible and reliable units, offering operation and maintenance at reasonable cost, in order to serve the niche of isolated users. On that level, the development of battery-less systems, as well as the use of recovery devices is of special importance.

Obviously, batteries increase the overall productivity of the PV system in an intermittent electrical power context induced by fluctuating solar radiation. However, they require careful maintenance and, hence, higher skills for sustainable operation, conditions which are proved to be difficult to achieve or secure at remote sites. For this reason, intermittent operation of direct connected PV-RO and PV-ED plant may be a promising option, which requires modification of common design rules for the electronics and the water processing part of the plant [22].

Another promising option is this of the energy recovery devices, especially in the case of seawater desalination. Pelton wheel turbines and pressure exchangers are commonly used in RO desalination to recover part of the feed pressure, but both systems have been available for large plants only. However, some applications have recently been reported, in which hydraulic motors and a Spectra Clark Pump were used to recover energy for smaller plants [23, 24].

3.2.2.2 Wind power driven RO and ED process

The electrical or mechanical power generated by a wind turbine can be used to power desalination plants. Like PV, wind turbines represent a mature, commercially available technology for power production. Wind power is an interesting option for seawater desalination, especially for coastal areas presenting a high potential of wind energy resources. Wind turbines may, for instance, be coupled with RO and ED desalination units shown in Fig. 3.5[25].

Several simulation studies examine the feasibility of wind powered desalination technologies, through the analysis of different types of membranes and feed water quality levels. There are also several installations powered by wind turbines, either connected to a utility network or operating in a stand-alone mode.

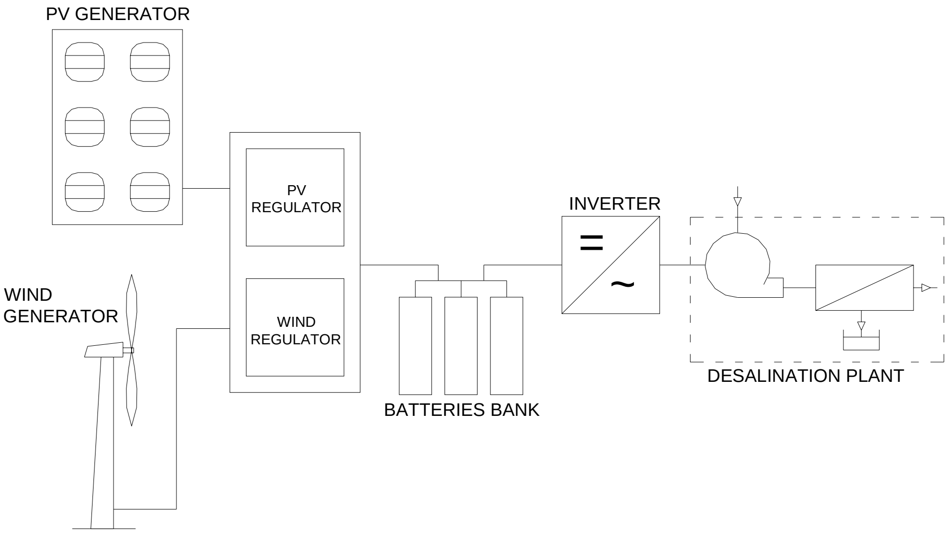

Figure 3.5. Diagram of a Hybrid (solar-wind) Desalination System [25]

3.3 CHOOSING THE BEST ADS UNIT

RES and desalination plants are two different technologies, which can be combined in various ways. The interface between the renewable energy system and the desalination system is met at the place/subsystem where the energy generated by the RES is serving the desalination plant. This energy can be in different forms such as thermal energy, electricity or shaft power. Fig. 3.6 shows the possible combinations [15]. It should be noted that, some changes have been introduced in the figure regarding relevant references [26]. These changes concern the insertion of direct Solar Distillation (SD), Humidification-Dehumidification (HD) and Membrane Distillation (MD) systems.

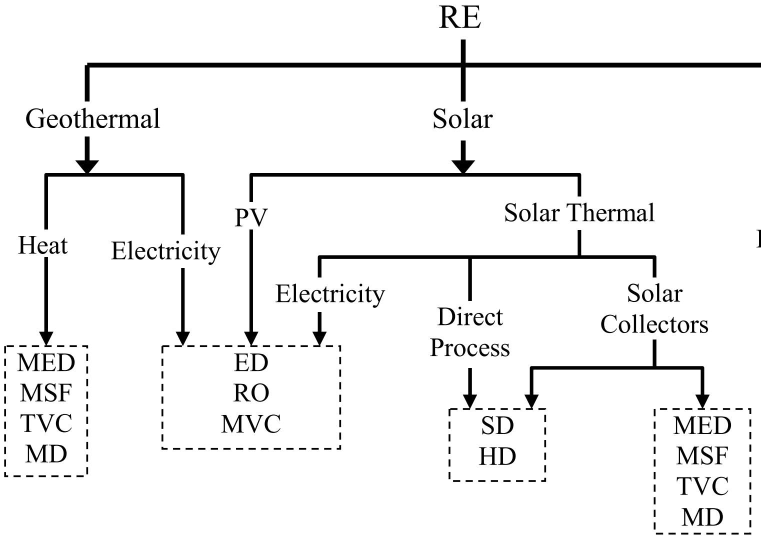

Figure 3.6. Possible Technological Combinations of Main Renewable Energies and Desalination Methods [15]

As it has been described in more detail in section 3.2, RES driven desalination systems fall into two main categories: (i) thermal process and (ii) electromechanical process. With regard to the energy source, a desalination plant powered by renewable energy is likely to be a stand-alone system at a location which has no grid electricity. Stand-alone systems are often hybrid systems, combining more than one type of renewable energy source, for instance, wind and solar energy or including a diesel generator. In order to ensure continuous or semi-continuous operation independent of weather conditions, stand-alone systems usually include a storage device.

In recent years, due to intensive Research and Development (R&D) efforts and to operation experience gained, advances in conventional desalination plants, steam or electrically driven, relate to significant efficiency increase and reduction of cost. On the other hand, the situation with renewable energy driven desalination systems is quite different. At present, these systems evolve through the R&D stage, or they are implemented as pilot plant size applications, presenting, in general, capacities from few m^3 up to 100 m^3. There have also been some demonstration plants of medium size, mainly powered with solar energy, but only a minority of those has presented satisfactory operation characteristics [7].

Not all the combinations of RES driven desalination systems are considered to be suitable for practical applications; many of possible combinations may not be viable under certain circumstances. The optimum specific technology combination must be studied in connection with various local parameters as geographical conditions, topography of the site, capacity and type of energy available in low cost, availability of local infrastructures (including grid electricity), plant size and feed water salinity. General selection criteria may also include robustness, simplicity of operation, level of maintenance required, size, transportation to site, pre-treatment needs and intake system to ensure proper operation and endurance of a plant at the often difficult conditions of the remote areas.

Fig. 3.7 shows that the most popular combination is the use of PV with RO [27]. Table 3.1 gives an overview of recommended combinations depending on several input parameters, noting though that some other additional combinations are also possible [7]. Indeed, PV is considered to be a proper solution for small applications in sunny areas. For larger units, wind energy may be more attractive as it does not require anything like as much land area. This is often the case in islands where there is a good wind regime and often very limited flat ground.

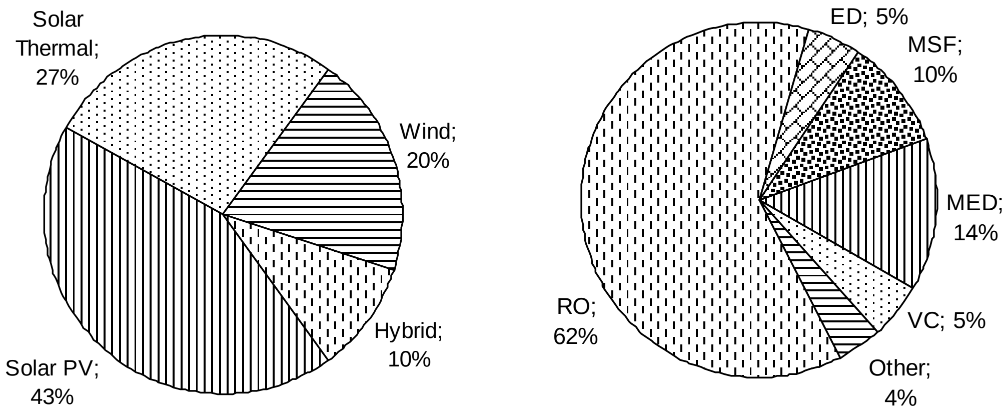

Figure 3.7. Renewable Energy Driven Desalination Processes and Energy Sources [25]

The general tendency is to combine thermal energy technologies (solar thermal and geothermal energy) with thermal desalination processes and electromechanical energy technologies with desalination processes requiring mechanical or electrical power. Therefore, the following combinations are the options most commonly used when desalination units are powered by renewable energy [7]:

- PV or wind-powered reverse osmosis, electrodialysis or vapour compression;
- Solar thermal or geothermal energy and distillation processes.

Table 3.1 Recommended Renewable Energy (RE) and Desalination Combinations [7]

Feed water quality	Product water	RE resource available	System size			Suitable combination
			Small (1-50 m^3/d)	Medium (50-250 m^3/d)	Large (>250 m^3/d)	
Brackish Water	Distillate	Solar	*			Solar Distillation
	Potable	Solar	*			PV-RO
	Potable	Solar	*			PV-ED
	Potable	Wind	*	*		Wind-RO
	Potable	Wind	*	*		Wind-ED
	Distillate	Solar	*			Solar Distillation
	Distillate	Solar		*	*	Solar Thermal-MED
	Distillate	Solar			*	Solar Thermal-MED
	Potable	Solar	*			PV-RO
Sea Water	Potable	Solar	*			PV-ED
	Potable	Wind	*	*		Wind-RO
	Potable	Wind	*	*		Wind-ED
	Potable	Wind		*	*	Wind-MVC
	Potable	Geothermal		*	*	Geothermal-MED
	Potable	Geothermal			*	Geothermal -MED

On a more practical level, the factors affecting the selection of the best (optimum) desalination technology include:

- *Feed water quality (availability, salinity):* distillation technology suits seawater, ED suits only brackish water and RO can be used in both.

- *Product water quality*: Distillation technology produces distilled water with very low Total Dissolved Solids (TDS) of about 10-25 mg/l. Distillate water requires post treatment to make it less corrosive and be suitable as potable water. RO and ED produce potable water of 350 – 500 mg/l.

- *Product water quantity (or rate):* It represents the water demand that must be estimated prior to the design of desalination plant as it influences the plant overall system design. With RE the product water rate will vary from site to site, from winter to summer. Product water fluctuation can be accommodated quite easily with suitable water storage tank. For desalination plant using well water, the availability of feed water source should be determined and compared with product water demand.

- *Energy Requirement:* Selection of thermal, electrical or mechanical energy use shall be considered depending on the desalination plant requirement, and its cost. Furthermore, the unit power per cubic metre of product water affects the desalination plant size and renewable energy size and cost. For MSF and MED, around 80 kWh of thermal energy is required per cubic metre of product water in addition to 2.0 to 5.0 kWh electrical energy. For VC, energy is reduced to 8 – 10 kWh/m^3, whereas for RO, energy is influenced by feed water salinity and ranges from 4 – 13 kWh/m^3 for seawater. For brackish water, RO and ED plants requires from 0.5 to 2.5 kWh/m^3. It should be noted that often electrical power is more valuable and expensive than thermal power.

- *Desalination Technology:* Selected technology must meet the water demand, suits available feed water & product water quality, the specific energy required and match available RE.

- *RE source availability:* This depends on site, obstructions at a given site (that may causes shad for solar and turbulence for wind). As RE is variable, energy storage system would be needed for the case of the desalination plant operating continuously, increasing the energy cost. For example, battery for electrical and insulated tanks for thermal, possibility of hybrid system as wind/PV, Solar thermal with PV or with wind, etc.

- *Other Factors:* Such as capital & running costs, O&M expertise, brine disposal.

Annex 3.1 [28, 29] provides a brief table to aid in decision of best ADS option for the particular cases depending on the feed water, desired output, renewable resource, etc. together with helpful remarks on each case.

In any case, the final selection of the best pair and size of the system should be strongly dependent upon the conclusions of cost analysis. This analysis is usually based on a model, predicting the water outcome of the candidate systems under the specific site conditions. Very often, the accuracy of this model is limited by the lack of detailed process model or reliable meteorological data. Although there is no extensive reference concerning the actual cost of water produced by these installations, prices that have been theoretically calculated [8, 30] for large capacities are higher than those of conventional desalination plants. In conclusion, it should be considered whether this high cost is the main problem for RES driven desalination installations being scarce, as a glass of drinking water in remote and arid regions is actually precious and cost can be considered a matter of minor weight.

3.4 MARKET INFORMATION

The cost of desalting water is determined by a number of technical and economic factors. The major categories are capital costs, and operating - maintenance costs. These two categories are interdependent; that is, if one component increases the other component usually decreases. Furthermore, regarding renewable energy for desalination, not only the economic effectiveness but also the availability and maturity of each particular technology has to be considered. From this point of view, the situation of market regarding the required equipment presents a significant parameter, that has to be included in the process of best technology selection.

While the market of large installations, supported by conventional energy sources is more or less settled, the market of ADS is at its infancy, presenting a rather fuzzy situation. In effect, it is difficult to talk about an ADS market, given the small number of installed ADS. Until now, commercial development of simple, reliable, and inexpensive desalting units has been very limited due to high engineering and manufacturing costs. Nevertheless, there is continuing interest in developing desalting systems for rural use. To maintain energy costs at reasonable levels, renewable energy technologies are expected to roughly compete with scarce and quite expensive conventional fuels, such as coal and oil, in small-scale applications. This is only the case for in remote areas, where the cost of energy transport is higher than the cost of local generation.

It is thus more realistic to refer to the market of the components that constitute an ADS, whether these concern the energy supply from the renewable source or the desalination unit itself.

Through a detailed examination of ADS technologies, concentrating to the more technologically mature products, the following observations are outlined based on the outcomes of the ADS market investigation performed within the framework of the ADIRA Project [31]):

3.4.1 Solar Stills

The "Solar Stills" concept has been widely used for its manufacturing simplicity, operation and maintenance. For this reason, a justifiable solution would be to develop installations based on local resources and materials. Significant advantage is the existence of local industry for flat plate solar collectors, due to the similarities in manufacture. There are, however, very few companies who can offer ADS units using solar stills technology. The reason is mainly due to the low market interest and the relatively low performance of the solar stills. It should be noted that typical productivity for a simple solar still lies within the order of 4-6 l/m^2/day for a sunny day. The unit capital cost for a typical commercially available unit is about 100-250 €/m^2.

3.4.2 Humidification - Dehumidification

Even though several experimental units have been developed through the last decades, today there is only one commercially available system based on the humidification-dehumidification. The capital cost for the desalination unit lies between 9.2-14.1 €/l of nominal daily production, depending on the size of the unit. Cost of the solar thermal system, which is strongly dependent on the quality of the collectors and the existence of local industry also has to be added to this cost. Nevertheless, a realistic estimate of this cost is within the range of 10-30 €/l of nominal daily production. In the case where a complete energy independency is targeted, cost of the subsystem for the electrical energy production (pumps, control system), also has to be considered, which ranges from 4 to 11 € per liter of nominal daily production.

3.4.3 MED System with Thermal Solar Collectors

There are not standardised commercially available solar-driven MED systems, thus it is obvious that the cost can present major fluctuation, depending on the specific characteristics of each application (type of solar collectors, existence of local resources etc). A plant that was installed in 1985, at Umm Al-Naar (United Arab Emirate) can be referred as an example. The unit used 1862 m^2 of solar collectors' field (evacuated tubes) and had been designed to produce 80 m^3/day of distilled water from sea water. According to the figures reported in 1996, the capital cost for the unit was 2,136,667 USD. A projected cost for larger solar thermal – MED unit of 5000 m^3/day, establishes a water cost around 2.0 €/m^3 and would require a land area over 10 ha covered with solar collectors.

3.4.4 Membrane Distillation with Thermal Solar Collectors

This technology is rather recent, and has only been used in pilot-demonstration applications, usually within the framework of funded research programs. Thus, there are no realistic market figures, apart from the cost of the solar thermal energy system. This is strongly dependent on local market characteristics, representing a value of the order of 200-500 €/m^2 when flat plate collectors are used. There are also other technological solutions which can be used i.e. waste heat, concentrating collectors, etc. and their cost has to be estimated in accordance to the specific requirements of each application.

3.4.5 PV Driven RO

A number of RES have been reported as the sufficiently promising for power supply to RO desalination systems, one which is the Photovoltaic (PV) electricity generation system. PV systems and membrane desalination units are available everywhere, and their prices decrease from year to year. Besides, RO plants are also available in small sizes (fractions of m^3/h). Small size (compact) PV-RO units can easily be built to supply water for small villages or even single houses or residence complexes.

As a general rule, a sea water RO unit has relatively low capital cost and significant operation and maintenance (O&M) cost due to the high cost of membrane replacement and energy. Energy requirements for sea water RO is around 5 kWh/m^3 for large units with energy recovery, while it may exceed 15 kWh/m^3 for small units without energy recovery. For brackish water, the energy requirement lies within the range of 1-3 kWh/m^3. The capital cost of a brackish-water RO unit ranges between 235 $€/m^3$/day and 1300 $€/m^3$/day, while for seawater RO it raises to 760 $€/m^3$/day to 3800 $€/m^3$/day. It should be noted that small units present higher capital cost than the large units. For a typical small RO unit (4.0 m^3/day), the capital cost can exceed 1500 €.

PV is a relative new technology and was originally used in space applications. Since its exploitation on earth applications, PV has presented a substantial cost reduction and prices keep falling. On the other hand, PV technology is economically attractive in remote applications as it is characterised by very low O&M cost in comparison with other RE technologies. Even at higher system cost, PV could be the solution for decentralised small size desalination units.

As a rule of thumb, the cost of 1.0 Watt peak (Wp) varies from 3 – 7 € depending on the power value, material used, manufacturer and the added auxiliaries. With the addition of supporting components (controller, batteries and DC/AD converter), the overall cost of Watt (peak) increases. As an example, a PV system that costs 6.0 €/Wp, would produce 1.7 kWh/kWp of electrical energy on an expected life time of 25 years, resulting to 0.25 €/kWh cost of electrical energy, (to this, one must add all relevant other costs associated with the installation and operation of the PV).

For a complete PV driven RO seawater unit, the water cost ranges from 5.5 to 20 $€/m^3$ referring to systems with capacity from 120 m^3/day to 12 m^3/day respectively. Also, for PV-RO brackish water desalination a water cost of around 5 $€/m^3$ for PV-RO systems of 250 m^3/day has been reported. For the same system size and same feed water salinity a cost of 4 $€/m^3$ for PV-ED system has also been reported [28]. It should be noted that the above mentioned cost figures include both investment and operational costs.

3.4.6 Wind Energy and PV Driven RO

Due to the random variation of wind power, appropriate power control is required for matching the input power to the desalination load. Power matching requires some form of energy storage devices such as flywheels, storage batteries or their combination. In addition, inverters rectifiers and variable frequencies devices are used in most designs as RO and VC motors require AC while ED requires DC. For a wind – RO system, in a windy location prices can be reduced to 5 $€/m^3$.

- As an indication, based on the experience of specific installation, cost of an RO unit can be 40,800 € for a unit with a capacity of 800 l/h, cost of a PV power supply system can be 25,200 € for 4.8 kWp (5.25 €/Wp) and cost of a wind power supply system can be 30,000 € for a nominal power of 15 kW [31].

3.5 GLOBAL EXAMPLES OF OPERATING ADS UNITS

Some examples of ADS units, currently in operation worldwide and plants that operate with various desalination and RES combinations with different capacities are summarised and presented in Table 3.2.

Table 3.2 Examples for ADS Applications

Plant location	Water type	Desalination unit, capacity	RES installed power	Year of commissioning	Unit water cost	Ref.
Abu Dhabi, UAE	SW[1]	80 m^3/d MED	1862 m^2, collectors	1984	6.6 €/m^3	[32]
Jeddah, Saudi Arabia	SW	3.2 m^3/d RO	8 kWp PV	1987	-	[33]
Red Sea, Egypt	BW[2]	50 m^3/d RO	20 kWp PV	1991	-	[34]
Borj-Cedria, Tunisia	BW	0.1 m^3/d SD[3] 0.25 m^3/h RO	4 kWp PV 2 W/T	1980	-	[34]
Lampedusa, Italy	SW	3 +2 m^3/h RO	100 kWp PV	1990	6.5 €/m^3	[33]
Maagan Michel, Israel	BW	0.4 m^3/h RO	3.5 kWp PV, 0.6 kW W/T [4]+3 kW diesel	1997	–	[33]
University of Almeria, Spain	BW	2.5 m^3/h RO	23.5 kWp PV	1990	–	[35]
Gran Canaria-ITC, Spain	SW	50 m^3/d MVC	230 kW W/T	1988	-	[33]
Pajara, Spain	SW	56 m^3/d RO	225 W/T +2 diesel engines	1993	-	[36]
Pozo Izquierdo-ITC, Gran Canaria	SW	3 m^3/d RO	4.8 kWp PV	1998	-	[37]
Almeria, Spain	SW	3 m^3/h MED	6.5MWht collectors	1988	3.5 €/m^3	[33]
Syros island, Greece	SW	900 m^3/d RO	500 kW W/T	1998	-	[33]
Kimolos island, Greece	SW	80 m^3/d MED	Geothermal, 61°C	2000	-	[38]
CRES, Greece	SW	130 lt/h RO	4 kWp PV, 1 kW W/T	2002	-	[33]
Agricultural University of Athens, Greece	SW	100 lt/h RO	846 kWp PV	2004	7 €/m^3	[22]

[1]: Sea Water
[2]: Brackish Water
[3]: Solar distiller
[4]:Wind Turbine

3.6 REFERENCES

[1] Delyannis E., Belessiotis V. (1996) A historical overview of renewable energies, Proc. Mediterranean Conference on "Renewable Energy Sources for Water Production", 10-12 June 1996, Santorini, Greece, EURORED network, CRES, EDS, p. 13-17.

[2] MEDRC R&D Report (2002) A comprehensive study of solar desalination with a humidification-dehumidification cycle, ZAE Bayern, Munich, Germany.

[3] Rheinlaender J. and Graeter F. (2001) Technologies for desalination of typically 10 m^3 of water per day, Desalination, 139, p. 393-397.

[4] Rommel M., Hermann M., Koschikowski J. (2000) The SODESA project: development of solar collectors with corrosion-free absorbers and first results of the desalination pilot plant, Proc. Mediterranean Conference on Policies and Strategies for Desalination and Renewable Energies, 21–23 June 2000, Santorini, Greece.

[5] Abu-Jabal Moh'd S., Kamiya I., Narasaki Y. (2001) Proving test for a solar-powered desalination system in Gaza-Palestine. Desalination, 137, p. 1-6.

[6] García-Rodríguez L. (2003) Renewable energy applications in desalination: state of the art, Solar Energy 75, Issue 5, p. 381-393.

[7] MEDRC R&D Report (2001) Matching Renewable Energy with Desalination Plants, IT Power Ltd.

[8] Rodríguez-Gironés, Rodríguez M., Pérez J., Veza J. (1996) A systematic approach to desalination powered by solar, wind and geothermal energy sources, Proc. Mediterranean Conference on Renewable Energy Sources for Water Production, Santorini, Greece, 10–12 June 1996, p. 20–25.

[9] Bucher W. (1998) Renewable energy sources and seawater desalination: an assessment of methods and potential, Proc. ASRE 89, International Conference on Applications of Solar & Renewable Energy, 19-22 March 1998, Cairo.

[10] Safi M.J. and Korchani A. (1999) Cogeneration applied to water desalination: simulation of different technologies. Desalination 125, p. 223–229.

[11] Lu H., Walton J.C., Swift A.H.P. (2000) Zero discharge desalination. The International Desalination and Water Reuse Quarterly 10/3, p. 35–43.

[12] Goosens M. F. A. Sablani S.S., Shayya W.H., Paton C. and Al-Hinai H. (2000) Thermodynamic and economic considerations in solar desalination, Desalination 129, p. 63-89.

[13] Adhikari R. S., Ashvini Kumar and Garg H.P. (2000) Techno-economic analysis of a multi-stage stacked tray (MSST) solar still, Desalination 127, p. 19-26.

[14] Bouchekima B., Gros B., Ouahes R. and Diboun M. (2001) Brackish water desalination with heat recovery. Desalination 138, p. 147–155.

[15] Mathioulakis E., Delyannis E., Belessiotis V. (2007) Desalination by using alternative energy: Review and Sate-of-the-art, Desalination, Vol. 203, 346-365,.

[16] Bourouni K., Chaibi M.T., Tadrist L. (2001) Water Desalination by humidification and dehumidification of air: state of the art, Desalination 137, p. 167-176.

[17] Müller-Holst H., Engelhardt M., Scholkopf W. (2000) Multi Effect Humidification Sea Water Desalination using Solar Energy or Waste Heat - Various Implementations of a New Technology, Proceedings of the Mediterranean Conference on Policies and Strategies for Desalination and Renewable Energies, 21-23 June 2000, Santorini Island, Greece.

[18] Drioli E., Lagana F., Criscuoli A. and Barbieri G. (1999) Integrated membrane operations in desalination process, Desalination, 122, p.141-145.

[19] Barbier E. (2002) Geothermal energy technology and current status: an overview, Renewable and Sustainable Energy Reviews 6, p. 3–65.

[20] MEDRC R&D Report (2003) PV powered desalination, Ecofys BV.

[21] MEDRC R&D Report (2000) VARI-RO Solar powered desalting study, SAIC, USA.

[22] Mohamed, Sh. E., Papadakis, G., Mathioulakis E. and Belessiotis, V. (2006) An experimental comparative study of the technical and economic performance of a small reverse osmosis desalination system equipped with a hydraulic energy recoverey unit, Desalination 194, p. 194: 239-250.]

[23] Mohamed, Sh. E., Papadakis, G., Mathioulakis E. and Belessiotis, V. (2007) A direct coubled photovoltaic seawater reverse osmosis desalination system toward battery based systems – a technical and economical experimental comparative study, Desalination (in press).

[24] Mohamed Sh., Papadakis G., Mathioulakis E. and Belessiotis V. (2005) The effect of hydraulic energy recovery in a small sea water reverse osmosis desalination system; experimental and economic evaluation, Desalination 184, p. 241-246.

[25] Carta J.A., Gonzalez J., Suibiela V. (2003) Operational analysis of an innovative wind powered reverse osmosis system installed in the Canary Islands, Solar Energy 75 153–168.

[26] Leitner G. F. (1998) Is There a Water Crisis?, Int. Desalination and Water Reuse Quarterly 7, No 4, p. 10-21.

[27] Tzen E. and Morris R. (2003) Renewable energy sources for desalination, Solar Energy 75, issue 5, p. 375–379.

[28] EC-THERMIE Program, (1996) Desalination Guide Using RE, EC-Contract No. SUP-0940-96-HE.

[29] Soldatos, P. G., Mohamed, E. and Assimakis D. (2007) Autonomous Desalination Systems (ADS) Sizing and Cost Analysis: Methodology, ADIRA project internal document, AUA, Greece.

[30] Glueckstern P. (1999) Design and operation of medium and small size desalination plants in remote areas, Desalination 122, p. 123- 140.

[31] Autonomous Desalination System Concepts (2007) Final WP2 Report, ADIRA Project internal document.

[32] El-Nashar, A.M. (1985) Abu Dhabi solar distillation plant, Desalination 52, p. 217–234.

[33] Desalination Guide Using Renewable Energies (1998) THERMIE Programme, CRES, Greece, ISBN 960-90557-5-3.

[34] Maurel, A. (1991) Desalination by reverse osmosis using renewable energies (solar-wind) Cadarche Centre experiment. Seminar on New Technologies for the Use of Renewable Energies in Water Desalination, Commission of the European Communities. DG XVII for Energy, Centre for Renewable Energy Sources, Athens.

[35] Andujar Peral, J.M., Contreras Gomez, A., Trujillo, J.M. (1991) IDM-Project: results of one year of operation. Seminar on New Technologies for the Use of Renewable Energies in Water Desalination, Athens, 26–28 September, 1991. Commission of the European Communities, DG XVII for Energy, CRES (Centre for Renewable Energy Sources).

[36] Garcia-Rodriguez, L. (2003) Renewable energy applications in desalination: state of the art. Solar Energy, 75, p. 381–393.

[37] Herold, D., Neskakis, A. (2001) A small PV-driven reverse osmosis desalination plant on the island of Gran Canaria, Desalination, 137, p. 285–292.

[38] Karytsas, C., Alexandrou, V., Boukis, I. (2002) The Kimolos Geothermal Desalination Project. In: Proceedings of the International Workshop on Possibilities of Geothermal Energy Development in the Aegean Islands Region, Milos Island, Greece, p. 206–219.

4

Institutional and Policy Issues

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4.1 INTRODUCTION

As this handbook is intended to be a decision support tool, after presenting the physical and technical aspects in the previous chapters, this chapter gives a summary of how the institutional and policy conditions and studies can affect both the promotion and implementation of ADS.

It intends to draw the attention of project developers to various institutional and policy issues they should check before engaging in the ADS installation business in a country. This chapter will guide the reader to a quick evaluation of the framework conditions and assist him to make an assessment of the administrative difficulties that will be faced during planning, constructing and operating ADS. The study focuses on four areas:

1. Governmental policy and programmes
2. Legislation and administrative issues
3. Water prices
4. Institutional framework

There are examples given below from four target countries, namely Morocco, Turkey, Jordan and Egypt, but the analysis applies to any country, especially in the Mediterranean region. At the end of this chapter are given recommendations on the conditions to check, procedures and rules to follow and criteria to use for the evaluation of the potentialities in a particular country for ADS business.

4.2 OVERVIEW OF FRAMEWORK CONDITIONS IN THE MEDITERRANEAN COUNTRIES

With the dramatic climate changes as observed in recent years, the south Mediterranean countries are facing an increasingly serious water scarcity problem due to decrease in precipitation levels, overexploitation of resources and inefficient use of water, such as traditional irrigation activities and network losses. The water policy in these countries tries to deal with these problems in various ways. The exploitation of non-conventional water resources, including desalination, has become necessary. ADS have been considered only in very few cases as potential alternatives for fresh water supply of remote rural settlements, where brackish and/or seawater is the only available resource within economically reasonable distances. In most cases, these areas have abundant solar/and or wind energy resources. ADS technology may therefore play a prominent role in this regard. The assessment of possible barriers to investing in the development of ADS is therefore required.

From the administrative and management point of view, many countries are turning to decentralisation and, partly, liberalisation of the water management sector in order to make the supply more efficient. For facing the inevitable imbalance between increasing demand and available resources, exploitation of non-conventional water resources has emerged as an alternative solution. This includes mainly wastewater reuse and seawater or brackish water desalination. The desalination option requires quite high energy input, which is a problem in itself as most of the water scarce countries are also poor in indigenous conventional energy resources. Still, autonomous desalination powered by renewable energy has not yet received sufficient attention as an alternative solution for rural areas.

By its nature, the water sector involves many actors that can be divided into three levels, according to their responsibilities. A typical Mediterranean country structure of the water sector includes [9]:

- *Decision making*: This includes typically Ministries or other entities directly related to the Government which are involved in policy and planning
- *Executive*: Usually this role is undertaken by Governmental organisations under the decision making bodies
- *User-level*: Various governmental or non-governmental organisations responsible for the operation and maintenance of the water supply structures

The decision making level usually includes one Ministry that has the overall control of the water sector. But there are always other Ministries that get involved to a smaller or a larger degree, such as the Ministries responsible for Agriculture, Development, Public Works, Environment, etc. This may lower the efficiency of the sector and impede decision making. Some countries, like Morocco, have shown good practice by establishing a national council that involves all relevant actors and is the higher body for setting the country’s water policy. This allows the ADS community to have a clear view of the decision makers that have to be targeted in order to bring the technology in the policy agenda. The main actors involved in the water sector of the four Mediterranean target countries (Egypt, Jordan, Morocco and Turkey) are summarised in Annex 4.1 [3].

The main critical bodies about the framework conditions in a country are the entities responsible for the executive level. The closer this is to the local actors, the more decentralised the system is, leaving room for local solutions, like autonomous desalination. The modern approach of integrated water resources management requires an executive level not narrower than the river basin. This is sometimes too complicated to achieve, as the traditional administrative borders are rarely the same with the river basin borders. Still most countries are moving towards this direction in their water supply structures.

The user-level is in most countries different for urban and rural areas. The cities have high water demand concentrated in a relatively small geographical area, which creates economies of scale, while the main infrastructure is usually already in place. This creates favourable conditions for a profitable utility operation and it is undertaken either by public or by private companies. In rural areas though, the water supply issue is more challenging and in many cases subsidies are necessary to provide safe drinking water to the population. Typically, the water supply responsibilities are undertaken by the municipality/local authorities in villages that are large enough to have adequate administrative structures. For smaller communities, the responsibility goes back to the executive level or even to Ministry Departments responsible for the rural areas. Good decentralisation practice is to pass the water supply responsibility to local water users’ associations, supervised by the responsible entities as has been already adopted in Morocco for example.

The structure of the water sector is constantly evolving as new challenges are appearing. Especially in the last decade, the decentralisation and privatisation trends have played an important role in transforming the water sector in the Mediterranean. This contributes to creating more favourable conditions for ADS. However, for a pragmatic assessment of the conditions in a country for ADS installations, a more detailed examination is required, especially of the available governmental support programmes, the licensing procedures, the current water prices, the administrative structures and the availability of the necessary technical staff.

4.3 IMPACT ON ADS IMPLEMENTATION

4.3.1 Governmental Policy and Programmes

ADS are not specifically mentioned or treated separately in the current water policies and programmes in any of the countries that have been examined. However, each country has a set of policies in the water and energy sector, which may affect ADS implementation. Population increase and water demand growth, water scarcity, industrialisation, promotion of efficient water use, rapid degradation of the quality of water resources and generalisation of access to fresh water are the main driving forces of the water policies. Integrated water management and exploitation of non-conventional resources are now being considered in order to alleviate the stress on the available resources. In addition, decentralised management oriented to the specific needs of the local level, privatisation and efficient use of water resources in agriculture are recognised as key issues. All these aspects are positive and will help in the implementation of ADS. However, the effectiveness of these policies depends on whether and how they are enforced.

In some countries, the governments set up programmes that offer support to rural communities in order to establish their water and energy infrastructure. This is the case for example of the INDH (National Initiative for Human Development) programme in Morocco. In the case of Turkey, the supports are in the form of VAT exemption of water supply for village residents. Solidarity type taxes to support the generalisation of access to water are also considered. These programmes can have positive effect on ADS implementation [7], [10].

Autonomous desalination of brackish (BW) or seawater (SW) is a relatively new approach for decentralised water supply for rural areas. The pursued decentralisation in the Mediterranean countries is expected to have positive effects on the adoption of ADS as a solution to water scarcity problems in rural areas. However, ADS is still considered as an expensive and not yet mature technology by the relevant decision makers in most countries, especially in rural areas. In many cases, the stakeholders may not even be aware of the ADS option. This shows that, even if policy conditions are favourable, targeted awareness raising efforts are necessary for ADS “fertility” on the good framework [5].

The political support for renewable energy that is already expressed or underway in most countries, does also offer a positive framework for ADS. However, sometimes the support is for grid connected systems and stand-alone installations are not addressed.

Decentralisation of water and energy supplies is implemented in rural areas with rural electrification and water supply programmes, as opposed to the traditional approach of centralised solutions and extended distribution networks. This approach is suitable for scattered villages and low population densities, which are the main targets of the ADS market. There are numerous national and international programmes that offer financial and technical support, expanding from the planning to the operation phases [6]. This will also lead to the promotion and dissemination of small-scale technologies such as ADS.

Governments should further encourage the transfer of responsibility for managing and exploiting water resources supply to the local level (Basin agencies, local authorities, Non Governmental Organisations (NGOs) and user associations). This will provide opportunities to consider alternative water supplies such as ADS and will allow efficient monitoring and management of the systems [2].

4.3.2 Legislation and Administrative Issues

As already mentioned, there are no specific laws or regulations addressing directly ADS. Therefore, for installing and operating ADS, various different licences may be required for the different components and processes involved. The exact number and nature of licenses depends on the country, the site within the country and the technical characteristics of the planned unit. Because the authorisation procedure is not designed for desalination units but for more general purposes, difficulties and inconsistencies may arise. There are various levels of complication in the different countries, but the situation is changing as the general water sector framework is evolving.

The required permissions and the related process is a key factor for assessing the friendliness of a country to ADS project developers. A detailed study of Morocco, Egypt, Turkey and Jordan has been carried out within the ADIRA project [7] where the exact conditions for these countries can be seen. The main results are summarised in Annex 4.2. Here, an overview of possible licences that any project developer has to examine and check in the target country is presented:

Withdrawal/utilisation of seawater and brackish water

Borehole drilling and well digging require authorisation from the relevant authorities. For example in Morocco the River Basin Agencies are responsible for issuing such permits. However, in most cases there are thresholds for borehole depths, below which no permission is necessary.

Water pumping from the well then requires sometimes a separate authorisation when the flow rate exceeds a threshold value. This separate authorisation process increases the required resources and time. Especially in the case of seawater withdrawal, in some countries a permit is also required, which is issued from the authorities that have to do with the Marine Environment and not with traditional water supply, which may further complicate things.

Brine disposal

There are no laws addressing directly brine disposal in most of the cases. However, there is usually regulation for liquid waste disposal in general and brine has to be considered and regulated by it. How helpful this is, or what barriers are imposed to ADS by the liquid discharge regulation, depends on the specific conditions in each country. There are very different kinds of regulations in place, and they are also updated quite often to adapt to the latest developments and international standards or EU Directives. However, until specific regulation appears for desalination as such, potential problems may arise. In many cases, small desalination units end up discharging the brine illegally as it is impossible to comply with existing legislation [1] or as the measures to enforce environmental protection laws are not yet taken rigorously.

Construction in coastal zones

Authorisations for constructions in coastal zones (Maritime Public domain) are given by Ministry in charge of the sea within preset distances from the coastal line (defined by laws); these distances are 50 m in the case of Morocco and Turkey and 200 m for Egypt. Constructions are forbidden at distances below these thresholds. In some countries authorisations have to be obtained from another governmental authority.

Drinking water quality

Monitoring the quality of water must be permanently ensured by the producer and the distributor. Most countries have drinking quality standards or use the WHO standards in this regard. The Ministry of Public Health is the main water quality regulator.

Renewable energy installations

Installation and operation of small scale standalone renewable energy systems may also require licensing in some countries (for example in Turkey). In Egypt, Jordan and Morocco, no licensing is needed for such systems but certification of the parts of the system (panels, batteries, etc.) can be performed by national renewable energy centres (example CDER in Morocco). Grid connected systems require permits and compliance with national standards regarding power quality, harmonics, frequencies.

Import taxes and VAT (Value Added Tax)

Import taxes and customs fees for renewable energy equipment have been reduced in some countries, but such fees need to be further reduced for this kind of equipment as well as for technologies intended for water treatment. This will contribute to lowering the initial investment cost of ADS closer to levels that will be not prohibitive for the targeted population groups known for their low incomes.

The administrative framework shows that procedures regarding water supply and renewable energy supply are separated in most countries and therefore separate applications need to be filled for each part of the ADS. In addition, even in the case of water supplies, several applications need to be submitted (digging wells or drilling boreholes, water withdrawal, brine disposal). This may lead to longer time requirements and consequent delays to obtain licenses for ADS and an increased cost.

Another point is that there are several governmental authorities involved in these procedures, especially in case of water treatment and supply, which usually fail to establish a proper coordination for the implementation of intended work.

The positive aspect is that legislations in all these countries provide some exemptions for several licenses in the case of small-scale applications. For example, wells with depths lower than 10 m and the plants that supply water intended for human consumption, with an output not exceeding 10 m³ per day are exempt from the requirements in Turkey. However, typical ADS destined for small (rural) communities with capacities higher than 10 m³/day, will require licensing. In Turkey, tourist facilities with small-scale ADS for their own freshwater requirements also do not need to get a license from the Ministry of Health [10].

The allowance for installation of water-treatment plants in coastal regions beyond the preset distances from the shoreline is also a positive factor for ADS implementation in coastal regions to operate with seawater.

The major positive aspect of the legislation on renewable energy sources is that in all countries, RES operators producing off-grid electrical energy for their own needs are exempt from licensing requirements. In addition reductions of VAT and import taxes are a positive aspect.

A clear procedure for licensing of decentralised, non-conventional water-treatment and supply units (such as ADS) should be developed and a single authority or a designated committee involving representatives from related institutions should be responsible for the evaluation and licensing of such approaches. Nonetheless, it would be more encouraging for possible ADS operators to be required to receive a single license for ADS implementation.

4.3.3 Water Prices and Subsidies

Water tariffs and the procedures of their definition vary from country to country. However, in all the cases examined, the municipal and rural tariffs are subsidised especially for social consumption blocks. In addition, cross-subsidies between consumption blocks are used in some countries.

The subsidies distort the market function and are not in favour of the development of ADS as an alternative water supply. These subsidies make municipal water prices very low when compared to water produced by desalination systems. The tariffs of irrigation water, which represents a very substantial part of the water consumption in the Mediterranean countries, are very cheap compared to municipal water.

Water tariffs based on the cost recovery principle will allow ADS to compete with other solutions especially when other externalities are also considered (health problems, time for other activities especially for women, etc).

The main problems faced in ADS implementation in rural areas of the Mediterranean countries are:

- The low income of rural population and the absence of access to the investment capital required for purchasing and installing ADS.
- The financial resources of the rural communes which are very limited
- The high initial investment cost of ADS.

Suitable support schemes, preserving market function, need to be developed, such as:

- Directly financing the infrastructure (the right of having access to potable water)
- Providing substantial financial incentives for ADS operators (users associations, village associations, NGOs, etc.)
- Encouraging private sector involvement in these decentralised water supplies
- Making the produced water affordable to the poor rural people by providing direct support to end-users (shifting cross-subsidies and taxes to ADS, solidarity taxes as in the case of the PAGER programme in Morocco). This will enable the sharing of additional cost of water produced by ADS among the entire population of a country. This approach has been followed in rural electrification by renewable energies in some countries as well as in improving access to drinking water.

Customs fees, import and VAT taxes have been substantially lowered for renewable energy systems, this provides an incentive for ADS implementation. Public funds can be directed to ADS-related public-private partnerships or business formation. Public funds can also be raised from additional fees on irrigation water, drinking water, fossil fuels. This practice is widely used in the development of renewable energies.

4.3.4 Institutional Framework

As presented above, the institutional framework of the water sector is rather complex, fragmented and characterised by multiple actors, mostly public organisations. Irrigation, water production, domestic water supply and sanitation, hydropower generation, water quality control and environmental compliance of water related projects are carried out separately, by different entities (ministries, departments, agencies, etc.). Very often, this results in lack of coordination and unproductive investments, insufficient management and inefficiency. This institutional structure of the water sector and the overlapping and interferences between the several governmental entities are not favourable conditions to promote the expansion of ADS. Furthermore the legislation and licensing procedures do not take into account autonomous desalination.

Reforms of the institutional set-up, which has been based on the traditional, centralised water supply models, are being gradually adopted (case of Morocco, Turkey). Decentralisation and demand-oriented management have been considered as well as alternative methods such as desalination.

The role of the private sector is also increasingly gaining importance especially in the distribution of drinking water and sanitation. The legislation on water supply, however, lacks terms for ADS practice, although the exploitation of non-conventional water sources (brackish and seawater, wastewater) is seen as a viable supply option, since the conventional water resources that can be utilised have reached their maximum, while, in the meantime, water demand keeps increasing. The decision makers are usually not aware of the ADS option and consequently they do not include it in their water master plans.

The decentralisation of drinking water supply planning and implementation will simplify the administrative procedures and increase local participation in the decision making process. It can also lead to closer monitoring of compliance with the relevant regulations. Continuation and strengthening of decentralisation and privatisation will also help ADS implementation.

The civil society as represented by village associations, cooperatives, non-governmental organisations, is increasingly getting active in the field of water and energy. This is a positive factor for ADS, as they unusually also involve the participatory approach in carrying out water related projects.

4.3.5 Capacity Building and Awareness Raising

Since ADS is a relatively new concept in most countries, there are no training programmes specifically addressing these systems. Consequently, the know-how for ADS initiation, formulation, installation, operation and maintenance is practically inexistent, especially at the village and the decision maker levels. Capacity building should therefore target different stakeholders (consumers, policy makers, installers, suppliers, potential users, technicians of rural communes and other water public services).

In the case of utilities, industry, research and development, and educational institutes, potentialities do exist in separate technologies (desalination, renewable energies). Very little expertise~~s~~ can be found today in RE and desalination systems combinations, but existing training curricula can easily integrate this change if the ADS market is getting developed and this situation will surely favour the implementation of ADS.

Training programmes are therefore needed to develop skilled workforce which is required for the design, installation, commissioning, operation and maintenance of ADS. In addition, in the case of systems operated by village associations, operation and maintenance technicians should be found or trained. In some cases, existing structure at the village/rural centres (for example energy houses in Morocco) can be retrained to provide such ADS services. This will also contribute to the sustainability of the installed systems and even the development of local industries and proximity services.

In order to promote decentralisation and efficiency of ADS, training should also be directed towards the personnel from local authorities and users/village associations on issues related to water supply planning, implementation and management.

The ADS training programmes can be integrated in the framework of the existing water and energy higher education training curricula and should consider all the theoretical, technical, environmental and socio-economic aspects of these systems. In addition, the development of these technologies (combination of wind/solar and desalination unit) requires expertise drawn from a range of disciplines and research fields which should also be strengthened. Collaboration with International institutions and research centres excelling in these fields should be multiplied and reinforced.

With the exception of some experimental and laboratory scale units, the combination of desalination and renewable energies is practically inexistent [8]. The ADIRA pilot installations will be the first field units in the south Mediterranean countries and will provide field training for local operators in the operation and maintenance of such systems

Awareness rising among populations and decision makers is a key issue for promoting ADS units; promotion of pilot unit experiences and best practices should be done by multiplication of conferences, seminars, training courses, and dissemination workshops and field visits

Training courses should be periodically organised for the central and local authorities to keep the personnel updated with the latest technological developments, to improve the knowledge and planning skills in water resources management and to strengthen the capacity of people and institutions.

National and international seminars, conferences and informative meetings should be organised by related institutions inviting all stakeholders, involving the private sector that could invest, produce or operate ADS [4].

4.4 GENERAL RECOMMENDATIONS

Given the high cost of produced water by ADS as compared to the low income of the rural population, ADS projects can hardly be carried out without some sort of public support.

However, for a pragmatic assessment of the conditions in a country for ADS installations, a more detailed examination is required, especially in the available governmental programmes, the licensing procedures and the availability of technical staff.

WHAT TO DO BEFORE:

- Clearly identify the steps required in the administrative setup. Regional investment centres can provide valuable information in this regard.
- Identify and obtain relevant licenses: construction, well digging and borehole drilling, water withdrawal, brine disposal, license to trade water, etc. as shown in Annex 4.2. Some of these procedures are not necessary if the water point is already available.
- Identify water quality certification bodies
- Involve the appropriate social body (village association, community leaders, elected representative) from an early stage (participatory approach), to promote the acceptance of the project and its sustainability.
- Identify the local structure that will manage the project and involve local authorities from early stages. Good management of the unit improves sustainability.
- Identify the possibility of other subsidies (for example infrastructure and basic needs programmes) in order to make the produced water price affordable to the targeted population. NGOs and village associations can help in this regard~~.~~
- Look for possible future policy changes foreseen, regarding water
- Clearly identify the legal status (for service provider, concession, etc.) and the duties and rights should be clearly identified in written agreements with local and concerned authorities. Examples can be found in the electricity supply sector (for example SHS in the case of Morocco). Cases have been encountered, where the clients refuse to pay for the systems, and this may be a problem for investment recovery and also for system operation and maintenance, if measures to take in such a situation are not predefined.

HOW TO EVALUATE?

Recommendations on criteria to be used in the evaluation of the conditions in the country are as follows:

a. Country level

- Existence of potential market:
    - Degree of access to potable water in rural areas,
    - Number and size of rural villages with BW/SW sources,
    - Number and size of potential tourist sites with BW/SW sources.
- Readiness of populations and actors (commune, public water utilities, local governments, basin agencies, etc.) to pay for the produced water.
- Existence of water purchase agreements and guarantees to safeguard the investment with rural water utilities or communes.
- Degree of social acceptance of such systems (lessons learned from pilot installations, socio-economic studies)
- Existence of policy directly or indirectly encouraging the use of ADS
- Existence of incentives for private participation in infrastructure building (water, electricity and sanitation)
- Degree of instructional and administrative set-up complexity for the implementation of ADS-related activities (water withdrawal, renewable energy systems installation, etc.)
- Availability of incentives for the investment in ADS (renewable energies and water), such tax reduction or exemption
- Availability of qualified workforce for the operation and maintenance of the systems
- Availability of training centres in ADS or ADS-related technologies
- Existence of national/local programmes for basic needs which could help to decrease investment costs of ADS by subsidies.

Site level

- Absence of short term plans to supply the village by other means (for example, potable water network)
- Matrix of indices, taking into account the social, economic, geographical, physical and technical aspects; these criteria as shown in chapter 2 should be qualitative and quantitative, each criterion having its own weight. Except for the physical and technical aspects (salinity, solar irradiation, flow rate, etc.) the acceptability of the ADS by the local population has to be acquired in order to secure the success of the project; this acceptability could be succeeded in different ways, depending on the type of operator (is he a private investor or an NGO); actions at the site level should take into account this difference.

4.5 REFERENCES

[1] Stefopoulou A., Soulis K., Papapetrou M. (2008) Institutional and policy framework analysis in relation to the application of autonomous desalination systems, Greece, Desalination 220, p. 455-467.

[2] Action Plan for the Promotion of Desalination Systems Powered by Renewable Energy in the Mediterranean (2006). Deliverable 7.3 of the ADURES Project (INCO-CT-2004-509093) developed by WIP-Munich et al, accessible on www.adu-res.org.

[3] Autonomous Desalination Systems - Main Actors and Operators in Turkey, Morocco, Jordan, Egypt and Cyprus (2005). Deliverable 4.1 of the ADIRA project (ME8/AIDCO/2001/0515/59610), prepared by AUA, ISE, ITU, FM21, JUST, EWE and WIP-Munich.

[4] Epp C., Papapetrou M. (2004) Co-ordination action for autonomous desalination units based on renewable energy systems - ADU-RES, Desalination 168, p. 89-93.

[5] Exploitation Plan (2006). Deliverable 8.8 of the ADURES ADURES Project (INCO-CT-2004-509093) developed by WIP-Munich, accessible on www.adu-res.org.

[6] Gibbons J., Papapetrou M., Epp C. (2008) Assessment of EU policy: Implications for the implementation of autonomous desalination units powered by renewable resources in the Mediterranean region, Desalination 220, p. 422 - 430.
[7] Master Plan for the Wide Implementation of Autonomous Desalination Systems in Turkey, Morocco, Jordan and Egypt (2007) Deliverable 4.2 of the ADIRA project (ME8/AIDCO/2001/0515/59610), prepared by ITU, FM21, JUST, EWE and WIP-Munich.
[8] Papapetrou M. Epp C., Tzen E. (2007) Autonomous Desalination Units Based On Renewable Energy Systems - A Review of Representative Installations Worldwide, Solar Desalination for the 21st Century (ISBN 978-1-4020-5506-5), Netherlands, p. 343 - 353.
[9] Papapetrou M, Epp C, Teksoy S, Sözen S, Subiela Ortin V, Seibert U, Vogt G (2005) Market analysis for Autonomous Desalination Systems powered by renewable energy in southern Mediterranean countries, Case study on Turkey, Desalination, 183 (1-3), p. 29 - 40.
[10] Sözen S., Teksoy S., Papapetrou M. (2008) Assessment of institutional and policy conditions in Turkey: implications for the implementation of autonomous desalination systems, Desalination 220, p. 441 - 454.

5

Planning, Implementation, Operation and Monitoring of ADS Units

H. Fath and V.J. Subiela Ortin

5.1 INTRODUCTION

Planning the ADS installation, especially in remote communities, requires careful analysis of the technical, financial and social aspects that prevail in the area of interest. Technical descriptions of various desalination and renewable energy equipment have been covered in detail in previous chapters as well as some market information on availability and unit prices.

This chapter aims to present some other crucial aspects in the installation planning, implementation, operation, and monitoring of ADS, for which it is also very important to make site-specific cost analysis and careful selection of financial implementation models. The social impacts, social sustainability and actors participation, which should be considered before the system is introduced to the community, play important roles in the successful implementation of such systems. Key points in purchasing of ADS equipment, installation, operation and maintenance are also presented in this chapter.

5.2 ADS ECONOMICS AND FINANCING

5.2.1 Cost Analysis

Cost Analysis of ADS usually aims to estimate the cost of a litre or a cubic metre of fresh water, and calculates the contribution of each cost item to the total cost. This identifies immediately the most significant cost items and attracts the attention to what should first be examined for possible improvement and cost reduction.

The calculation should always take into account both ongoing and future costs. Unit product cost is mainly affected by:

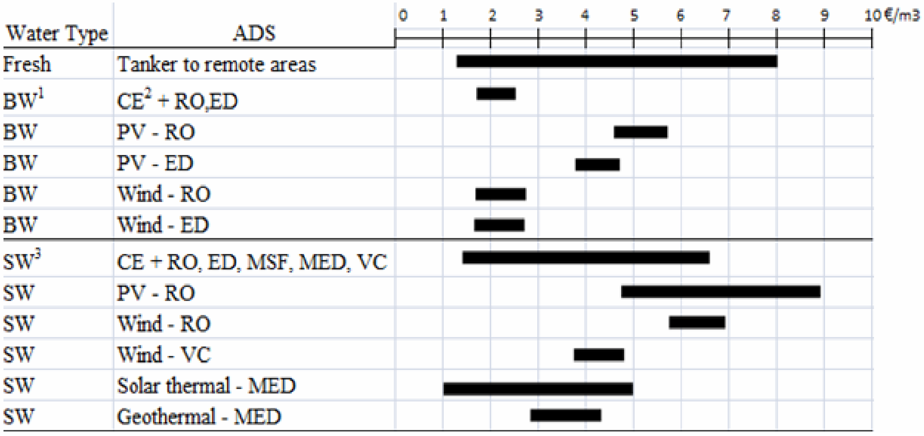
- ✓ **Unit capacity** – larger units require higher investment, but the product water cost (€/m^3) is lower due to economies of scale.
- ✓ **Quality of feed water** – for RO and ED technologies, for example, the lower the feed water TDS concentration, the lower the energy consumption and fewer chemicals are necessary for pre-treatment. Thermal systems are relatively independent of feed water quality
- ✓ **Energy cost** – is closely connected to average wind velocity, solar radiation or availability of other Renewable Energy (RE) sources

- ✓ **Type of technology** – determines requirements for pre- and post-treatment, energy efficiency, unit capacity and costs of equipment and its installation as well as Operation and Maintenance (O&M) cost.
- ✓ **Site conditions** – affect ADS infrastructure (wells, water distribution network) can decrease / increase the investment requirements and pre-determine part of the cost.
- ✓ **Costs of land and labour**
- ✓ **Additional costs** – such as taxes, permits, fees, brine disposal, etc.

It should be however noted, that for a given desalination technology, cost analysis is site-specific and usually cannot be generalised for applications in other situations. As a general rule, the cost of the produced water by ADS is normally much higher than the cost of water produced by plants that run on grid electricity or other conventional sources (fuel energy). However, in remote areas, far from fresh water and conventional energy sources as well as areas where the economy is driven by tourism, the ADS water price can be acceptable. Increasing energy costs and scarcity of water, suggest that water desalination applications will become more widespread. With increasing numbers of installations, costs will drop along the learning curve and desalinated water will soon become economically viable in more and more situations, especially in the developing world.

The total capital and running costs of ADS should be compared to the available budget and the expected benefit to potential users. Table 5.1 shows a general range of the costs of produced water for each technology combination. It indicates that, the cost of transported water in remote areas is high and desalination using RE will be a better alternative with the continuous oil cost rise.

Table 5.1 Range of Cost (€/m^3) for Various RES Technologies [1]



Water Type	ADS
Fresh	Tanker to remote areas
BW[1]	CE[2] + RO,ED
BW	PV - RO
BW	PV - ED
BW	Wind - RO
BW	Wind - ED
SW[3]	CE + RO, ED, MSF, MED, VC
SW	PV - RO
SW	Wind - RO
SW	Wind - VC
SW	Solar thermal - MED
SW	Geothermal - MED

[1]: Brackish Water [2]: Conventional Energy [3]: Sea Water

5.2.2 Decision Support Tool (DST)

To aid the process of cost calculation for a specific desalination technology and situation, a Decision Support Tool (DST) has been developed within the ADIRA Project. For a more detailed economic analysis of your system, please refer to DST software, [2]. For cost analysis, the DST authors, [2], suggest to divide the cost of ADS into following categories, Fig. 5.1:

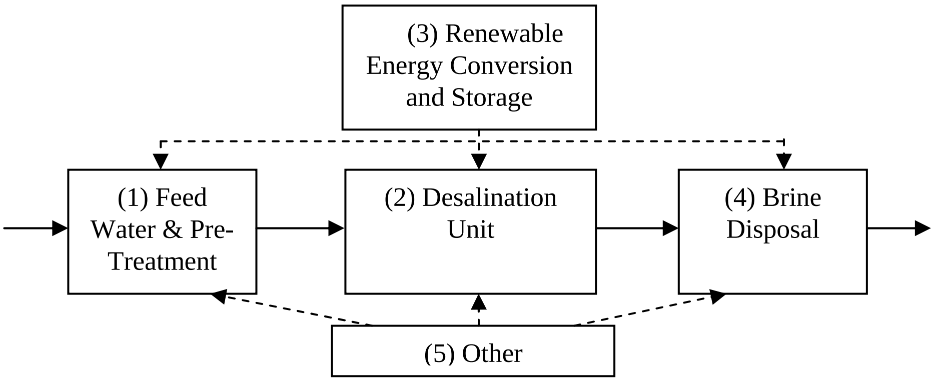


Figure 5.1 DST Cost Categories [2]

1. Cost of feed water system and pre-treatment, including all necessary investment and related expenses required for the supply of brackish or sea water to the desalination main system
2. Cost of desalination unit itself
3. Cost of supporting RE system, supplying all the energy needs for the desalination unit, feed water pumps and brine disposal
4. Cost of brine disposal, which could be anything from minimal to very expensive depending upon specific conditions
5. Other costs

Further details of these categories are given in Table 5.2.

Table 5.2 DST Cost Categories Details [2]

Category	**Details**
Cost of Feed Water Supply System	The required investment and running cost of this part of the system depends very much on the nature of each case, the elevation and horizontal distance of the water source to the desalination machine, the type and size of the piping system, etc. In most cases the Feed Water Supply System will require a pumping system (motor and pump) which will consume part of the energy offered by the RE system of the configuration. Drilling for underground water may be an important cost item under this heading. Depending upon the depth of the water basin it could be anything between a few hundred to many thousand €. The cost of borehole and associated fixed equipment is treated very much like the costs of desalination and RES system costs.
Cost of Desalination System	Cost of the Desalination Systems consists of the purchase and installation costs of all the pieces of equipment required for the actual desalination process. This may include some kind of pre-treatment items, the desalination unit itself, and possible auxiliary systems & components. Sometimes, if the Brine Disposal System is not significant, it is assumed and treated as part of the Desalination System. Each ADS needs some means of fresh water storage because of the irregular nature of the RE resource availability. The bigger the volume of the water tank, the more secure the water supply. However, the size of the tank is limited by the size of the desalination system and cost & effectiveness considerations which must be taken into account before sizing the water storage.
Cost of RE Supply System	The RES, exploiting the energy of the sun, the wind, etc. is supplying the desalination and supporting systems with the required energy in order to function properly. Its investment cost includes purchase and installation of the system[1]. As the availability of the RES involves an element of uncertainty, each ADS may have an associated energy storage system (battery), which, in combination with the fresh water storage system, smooth the fluctuations of the RES. The optimal size of battery and fresh water tank can only be estimated with very detailed weather data (e.g. hourly figures for several years), which may not be available, in which case sizing is based on less rigorous methods.
Cost of Brine Disposal System	The brine which remains after desalination, should be disposed in a way that does not harm the feed water or the environment in general. In the case of sea water source, the problem is minimal, since brine can be re-directed back to the sea. However, in the case of underground water, brine has to be sent back into the ground, sometimes in depths much deeper than the feed water location. The cost of brine disposal is very much site dependent and has to be studied for each individual case for a meaningful estimation of the required expense.
Other Costs	Costs under this heading are mainly costs of buildings, constructions or equipment supporting the operation of the ADS. Costs of other equipment are handled at exactly the same manner as other investment categories. In the case that an investment in this category is shared with other uses, only the proportion corresponding to the ADS use is considered

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[1] Installation costs of the RE system may be significant. In some cases, for example when the ADS are based on PV electricity, it might be necessary to prepare a fairly expensive construction to place the PV panels.

The usefulness of categorising costs as above allows estimation of each unit costs and facilitates comparisons, such as for example, between using different RES with the same desalination system, measures the cost of being *autonomous*, increases the scope of sensitivity analyses and helps to optimise system configuration.

Most, if not all, of the above categories have (a) an *investment* and (b) a *running* cost. The first reflects the annual cost of purchasing and installing equipment or other fixed asset, while the second relates to annual expenses and the cost of various consumables which are necessary. The cost per litre or cubic metre of fresh water is estimated by dividing the sum total of all annualised investment plus running costs of all categories by the volume of fresh water produced.

5.2.3 Cost Figures from a Typical Case

The PV-RO unit in Lempedusa, Italy uses sea water to produce 5 m^3/hr of <500 ppm water quality. The total cost of produced water is around 6.5 €/m^3. The capital as well as the O&M costs are shown in the following Table 5.3. The unit was operated under the supervision of water utility of part time experienced staff. The cost of personnel will remain high if the plant does not collaborate with an organisation capable to operate it, possibly with part timers of its own personnel [1].

Table 5.3 Cost of PV-RO Unit of Lampedusa (Italy), [1]

Equipment	**Cost**	Units
PV array	10,000	€/kWp
Batteries	125	€/kWh
RO unit	19,000	€/m^3.h
O&M Cost		
Labour	20,000	€/year
Energy	0.7	€/m^3
Chemicals	0.1	€/m^3
Membrane Replacement	0.25	€/m^3
Spares	0.05	€/m^3
Electricity Production Cost	0.7	€/kWh
Total Water Cost	**6.5**	**€/m^3**

5.2.4 Financing Mechanisms

Successful projects should manage to have at least their running costs plus depreciation covered. Ensuring manageable pricing schemes for selling the desalinated water after the completion of the project can increase viability. Possible financing and/or water pricing or subsidisation agreements with local or international organisations should be carefully examined.

Most of RE projects need considerable investments and cooperative financing. Each project is financed differently, depending on the purpose, country, size and other particularities. One can however distinguish several typical ways to finance such projects [3]:

- ✓ Personal savings, assets from users and/or promoters
- ✓ Subsidies or grants to support technological innovations
- ✓ Loans from International Funding Agencies (e.g. World Bank Group, Global Environment Facility, Regional Multilateral Development Banks)
- ✓ National Funding Agencies
- ✓ NGO's
- ✓ European Commission Programmes (like Europe Aid, etc.)
- ✓ Combined projects with strong financial partners - Private Sector Investment
- ✓ Financing of the project with limited guarantees over anticipated future cash flows

According to previous experience with the financing of RE applications, a fee for the service or product offered is essential for the success of project sustainability. Therefore, an appropriate tariff system for the users should be implemented.

Financing schemes/models

Due to high initial costs of RE powered desalination, a good financing scheme is necessary. Some of the possible financing models are briefly discussed below [4]:

Which financing model (or mix of various models) is best suited for a project depends on specifics. Thus, the financial concept must be planned exactly at the outset, and local features must be taken into consideration. The model should be selected to fit into the local water and energy markets and suit users' standards of living. In any of the models it will always be the matter of selling products and services in order to fulfil clients' water (possibly, also energy) needs. Table 5.5 provides an overview of these financing models or schemes, [3].

- **Cash sales** - The companies sell their systems to end users directly (possibly via retailers). End users own the system as soon as they have bought it.
- **Consumer credit**s - Manufacturers (or their dealers) sell systems directly to end users, but here users can pay for the systems in instalments. Hence, the seller grants credit. Legally, depending on the agreement, users either own the system as soon as they receive it or when payment has been completed.
- **Credit institutions** - Companies sell the systems to end users, with a third institution granting credit to the users. Legally, depending on the agreement, the system either becomes the property of the user upon delivery or upon final payment.
- **Lease** - The companies or a financial intermediary, lease the system to users, who can purchase it at the end of the leasing period. However, during the leasing period, the vendor retains ownership of the system and is also responsible for maintenance and repairs.
- **Fee for service** - A company or institution (also public water supplier) owns the system and makes it available to users, who in return pay a usage fee. A financial institution (bank, lease company) can be involved to share the risk. The provider retains responsibility for maintenance and repairs, and users never become owners.

Table 5.5 Characteristics of Financing choices [3]

	Cash sales	**Consumer credit**	**Credit institution**	**Lease**	**Fee for service**
Capital needed by the company	Low	Medium	Low	High	Highest
Access for users without means (poor communities)	Most difficult	Medium	Medium to high	Medium to high	Best
Infrastructure required	Low	Medium to high	High	High	High
Political framework	Not necessarily needed, but helpful	Credit generally has to be regulated	Possibly development and water supply aid	Lease contract designs and related tax issues	Concessions to sell water (and energy) helpful.
Responsibility for installation and maintenance	Users, in some cases dealer will carry out the installation	Users, possibly installing company	Usually the installing company, possibly users	Initially technicians from installing company	Owner (company, public water supplier)
Risk allocation	End-User, (for dealer until warranty period expires)	Distributed among all parties, highest with the dealer	Distributed among all parties	Distributed among all parties, highest with the lessor	All risk with the owner

Attention: All these models assume that the users are paying for the water, which, in practice is not always the case. The financial actor may fully or partially undertake this responsibility, especially in cases with poor village communities.

5.3 SOCIAL ASPECTS, SOCIAL SUSTAINABILITY AND ACTORS PARTICIPATION

5.3.1. Social Aspects

Social aspects have received less attention than technical-economic considerations, even though the latter are of considerable importance for the successful and sustainable operation of any technology, and particularly those in remote areas. For example, membrane technology is prone to membrane fouling, which requires careful management in remote locations. Problems like this may give the new technology an unjustifiably poor reputation, which does not reflect real problems of the technology itself, but rather the way it has been implemented and is managed. Therefore, in order to be *socially* sustainable, such technologies must:

- be accepted by the community,
- meet existing water needs, and
- be within the installers’ capacity to operate and maintain.

Another general consideration all water resource planners should keep in mind is that the cheapest, easiest and most environmentally friendly water supply plans always include demand management and careful use of naturally available and renewable water resources (rainfall, rivers and renewable groundwater). A community should resort to desalination only after these options have been exhausted.

The social aspects of desalination technologies should ideally be considered *before* they are brought to the communities. This can be carried out by examining the water uses and needs of a community, the human resources available for the management and operation of desalination unit, and the response of communities in remote areas [5]. These communities usually have essential services such as power and water supplied through a community council, which also employs an Essential Services Officer (ESO) to look after a number of small sites that the broader community to a prototype of such a unit. A field trip for testing ADS site and installation will provide the opportunity to investigate these social factors using social science research methods, such as small-scale interviews and surveys, and theoretical insights from the fields of appropriate and sustainable technologies. The practical application of these theories to the case study can result in an assessment of the prototype’s suitability, and the identification of strategies to contribute to the successful development and implementation of ADS units in remote areas. Table 5.6 summarises a few basic principles that should be kept in mind for ADS social study, [8].

Table 5.6 Basic Principles for ADS installations [8]

Principle	Discussion
The socio-technical approach	A system can only run optimally when the interdependency and interaction of people, technologies, and organisations are taken into account. This approach aims to link the social and technical aspects within the system in order to jointly optimise them. If users are viewed as an active part of the system, it is much easier to design the technology adequately.
Focus on people	People affected by the project must be put in the foreground. It means letting them provide input into important decisions, but also recognising and respecting their values, as in such projects people with quite different values often interact. This becomes easier the more the actors involved identify with the target group. Users should be included in the planning and design of the project at an early stage.
Learning	In order to be able to benefit from new technologies such as RE powered ADS, people have to learn. The possibility of learning and receiving training has to be provided at the outset, so that the knowledge gained can be put into practice in a second step. The sooner those affected are given the opportunity to learn and provided with resources for this purpose, the greater are the chances that problems can be remedied and project will be successful.
Participation, independence & autonomy	Users must actively take part in the preparation, design, and implementation of a project. Any of the actors involved can take the initiative to participate, but participation does not mean that all of those involved have to take part in all activities at the same time. The willingness of potential ADS users to collaborate, largely depends on the degree of independence they are given and the autonomy permitted. That means that those affected should be able to make decisions about their lives themselves. They can thus also control where they allow changes to take place and where they consciously reject innovations.

Process orientation	The general frameworks and conditions for rural water supply change quickly. Inflexible methods are not able to cover the great variety of needs to ensure the success of projects. For this reason, procedures should be flexible, which means that no unified strategies or generally applicable procedures can be drawn up and recommended for the implementation of projects. Rather, strategies have to be process oriented to be able to react to changes.
Sustainability	Sustainability means that the actors will support a project after it has been completed, and the systems will remain in operation. Continuation of the projects even under changing conditions and in the face of difficulties is especially desirable. Checks of sustainability are only possible once a project has ended - sometimes only years later. Factors that influence sustainability have to be detected as early as possible - at best, during planning and implementation. Sustainability criteria have to be defined and formulated for each project. All project activities will then address them and be evaluated based on these criteria at a later date. In this manner, the degree to which the goals of the project were met can be assessed and quality improved.
Realism	Planned objectives and results should not be too demanding or unrealistic. A distinction has to be made between the feasible and the desirable. Modest goals can protect the project and the partners from being overtaxed by excessive expectations. Realistic project designs require consideration of the conditions for the project. Each of the countries for which projects are planned has its own reality. Getting to know this reality and analysing it should be a central task in preparing the project. Both the actors and the local population should develop a feeling for the project's feasibility alongside the ideal.

5.3.2. Social Sustainability

A number of attributes have been identified as important contributors to the success and ongoing social sustainability of small-scale desalination units [5]. These can be summarised as:

- The capacity of the unit to produce sufficient water quality and quantity to fulfil local needs;
- The capacity of the local community to construct (where appropriate), operate and maintain the unit;
- The ability of the unit to operate reliably and independently in a decentralised context;
- The response of the community to the unit and thus its ability to operate with minimal disruption caused to the local community.

Interestingly, many of these attributes are common to small-scale desalination systems in very diverse social settings, e.g. in rural communities in Egypt [6].

An examination of RE power supply systems in remote areas should also provide some insights regarding the social sustainability of such technologies. A review of such systems in remote Australian communities found that inadequate maintenance support, caused by a lack of "effective trained personnel to maintain and service RE systems" [5], was a major contributor to the failure or sub-optimum operation of such systems. The distance of systems from service centres was also a problem, and a strong influence upon maintenance costs. Responses highlighted that pastoralists tended to be most concerned about the high costs of renewable energy systems, while Indigenous communities had concerns about their reliability. Some solutions suggested to these social issues include training programs for maintenance providers and accreditation for system installers, education about energy demand management for consumers, and the development of more reliable systems (hardware).

On the other hand, social sustainability for ADS has to be assessed in the selected remote area. This will involve examining ADS compatibility with or ability to be adapted to relevant aspects of the social environment, such as:

- water quality and quantity needs,
- human resources available to operate and maintain such a unit, and
- attitudes of community members to a prototype of ADS.

This approach is illustrated schematically in Fig. 5.2.

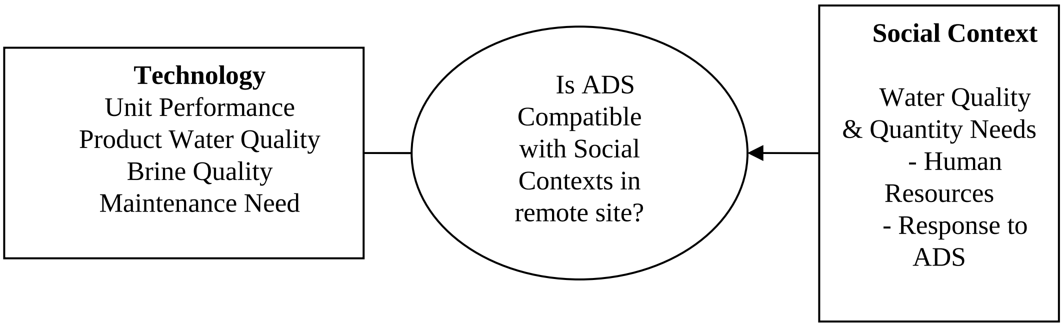

Figure 5.2 Schematic view of the Approach to Evaluate Social Sustainability

Two social science research methodologies can be applied. The first is a “case study” approach which includes interviews and site visits. This approach is considered to be the best methodology for studying in greater detail the social aspects of water use and the provision of water in different types of remote settlements.

The interviews are advised to include the following items:

- Population at the site
- Main socio-economic activities undertaken at the site
- Existing water system, including the number and quality of bores available and other water sources
- Shortfalls they observed in water quality and quantity
- Responsibility for water system management, operation, maintenance and financing.

By developing an understanding of these aspects of the water system at each site, an assessment of ADS’s potential compatibility can be made.

The second research activity needs to gather the feedback of a range of people relating to ADS. The choice of a questionnaire rather than interviews can be made because questionnaires are simpler to execute and allow for a greater number of responses to be gathered using fewer resources. The completion of a questionnaire in private also allows for unbiased information to be gathered by avoiding the interactions required with an interview, and when they are anonymous can encourage respondents to give more honest responses. The topics to be covered by the questionnaire include the views of respondents regarding:

- Their opinions of the combination of desalination and renewable energy (on a scale from poor to excellent)
- What they liked most about ADS
- What they felt most needed to be improved in ADS
- The situation / location in which they felt ADS would be most useful
- What are their concerns (if any) about consuming water from ADS
- Any other comments they wanted to make about ADS.

By gathering responses to such questions, the community response to ADS can be evaluated, which will contribute to a determination of its social sustainability.

5.3.3 Actors Participation

There are different actors (stakeholders) involved in the ADS installation process. They should be introduced, pointing out their main interests, influence on the project and possible contributions. A step-by-step Stakeholder analysis scheme should be used to identify them and analyse their role, relation to the project.

Key stakeholders are those individuals or institutions that may (directly or indirectly, positively or negatively) affect or be affected by the outcomes of the project. In addition to the main project management team; (1) Project coordinator, (2) Project partners, and (3) Project Consultants, the other stakeholder and their interest, influence on the project, and potential contributions is shown in Table (5.18). In addition, the ‘Informers’, (i.e. ministries, universities, research institutes, consultants, meteorological stations, utilities) are of particularly important in the site selection process, where data collection plays a key role**.**

The following steps are to be taken for the stakeholder analysis, [8];

1. Start with identifying the various stakeholders, who
    - might be affected by or might affect the project
    - might become useful project partners
    - might become conflict partners
    - will anyway be involved in the project
2. Categorise them according to their role
    - partner, financial, beneficiaries, supporters, controllers etc.
3. Characterise them from a social and organisational point of view
    - social and economic characteristics (take gender into account)
    - structure/organisation
    - status, etc.
4. Analyse them with regard to expectations and relationships
    - interests and expectations
    - the links and relationships between the various stakeholder groups
5. Characterise their sensitivity towards and respect to certain issues (gender equality, environment)
6. Assess the potential, resources and capacities of the stakeholders
    - strengths on which the project could be build up
    - potential contributions
    - existing deficiencies
7. Draw conclusions and make recommendations for the project

Table 5.7 Stakeholders and their Relation to the Project [9]

Stakeholder	**Interest**	**Influence on the Project**	**Potential contributions**
Governments, ministries or local authorities	Environmental impacts, costs of water production, wellbeing of the community, employment and regional development, support to R&D	Laws and regulations	Subsidies, reduced import duties, tax and fiscal incentives, awareness raising, promotion campaigns, quality control.
The beneficiary community	Availability, costs of product water employment possibilities, regional development, environmental impacts, technical simplicity, sustainability, training	User, acceptance or rejection of the project. CRUCIAL for the success of the project	Information about the site, participation in planning, building and maintenance, possibly buying water
Investors, financial partners	Minimising the site related risks (such as environmental risks), water selling price, life time period	Financing	Supply of capital, Know-how, etc.
Installing companies, subcontractors	Business	Financing	Installation and maintenance of the system
Land owners	earning money, keeping land intact, minimising environmental impacts, adhering to regulations, ensuring sustainability,	Provision of water, need to agree	Know-how of the site, help in maintenance

5.4 ADS INSTALLATION AND O&M GUIDE

Once the site, technology, actor's participation and local contacts have been decided, as described in the previous sections, the specific process of installing and operating the system should be made according to the following suggested plan:

5.4.1 Selection of Suppliers

The selection of suppliers has to be made according to the regulations of the financing entities. Generally, this selection follows a tender procedure. This process can be summarised as follows:

1. Writing of tender documents:
    - Tender call advertisement in both English and national (local) languages: short informative public document issued in different media (newspapers, websites, etc.) to disseminate the call for tender. Turn Key project is recommended if the ADS owner has no installation experience.
    - Specifications and conditions: descriptive documentation about all the technical and administrative details of all the elements included in the tender (civil works, equipment, training, required guarantees, payment conditions, etc.)[2]
2. Publication of advertisement and specifications
3. Reception of offers: a reasonable period is indicated in the advertisement, normally about 30 days.
4. Analysis of offers: a committee of experts analyse the offers and check them according to the specifications.
5. Selection of the bidder(s): the committee makes a decision following the evaluation process.

5.4.2 Bid Finalisation and Contracting

After the bidder has been selected, a series of technical meetings shall be held, between the ADS team and the winning bidder (contractor, supplier of equipment), in order to discuss the details of the final design, schedule, bill of quantities, and make the necessary action plan. Technical discussions may include new ideas to improve the proposed design from the supplier to be adapted to the local conditions. Visits to the site and to suppliers will be needed at this stage to finalise the design and select out of alternatives (if needed). Adjustment of the technical drawings, some design re-calculations might also be needed at this stage. The updated design might need schedule and technical drawing updating. All should be approved by both the ADS owner and contractor.

A draft of the contract is written (either in English or local language or both). The contract will be reviewed, updated and finalised by both parties (ADS owner and the contractor). The contract will identify the role of both parties. For the supplier of the equipment; the equipment delivery, installation, testing, unit overall commissioning, O&M, staff training and documents to submit (such as Bank guarantee, catalogues, equipment specifications, etc.) whereas for the ADS owner, the payment schedule, supervision & approval, etc., shall be clearly identified.

5.4.3 Local Actions

ADS owner should contact local and national authorities for different permissions to install the ADS unit. Possible actions related to the authorisation are the well digging, construction of civil works, use of sea water & intake system, brine disposal location, possible electrical power connection to the grid, etc. Contacts to ministries of water, environment and energy as well as local city councils, governorate staff, local NGO(s) and local community heads should be carried out.

It is advisable to sign a protocol of cooperation (or similar agreement with local / national authorities) and get them involved as part of the process.

5.4.4 ADS Installation and Commissioning

5.4.4.1 Preparation of ADS Set-up

It is recommendable to plan a preliminary meeting and a site visit for ADS installation team and the contractor to review the steps to be taken and the action plan to take place. Within this meeting all scheduled tasks should be discussed and the selection of components to be imported or locally supplied to be defined and finalised. The meeting should focus on the basic elements of the system: state of feed

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[2] Further information and downloadable templates and informative documents for EC projects can be consulted in: http://ec.europa.eu/europeaid/tender/practical_guide_2006/annexes_services_en.htm

water source and existing pipes, optimum location of the system considering the local users necessities for fresh water access, wind and solar conditions, and destination of the brine.

The quality of the water has to be analysed and the results shall be provided to all parties specially the ADS manufacturing company to readjust the system design accordingly. Similarly, the supporting systems (for example, cooling water system for the case of a thermal distillation unit), the water and energy consumption for pumping and the different solution and alternatives proposed within the scope of the project should be addressed.

The organisation of the set-up of the components and the necessary work for preparation should be reviewed and finalised with the project contractor. This includes the following elements:

- Hydraulic part
  - Final design of installation (Piping adaptation for the complete installation of the three main circuits: feed water, fresh water, and rejected flows)
  - Improvements/actions for the feed water system
  - Identification of the best location for the brine disposal system.
- Electrical part
  - Security aspects: protection for high voltage devices, earth wire installation
  - Final design of electrical elements
- Civil works
  - Foundations of the selected components
  - Construction and installation of buildings, water tanks (feed, product)
- Control and monitoring part
  - Final definition of control philosophy, and selection of control system elements. Final definition of the variables to be monitored.
  - Measuring devices and data acquisition system

5.4.4.2 Transport and local delivery

With regard to the contact (agreement between contractor & ADS owner), and according to the scheduled installation plan, the contractor starts civil works, the transport of equipment from the manufacturer to the ADS site. Some equipment might be locally available or manufactured and the rest may be imported. All those should be taken into account in the project schedule [7].

The system components have to be shipped to the site under the supervision of the contractor. This shipment may contain ADS main components (as the solar collectors and support structure, distillation module components, PV panels, wind mills, RO or Distillation membranes, etc) in addition to instrumentation & control devices (data acquisition devices and sensors and some of the controlling devices). Upon the components container arrival, it will be transported to the ADS site. Caution has to be taken during these processes specially for handling sensitive devices and components. The contractor organises and undertakes the transport of the container from port to the site.

5.4.4.3 Site Preparation

In parallel to component transport, site preparation may start. Site preparation requires specific actions such as:

(i) Pavement of the land & concrete foundations and fences,

(ii) Constructions for labour, storage, control panel room(s) and other civil works,

(iii) Piping for feed water supply and brine disposal,

(iv) Water tanks insulation if needed,

(v) Initial electrical connection (for the pumps and data acquisition system), and other utilities needed for site preparation requirements.

The site preparation and ADS installation process can be very well supported by local authorities and community (as end user). In case of serious problems, local authorities & NGOs will assist ADS team. The set-up should be performed in very close collaboration with these parties, and a helping hand missing somewhere to be made available in an easy and co-operative atmosphere.

5.4.4.4 ADS Commissioning

The start-up of the ADS will take place after the unit's components arrive to the site. The installation of the measuring devices, controlling equipment and the co-ordination of the set-up work is carried out by the supplier of the equipment under the supervision of the ADS installation team. Some amendments to the set-up to improve the performance may be needed. Once the ADS unit is installed and tested for the start-up, then the plant is set into commissioning stage of operation.

It might take few days to reach steady state operating conditions (as heat up the storage tank in thermal unit). Afterwards the parameters of the control devices are to be determined and adapted to the operating conditions. After a first period in which the system is left to equilibrate, the ADS and its sub-systems well be investigated. ADS commissioning will be closely monitored under different environmental & operation conditions (solar intensity, wind speed).

5.4.5 ADS Operation

5.4.5.1 Monitoring ADS operation

Starting from the day of installation, a regular monitoring of measuring data has to be performed. At the start of the period, several problems (as the stability of the electricity supply) may prevent continuous operation. These and similar problems will be overcome by specialised operation staff. The acquired data has to be regularly evaluated and in very close co-operation between operator, contractor, supplier & ADS team, and the results of the evaluation have to be used to optimise the operation strategy of the whole system.

The ADS unit can be monitored by a data acquisition equipment to run reasonably well. Common data to be collected in the demonstration include;

i. Temperatures (ADS loop, mixing unit, storage tank, distillation unit-case of solar distillation systems);
ii. Pressures (feed water before and after the membranes-case of reverse osmosis units);
iii. Flows; mainly feed water inlet, fresh water outlet, and brine outlet;
iv. Local conditions: ambient temperature, wind speed, solar irradiation on collector area;
v. Conductivities: especially of fresh water, and at periodic measurements of feed water;
vi. Power: in the generation system (PV panels and wind mill units) and in the load system (batteries, desalination unit, feed water pump, etc.)

This wide set of data is not necessary in fresh water supply plants where the most important values to be controlled are quality and quantity of fresh water, and of course the specific energy consumption (heat and/or electricity consumed per cubic meter of product water). However, these measurements will be useful during commissioning and if the technology is new and requires close monitoring.

5.4.5.2 Evaluation and supervision

In order to assure that the system is sustainable from a social, ecological and economic view, ADS project has to be continuously evaluated. This will assess building up expertise and offer additional arguments in favour of the introduction of ADS. The projects should be evaluated systematically using qualitative and quantitative methodologies. Usually the operators carry out the responsibility for evaluation and to react to problems with measures to optimise or to enlarge the system performance and improve its economy. However, from a scientific point of view, it can also be done by external members of a project team (outsourcing).

5.4.5.3 Changes in operation mode

Several unexpected operational defects may cause the need for changes in the operation strategy as it was planned before the set-up of the system. Example of this could be the need for a windshield to be fixed around the ADS unit in order to decrease wind losses from the solar collectors or solar stills in the thermal system, and fix insulation on the pipes or put fences in the direction of possible sand storms. Another example from the ADIRA solar stills unit in Egypt: It was observed during the testing of similar solar stills, that the product water and brine temperature were 5-15 ^{0}C above the feed water temperature. A system for energy recovery was proposed to improve the still performance. A protocol or agreement of ownership transfer is recommended.

5.4.5.4. Hand over and withdrawal

If an outside entity (such as scientists or NGOs) initiates the implementation of ADS and they do not plan to operate it for themselves, the hand over to the new operator and the withdrawal of the original organisation from the project, has to be planned carefully. Apart from securing suitable mechanisms of organisation and for financing, they should provide long term guarantees for technical assistance to the community and/or the operator.

5.4.6 ADS Maintenance

There are many problems involved that arises from combining a desalination plant to a renewable energy source. Each desalination system has specific problems when it is connected to a variable power system, [1]. For example:

- The RO system has to cope with the sensitivity of the membrane regarding fouling, scaling as well as unpredictable phenomena due to start-stop cycle and partial load operation during periods of oscillating power supply
- The VC system has considerable thermal inertia and needs to consume a great deal of energy to get to normal working position.
- The ED system has the same problems as RO about the sensitivity of membranes regarding iron scaling and fouling and is not capable to desalt high salinity water at reasonable cost & electrical power consumption.

The performance of the ADS unit should be guaranteed to be very satisfactory. Looking at the data, a low performance of the ADS system may indicate failure or malfunction of component(s). The ADS unit may be opened, therefore, to check the major points of maintenance referring to the former experience. There are three types of maintenance; (i) preventive maintenance, (ii) predictive maintenance and (iii) corrective maintenance. These three types will be discussed below for a typical ADS component; pumps, while Annex 5.1 summarises the maintenance needed for some ADS components [8].

5.4.6.1 Preventive maintenance

Preventive maintenance aims at preventing unexpected equipment failure. Depending on the circumstances, an unscheduled failure can be very inconvenient and extremely costly. A suitable programme of preventive and routine maintenance will reduce equipment failures, extend the life of the equipment, and reduce the overall operating costs. The preventive maintenance should be carried out according to the manufacturer’s recommendations. This includes; daily visual inspection of the various parts, monthly check of the lubrication of bearings (if any), monthly check of packing and seals for wear and tear (the first sign of wear is a loss of the pressure and eventually water leaks), motor and pump alignment for proper torque transfer, and pump mounting.

A thorough maintenance inspection should be scheduled annually and may include: cleaning of the pumps, check (replacement) of bearings and drive belts for indirectly coupled pumps, inspection of motor (temperature and vibration).

Detecting wear and tear in the early stages can reduce repair costs and downtime. Prolonged operation with worn parts can result in costly repairs. Wear parts, such as shaft seals, bearings, and casing wear rings have defined service lives and should therefore be replaced per the manufacturer’s recommendations.

5.4.6.2 Predictive maintenance

Predictive maintenance can also be performed. Maintenance is scheduled based on the analysis of data collected during the monitoring of the condition of the pump, not necessarily on any set maintenance programme. This requires close monitoring of the pumps performance, noise, vibrations, and temperature of the motor.

- Overheating of motors is a sign of bad bearings, mechanical overload (plugged pump outlet or locked rotor), or insulation failure in the motor windings.
- Leakage of water is a sign that the mechanical parts might need replacement.
- Noise is an indication of cavitations, bad bearings and shafts non-alignment.
- Vibration – is an indication; the beginning of a failure.

5.4.6.3 Corrective maintenance

Good practices in predictive and preventive maintenance will strongly reduce the necessity for corrective actions. Nevertheless, some common corrective activities should be mentioned:

- Hydraulic part:
    - Correction of small leakages, typical in water circuits especially where there is high pressure or screw connections
    - Replacement of components: case of dirty filters, membranes, etc.
- Energy part:
    - Replacement of damaged elements. In PV systems, for example, the weakest part is the converter part (charge controller, inverter) especially when operation is under high temperature/humidity conditions
- Other parts:
    - Treatment on rusted surfaces of metallic components

5.4.7 O&M Staff Training

At each site, the responsibility for the ADS lays with either the site manager and/or operator(s). They will carry out the day-to-day operation and maintenance of the system and call specialists when a greater level of expertise is required. These people should have a good knowledge of the ADS unit's system, components and water/energy storage. There is a necessity to train them to be able to cope with the requirements the system poses on them, [9]. The overall aims of the training are:

- To ensure long lasting operation of the ADS,
- Increase user satisfaction,
- Prevent or minimise problems arising from inappropriate use and wrong expectations,
- React to arising problems in a competent way.

For the process of training, several steps have to be taken in order to make sure that each O&M staff member receives the kind of training s/he needs to ensure the sustainability of the system, i.e., training will be different (adapted) to each member to be trained. The design of the training process consists of the following steps:

1. Situation analysis
2. Assessment of the training needs for each group of trainees
3. Planning of the training for each group of trainees
4. Realisation
5. Evaluation of the training programme

Table 5.8 Training Checklist [9]

Who	Who are the stakeholders that are involved with the ADS? What is their role concerning the project and the long-term sustainability of the ADS (e.g. operation and maintenance, administration, use etc.)?
What	Which are the goals of the project and how can they be supported by training? What kind of problems can arise in the course of the project and which of them can be addressed or prevented by training?
When	Training Schedule: At which stage of planning and installation? Before, while or after?
How	Methodology of training (knowledge, skills, workshop, lab., and OJT)
By whom	Trainers (Technical experience and training capability)
Where	Location, Timing, Can everyone reach this location, Is there enough space
Evaluation	Indicators, methods, time of sampling?
Resources needed	Financial resources? Time? Knowledge and qualification of the trainers? Material? What is needed? What is available?

For each step the social and economic aspects of all kinds of trainees have to be considered as well as the technical requirements of the ADS unit. A checklist was proposed, [9], with important questions that have to be asked in order to develop a training that helps to bridge the gaps between people and technology optimally, Table 5.8. An example of training contents can be found in Table 5.9.

Training will be carried out in classrooms (knowledge), workshops & Labs, (skills) in addition to “On the Job Training”. It is important to realise that training is a process which has to be repeated continuously.

Table 5.9 Example training contents for end users [9]

General Information about the benefits of the ADS	- Drinking clean water protects family members from sickness - Accessible safe water saves women's and kid’s time, improves welfare of women and provides more time for family care or income-producing activities. - The renewable energy source reduces costs and enhances sustainability It also has to be made clear that: - Improved water supply will only lead to benefits if linked with proper use - Community must assume responsibility for the ADS - Water is precious and is worth paying
Organisational Information	- General organisation of the ADS - Ownership and responsibility - Role of the key person/guard/caretaker - Amount of water available for every household -Distribution among the households and persons responsible for the distribution and controls
Technical Information	- Components of the ADS: e.g. the desalination unit and its most important features (for example, RO membrane); the renewable energy source and it’s most important features (e.g. the solar panel, the battery); displays informing about the state of the water supply - Use of the ADS: e.g. the steps to withdraw the water from the system; pre treatment and post treatment; what kind of problems can arise from inappropriate use; how to determine whether there is enough water in the tank; dangers such as high pressure in the RO-Unit - Maintenance and Monitoring: e.g. flushing operation to clean the membrane, the regular cleaning of the PV-Module, the cleaning of taps or the removal of brine; who to contact in case of problems and how
Quality, quantity and availability of water and restrictions of the ADS	The restrictions in the use of water have to be explained thoroughly and it has to be made sure that every user accepts these in order to prevent disappointment. - The water has a very high quality, but if it stays in the tank too long, bacteria can grow - The amount of water that is produced per day is restricted. - If there is no wind/no sun, no water can be produced. - The ADS produces a noise that might be disturbing
The wise use of water	The water produced by the ADS is likely to be still a scarce resource and the users have to be made aware of that. It is important that they do understand that they must not waste this. - The wise use of water: ways of saving water and ways of keeping the water clean; suitable and unsuitable uses of water.
Payment	How costs arise and modes of payment

5.5 REFERENCES

[1] EC-THERMIE Program (1996) Desalination Guide Using RE, EC-Contract No. SUP-0940-96-HE.

[2] Soldatos P. G., Mohamed E. and Assimakis D. (2007) Autonomous Desalination Systems (ADS) Sizing and Cost Analysis: Methodology, ADIRA project internal document, Agricultural University of Athens, AUDESSY Software Package: p.soldatos@aua.gr.

[3] Subiela V. J. (2005) Installation Guidelines for ADIRA Project, ADIRA Project internal document.

[4] Loupasis S. (2002) Technical analysis of existing RES desalination schemes – RE Driven Desalination Systems REDDES, Report, Contract # 4.1030 / Z /01-081/2001.

[5] Werner M. and Schafer A. I. (2007) Social aspects of a solar powered desalination unit for remote Australian communities, Desalination 203, p. 375–393.

[6] Fath H.E.S., El-Shall F.M., Vogt G. and Seibert U. (2005) A stand alone complex for the production of water, food, electrical power and salts for the sustainable development of small communities in remote areas, Desalination 183, p. 13–22.

[7] Müller-Holst, H. (2001) Small Scale Thermal Water Desalination System Using Solar Energy or Waste Heat, MEDRC Series of R&D Reports, MEDRC Project: 97-AS-024b.

[8] Co-ordination Action for Autonomous Desalination Units Based on Renewable Energy Systems (ADU-RES): GUIDELINES, May (2006) WP 6 - Deliverable 6.2, Co-ordinated by Fraunhofer ISE, INCO – CT-2004-50 90 93.

[9] Co-ordination Action for Autonomous Desalination Units Based on Renewable Energy Systems (ADU-RES): GUIDELINES, November (2005) WP 4 – Technical Report on Cost Reduction Strategy, INCO – CT-2004-50 90 93.

Additional References

[10] Lindemann J. H. (2004) Wind and Solar Powered Seawater Desalination; Applied Solution for Mediterranean, the Middle East and the Gulf Countries, Desalination 168, p. 73-80.

[11] Kalogirou S. A. (2005) Seawater Desalination Using Renewable Energy Sources, Progress in Energy and Combustion Science 31, p. 242 – 281.

[12] Carta J. A., Gonzalez J., Subiela V. (2004) The SDAWES Project: An Ambitious R&D Prototype for Wind-Powered Desalination, Desalination 161, p. 33-48.

[13] Tzen E, Theofilloyianakos D., Sigalas M. and Karamanis K. (2004) Design and Development of a Hybrid Autonomous System for Seawater Desalination, Desalination 166, p. 267-274.

[14] Assaf S. A. (2001) Existing and the future planned desalination facilities in the Gaza Strip of Palestine and their socio-economic and environmental impact, Desalination 138, p. 17-28.

[15] Gräter F. (2001) Technologies for the desalination of typically 10 m³ of water per day DESAL10 – a tool for the identification of appropriate de-central solutions, Desalination 139, p. 393-397.

[16] Mohsen M. S., Jaber J. O. (2001) A photovoltaic-powered system for water desalination, Desalination 138, p. 129-136.

[17] Chaibi A M.T. (2000) An overview of solar desalination for domestic and agriculture water needs in remote arid areas, Desalination 127, p. 119-133.

[18] Reddy K.V., Ghaffour N. (2007) Overview of the cost of desalinated water and costing methodologies, Desalination 205, p. 340-353.

[19] Banat, F., Subiela V. Qiblaweya H. (2007) Site selection for the installation of autonomous desalination systems (ADS), Desalination 207, p. 410-416.

[20] Paulsen K, Hensel F. (2007) Design of an autarkic water and energy supply driven by renewable energy using commercially available components, Desalination 207, p. 455-462.

[21] Rodriguez L.G. (2003) Renewable energy applications in desalination: state of the art, Solar Energy 75, p. 381-393.

[22] Johannes H. (2004) Wind and solar powered seawater desalination: Applied solutions for the Mediterranean, the Middle East and the Gulf Countries, Desalination 168, p. 73-80.

ANNEXES

ANNEX 1

Annex 1.1 Thermal Desalination Process

Multiple-stage flash distillation

Process Description	Multiple stage flash (MSF) distillation is the most widely used desalination process, in terms of capacity. The performance ratio (mass of distillate produced per unit mass of steam consumed) is an important parameter used for gauging the performance of a plant. A performance ratio of 8-10 is the practical upper limit for this type of plant. An MSF plant can contain from 4 up to 40 stages. Increasing the number of stages reduces the heat transfer surface that is required, reducing the capital cost. This has to be offset against the cost of providing extra stages. Complicated optimisation calculations have to be undertaken where the main parameters are capital cost versus operating cost. MSF plants usually operate at top brine temperatures of between 90-120 C, depending on the feed water treatment. Operation at higher temperatures than 120 C is not workable because of problems of scale deposition in the brine heater. Looking for methods to increase TBT (new anti scalant or Nano Filtration) or the flashing range will increase the system performance, productivity and, therefore, water production cost. The advantages of the “brine recirculation” configuration are that the sea water pre-treated is in the order of only one third of the once-through design. However, new configurations as mixed and brine recirculation with higher make-up rate (up to once through) are considered for future developments. The majority of the tube bundles work with de-aerated brine water with lower corrosion and the in-condensable gases released are reduced thus achieving higher efficiency of the stages. In general, MSF plants are relatively easy to operate. Special attention is required in order to avoid scaling and corrosion of materials. With the appropriate maintenance, modern plants can operate with long intervals between shutdowns. Life spans of up to 40 years are now being predicted for large plants in the Arabian Gulf area.
Technology deployment	MSF distillation process has played a vital role in the provision of water in many areas, particularly in the Middle East. The installed capacity of the process has grown considerably over the last twenty-five years. MSF has been developed and adapted to large-scale applications, usually greater than 5000 m3/d. At present, the largest MSF plant, contracted or in operation is of 60000 m3/d product water capacity. Plans for 75,000 – 100,000 m3/d are under consideration. The process is widely used in the Gulf countries with 75% of the global total installed capacity. In Europe the MSF process is mainly used in Italy and in Spain.
Manufacturing	Concerning manufacturing, Japanese and Korean manufacturers produce 45% of the world production of the MSF plants. European manufacturers produce 43% of the total production and the USA 8%.
Economics	The capital cost as well as the energy cost of an MSF plant is significant. The main energy requirement is thermal energy. Electricity demand is low and is used for auxiliary services such as pumps, dosifiers, vacuum ejectors, etc. For instance, for a plant that operates at a performance ratio equal to 8 the thermal energy consumption is around 290 kJ/kg of produced water while the electricity consumption can be ranged from 4 to 6 kWh/m3.

Multiple effect distillation

Process Description	Multiple effect distillation (MED or ME or MEE) was the first process used for seawater desalination. It is widely used in the chemical industry where the process was originally developed. The MED process is similar to the MSF process since it also operates in part by flashing, however, the majority of the distillate is produced by boiling. Most of the new MED plants have been built around the concept of operating at lower temperatures. Some of the more recent plants have been built to operate with top temperatures (in the first effect) around 70 C reducing the potential for scaling within the plant. MED plants tend to have smaller number of effects than MSF stages. Usually 8-16 effects are used in typical large plants, due to the relation of the number of effects with the performance ratio (which cannot exceed the number of effects of the plant). As in an MSF plant, special attention is required concerning the operating temperature to avoid scaling and corrosion of materials. Also, extra care is required concerning the control of the brine level in each effect.
Technology deployment	MED has been widely used for industrial applications (e.g. for sugar production by juice distillation) and for salt production by seawater distillation. Some of the early water distillation plants used the MED process, but this process was displaced by the MSF units because of cost factors, fewer operating problems, and their apparent higher efficiency. However, interest in the MED process has increased and a number of new designs have been developed. MED units of more than 5000 m/d in capacity have been constructed. However, small single and multiple effect units are more common. MED process is primarily used in the former USSR, which accounts 39% of the global MED installed capacity, 10% in the Caribbean islands, 7.2% in USA, and 12.7% in Europe.
Manufacturing	A number of European companies are developing innovative MED designs which offer lower energy consumptions than conventional MSF. The desalination market is particularly conservative and there is a reluctance to move from the well-proven MSF design.
Economics	The cost of an MED plant heavily depends on the performance ratio. Capital and energy costs are significant factors. The main energy requirement is thermal energy. For a plant operating with a performance ratio equal to 8 the thermal energy consumption is around 290 kJ/kg of produced water. Electrical energy demand is low around 2.5-3 kWh/m^3.

Vapour compression

Process Description	There exist two vapour compressor (VC) processes. The first configuration is mechanical vapour compression (MVC), in which a mechanical compressor is used. The second, is thermal vapour compression (TVC), in which a thermo compressor or ejector is used to increase the vapour's pressure. Both types are widely used. The fundamental concept of this process is inherently simple, in that after vapour has been produced it is then compressed to increase its pressure and consequently its saturation temperature before it is returned to the evaporator as the heating vapour for the evaporation of more liquid.
Technology Deployment	Vapour compression plants have been in use since the end of the 19th century. The vapour compression process is usually used for small and medium scale water desalination units in a range of 20-2500 m^3/d. Many applications for this process have been found. Because of its compactness, ease of operation and transportability, military versions have been developed. The process is mainly used in Western countries. 20% of the total installed capacity is in USA, 13% in the Middle East, and 22% in Europe.
Manufacturing	Concerning VC manufacturing, 48% of the capacity was sold by European companies, 32% by US companies and 18% by an Israeli company.
Economics	Capital and energy costs are significant factors in the determination of the total water production cost. The energy demand mainly required to drive the vapour compressor motor. Its operation and maintenance sometimes covers half of the total operating and maintenance cost. However, the energy requirements of VC plants have been reduced (from 20 kWh/m^3) and currently range between 8 to 12 kWh/m^3 - with the potential for further reduction.

Annex 1.2 Membrane Desalination Process

Reverse osmosis

Technology Description	Reverse osmosis (RO) is the most widely used process for seawater desalination. RO process involves the forced passage of water through a membrane against the natural osmotic pressure to accomplish separation of water and ions. A typical RO system consists of four major subsystems; pre-treatment system, high pressure pump, membrane modules, post-treatment system Feed water pre-treatment is a critical factor in the operation of an RO system due to membranes sensitivity to fouling. Pre-treatment commonly includes feed water sterilisation, filtration and addition of chemicals in order to prevent scaling and bio-fouling. The post-treatment system consists of sterilisation, stabilisation and mineral enrichment of the product water. The pre-treated feed water is forced by a high-pressure pump to flow across the membrane surface. RO operating pressure varies from 17-27 bar for brackish water and from 55-82 bar for sea water. Part of the feed water, the product or permeate water, passes through the membrane, removing from it the majority of the dissolved solids. The remainder together with the rejected salts emerges from the membrane modules at high pressure, as a concentrated reject stream (brine). In large plants the reject brine pressure energy is recovered by a turbine, recovering from 20% up to 40% of the consumed energy. Two types of RO membranes are used commercially. These are the spiral wound (SW) membranes and the hollow fiber (HF) membranes. SW and HF membranes are used to desalt both seawater and brackish water. The choice between the two is based on factors such as cost, feed water quality and product water capacity. Now SW is dominated as the only HF company was sold. Due to the R0 unit operation at ambient temperature, corrosion and scaling problems are diminished in comparison with distillation processes. However, effective pre-treatment of the feed water is required to minimize fouling, scaling and membrane degradation. In general, the selection of the proper pre-treatment as well as the proper membrane maintenance are critical for the efficiency and life of the system A large number of RO plants has been installed for both sea water (SWRO) and brackish water (BWRO) applications. The process is also widely used in manufacturing, agriculture, food processing and pharmaceutical industries. 32% of the total RO units installed capacity is found in the USA, 21% in Saudi Arabia, 8% in Japan, and 8.9% in Europe. RO units are available in a wide range of capacities due to their modular design. Large plants are made up of hundreds or thousands of modules which are accommodated in racks. Also, very small units (down to 0.1 m3/d) for marine purposes, for houses or hotels are available.
Manufacturing	The main membranes manufacturers are in USA and Japan. Concerning RO systems manufacturing 23% are produced in USA, 18.3% in Japan and 12.3% in Europe.
Economics	As a general rule, a seawater RO unit has relatively low capital cost and significant maintenance cost due to the high cost of the membrane replacement. The cost of energy used to drive the plant is also significant. The major energy requirement for reverse osmosis desalination is for pressurizing the feed water through the membranes. Energy requirements for SWRO have been reduced to around 2.5 kWh/m^3 for large units with energy recovery systems, while for small units this may exceed 15 kWh/m3. For brackish water desalination the energy requirement is between 1 to 3 kWh/m^3.

Electro-dialysis

Process Description	ED is an electrochemical process and a low cost method for the desalination of brackish water. Due to the dependency of the energy consumption on the feed water salt concentration, the Electro-dialysis process is not economically attractive for the desalination of seawater. In electro-dialysis (ED) process, ions are transported through a membrane by an electrical field applied across the membrane. An ED unit consists of the following basic components; pre-treatment system, membrane stack, low pressure circulation pump, power supply for direct current (rectifier), post-treatment The principle of electro-dialysis operation refers to the following, When electrodes are connected to an outside source of direct current, like a battery, in a container of water, electrical current is carried through the solution, with the ions tending to migrate to the electrode with the opposite charge. Positively charged ions migrate to the cathode and negatively charged ions migrate to the anode. If between electrodes a pair of membranes (cell), anion permeable membrane followed by a cation permeable membrane is placed, then, a region of low salinity water (product water) will be created between the membranes. Between each pair of membranes, a spacer sheet is placed in order to permit the water flow along the face of the membrane and to induce a degree of turbulence. One spacer provides a channel that carries feed (and product water) while the next carries brine. By this arrangement, concentrated and diluted solutions are created in the spaces between the alternating membranes. ED cells can be stacked either horizontally or vertically. In practice, several membrane pairs are used between a single pair of electrodes, forming an ED stack. Feed water passes simultaneously in parallel paths through all the cells, providing a continuous flow of product water and brine to come out from the stack. Stacks on commercial ED plants contain a large number, usually several hundred of cell pairs. Concerning the maintenance of an ED plant, extra care is required for the feed water pre-treatment to prevent membrane degradation. A modification to the basic electro-dialysis process is the reversal electro-dialysis, EDR. An EDR unit operates on the same general principle as a standard ED plant, except that both, the product and the brine channels are identical in construction. In this process the polarity of the electrodes changes periodically of time, reversing the flow through the membranes. This inhibits deposition of inorganic scales and colloidal substances on the membranes without addition of chemicals to the feed water. This development has enhanced the viability of this process considerably as the process is now self-cleaning. In general, EDR requires minimum feed water pre-treatment and minimum use of chemicals for membrane cleaning.

Electro-dialysis (continued)

Technology deployment	Electro-dialysis has been in commercial use since 1954, over ten years before RO Since then, this process has seen widespread applications for a number of purposes, of which the production of potable water is one of the most important. Due to its modular structure, ED is available in a wide range of sizes, from small (down to 2 m3/d) up to large product water capacities. ED is widely used in USA with a 31 % of the total installed capacity. In Europe ED process accounts a 15% while in the Middle East a 23% of the total installed capacity. The EDR process was developed in the early 1970s. Today, the EDR process is in use in over 30 countries around the world with 1,100 installations. Typical industrial users of EDR include power plants, semiconductor manufacturers, pharmaceutical industry, food processors, etc.
Manufacturing	Manufacturing of ED and EDR plants is largely controlled by one company, Ionics of U.S.A. Ionics company was sold to GE.
Economics	In a general rule electro-dialysis is an economically attractive process for low salinity water. In capital cost terms, EDR requires some extra equipments (timing controllers, automatic valves etc.), in comparison with ED, but reduces or almost eliminates the requirement for chemical pre-treatment. In general, the total energy consumption, under ambient temperature conditions and assuming product water of 500 ppm TDS, would be around 1.5 and 4 kWh/m3 for a feed water of 1500 to 3500 ppm TDS, respectively. Additionally, pumping energy requirements are minimum.

ANNEX 2

Annex 2.1 Basic questionnaire for selection of regions

PART a) General data of the region

LOCATION	
Name of the region *	
Country *	
Location in the country * **(N. S. W, E, NW).**	

SOCIOECONOMIC BASIC DATA				
Population				
Total	**Women population (%)**	**Growth due to migrations (%/year)**	**Natural growth (%/year)**	**Number of villages**

Basic Economics		
General data		
Main occupations	**Per capita incomes ($/year)**	**Unemployment level (%)**

Industrial estate data (Secondary sector)	
Industrial Sectors[d]	**Water demand (m^3/day)**

Tourist data[1]	
Hotels or other tourist infrastructure	**Water demand (m^3/day)**

Agricultural data (primary sector)		
Main crops	**Total cultivated area (hectares)**[2]	**Water demand (m^3/day)**

ENVIRONMENTAL BASIC DATA				
Total surface of the region (km^2) *	**Type of weather**	**Average annual rainfall*** **(litres/m^2)**	**Rains period***	**Average annual ambient temp. (^{o}C)**

WATER INFRASTRUCTURES BASIC DATA	
Supply Water Companies **(Private or public water companies, independent producers)**	
Name[d]	**Contact details**
Distribution Water Companies **(if not already mentioned above – also service providing companies, like for example billing companies)**	
Name[d]	**Contact details**
O&M or other related Water Companies **(Suppliers of desalination plant spare parts and other technical services)**	
Name[d]	**Contact details**

State of mains			
Leakages (%)	**Extension of operating circuits (km)**	**Covered area (km^2)**	**Supplied flow (m^3/day)**

ELECTRICITY INFRASTRUCTURES BASIC DATA			
Companies			
Supply	**O&M**	**Distribution**	**Other**
☐**Y. Name(s):** ☐**N**	☐**Y. Name(s):** ☐**N**	☐**Y. Name(s):** ☐**N**	☐**Y. Name(s):** ☐**N**

State of mains		
Extension of operating circuits (km)	**Covered area (km^2)**	**Supplied energy (MWh/year)**
Technical data *		
Consumer Voltage (V AC)	**Frequency (Hz)**	**Installed power (MW)**

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[1] Do not complete data from a specific hotel, but from the whole hotels sub-sector and other tourist sub-sectors as apartments, golf courses…)

[2] 1 hectare = 10,000 m^2

WATER BASIC DATA		
Number & type of raw water sources * / Quality[3]		
River(s)	**Inland well(s)**	**Others (specify)**
☐ /	☐ /	**(Name) (Quality)**
Number of rivers	**Number of inland wells**	**Number of other sources**
Mark those sources which are used to supply demand / Specify the pre treatment if it exists		
☐ /	☐ /	☐ /

Other operating water sources to supply demand * / Quality[4]			
External supply (tank wagon, general pipe)	**Others 1**	**Others 2**	**Others 3**
☐ /	☐ /	☐ /	☐ /

Real current water demand						
Drinking (l/d)	**Irrigation (m3/d)**	**Industry (m^3/d)**	**Tourism (m^3/d)**	**Other (m^3/d) (please specify)**	**Estimation total (m^3/d)**	**N° of Users ***
Desirable water demand[4]						
Drinking (l/d)	**Irrigation (m3/d)**	**Industry (m^3/d)**	**Tourism (m^3/d)**	**Other (m^3/d) (please specify)**	**Estimation total (m^3/d)**	**N° of Users ***

BIOMASS		
Agricultural (vegetal) wastes	**Cattle (animal) wastes**	**Urban Wastes**
☐**Y** **Estimate the production (t/yr)…………………………..** ☐**N**	☐**Y** **Estimate the production (t/yr)…………………………..** ☐**N**	☐**Y** **Estimate the production (t/yr)…………………………..** ☐**N**

ENERGY BASIC DATA *	
Solar data	
Does the region have a relevant solar energy potential? (Daily average global solar radiation > 4,500 Wh/m2) OR (The number of sunny days per year > 200).	
Write the location(s) (All, N, S, E, W, NE, NW, SE, SW) in affirmative case.	
☐ **NO**	☐**YES**

Do you know some solar radiation data? Write the value [5](s) / location (s) (name of places) in affirmative case	
☐ **NO**	☐**YES** **1. …………………………/……** **2. …………………………/…**
Wind data	
Does the region have a relevant wind energy potential? (Annual average wind speed > 6.5 m/s). Write the location(s) (All, N, S, E, W, NE, NW, SE, SW) in affirmative case.	
☐ **NO**	☐**YES ………………………………..**
Do you know some wind speed data? Write the value (s) / location (s) (name of places) in affirmative case	
☐ **NO**	☐**YES** **1. ………………………** **2. …………………………**

PART b) List of interesting villages / rural areas

Please, list the villages or rural areas located in the region that accomplish with the following criteria:

1. Availability of a raw water source (sea, inland well or other)
2. The number of inhabitants will not be more than 2,500
3. The area should have a significant wind and/or solar energy potential[6]

List of villages / rural areas [a d]			
Name	**Population (inhs.)[b]**	**Solar energy assessment[7]**	**Wind energy assessment[8]**
………………… ……	………………… ……	………………… ……	………………… ……
………………… ……	………………… ……	………………… ……	………………… ……

OBSERVATIONS

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[3] Please, indicate the unit (µS/cm or ppm)

[4] Indicate the water supply that, in your opinion, would be required to achieve a suitable quality of life

[5] Indicate the unit (Wh/m^2/year; Wh/m^2/month; Wh/m^2/day…)

[6] Daily average global solar radiation > 4,500 Wh/m^2 or the number of sunny days per year > 200.

[7] Indicate a qualitative estimation according to the following scale (1: very low; 2: low; 3: medium; 4: high; 5: very high)

Annex 2.2 Detailed questionnaire for site selection

WATER DATA											
	Code	**Data definition**	**Unit**	**Mandatory**	**Value**	**Real / Estimated (R/E)**	**Minimum Value**	**Maximum value**	**Minimum Value Month**	**Maximum value month**	**Observations**
General data of feed water (seawater or brackish (well) water)	WD1	Source of water	-	*							River, Brackish (inland) well, Beach Well, Sea Direct Intake, Others (specify)
	WD2	Depth, (in case of well)	m	*							Stational variation should be included (use the Minimum Value and Maximum Value columns).
	WD3	Total dissolved solids	mg / l								
	WD4	Conductivity	mS/cm	*							
	WD5	pH	-								
	WD6	Temperature	ºC								
	WD7	Turbidity	NTU								
	WD8	Silt Density Index (SDI)	-								
Cations in feed water	WD9	Na(+)	mg / l								Stational variation should be included (use the Minimum Value and Maximum Value columns).
	WD10	K(+)	mg / l								
	WD11	Ca(+2)	mg / l								
	WD12	Mg(+2)	mg / l								
	WD13	NH(+4)	mg / l								
	WD14	Fe(+2)	mg / l								
	WD15	Mn(+2)	mg / l								
	WD16	Ba(+2)	mg / l								
Anions in feed water	WD17	Cl(-)	mg / l								Stational variation should be included (use the Minimum Value and Maximum Value columns).
	WD18	SO4(-2)	mg / l								
	WD19	NO3(-)	mg / l								
	WD20	PO4(-3)	mg / l								
	WD21	HCO3(-)	mg / l								
	WD22	CO3(-2)	mg / l								
	WD23	F(-)	mg / l								

WATER DATA (continued)

	Code	Data definition	Unit	Mandatory	Value	Real / Estimated (R/E)	Minimum Value		Code	Data definition	Unit
Others (feed water)	WD24	Hardness ($CaCO_3$)	mg / l								Stational variation should be included (use the Minimum Value and Maximum Value columns).
	WD25	Silica	mg / l								
	WD26	Total coliform	UFC/100 ml								
	WD27	Fecal Bacteria Coliform	UFC/100 ml								
Water uses	WD28	Water demand for drinking	m3/day	*							Stational variation should be included (use the Minimum Value and Maximum Value columns).
	WD29	Water demand for hygiene	m3/day	*							
	WD30	Water demand for industry	m3/day	*							
	WD31	Water demand for agriculture	m3/day	*							
	WD32	Water demand for irrigation	m3/day	*							
	WD33	Water demand for livestock	m3/day	*							
Irrigation	WD34	Cultivated fields	hectares								
	WD35	Fields irrigated with sprinkler irrigation	%								
	WD36	Fields irrigated with burrow or drip irrigation	%								

ENERGY DATA

Code	Data definition	unit	Mandatory	Value	Real / Estimated (R/E)	Minimum Value	Maximum value	Minimum Value Month	Maximum value month	Observations
ED1	Global solar radiation	W/m^2	*							If available, 1 data/month (average), fill the next sheet. At least include the maximum and minimum values along the year
ED2	Average wind speed data	m/s	*							If available, put 1 data /month, fill the next sheet. At least include the maximum and minimum values along the year
ED3	Height of the wind speed sensor	m	*							
ED4	Most frequent wind address	-								N, S, E, W, NE, NW, SE, SW,
ED5	Wind speed typical deviation data	m/s								If available, indicate the source of data to obtain it
ED6	Total electric installed power	kW	*							If the site is connected to the grid
ED7	Annual electricity consumption	kWh	*							If the site is connected to the grid
ED8	Availability of diesel fuel supply	Y/N	*							

MONTH	GLOBAL SOLAR RADIATION AVERAGE DATA (W/m^2)	Real / Estimated (R/E)	AVERAGE WIND SPEED DATA (m/s)	Real / Estimated (R/E)
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

INFRASTRUCTURE DATA

	Code	Data definition	unit	Mandatory	Value	Real / Estimated (R/E)	Observations
	ID1	Supplier A: Piping and valves: PVC, PE, SS	Y/N	*			In affirmative case, specify contact data: person phone, fax, address, e-mail, web page. Fill the next sheet
	ID2	Supplier B: Electrical devices & elements	Y/N	*			
	ID3	Supplier C: Hardware	Y/N	*			
	ID4	Supplier D: Chemical products and filtration system for desalination plants	Y/N	*			
	ID5	Supplier E: Civil infrastructure Works	Y/N	*			
	ID6	Distance site - Supplier A location	km				
	ID7	Distance site - Supplier B location	km				
	ID8	Distance site - Supplier C location	km				
	ID9	Distance site - Supplier D location	km				
	ID10	Distance site - Supplier E location	km				
	ID11	Estimated time to get to the supplier A location	hours				Estimate the time to arrive at the site
	ID12	Estimated time to get to the supplier B location	hours				Estimate the time to arrive at the site
	ID13	Estimated time to get to the supplier C location	hours				Estimate the time to arrive at the site
	ID14	Estimated time to get to the supplier D location	hours				Estimate the time to arrive at the site
	ID15	Estimated time to get to the supplier E location	hours				Estimate the time to arrive at the site
Electric infrastructure	ID16	Location of grid connection points	-	*			Specify if there is any close. A map with the location would be advisable
	ID17	Local grid AC Voltage	V	*			
	ID18	Local grid frequency	Hz	*			
	ID19	Electric supply company?	Y/N	*			In affirmative case, specify contact data: person phone, fax, address, e-mail, web page. Fill the next sheet
Hydraulic infrastructure	ID20	Location of fresh water distribution grid	-	*			Specify if there is any close. A map with the location would be advisable
	ID21	Location of water discharge point	-	*			
	ID22	Location of raw water pipes	-	*			
	ID23	Location of water storage tanks	-	*			
	ID24	Water distribution company?	Y/N	*			In affirmative case, specify contact data: person phone, fax, address, e-mail, web page. Fill the next sheet
	ID25	Losses in the urban/rural pipe mains	%				
	ID26	Rain water infrastructure to reuse it	Y/N				
	ID27	Storage water tanks (total volume) in current use	m3				
	ID28	Present state rain water infrastructure	Y/N				In affirmative case, select an option: good, regular, bad,

SOCIO-ECONOMIC DATA

Code	Data definition	unit	Mandatory	Value	Real / Estimated (R/E)	Minimum Value	Maximum value	Observations
SED1	Current population	inh	*					Total resident population (use the most recent data)
SED2	Female population	%	*					
SED3	Non sedentary population	Y/N						In affirmative case, indicate % or number of residents who leave the village along the year, and the number of months of absence
SED4	Immigrant population flow	persons/yr	*					Foreign (non local) people who starts to live in the village along one year
SED5	Emigrant population flow	persons/yr	*					Resident people who leave the village for a long time (more than one year)
SED6	Number of births in one year	persons/yr						Use the most recent data
SED7	Number of deaths in one year	persons/yr						Use the most recent data
SED8	Occupation	-						Agriculture, industry, others
SED9	Per capita incomes	$/month/inh						
SED10	Unemployment level	%						
SED11	Female unemployment	%						
SED12	Number of houses	units	*					
SED13	Livestock number (heads)	units						
SED14	Type of livestock	-						cows, hens, sheeps, goats, horses, camels, other (specify)
SED15	Basic diagram of the site	-	*					Map with the most relevant buildings and the geographic details (orientation, coast line, mountains, trees, etc.)
SED16	Real expenses for current fresh water supply on – site	$/m3						
SED17	Water prices (if appropriate differentiated by consume purpose and by consume quantity)	$/m3						
SED18	Real expenses for current electricity generation	$/kWh						
SED19	Electricity prices	$/kWh						

ENVIRONMENTAL DATA										
Code	**Data definition**	**unit**	**Mandatory**	**Value**	**Real / Estimated (R/E)**	**Minimum Value**	**Maximum value**	**Minimum Value Month**	**Maximum value month**	**Observations**
END1	Minimum Temperature	ºC	*							If available, 1 data/month (average). At least include the maximum and minimum values along the year
END2	Maximum Temperature	ºC	*							If available, 1 data/month (average). At least include the maximum and minimum values along the year
END3	Type of weather	-								Wet, dry, cold, hot
END4	Rainfall	litres/(m^2. year)	*							If available, 1 data/month (average). At least include the maximum and minimum values along the year
END5	Rain season	-								Put the Months
END6	Possible obstacles in the area	-								Trees, buildings, houses and others to consider thier influence in shadows and wind
END7	Latitude of the site	º	*							
END8	Altitude (from the sea level)	m	*							
END9	Presence of air pollutants	-								Only if it is relevant, specify type (dust, sand, others)
END10	Quality of the present water supply	scale 1 - 5								1: Very Bad; 2: Bad; 3: Medium; 4: Good; 5: Very Good (Include in your decision visual, taste, and odour aspects)
END11	Description of the area	-								Vegetation, mountains, dessert, beach, others

OTHER DATA										
Code	**Data definition**	**unit**	**Mandatory**	**Value**	**Real / Estimated (R/E)**	**Minimum Value**	**Maximum value**	**Minimum Value Month**	**Maximum value month**	**Observations**
OTD1	Other water treatment in the village	Y/N	*							In affirmative case, please complete the data of the next sheet
OTD2	Water treatment installations out of order?	Y/N	*							In affirmative case, please complete the data of the next sheet
OTD3	Local regulations to introduce equipment into the country	Y/N	*							Local authority contact data. In affirmative case, specify taxes in the next sheet
OTD4	Local permissions to install water or energy plants	Y/N	*							Local authority contact data. In affirmative case, specify taxes in the next sheet
OTD5	Interest of local authority for renewable energy systems	-	*							Very High / High / Normal / Low / Very Low
OTD6	Interest of local authority for decentralised desalination	-	*							Very High / High / Normal / Low / Very Low
OTD7	Interest of water consumers for ADS	-	*							Very High / High / Normal / Low / Very Low

ANNEX 3

Annex 3.1Evaluation of the various RES - desalination options

Input	**Output**	**Water Quantity Requirement**	**Resource availability**	**RES- Desalination technically feasible Technology**	**Remarks on technology applicability**
Brackish	Potable	Low	Solar	PV – RO	most applicable
				PV – ED	limited experience
		medium		PV – RO PV - ED	because of high cost of PVs only recommended for quantities of output water
		Large		PV – RO PV - ED	because of high cost of PVs only recommended for quantities of output water
Brackish	Potable	Low	Wind	Wind – RO Wind - ED	most applicable
		medium		Wind – RO Wind - ED	most applicable
		large		Wind – RO Wind - ED	not recommended because of high storage costs of autonomous wind energy systems
Brackish	Distillate	low	Solar	Solar Still	most applicable
				Solar thermal – MED	MED not recommended for brackish water desalination, not used for low quantities of output water
				Solar thermal – MSF	MSF not recommended for brackish water desalination, not used for low quantities of output water
		medium		Solar Still	high cost due to large land requirements
				Solar thermal – MED	MED not recommended for brackish water desalination
				Solar thermal – MSF	MSF not recommended for brackish water desalination, not used for low quantities of output water
		large		Solar Still Solar thermal - MED Solar thermal - MSF	significant large land requirements MED not recommended for brackish water desalination MSF not recommended for brackish water desalination
Brackish	Distillate	low	Wind	Wind – MVC	MVC not used for low quantities of output water, not recommended for brackish water desalination
		medium		Wind – MVC	MVC not recommended for brackish water desalination
		large		Wind – MVC	MVC not recommended for brackish water desalination

Annex 3.1Evaluation of the various RES - desalination options (Con't)

Input	**Output**	**Water Quantity Requirement**	**Resource availability**	**RES- Desalination technically feasible Technology**	**Remarks on technology applicability**
Brackish	Distillate	low	Geothermal	Geothermal - MED Geothermal - MSF	MED, MSF- not used for low quantities of output water, not recommended for brackish water desalination
		medium		Geothermal - MED	MED not recommended for brackish water desalination
				Geothermal MSF	MSF not recommended for brackish water desalination and for low quantities of output water
		large		Geothermal - MED Geothermal - MSF	MED, MSF not recommended for brackish water desalination
Sea water	Potable	low	Solar	PV - RO	most applicable
				PV - ED	ED not recommended for sea water desalination due to high energy requirements
		medium		PV - RO	because of high cost of PVs only recommended for low quantities of output water
				PV - ED	ED not recommended for sea water desalination due to high energy requirements
		large		PV - RO	because of high cost of PVs only recommended for low quantities of output water
				PV - ED	ED not recommended for sea water desalination due to high energy requirements
Sea water	Potable	low	Wind	Wind - RO	most applicable
				Wind - ED	ED not recommended for sea water desalination due to high energy requirements
		medium		Wind - RO	most applicable
				Wind - ED	ED not recommended for sea water desalination due to high energy requirements
		large		Wind - RO	not recommended because of high storage costs of autonomous wind energy systems
				Wind - ED	not recommended for sea water desalination due to high energy requirements and high storage costs of autonomous wind energy systems

Annex 3.1Evaluation of the various RES - desalination options (Con't)

Input	**Output**	**Water Quantity Requirement**	**Resource availability**	**RES- Desalination technically feasible Technology**	**Remarks on technology applicability**
Sea water	Distillate	low	Solar	Solar Still	most applicable
				Solar thermal - MED	MED not used for low quantities or output water
				Solar thermal MSF	MSF not used for low quantities of output water
		medium		Solar Still	high cost due to large land requirements
				Solar thermal - MED	most applicable
				Solar thermal - MSF	MSF not used for low quantities of output water
		large		Solar Still	high cost due to large land requirements
				Solar thermal - MED Solar thermal - MSF	most applicable
Sea water	Distillate	low	Wind	Wind - MVC	MVC not used for low quantities of output water,
		medium		Wind - MVC	most applicable
		large		Wind - MVC	most applicable
Sea water	Distillate	low	Geothermal	Geothermal - MED Geothermal - MSF	MED, MSF not used for low quantities of output water
		medium		Geothermal - MED	most applicable
				Geothermal - MSF	MSF not used for low quantities of output water
		large		Geothermal - MED	most applicable

(1) Brackish water: 3000- 11 000 ppm TDS, sea water: 35 000 ppm TDS

(2) Potable: 250- 700 ppm TDS, distillate: < 20 ppm TDS

(3) Low: 1-50 m^3/ d, medium: 50- 250 m^3/d, large:> 250 m^3/d

ANNEX 4

Annex 4.1 The main actors involved in the water sector for Egypt, Jordan, Morocco and Turkey

	Egypt	Jordan	Morocco	Turkey
Sector Policy	▪ The Ministry of Water Resources and Irrigation (MWRI) ▪ Ministry of Agriculture and Land Reclamation, ▪ Ministry of Health (potable water quality monitoring ▪ Ministry of Housing, Public Utilities and New Communities	1. Ministry of Water and Irrigation 2. Ministry of Environment 3. Jordan Valley Authority 4. Water Authority of Jordan (WAJ) 5. Ministry of Health (MoH), local and regional	6. HCWC 7. MATEE[*] 8. Ministry of Agriculture 9. Ministry of Interior 10. Ministry of Health 11. Ministry of Finance 12. Ministry of Energy and Mines[*]	13. Ministry of Energy and Natural Resources MENR 14. General Directorate of State Hydraulic Works under MENR SHW ▪ Ministry of Agriculture and Rural Services MARS ▪ General Directorate of Rural Services under MARS GDRS
Sector planning and Management	• National Organization for Potable Water and Sanitary Drainage (NOPWASD). • Ministry of Health (potable water quality monitoring	▪ The Water Authority of Jordan (WAJ) ▪ The Jordan Valley Authority (JVA)	▪ Secretariat of state for Water SSCW (Direction of Water Research and Planning, DRPE) ▪ Secretariat of state for Environment (SSCE) ▪ Immunology Department ▪ General Directorate of the Local Communities ▪ Directorate of the “Régies” and the Conceded Services (DRSC) ▪ Inter ministerial Pricing Committee ▪ Department of Irrigation and Rural Engineering	▪ General Directorate of State Hydraulic Works (SHW) ▪ Bank of Provinces (BoP) ▪ General Directorate of Rural Services (GDRS) under aegis of the Ministry of Agriculture and Rural Services (MARS) ▪ Ministry of Health (MoH), local and regional ▪ State Planning Organization (SPO) ▪ General Directorate of Electric Power Resources Survey and Development (GDESD) Ministry of Environment and Forestry (MEF)

[*] following of the appointment of the government in October 2007, the water, environment and energy sectors are now under the aegis of the Ministry of Energy Mines, Water and Environment.

Annex 4.1 The main actors involved in the water sector for Egypt, Jordan, Morocco and Turkey (Con't)

	Egypt	Jordan	Morocco	Turkey
Water resources management	• Organization for Potable Water and Sanitary Drainage (NOPWASD).	▪ Northern Governorates Water Administration (NGWA)	▪ General Directorate of Hydraulic ▪ Installations (DGH), SSCW ▪ Department of hydraulic planning (DAH), SSCA ▪ Basin Agencies	▪ General Directorate of State Hydraulic Works (SHW)
Water production and treatment	• NOPWASD., Alexandria Water General Authority AWGA, Private Water companies	▪ Northern Governorates Water Administration (NGWA)	▪ River basin agencies, National office potable water (ONEP) and NGOs (rural)	▪ General Directorate of Rural Services, Municipalities
Bulk/drinking water distribution, sanitation	• NOPWASD, Alexandria Water General Authority AWGA Private Water companies • Non-Governmental Organizations	▪ Private sector (concession),	▪ ONEP, Regies and concessions, Agricultural development offices (ORMVA, irrigation)	▪ Municipalities, village councils and the director
Consumers	• Farmers, Users Associations (agriculture) Industries, urban and rural consumers	▪ Farmers, Users Associations (agriculture) Industries, urban and rural consumers	▪ Farmers, Users Associations (agriculture) Industries, urban and rural consumers	▪ Farmers, Users Associations (agriculture) Industries, urban and rural consumers

Annex 4.2 Permits and authorizations required for the implementation of ADS in some Mediterranean countries

Authorization/licensing	Egypt	Jordan	Morocco	Turkey
Borehole drilling and well digging:	-Yes	- Yes, - Ministry of water and irrigation	- Yes, thresholds depths depend on the region - Basin Agencies	- Yes, for depths greater than 10 m . - State Hydraulic Works
Water withdrawal (wells and boreholes)	- Yes	Yes, fees depend on the volume, no threshold - Ministry of water and irrigation	- Yes, threshold flow rates, - River Basin Agency	- Yes - State Hydraulic Works
Brine disposal	- No specific law - Environment affairs office	- No specific law	- No specific law - MATEE* (Environment)	- No specific law - Ministry of Environment and Forestry
Construction in coastal zones	- Yes (200 m of the shore line) - Egyptian general authority for costal protection - Ministry of environment affairs	- Yes	- Yes - Direction des Ports et du Domain Publique Maritime - MATEE* (Environment)	- Yes, 50 m beyond the shoreline - Ministry of Public Works and Settlement
Drinking water quality	Yes Ministry of Health	- Yes, Ministry of Health	Yes, Ministry of Health, accredited laboratories	Yes, - Ministry of Health
Installation and operation of standalone renewable energy systems	No	No	No	Yes; - Energy Market Regulation Authority (EMRA

* following of the appointment of the government in October 2007, the water, environment and energy sectors are now under the aegis of the Ministry of Energy Mines, Water and Environment

Annex 4.3 Legislations pertaining to water energy and environment in Egypt, Jordan, Morocco and Turkey

	Law	Date	Objective
Egypt	The Irrigation & Drainage Law #12	1984 - updated in 1987	Controls all the national water related activities
	Law # 4	1994	National environmental protection code of this law addresses the ground water and drainage.
	Law # 27	1978	Regulating the General Resources of Water Needed for Drinking & Human Use
Jordan	By-law No. 85	2002	Regulation of underground water use in Jordan
	Law No. 12 of 1995		Protection of Environment
	Temporary Law No(64) for	2002	General Electricity Law, creation of Electricity Sector Regulatory Commission (licensing, setting up the tariffs, determining the requirements of environmental standards)
	Water Authority Law No. 18, 1988		
Morocco	10-95 law on water	1995	Main water law, gives comprehensive framework for integrated water management; a set of legislative instruments for organization, planning and repartition of resources , regulation of the exploitation, the distribution and selling of water destined to human consumption, and degradation of the quality of water and the environment.
	11-03 law	May 12, 2003	Sets basic rules and the general principles of the national policy in the field of protection and the development of the environment
	12-03 Law	May 12, 2003	Defines projects likely to produce negative impacts and requiring an environment impact study
	Dahir (Royal decree) n° 1-63-226 ,	August 5, 1963, completed modified in 1994	Creation of the national office of electricity, sets the threshold for IPP and auto producers (10MW)
Turkey	The Groundwater Law (No. 167)	December 16, 1960	The case of withdrawing groundwater from any type of well (inland, beach well, etc.).
	Water Pollution Prevention Directive-WPPD (No. 19919)	September 4, 1988	Utilization of wells near the shoreline has to comply with the safe yields for withdrawal of water from the groundwater resources as a measure to prevent salty-water intrusion.
	The Directive on Water Intended for Human Consumption' (WIHC)	17 February 2005 (No. 25730)	Directive also sets the rules and procedures for the licensing, installation and monitoring for the plants that supply water intended for human consumption.
	Electricity Market Licensing Regulation (No. 24836).	August 4, 2002	Refers to the licenses for renewable energy installations is
	the 'Law of Electricity Market' No. 4628/24335)	February 20, 2001	Electricity generation, transmission, distribution, wholesale, retail, retail service, and import and export.

ANNEX 5

Annex 5.1 Maintenance needed for some ADS components

Component	Maintenance Needed
Pre-treatment and feed water system	Maintenance tasks concerning the pre-treatment process consist mainly of checking frequently the level of chemical tanks as well as checking the filters. Cartridge filters must be replaced when the difference between the output and input pressure is equal to or greater than specified in the maintenance manuals provided by their manufacturers. Sand filter must be backwashed if pressure drop between the input and output of the sand filter exceeds 0.5 bars. The systems for dosing of chemicals rarely present problems if have been made of adequate materials, except the diffuser of acid to the feed line, that is usually replaced yearly. When membrane fouling is prevented or minimized by effective pre-treatment, maintenance requirements in the entire RO plant are minimal.
High pressure pumps	Pump failure tends to be caused by one or more of four following conditions: • Inadequate pump (type, sizing); • Improper installation; • Inappropriate operation; and • Incorrect and irregular servicing. • Failure to follow the recommendations of the manufacturer (OEM spare parts, ...) • Operating a pump in dry conditions, as the motor will overheat and burn out. Water is needed for lubrication and heat dissipation. Positive displacement pumps use more components that are subject to wear. For this reason, maintenance requirements are higher than with other pump types. Under normal operating conditions, diaphragms need replacement every 2 to 3 years. The seals in a piston-type pump may last 3 to 5 years. Labour cost for maintenance depends on the country and is on the average €5/hour in addition to spare parts and consumables
Pump motor	Brushless DC and AC motors require little maintenance aside from preventing water and dust from entering the motor housing (in the case of open motors). Brushless DC and AC motors can last 10–20 years or more under ideal conditions. Brushed DC and AC motors require periodic replacement of brushes. Brushes are inexpensive but the unit must be stopped for this operation (downtime costs). The replacement should be performed according to the manufacturer's recommendations. Depending on the duty, a small brushed-motor may last 4 to 8 years. The bearings motors require grease lubrication and sometimes replacement after about 5000 hours of operation. Maintenance requirements depend also on the type of coupling (direct, drive, gear).

Annex 5.1 Maintenance needed for some ADS components (Con't)

Component	Maintenance Needed
Energy recovery systems	Maintenance tasks will vary among the different configurations offered. However, available energy recovery systems usually have little maintenance needs.
Storage of batteries before installation	Lead-acid batteries, before installation, should be stored in a dry and cool atmosphere. The long time storage at high temperature will have a detrimental effect on life as the corrosion of the lead electrodes is accelerated at elevated temperatures. Humid atmosphere will create a leakage current flowing over the battery cover between the positive and negative terminals. In the long run, but much faster than due to the internal self discharge, the battery will be deeply discharged decreasing thus the battery life due to sulphation of the electrodes. It is recommended to recharge batteries periodically (typically every six months), if they are to be stored for a long time. The capacity drain is otherwise very harmful to the battery life since self-discharge, going on inside the battery. Permanent damage is created if the self-discharge of the battery drains the battery completely Batteries can be protected against deterioration when stored before installation by a process called dry charging. The battery is then shipped fully charged but in dry condition and the acid is not filled in the cells until it is to be installed. Such dry charged batteries can usually be stored for almost two years without important degradation. When acid is introduced, the battery becomes operational very quickly.
PV systems	Operation and maintenance (O&M) costs can be significant for PV installations. For small PV systems, one maintenance visit per year can offset the value of energy produced per year by the system. Improving the reliability and fault tolerance of systems and equipment can have a significant effect on reducing O&M costs, and can improve overall system performance. While there have been very few problems associated with PV modules and arrays, a number of reliability issues have been identified with inverters and power conditioning equipment in grid-connected and AC systems. Over fifty percent of these installations have experienced problems with power conditioning subsystem components that required a site visit to correct the problem and return the system to normal operation. Unscheduled maintenance has been required to change out complete inverters, replace fuses, reset circuit breakers, and upgrade software. Based on the amount and value of energy produced from these systems, the estimated costs for maintenance have ranged from 0.04 to 0.20 € per kWh ac during the first year of operation. Other studies have identified O&M costs ranging from 0.01 to 0.16 per kWh. Challenges to reduce PV system maintenance costs include developing inverter designs that offer improved reliability and fault-tolerant features consistent with those for PV modules.
Wind energy	There are several maintenance needs for a wind turbine such as the alternator bearings replacement, yaw bearings replacement with their significant loading. Dust, debris, and even insects in the wind will eventually erode the most durable blade materials, leading edge tapes, and paint coatings. Tail bushings and governor components, subjected to dirt and moisture; inevitably wear as the turbine governs in storms or during windy periods. Paint coatings, subjected to sunlight, moisture, and temperature extremes will eventually deteriorate. If the wind turbine system has a gearbox, the lubricant will degrade over time. Typically direct driven wind turbines costs about 1% of the installed cost per year for the O&M costs, and 2% for wind turbines with gearbox.

Annex 5.1 Maintenance needed for some ADS components (Con't)

Component	Maintenance Needed
Storage Tanks	Water storage tanks do not involve any operation costs. Also the maintenance requirements are very low under normal conditions. All that has to be done is to have the tank drained, cleaned and professionally evaluated every three to five years. In addition in regular basis tanks should be checked for obvious problems like leakages or vandalism. Should such circumstances occur tank engineers have to be called in for repairing the damage. If these very simple maintenance procedures are followed water tanks can be functional for many decades, much longer than any autonomous desalination unit has ever operated. Tanks made of reinforced concrete or steel are more probable to require some maintenance operations than plastic tanks. Steel tanks are subject to corrosion, while concrete tanks may be affected by trees growing close to them. Additionally, those kind of tanks are coated and the coating may deteriorate needing repair.

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