



Sustainable Water Integrated Management - Support Mechanism (SWIM- SM)

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REVISED Final Report
**ASSESSMENT OF BEST AVAILABLE TECHNOLOGIES FOR
DESALINATION IN RURAL/LOCAL AREAS**

Version	Document Title	Author	Review and Clearance
2	ASSESSMENT OF BEST AVAILABLE TECHNOLOGIES FOR DESALINATION IN RURAL/LOCAL AREAS	Dr Adil Bushnak	Hosny Khordagui, Stavros Damianidis and Vangelis Konstantianos

Contents

Executive Summary	8
1. Introduction	10
2. Survey of BAT for desalination with focus on rural areas and description of renewable energy technologies for desalination	11
2.1 Description of available desalination technologies, their merits and weakness related to use in rural areas:.....	11
2.1.1 Multi-Stage Flash (MSF)	11
2.1.2 Multi-Effect Distillation (MED)	13
2.1.3 Vapour Compression Distillation.....	15
2.1.4 Reverse Osmosis	16
2.1.5 Electro-dialysis	19
2.1.6 Electro-dialysis Metathesis (EDM)	20
2.1.7 Membrane distillation (MD).....	21
2.1.8 Thermo-Ionic™ Desalination (Saltworks Technologies Inc.).....	23
2.1.9 Forward Osmosis.....	25
2.1.10 Solar Stills	27
2.1.11 Humidification/Dehumidification (HDH).....	27
2.2 Description of renewable energy technologies for desalination BATs.....	32
2.2.1 Solar energy	32
2.2.2 Wind energy	32
2.2.3 Geothermal	33
2.2.4 Waste Heat Availability	34
2.3 Process/RE resource combinations	34
2.3.1 Solar thermal-MED.....	34
2.3.2 Solar thermal-HDH	35
2.3.3 Solar thermal-MD.....	36
2.3.4 PV-RO	37
2.3.5 PV-ED.....	38
2.3.6 Wind-RO	39
2.3.7 Wind-MVC.....	39
2.3.8 Geothermal MED	39
2.3.9 Geothermal HDH and other thermal processes.....	39

3. Decisions, data and information before considering technologies for implementation of a desalination project.....	40
3.1 Integrated Water Resource Management Plan or diagnostic study	40
3.2 Capacities of Desalination Plants	40
3.2.1 Definitions	40
3.2.2 Desalination Plant Capacity.....	41
3.3. Desalinated water quality	41
3.4 Demographic and socio-cultural considerations	42
3.5 Cultural, religious & gender related issues:.....	42
3.6 Raw water resource availability & quality	43
3.7 Brine discharge location.....	43
3.8 Pricing structures & financing schemes (Affordability)	43
3.9 Institutional and regulatory factors	44
3.9.1 Institutional Factors	44
3.9.2 Regulatory Factors	45
3.10 Desalination Project systems	46
3.11 Selection of the site of the desalination plant.....	47
3.12 Budgeting and implementation costs including total cost of water	47
4. Guidelines to screen and assess BAT options for desalination with focus on rural areas....	49
4.1 Evaluation of available water resources and demand characteristics	49
4.2 Evaluation of available renewable energy sources and grid connectivity	50
4.3 Short listing of candidate desalination processes based on available RES	51
4.4 Maturity and level of deployment of the processes	51
4.5 Pre-treatment requirements	52
4.6 Operational skill level required.....	52
4.7 Energy storage vs Water storage options.....	53
4.8 Brine disposal	54
4.8.1 Brine Disposal methods and comparison.....	54
4.8.2 General on Brine disposal	58
4.9. Other practical site characteristics	59
4.10 Capital and operating costs of the total proposed solution (See also section 3.12).....	59

5. Modality for assessing community needs	59
5.1 Geographical considerations	59
5.2 The human factor: demographic and socio-cultural considerations.....	60
Cultural, religious and gender related issues.....	61
Capacity building	62
5.3 Water resource availability	62
5.4 Pricing structures and financing schemes	62
5.5 Institutional and regulatory factors	63
5.6 Additional Guidelines to Screen and assessment of Desalination BAT using RES	64
6. Recommendation of integration into National IWRM plans.....	65
References	69

List of Abbreviations

ADS	Autonomous Desalination System
AGMD	Air gap membrane distillation
BAT	Best Available Technology
BOOT	Build, Own, Operate and Transfer
BOT	Build, Operate and Transfer
CDE	Core Desalination Experts
CDG	Core Desalination Group
CSP	Concentrating Solar Power
DC	Direct current
DCMD	Direct contact membrane distillation
DES	Desalination
EC	European Commission
ED	Electro dialysis
EDM	Electro dialysis metathesis
EDR	Electro dialysis Reversal
EIA	Environmental Impact Assessment
EMP	Environmental Mitigation Plan
EU	European Union
FPs	Focal Points
GOR	Gain Output Ratio
GWP	Global Water Partnership
HAWT	Horizontal axis wind turbines
HDH	Humidification-dehumidification
IT	Information Technology
IWRM	Integrated Water Resources Management

KSA	Kingdom of Saudi Arabia
LLNL	Lawrence Livermore National Laboratory
MAP	Mediterranean Action Plan
MD	Membrane Distillation
MECO	Mechanical Equipment Company
MED	Multiple Effect Distillation
MED-POL	Program for the Assessment and Control of Marine Pollution in the Mediterranean Region
MES	Multiple Effect Stack
MSF	Multi-stage Flash
MVC	Mechanical Vapour Compression
NF	Nano filtration
NGO	Non-governmental Organisation
PC's	Participating Countries
PPP	Public Private Partnership
PR	Performance Ratio
PV	Photovoltaic
RBO	River Basin Organisation
RES	Renewable Energy System
RO	Reverse Osmosis
SGMD	Sweeping gas membrane distillation
SMC'a	South Mediterranean Countries
SWIM	Sustainable Water Integrated Management
SWIM-SM	Sustainable Water Integrated Management-Support Mechanism
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids
TL	Team Leader
TVC	Thermal Vapour Compression

TBT	Top Brine Temperature
UNEP	United Nations Environment Programme
VAWT	Vertical axis wind turbines
VMD	Vacuum membrane distillation
VSEP	Vibration Shear Enhanced Process
WESCO	Water and Environmental Services Co.
WP	Work Package

Executive Summary

Countries in the south of the Mediterranean Sea are facing increasing water scarcity. This scarcity is driving the need for augmenting conventional water supply with alternative water sources. Rural and remote areas are particularly disadvantaged because such areas are often located far away from municipal water supply systems and conventional water sources, and are often not connected to the electric power grid.

There is good potential for addressing the water scarcity problem in rural and remote areas through sustainable saline water desalination technologies. Seawater and brackish water desalination are well-established industries comprising a wide variety of available technologies with decades of accumulated experience.

Rural and remote areas have special requirements that influence the appropriate selection of technologies. These include technical requirements related to small-scale application using renewable energy sources, ease of operation and maintenance, and simple design; requirements dictated by geographical location; as well as socio-economic and socio-cultural requirements related to the communities that are intended to operate and benefit from the technology. Successful implementation and long term sustainability (operational and environmental sustainability) of desalination projects for rural and remote locations requires that all the relevant requirements be identified and addressed from the earliest stages of the project.

The present report provides a review of the Best Available Technologies (BAT) for desalination in rural areas suitable for the SWIM-SM participating countries (PC). The focus of the review is exclusively on sustainable desalination technologies. Both seawater and brackish water desalinations are considered.

The report begins with an overview and description of desalination process technologies, ones that are presently available as well as some that are expected to be available in the near future. The focus of the discussion is on relevance for application in rural and remote areas. This is summarized in Table 1 on page 30. Following that, a brief review of the main renewable energy technologies that are relevant for coupling with the BATs for desalination as well as a discussion of the main applicable process/renewable energy system (RES) combinations are provided. The major advantages and disadvantages of each RES relevant to the present purpose are discussed. The main renewable energy sources available in the PCs are solar energy (solar thermal and PV), wind power, and geothermal energy.

Two main factors play the major role in narrowing down the choice of process technologies:

- 1) The salinity of the feed water;
- 2) The type of energy available at a given location.

For brackish water sources up to about 3000 ppm, either RO or ED can be recommended as a good choice of desalination process for the purpose. For brackish sources at higher salinities ED no longer becomes suitable, leaving RO as the best choice presently available. Both of these processes are driven by mechanical or electrical power, which means that either solar PV or wind power is a suitable choice for off-grid sites, depending on the quality of the source at the location.

The situation is less clearly defined in the case of seawater desalination. At present, it can generally be said that two desalination processes stand out as being the most reliable and mature processes; one from each of the two families of power-driven and thermally driven processes: RO and MED. The best choice among these depends largely on the type and quality of RESs available at the location in question.

If the wind energy quality at a site is high, then wind-powered RO needs to be considered.

When geothermal energy is available, the stable and continuous nature of this RES constitutes a very desirable feature that warrants its serious consideration. Geothermal energy allows 24-hour plant operation without the need for energy storage. In such case, a good choice of process at the present state of technology would be MED, but other choices are possible and should be considered for small capacities, such as MD and HDH.

In most of the PCs, the amount of sunny days is high, and thus solar energy can almost be considered as the

default RES. In such cases, there are two major possible alternatives:

1. PV-RO: The system needs to be over-sized to provide the required daily capacity during the sunshine hours (~9-10 hr. /day), since it is not economically feasible at present to store electrical energy long enough for night operation.
2. Solar thermal-MED: Thermal energy storage can easily be applied economically, and the system can be sized to the desired daily capacity as usual. Other choices of thermal process are possible for small capacities.

A detailed comparison between these two alternatives needs to be carried out in order to select the best option.

This selection process is elaborated further in Chapter 3, which provides a guideline and methodology for screening and selecting the most appropriate technologies for application to a particular case. It is emphasized that optimum technology selection is a very case-dependant issue, and it is thus difficult to specify a fixed solution or solutions that are universally applicable. Instead, the present report provides a methodology for selection that begins by defining the scale of the problem to be addressed by the technology and an identification of the renewable energy resources available.

The report also emphasizes the importance of identifying the requirements of the local community as a critical factor for success of project success. The modalities for assessing community requirements comprise the subject material of Chapter 4. These include groups of factors and requirements dictated by geography, demographic and socio-cultural considerations, water resource availability, appropriate pricing structures and financing schemes, as well as institutional and regulatory factors.

Finally, the report discusses aspects and recommendations for integration of BATs for rural and remote area desalination projects within the context of national Integrated Water Resources Management (IWRM) plans. This takes into account the main principles of IWRM, and outlines a number of opportunities for strategic level Environmental Impact Assessments (EIA), as well as synergies that can be realized by integrating with wastewater treatment and re-use.

1. Introduction

The Sustainable Water Integrated Management (SWIM) is a European Union(EU)-funded Regional Technical Assistance Program [1] that “aims at supporting water governance and mainstreaming by promoting sustainable and equitable water resources management to become a prominent feature of national development policies and strategies (agriculture, industry, tourism, etc).” [2]

Countries in the south of the Mediterranean are facing increasing water scarcity. This scarcity is driving the need for augmenting conventional water supply with alternative water sources. Rural and remote areas are particularly disadvantaged because such areas are often located far away from municipal water supply systems and conventional water sources, and are often not connected to the electric power grid. There is good potential for addressing the water scarcity problem in rural and remote areas through sustainable saline water desalination technologies. Seawater and brackish water desalination are well-established industries comprising a wide variety of available technologies with decades of accumulated experience. There are many advancements and evolution in desalination technologies. The numerous technologies and processes available have different characteristics, advantages and disadvantages that make each suitable for particular market segments or specific niches. Moreover, much of the cumulative technology experience is related to large urban supply plants that are either connected to the grid, or are themselves part of large power and desalination cogeneration plants. Rural and remote areas have special requirements that influence the appropriate selection of technologies. These include technical requirements related to small-scale application using renewable energy sources, ease of operation and maintenance, and simple design; requirements dictated by geographical location; as well as socio-economic and socio-cultural requirements related to the communities that are intended to operate and benefit from the technology. Successful implementation and long term sustainability (operational and environmental sustainability) of desalination projects for rural and remote locations requires that all the relevant requirements be identified and addressed from the earliest stages of the project.

To this end, SWIM-SM has commissioned the present report to provide a review of the Best Available Technologies (BAT) for desalination in rural areas suitable for the PCs. The focus of the review is exclusively on sustainable desalination technologies. LDK Consultants and European Union contracted Water and Environmental Services Co. (WESCO) to carry out a study to assess the BAT for desalination in rural areas suitable for the PCs.

The main goal is to produce a report reviewing and compiling the BATs, which can then be catered to the specificity of the PCs to supplement water supplies to remote communities, whether they are on coast or inland communities. Both seawater and brackish water desalination shall thus be considered. Prevailing socio-economic, political, and cultural constraints are to be taken into consideration.

The aim of the report is to provide PCs and decision-makers with an overview and assessment of the BATs on desalination in remote areas.

The report begins with Chapter 2, which provides a survey of the Best Available Technologies (BAT) for desalination, the main renewable energy technologies for desalination and an overview of the combination of the best available technology with the available renewable energy. Specifically Section 2.1 provides a description of the main desalination process technologies available today, along with a presentation of their relative merits. Section 2.2 provides a brief review of the main renewable energy technologies that are relevant for coupling with the desalination process best for implementation in remote rural areas. Finally, section 2.3 provides an overview of the main renewable energy/desalination technology combinations that are suitable for application in the PCs.

Chapter 3 provides Decisions, data and information before considering technologies for implementation of a desalination project. In short sections it provides the IWRM concept approach, the definitions on desalination capacities, the plant capacity calculation, the desalinated water quality, the demographic and socio-cultural considerations, the EIAS, the desalination project systems, criteria for site selection and budgeting and implementation costs etc.

Chapter 4 provides a guideline and methodology for screening and selecting the most appropriate technologies for application to a particular case. The chapter adopts a flexible approach that emphasizes that optimum technology

selection is a very case-dependant issue, and it is thus difficult to specify a fixed solution or solutions that are universally applicable. Instead, the chapter provides a methodology for selection that begins by defining the scale of the problem to be addressed by the technology and identification of the renewable energy resources available. These elements set the stage for the remainder of the selection process outlined in Chapter 4.

Identifying the requirements of the local community and the modalities for assessing them are the subject of Chapter 5. These include groups of factors and requirements dictated by geography, demographic and socio-cultural considerations, water resource availability, appropriate pricing structures and financing schemes, as well as institutional and regulatory factors.

The final chapter briefly discusses aspects and recommendations for integration of BATs for rural and remote area desalination projects within the context of national Integrated Water Resources Management (IWRM) plans.

2. Survey of BAT for desalination with focus on rural areas and description of renewable energy technologies for desalination

Section 2.1 provides a description of the available desalination technologies and section 2.2 a description of the renewable energy technologies for desalination.

2.1 Description of available desalination technologies, their merits and weakness related to use in rural areas:

A wide variety of technologies for seawater and brackish water desalination exist today. Many of these technologies are already well established and mature; some are in advanced stages of development, while other new technologies based on innovative ideas and new scientific developments continue to emerge. This section will describe the process and salient features of various successful desalination technologies, as well as their merits and weak points related to their adaptation in rural areas.

2.1.1 Multi-Stage Flash (MSF)

In the MSF process, seawater is evaporated by flashing in stages of consecutively decreasing pressure. The seawater is first pressurized and raised to its maximum temperature, the *top brine temperature* (TBT), after which it is introduced into the first stage, maintained at a pressure that is lower than the saturation pressure that corresponds to the TBT. This causes the seawater to boil violently in what is called *flash* boiling. The vapour thus released, which is pure water vapour, rises to the top of the stage where it encounters a bundle of condenser tubes inside which cooler feed water flows on its way to the brine heater. As the distillate vapour passing through the demister reaches the condenser tubes it begins to condense and form water droplets, which in turn fall onto special trays that collect and transport the distillate water. The brine from the first stage subsequently enters the next stage where the pressure is again lower than the previous stage, and the same process is repeated along all the stages. What happens in the final few stages will depend on the type of flow configuration the plant has. There are two main types of flow configuration in MSF plants: once-through, and brine-recirculation plants. In the simpler, once-through configuration, all the stages are identical; while in brine-recirculation plants the last few stages comprise what is called the heat rejection section, and the flow of seawater in the stage condensers will be larger than the flow in condensers of the remaining stages, allowing better control over the temperature in the final stage, thus achieving a larger overall flashing range in the plant. The performance of MSF plants and thermal plants in general, is typically measured either by the ratio of mass of distillate generated by a unit mass of input steam, which called the *gain output ratio* (GOR), or the ratio of the mass of distillate water produced to the thermal energy of the steam required to produce it, which is called the *performance ratio* (PR). In some references,

the PR is defined as a ratio of the thermal energy content of the distillate produced to the amount of thermal energy of the input steam. This latter definition of the PR has the attractive feature of being a dimensionless ratio, but appears to be less commonly used. The higher the GOR and PR, the more distillate it can produce using a given amount of input steam; i.e. the more efficient the unit is. However, more stages are required to achieve higher GOR and PR, which is associated with a higher capital cost. Simple schematics of MSF plant is illustrated in figure 1.

A small capacity MSF plant with a performance ratio of 6 requires around 70 -80kWh of equivalent thermal energy per kg of distillate water produced, in addition a power consumption of 4-6 kWh/m³ for pumping and auxiliary systems[1]. A large size MSF unit with a PR of 9.5 consumes close to 38 kWh/m³ of energy equivalent, compared to ≈4.5 kWh/m³ for similar capacity SWRO units. It should be noted that in converting from thermal energy to equivalent power consumption the efficiency of conversion needs to be accounted for. Doosan Heavy Industries & Construction has fabricated the world's largest multi-stage flash (MSF) evaporator unit of capacity 91,000 m³/d for Ras Al Khair seawater desalination plant in Saudi Arabia.

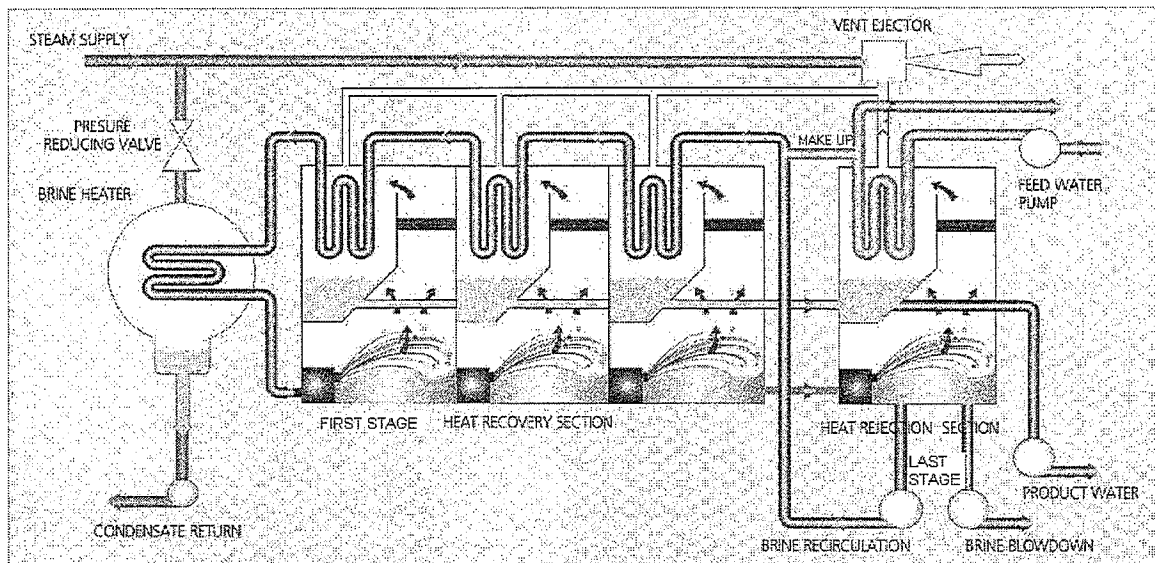


Figure 1: Schematic diagram of a simple MSF Unit

Merits:

- ⊠ Matured technology with hundreds of installations in operation worldwide for several years with successful record of accomplishment.
- ⊠ The MSF process has the largest installed capacity among all desalination process due to scalability, robustness and reliability of the process.
- ⊠ Requires minimum pre-treatment compared to RO process.
- ⊠ Produces very low TDS water.
- ⊠ Many reputed manufacturers like Doosan, Fisia, Aqua Tech, Hitachi Zosen, etc. can supply the unit.

Weak points related to the use of MSF Plant in rural areas:

- ⊗ Very high specific energy consumption would be required for the small capacity units generally designed with low GOR and PR. It is cost effective only if low cost (free) steam/heat energy is available.
- ⊗ Very low recovery (ratio of distillate produced to feed water supplied) in the range of 10 to 20%. High cooling water requirement makes it suitable for coastal areas only.
- ⊗ The heating energy required has less dependence on the salinity of feed water and hence it is uneconomical for desalination of brackish water.
- ⊗ Re-mineralisation chemicals requirement is high when compared to RO process.
- ⊗ Small capacity units are expensive compared to RO and MED plants.
- ⊗ Relatively precise pressures need to be achieved in the stages before the stable operation can proceed, which makes it difficult to match with a variable heat source such as solar energy without adding thermal storage [2]

2.1.2 Multi-Effect Distillation (MED)

The MED process is similar to the MSF process in that seawater is consecutively introduced into chambers of decreasing pressure, which serves to consecutively lower the temperature required to bring the water to boil; but the MED process differs in that boiling is mostly achieved on heat transfer surfaces (tube bundles) rather than by flash evaporation. A small amount of flashing does occur, but it has a small relative contribution to the total. Each one of the chambers is called an *effect*. A primary source of heat is needed to provide the steam for the first effect, the one at the highest temperature. In a typical plant, the seawater entering the first effect is sprayed down over a bundle of *evaporator* tubes, while the steam driving the boiling process flows inside the evaporator tubes. Such an arrangement is called a *falling film evaporator*.

The distillate vapour released from this evaporation process is at a higher temperature than the saturation temperature in the second effect, thus it is introduced on the tube side of the evaporator in second effect, where it condenses, giving up its heat to drive the evaporation of the rest of the seawater, coming from the first effect. This process is repeated in each consecutive effect. A separate condenser is required to condense the distillate vapour generated in the last effect, which also serves to preheat the feed seawater slightly and decrease the required heat input. The condensed distillate from each stage is collected in a common header and transported for post-treatment. Simple schematic of a MED-TVC plant is illustrated in figure 2.

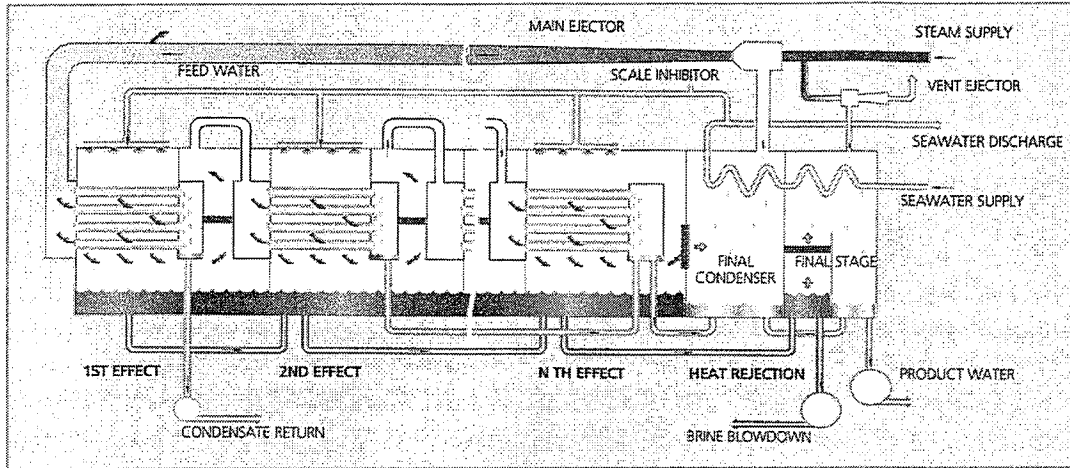


Figure 2: Schematic diagram of a simple MED-TVC unit

The GOR of an MED plant is tied to the number of effects as its theoretical maximum. This is because the number of effects determines the number of times the energy imparted by the steam to the distillate can be reused to evaporate an additional similar amount of distillate. It is worth noting however that this restriction applies only to the basic MED process; the incorporation of TVC (described below) removes this limitation, making it possible to achieve a GOR higher than the number of effects. Doosan Heavy Industries & Construction is building the world's largest MED unit of capacity 68,000 m³/d for Yanbu seawater desalination plant in Saudi Arabia.

MSF and MED plants with similar GORs will, by definition, have a similar specific consumption of thermal energy, but the specific power consumption of an MED plant is lower, at around 1.0-3 kWh/m³ [1]. However, it should be noted that MED plants achieve the same GOR achievable in MSF plants with a fewer number of effects.

Merits:

- Matured technology with hundreds of installations in operation worldwide for several years with successful record of accomplishment.
- Recently, very low temperature drops per effect have been achieved, approximately 1.5-2.5 deg C, which makes it possible to accommodate a relatively large number of effects. This leads to higher GORs, even with a low TBT around 70 deg C.
- The ability to operate using low-grade thermal energy input (~70 deg C) at higher thermodynamic efficiencies than MSF. This makes it a natural choice for coupling with thermal RESs such as solar thermal and geothermal energy.
- The MED process has the largest installed capacity among all thermal desalination process next to MSF due to scalability, robustness and reliability of the process.
- Requires minimum pre-treatment compared to RO process.
- Produces very low TDS water.
- Consumes less power than MSF process.
- Many reputed manufacturers like Doosan, Sidem, Aqua Tech, Sasakura, Entropie etc. can supply the unit.

Weak points related to the use of MED Plant in rural areas:

- ☒ Generally high specific energy consumption compared to RO. It is cost effective only if low cost or free heat energy is available.
- ☒ Very low recovery in the range of 15 to 25%. High cooling water requirement makes it suitable for coastal areas only.
- ☒ The heating energy required has virtually no dependence on the salinity of the feed water and hence it is uneconomical for desalination of brackish water compared to RO and ED.
- ☒ Small capacity units are expensive compared to RO plant.
- ☒ Re-mineralisation chemicals requirement is high when compared to RO process.

2.1.3 Vapour Compression Distillation

In the vapour compression process, which can have a single effect or multiple effects, the distillate vapour released from the evaporator is taken to a vapour compressor. By raising the pressure of the vapour in the compressor, the saturation temperature is raised. Thus, the compressed distillate vapour is used to drive the evaporation process in the same stage from which it was produced, while itself condensing at the higher saturation temperature corresponding to the compressor discharge pressure. There are two major types of vapour compression processes, based on the method of compression: mechanical vapour compression (MVC), and thermal vapour compression (TVC). In the former, a mechanical compressor is used to achieve the required compression; while in the latter a steam jet ejector is used for this purpose. The steam jet ejector is a convergent-divergent nozzle that uses medium pressure (2-10 bars) motive steam to entrain the distillate vapour from an effect and raise its pressure as it is discharged. The main input for each of these processes is different; in the case of MVC it is the mechanical power exerted by the compressor, while in the case of TVC it is the thermal power of the motive steam. Sometimes MVC plants require an auxiliary boiler for start-up and augmentation of the energy input.

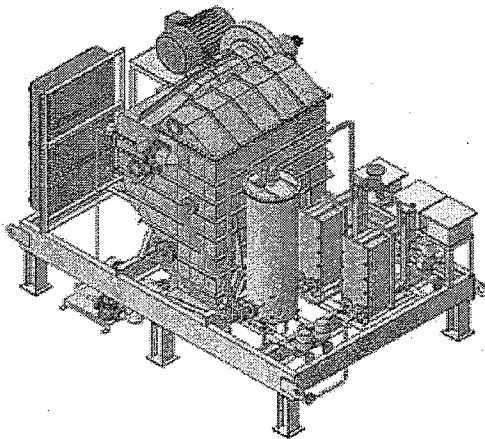


Figure 3: MECO's MVC unit

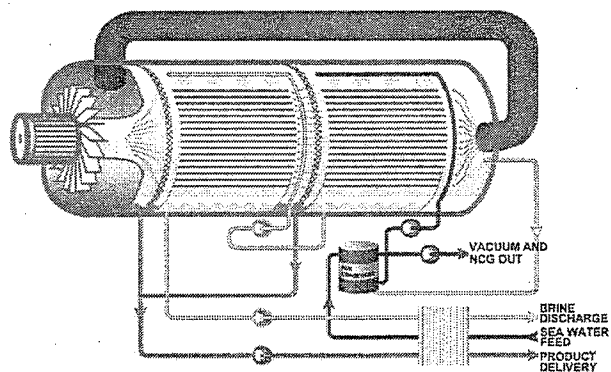


Figure 4: IDE's MVC unit

Merits of MVC:

- ☒ Established technology with many installations in operation with successful record of accomplishment.
- ☒ Compact compared to MED and MSF processes are still being manufactured in small capacity units.
- ☒ High recovery (up to 40%) compared MSF & MED process.
- ☒ Requires minimum pre-treatment compared to RO process
- ☒ Produces very low TDS water.

- Consumes very less steam under normal operation.
- Many reputed manufacturers like MECO, IDE, HamworthySerck Como GmbH, etc. can supply the unit.

Weak points related to the use of MVC Plant in rural areas:

- Relatively high specific power consumption (compared to RO) would be required for the small capacity units suitable for rural areas.
- Requires virtually the same specific power for seawater and brackish water desalination, which makes it an uneconomical choice for desalination of brackish water.
- Power intensive compared to MSF, MED and RO processes. 10.4 to 15 Kwh/m³ of electric power is required to run the vapour compressor. Hence, not desired where electricity tariff is high.
- Re-mineralisation chemicals requirement is high when compared to RO process.
- Small capacity units are expensive compared to RO plant.
- High scaling potential due to higher recovery and slight upset in acid injection will result in heavy scaling.
- Maintenance intensive and skilled technicians required for the high-speed vapour compressor.

2.1.4 Reverse Osmosis

The process of desalination by reverse osmosis is based on the use of semi-permeable membranes. Such membranes allow the passage of water, but are impermeable to salts. Under normal circumstances, when such a membrane is used to separate two solutions with different salt concentration, water flows from the low salinity side to the high salinity side. This is called osmosis, and is a process that is commonly found in nature. If, however, one applies sufficient pressure on the high salinity side, it is possible to reverse the direction of pure water passage, so that pure water flows from the high salinity side to the low salinity side. This is the principle behind desalination by reverse osmosis. The amount of pressure one needs to apply to bring about this reversal in the direction of water flow is determined by a property of the solution called the osmotic pressure, and it increases as the salinity of the solution increases. For this reason the pressure, and hence the pumping power required to desalinate seawater is much higher than that required to desalinate brackish water. It is important to note that continuous improvements in commercial RO membrane properties, and the various efficient systems for recovering energy from the high-pressure brine stream in seawater RO plants, have led to RO being the most energy efficient method for seawater desalination presently available.

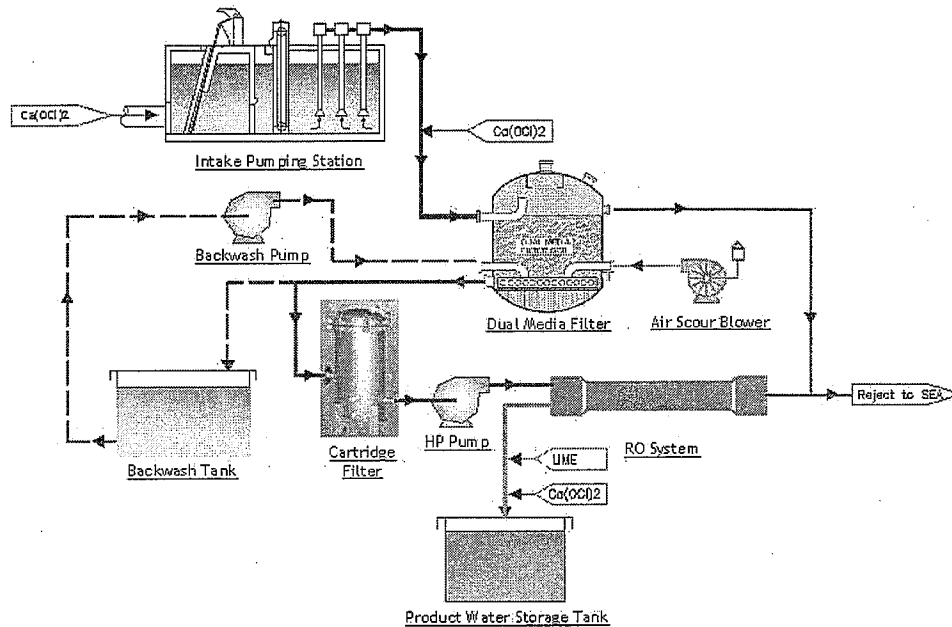


Figure 5: SWRO process schematics

Two types of RO membranes exist in the market; namely spiral wound and hollow fibre membranes. The spiral wound membranes are made by Hydranautics, Filmtec, GE, Toray, Koch, etc. and hollow fibre membranes are made by Toyobo. Hollow fibre membranes are only available for seawater application whereas spiral wound membranes are available for seawater and brackish water application.

Merits:

- Proven technology with good record of accomplishment.
- Can be used effectively for seawater, high salinity brackish water or brackish water
- Uses less energy than thermal processes.
- Lower capital cost than thermal processes.
- Requires less feed water than thermal processes
- Compact when compared to thermal process.
- Membranes made by different manufacturer are interchangeable, which avoids dependence on a single manufacturer.
- Can be started and stopped in short time.
- Development of new membranes with high productivity, less fouling and less energy consumption are driving further improvements in the process and makes it more attractive.

Weak points related to the use of RO Plant in rural areas:

- An elaborate pre-treatment system is required compared to thermal processes.
- Slightly complex to operate compared to MSF & MED process, requiring a higher level of skill on the part of the plant operators.
- Susceptibility to membrane fouling.

- ⊗ Frequent variability in operating conditions and/or frequent start-up and shutdown cycles can shorten membrane life.

RO was estimated in 2011 to account for 65 % [33] of the global desalination production capacity and it is expected to reach 71.4% in 2016. Two of the recently developed membranes for the RO process are explained below

Thin-Film Nano composite membranes - NanoH2O

The use of thin-film nano-composite (TFN) membranes for water purification was first described for brackish water RO membranes in 2007[3]. The basic principle is that zeolite nano-particles were dispersed in the organic solution of an interfacial polymerization. As polymerization proceeds in the organic solution, nano-particles present near the aqueous-organic interface became incorporated within the polyamide layer. This resulted in increased permeability of the membrane, and altered surface properties potentially related to fouling and maintained salt rejection. Subsequent to that, the membrane has been improved for treating seawater. Since the membrane is essentially of flat-sheet type, the new TFN membrane is manufactured the same way as existing spiral wound RO membranes. Hence, production is not an issue. A new company, NanoH2O Inc., has been working towards the commercialization of the membrane[4] for various applications with specific emphasis on seawater applications. It was reported that the company shipped its first commercial seawater membrane product for testing by various consumers.

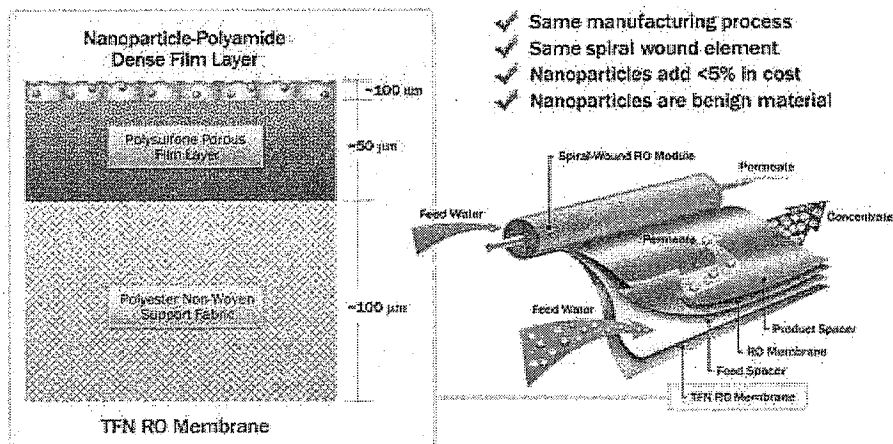


Figure 6: Nano membranes by Nano H₂O

RO membranes made of carbon nano-tubes

Several researchers are attempting to improve the performance of RO membranes by incorporating nano-materials. At least two such efforts are ongoing, one at Lawrence Livermore National Laboratory (LLNL), USA, and the other at University of California, Los Angeles, USA.

The LLNL team has discovered that carbon nano-tubes can be used to form membranes[5]. Initial laboratory scale results indicated that these nano-pores are capable of allowing large flows of water, while rejecting dissolved constituents. It is hypothesized that the water molecules behave different when confined to carbon nano-tubes – that they form tubular structures that pass through the nano-tubes. The dominant mechanism for dissolved constituents is not yet identified, although size exclusion and surface charge effects could play a role. Initial estimates indicate that energy consumption could be as much as 80% lower than that for typical RO membranes. Now, NanOasis is commercializing the technology. Currently laboratory scale efforts are on going and it may be another year before a pilot or demonstration scale level study could be considered. Another company, Porifera, is also attempting to work on similar membrane using carbon nano-tubes.

2.1.5 Electro-dialysis

The idea of the electro-dialysis process is to use ion exchange membranes. Each such membrane allows either cations (cation permeable membrane) or anions (anion permeable membrane) to pass through it exclusively. Thus if a solution is placed between a pair of ion exchange membranes, and a DC voltage is applied across a set of electrodes placed on the outer sides of the membranes, salt ions will flow to the electrodes according to their charge. The central region will eventually be depleted of ions and its salinity will thus decrease. This is called an electro-dialysis cell. In practice, an electro-dialysis *stack*, created by placing a stack of alternating anions and cations exchange membranes in series, is usually employed to increase productivity. The ion-depleted channels in a stack constitute the desalinated product streams, while the adjacent channels contain the concentrated brine streams where ions from the neighbouring product channels migrate and accumulate.

In a variant of the ED process, called electro-dialysis reversal (EDR), the polarity of the electrodes is reversed periodically in order to reverse the flow direction, thereby inhibiting fouling and scale deposition and providing a self-cleaning mechanism [6].

The ED process is generally suitable for relatively low to medium feed salinity brackish water, not for seawater desalination. The need for good electrical conductance also means that ED is not suitable for treating feeds with salinity below 400 mg/l [2]. The energy required by the process depends on the feed salinity. The ED/EDR processes are mature and well established commercially.

An attractive feature of ED/EDR is that, because it uses a DC voltage, it is suitable for pairing with solar PV power without the need for DC to AC conversion. Electro-dialysis metathesis (EDM) is being developed which is a modification of electro-dialysis designed to increase product water recovery and it is explained below.

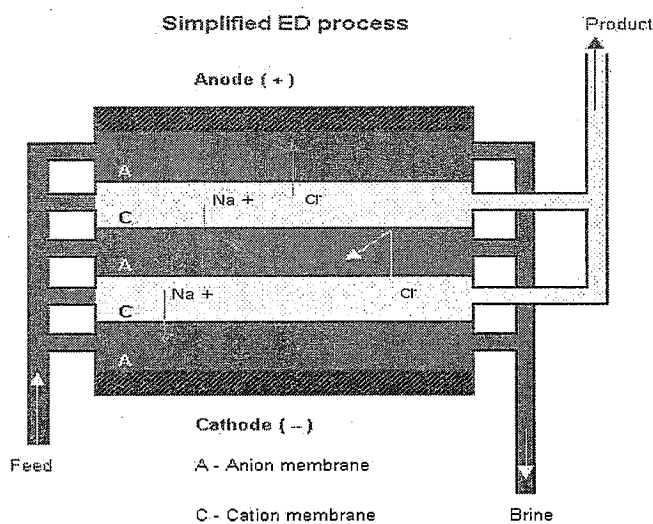


Figure 7: Simplified ED process

Merits of EDR process:

- Proven technology with good track record
- Recovery is as good as or better than RO process.
- Uses less energy than thermal processes.

- ☒ Tolerant to more feed water turbidity, silica, TOC, free Cl₂, Fe & Mn compared to RO
- ☒ Lower capital cost than thermal processes.
- ☒ Requires less feed water than thermal processes
- ☒ Lower operating pressure required compared to RO process and for feed TDS <2000 ppm power consumption is lesser than RO process.
- ☒ Life of the EDR/ED membrane is more than RO membranes and the membrane is rugged compared to RO membranes.
- ☒ Compact when compared to thermal process.
- ☒ Can be started and stopped in short time.
- ☒ Development of EDR increased recovery, productivity, reduces fouling and lesser energy consumption makes it a preferred process out of the established desalination processes for brackish water desalination.

Weak points related to the use of ED/EDR Plant in rural areas:

- ☒ Best Suited for feed water TDS ranging between 400 and 3000 mg/l. Can be used effectively for brackish water; but not for high brackish water and seawater.
- ☒ Salt rejection (50 – 90%) is not as good as RO process (which is 90-99%)
- ☒ Non-charged particles cannot be removed so the process cannot remove silica, which can be removed 90%, by RO process.
- ☒ Power required is more than RO for feed TDS exceeding 3000 ppm.

2.1.6 Electro-dialysis Metathesis (EDM)

Electro-dialysis (ED) processes have been used for decades in industrial and municipal applications to remove ions from water. In ED, ions are transported under the driving force of an electrochemical potential gradient and separated from feed water by ion selective membranes. Electro-dialysis metathesis (EDM) is a modification of electro-dialysis designed to increase product water recovery and facilitate development of salt products from concentrate. The primary difference between EDM and ED is the number of cells in the repeating unit comprising the electro-dialysis stack. The basic unit of ED is a cell pair formed by two solution compartments separated by two ion selective membranes. The EDM repeating unit comprises four cells and four membranes: one dilute compartment, two concentrate compartments, one NaCl solution compartment, one anion exchange membrane, one cation exchange membrane, one monovalent selective anion exchange membrane, and one monovalent selective cation membrane (Figure 8). This unique configuration of cells is designed to separate EDM concentrate into two streams of highly soluble salts: one containing sodium with anions and the other containing chloride with cations. This characteristic of EDM provides a significant advantage in maximizing recovery because the membrane fouling potentials of typical scalants such as CaSO₄ and CaCO₃ do not increase with recovery as is the case with RO, NF, and other forms of ED. Generation of two concentrate streams that are individually highly concentrated yet highly soluble facilitates conversion of concentrate to salt products. The two streams can be combined in a sequential series of treatment steps to generate salts products such as calcium sulphate, calcium carbonate, dolomite, magnesium hydroxide, sodium chloride, calcium chloride, and magnesium chloride. EDM was conceived in 1998 [7] and has since been evaluated extensively at pilot-scale [8]. EDM is currently being developed for full-scale application by Veolia. Although the EDM technology is new, it is nevertheless simply electro-dialysis with an innovative arrangement of membranes. Electro-dialysis is a matured technology with large-scale installations dating back to the early 1960's. Two concentrate streams are produced during desalination with EDM. The amount of concentrate generated, however, might be only 20 percent of the concentrate generated by RO because of higher EDM recovery. As previously noted, there is potential to develop salt and brine products from EDM concentrate to eliminate waste disposal. This emerging technology is expensive and can be used where zero discharge is preferred.

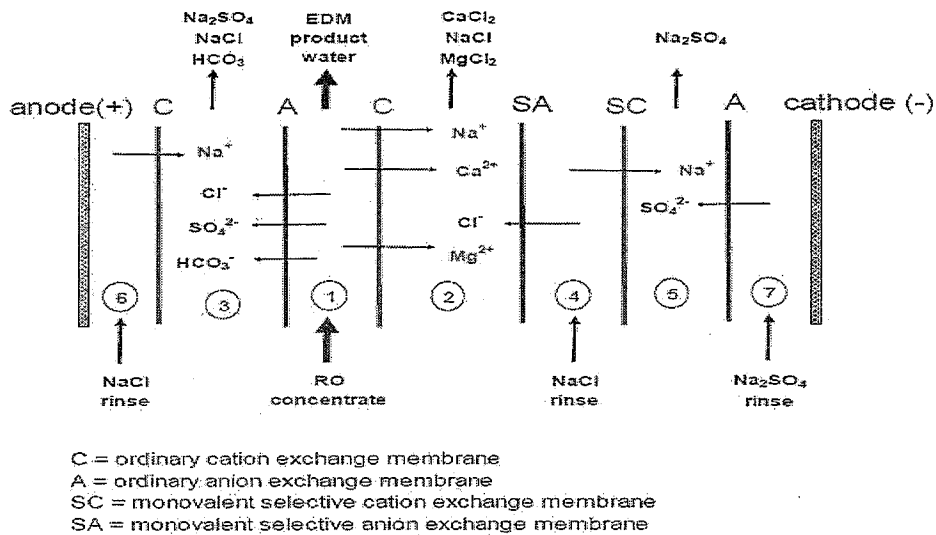


Figure 8: Electro-dialysis Metathesis Schematics

Merits of EDM process:

- Improved version of ED process with higher recovery compared to RO process
- Can be used where zero discharge is preferred. Salt and brine products can be developed using this process.

Weak points related to the use of ED/EDR Plant in rural areas:

- Emerging technology and expensive process.
- Needs skilled operation staff.

2.1.7 Membrane distillation (MD)

Membrane distillation is a thermally driven process that uses a *hydrophobic* membrane, one that is impermeable to liquid water, to distil the saline feed water. A source of heat is required to heat the feed water to temperature in the typical range of 70-90 °C. As the heated feed flows along the membrane surface, the hydrophobic nature of the membrane allows water vapour released because of the elevated temperature to pass through the membrane, but not the saline liquid feed. The distilled water vapour accumulating on the other side of the membrane is then condensed by various possible means to provide the required distilled product water.

There are four major variants of the MD process:

1. Direct contact membrane distillation (DCMD);
2. Air gap membrane distillation (AGMD);
3. Vacuum membrane distillation (VMD);
4. Sweeping gas membrane distillation (SGMD).

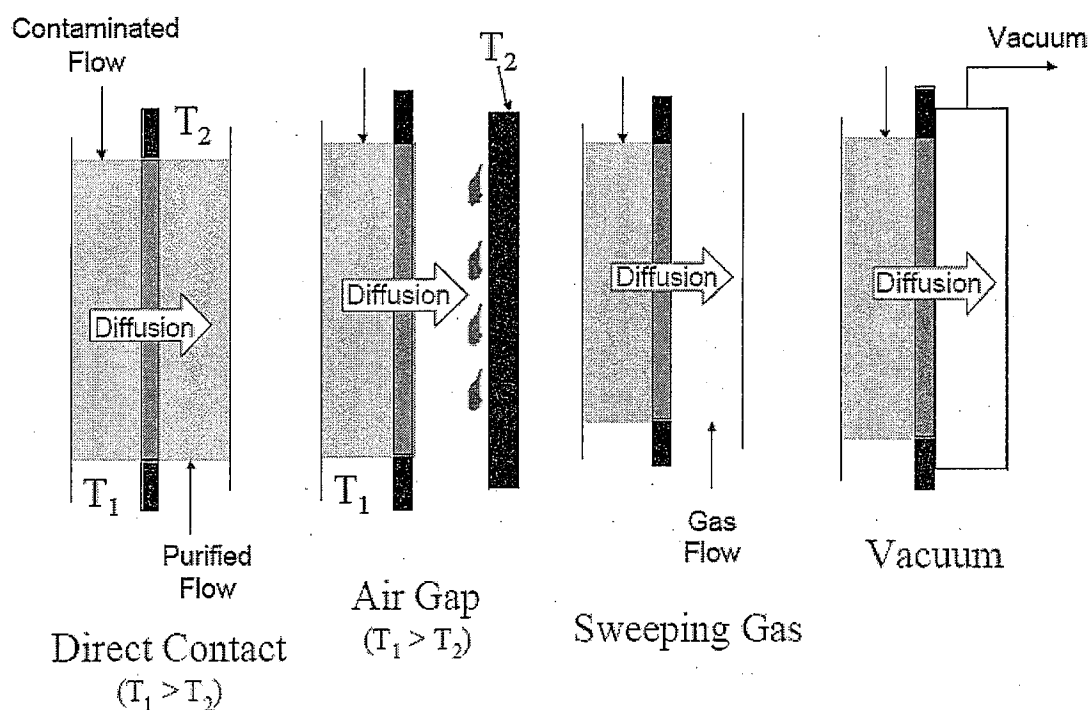


Figure 9: Different membrane distillation process

In DCMD, cooled distillate condensate is re-circulated into the distillate side of the membrane, so that vapour passing through the membrane from the feed side comes into direct contact with the liquid condensate stream, where the vapour condenses. In AGMD on the other hand, the feed and cooling water streams are separated by an air gap where the distillate vapour accumulates and condenses on the outer wall of the cooling water channel. In the VMD configuration, a vacuum is applied to the distillate side of the membrane to enhance the flux of distillate vapour. In this case, the distillate is accumulated in the vapour phase and conveyed to an external condenser where condensation takes place to provide the distilled product water. The similar objective of enhancing distillate vapour flux motivates the SGMD design, but in this case, it is achieved by the use of a flowing gas that entrains the distillate vapour.

Even though the MD process was invented in the 1960's, it has not to this date enjoyed wide-scale commercial application. This is primarily due to the relatively high energy consumption and relatively low membrane productivity compared to RO [9]. Recently, MD has gained increased interest because of improvements in membrane characteristics and the potential for coupling with low-grade heat sources.

One exciting development that should be watched closely is the MD-based system developed by the German company Memsys [10]. The company developed a variant of the MD process that combines features of MED in a process they termed vacuum multi-effect membrane distillation (V-MEMD). Each MD-based effect utilizes a plate and frame module that can easily be stacked to achieve a multiple effect flow configuration. The MD effects resemble the AGMD configuration, but the condensation of vapour in the air gap is used to heat the water in the adjacent effect, while applying progressively increasing levels of vacuum, as in MED. This re-utilization of the latent heat of condensation, in several effects, is key to achieving higher GORs than previously possible in MD.

A 1 m³/d pilot unit was installed last year in Singapore. The unit is reported to have a GOR of 4.2, which is remarkable for the MD process. Memsys claim that larger units with a GOR of 10 are possible. Another pilot project planned for a remote location in Western Australia called Tjuntjunjarra has recently been announced [11]. The 1 m³/d unit is to be partly powered by waste heat from small-scale power generators and partly powered by the sun.

Preliminary estimates of the cost of membrane modules are currently at 1000 €/m³/d [11], but the technology is still at a very early stage of commercialization, and the company has plans to scale up the process to the range of 1000-2000 m³/d, which is expected to drive down cost.

Merits:

- ☒ Ability to utilize low-grade heat (solar collector, geothermal, waste heat, etc.)
- ☒ Use of multiple stages can reduce energy requirements.
- ☒ Less organic fouling propensity compared to RO
- ☒ Less pre-treatment compared to conventional membrane desalination processes
- ☒ The only membrane process that can maintain process performance (such as water flux and solute rejection) almost independently of feed solution TDS concentration.
- ☒ MD membranes are more chemically inert and resistant to oxidation than traditional RO and NF membranes, which allows for more efficient, chemically aggressive cleaning
- ☒ Produces higher-quality water than NF/RO, EDR and CD.

Weak points related to the use of MD Plant in rural areas

- ☒ Still under development. Knowledge about the following has not been established: treatment efficiencies of larger-scale installations, economics, short- and long-term performance, and fouling/scaling of MD.
- ☒ Requires special hydrophobic membranes. Commercially available hydrophobic membranes have not yet been optimized for the MD process. This is an area of active R&D.
- ☒ Membrane modules for MD have not undergone extensive optimization and may require larger footprints than a pressure-driven system with equivalent capacity.
- ☒ Contamination of distillate occurs when the membrane fouls and wets the membrane pores.
- ☒ Use of multiple stages can reduce energy requirements but increases capital cost associated with membrane.
- ☒ Presently expensive compared to RO and EDR process.

2.1.8 Thermo-Ionic™ Desalination (Saltworks Technologies Inc.)

Saltworks has developed a patented desalination process that uses thermo-ionic gradient to treat high salinity water. A simplified schematic of the process is shown in Figure 10 below.

The primary driving force for desalination is concentration gradient energy (i.e., latent chemical potential energy) between two solutions. Hence, to treat a saline water source, another source with higher salinity is required (referred to a “concentrate”). This is initially achieved by concentrating the feed saline water to a salt concentration of 18%. Evaporation processes such as spray pond or cooling tower could be used to concentrate the feed water. Adding heat to raise the temperature by 5 to 15 deg C higher than ambient temperature also boosts evaporation rates and performance. The heat source could be solar or waste process from a nearby industrial process. The concentrate and the feed saline water are fed to the patented Saltworks proprietary modular desalting device in two streams – one as feed water to be treated and another as “dilute” water. The dilute water and the concentrate (indicated as hyper concentrate) are separated by ion exchange membranes.

Because of the electrochemical potential difference, ions move from hyper saline solution into the dilute solution on either side. Thus, the hyper saline solution loses salt and the dilute solution gains it. However, since only cations (on left side) and anions (on right side) are moving into the dilute streams, these streams need to draw counter ions to maintain charge balance. These counter ions are drawn from the feed water, thereby desalinating it. As in EDR process, periodically ionic current direction is reversed during operation to descale the system

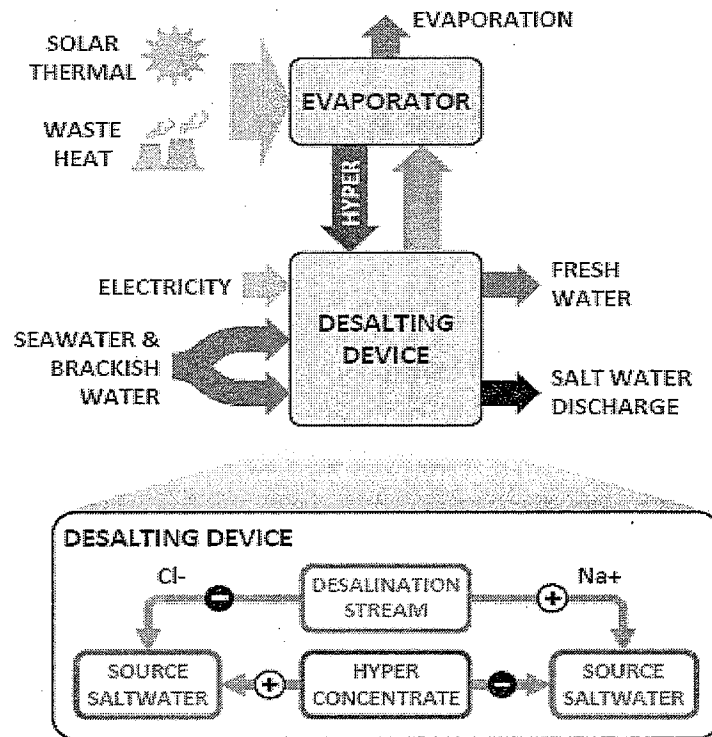


Figure 10: Schematics of Saltworkstechnology [34]

Merits:

- ▣ Ability to utilize low-grade heat (solar collector, waste heat, etc.)
- ▣ Less organic fouling propensity compared to RO
- ▣ Less pre-treatment compared to conventional membrane desalination processes

Weak points related to the use of Thermo-Ionic desalination in rural areas

- ▣ Still under development. Knowledge about the following has not been established: treatment efficiencies of larger-scale installations, economics, short- and long-term performance, and fouling/scaling of membranes.
- ▣ Since the technology is developed by Saltworks most of the information on the desalting device is kept confidential.
- ▣ Desalting device not undergone extensive optimization and may require larger footprints than a pressure-driven system with equivalent capacity.
- ▣ Expensive compared to RO and EDR process.

2.1.9 Forward Osmosis

Forward osmosis process uses the natural osmosis to achieve desalination. Isobaric solutions with different solute concentrations (salinity) have different chemical potentials. Chemical potential gradients are the result of differences in solute concentration and hydraulic pressure. When they are separated by a semi-permeable membrane, that allows only transport of water, and they exert a driving force for ion transport by diffusion. Water is transported from the dilute solution side to the more concentrated solution side, a process referred to as osmosis.

In the forward osmosis process, the osmotic pressure of the fresh water is increased by addition of various solutes (Figure 11). In FO terminology, the concentrated solution on the permeate side of the membrane is referred to as the draw solution. Once the osmotic pressure of the fresh water (after addition of solutes) is greater than that of the saline water, pure water diffuses from the saline waterside to the fresh water side. Hence, the driving force is the osmotic pressure itself and not hydraulic pressure as in a conventional reverse osmosis process. The viability of the process is dependent on the selection of the solute that is added to the fresh waterside and ability to remove it from the fresh water and reuse it, once saline water is desalinated. A good draw solution has high osmotic pressure and an easily separable solute. The solutes under consideration include salts that can be precipitated out, gases such as ammonia and carbon dioxide, and nano-particles [12]. Currently, the most preferable method appears to be ammonia-carbon dioxide draw solution as it imparts a high osmotic driving pressure and later can be decomposed to ammonia and carbon dioxide gases upon moderate heat (near 60 °C).

In ammonia-carbon dioxide FO system, the salt species formed include ammonium bicarbonate, ammonium carbonate and ammonium carbamate [13]. Of these, ammonium carbonate is by far the most soluble. Removal and recycling of draw solutes is achieved through use of distillation column. Depending on the thermal energy available to heat the solution, one or several distillation columns would be required.

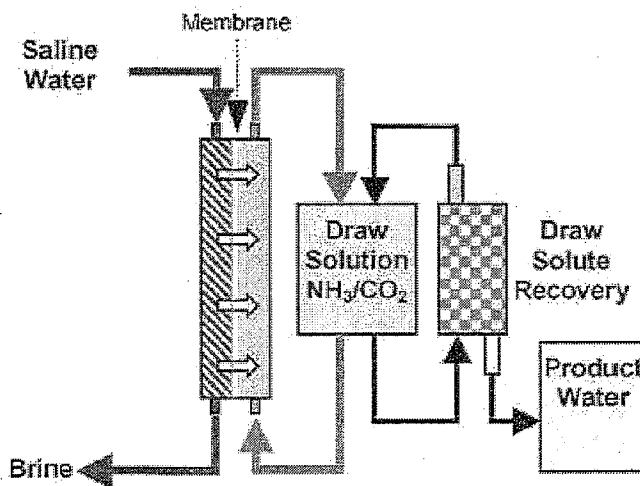


Figure 11: Simplified process schematics of FO

Oasys (Osmotic Application Systems) is currently developing this technology and is one of the early companies. Because it is in the process of developing and commercializing the technology, not much information has been provided.

QuantumSphere Inc. filed for a US patent in January 2009 for its water purification process, which, it claims, serves as a more energy-efficient alternative to desalination methods now commonly used. The QuantumSphere forward-osmosis process uses certain organic solutions to separate water from salty or polluted water in an osmotic purification process. They indicate that the organic solution can increase the osmotic pressure of draw solution by 5 to 10 times higher than seawater. The process uses a semi-permeable membrane to separate water from salt water into a special organic solution across the membrane.

Manipulated Osmosis Desalination (Modern Water)

Manipulated osmosis desalination (MOD), being commercialized by Modern Water, is based on forward osmosis principle. Indeed, it is the first forward osmosis process that has been commercialized. As discussed earlier, forward osmosis process requires addition of a solute to pure water to result in osmotic pressure greater than the saline water source to be treated. Typically, this solution is referred to as draw solution. As the feed water is desalinated, the draw solution is diluted. The solute that was added to the draw solution is then removed to get purified water. The solute can be reused.

Modern Water refers to this solute as "osmotic agent". The forward osmosis system is linked to generation system that treats the diluted draw solution to obtain product water and concentrated draw solution that can be reused in the forward osmosis process. In the first stage, feed water is fed under low pressure to the manipulated (forward) osmosis membranes

(Figure 12).

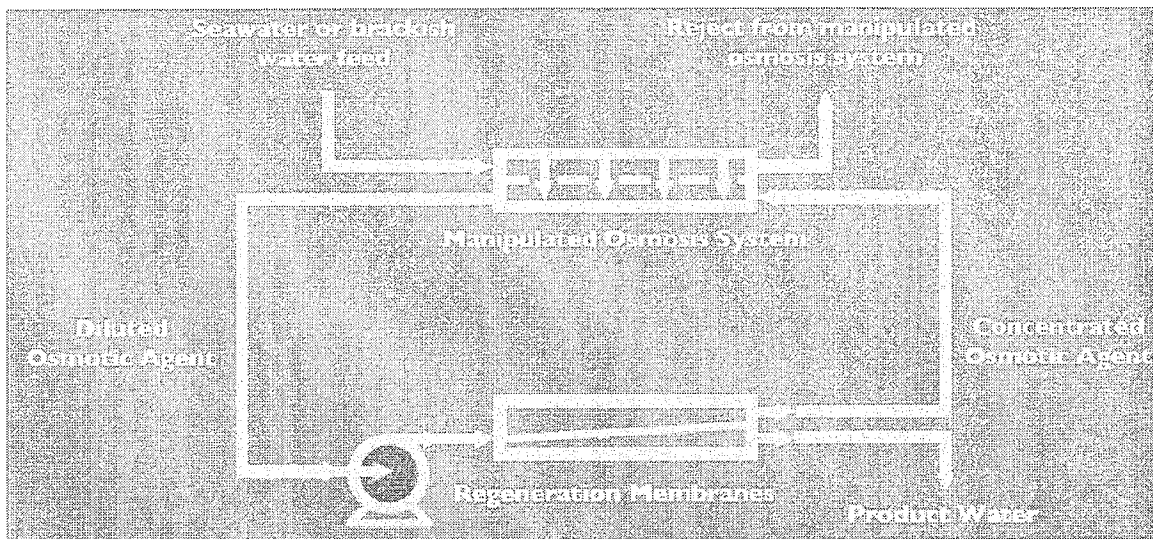


Figure 12: Modern Water's Manipulated Osmosis Desalination Process

These membranes are reported to be resistant to fouling and oxidizing agents. The osmotic agent, on the other side of the membrane draws fresh water from the seawater due to a difference in osmotic pressure. The fresh water dilutes the osmotic agent. In the second stage, permeate is extracted from the system. The pure water is removed from the dilute osmotic agent, which is regenerated (or concentrated) for reuse in the first stage. This can be achieved in a number of ways depending on the proprietary osmotic agent selected. As one example, RO process is used in the second stage example to extract the fresh water and concentrate the osmotic agent.

Merits of FO process:

- Operates at low pressure, which results in much lower energy consumption compared to conventional membrane and mechanical/thermal evaporative desalination technologies
- Membrane compaction is not typically an issue
- Less fouling propensity compared to RO

Weak points related to the use of FO Plant in rural areas

- Still under development. Knowledge about the following has not been established: treatment efficiencies of larger-scale installations, economics, and short- and long-term performance and fouling/scaling

- ☐ Requires special membranes. Existing commercially available RO membranes are not suitable for FO because such membranes have a relatively low product water flux, which can be attributed to severe internal concentration polarization in the porous support and fabric layers of RO membranes
- ☐ Use of ammonium carbonate as draw solution may provide desired osmotic pressure. However, diffused ammonia to the permeate stream should be removed using a low cost technology (such as waste heat to strip ammonia).

2.1.10 Solar Stills

The solar still is probably the simplest type of seawater distillation system. It consists of a basin containing saline water with a transparent glass roof, often in the shape of an inverted V. The basin is lined with a dark material to maximize the absorption of solar radiation. This arrangement creates a greenhouse effect, whereby the glass allows incoming solar radiation to pass through, but the infrared radiation returning emitted from the still is mostly blocked by the glass, thus trapping the heat inside the still. The resulting temperature rise causes the saline water to evaporate, and the vapour rises, condenses on the glass roof, and flows down into collection gutters at the lower edges of the roof. The typical output of a well-designed solar still is around 3-4 l/m²d[2], [14]. The cost of building solar stills is in the range of US\$ 50-150/m²[14]. The Water cone, a small portable solar still, shown in figure-13, produced by Mage Water Management produces 1-1.5 l/d of distilled water, corresponding to a maximum rate of 8.8 l/m²/d. Solar stills are acceptable to produce small quantities of water for basic needs but not economical for large production for all daily needs. SolAqua supplies Rainmaker™550 (figure 14) as do-it-yourself kit.



Figure 13: Water Cone

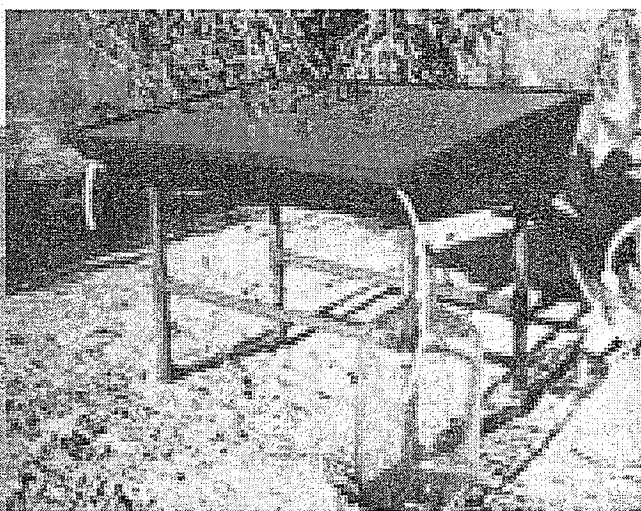


Figure 14: Solar Distiller: Rainmaker™ 550

2.1.11 Humidification/Dehumidification (HDH)

Humidification-dehumidification (HDH) desalination mimics the natural water cycle to desalinate the water. Normal atmospheric air is used as the medium to convert seawater to freshwater. HDH desalination involves two processes. Saline water is first converted to water vapour by evaporation into dry air in an evaporator

(humidification). This water vapour is then condensed from the air in a condenser to produce freshwater (dehumidification). Heat for evaporation can be obtained from various sources, including solar, thermal, geothermal, and combinations of these. A simplified process schematic of HDH is presented in Figure 15

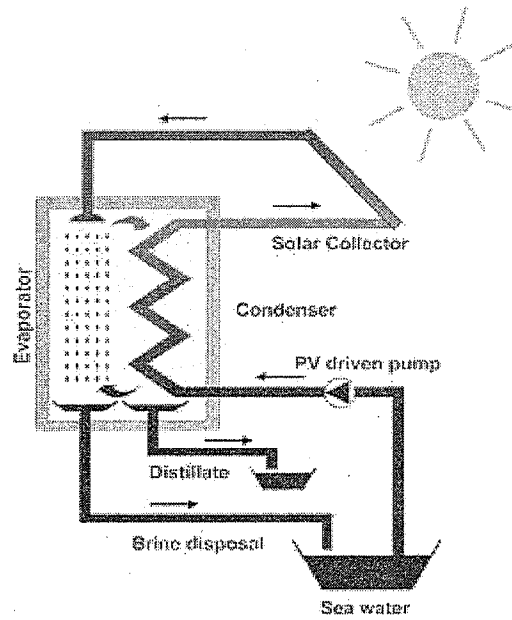


Figure 15: Simplified process schematics of HDH

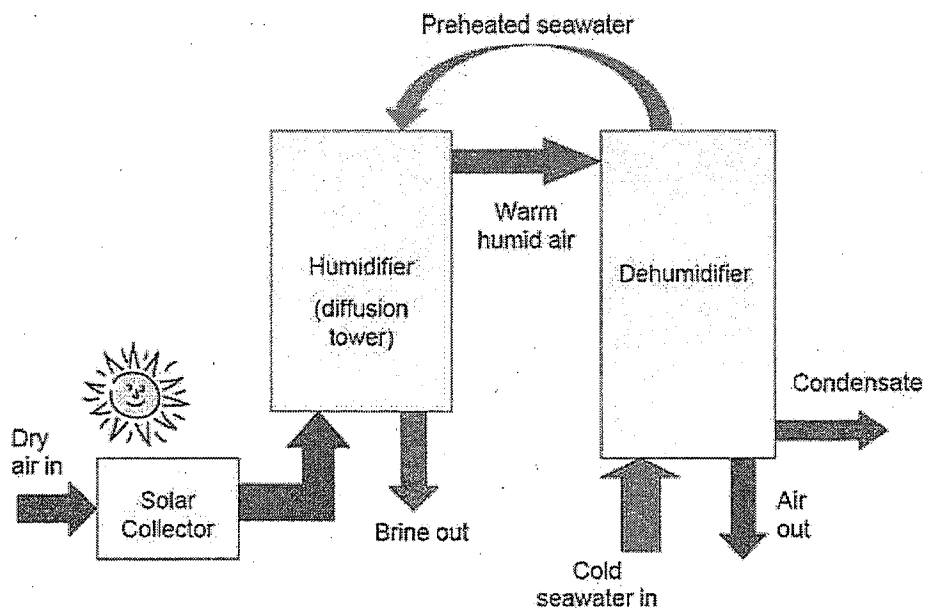


Figure 16: Simplified process schematics of HDH with solar heat transferred by air

The HDH process illustrated above in figure 16 is simple distillation system that can be driven by solar thermal energy and is suitable for small-scale applications. The thermal energy from the sun is used to heat the saline water in the dehumidifier, which is then sprayed down a packed column against an upward draft of dry air. The air, having been humidified by the water vapour, is then conveyed to a condenser where the moisture carried by the air condenses on the outer surface of the tubes and accumulates at the bottom. The latent heat associated with the vapour condensation is used to preheat the saline feed water flowing inside the condenser tube. This feature represents an advantage of the HDH process over the simple solar still, where the latent heat of condensation is usually not recovered.

HDH systems can be classified under three broad categories. One is based on the form of energy used such as solar, thermal, geothermal, or hybrid systems. This classification highlights the most promising aspects of the HDH concept: the prospect of water production by use of low-grade energy, especially from renewable sources. The second classification of HDH processes is based on the cycle configuration (such as closed-water open air [CWOA]). The third classification of the HDH systems is based on the type of heating used: water- or air-heating systems. Energy requirements of HDH include latent heat of vaporization, energy transport air, and cooling energy to condense the vapour. As a result, it is an energy-intensive process. Approximately, 650 KWh/m³ of energy is required for vaporization, with additional energy required for mechanical equipment (Huehmer and Wang, 2009).

The expected output of an HDH system is in the range of 20-30 l/m²/day of solar collector area [14]. Commercial HDH systems are available from a German company called Mage Water Management[15].

To enhance heat recovery, Muller and Holst have proposed the concept of multi-effect HDH. Air from the humidifier is extracted at various points and supplied to the dehumidifier at corresponding points. This enables continuous temperature stratification, resulting in a small temperature gap to keep the process running. This in turn results in a higher heat recovery from the dehumidifier. In fact, most of the energy needed for the humidification process is regained from the dehumidifier, lowering the energy demand to a reported value of 120 kWh/m³. This system is being commercially manufactured and marketed by a commercial water management company, Tinox GmbH.

Merits:

- Low-grade thermal energy is used to drive the process, which makes it suited for PCs rural areas where electricity is not available.
- Simple design and relatively cheap materials of construction make it suitable for small capacity stand-alone in rural areas units, with higher output per unit area than simple solar stills

Weak points:

- Difficult or impractical to scale up capacity.
- High heat energy requirement makes it an uneconomical process for anything beyond small-scale units driven by renewable energy or waste heat. Multi-effect HDH that requires less energy is still under development stage.

Table 1: Comparison of desalination technologies in reference to rural areas

Process	Capital Cost	Energy consumption	Other O&M cost	Major merits	Major Weak Points	O&M Skill required (scale 1-5)	Type of energy required
Multi-Stage Flash (MSF)	High	High	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Robust and reliable 3. Less pre-treatment required. 4. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. High Feed water Requirement. 2. More brine to be disposed. 3. High specific energy consumption 	2	Heat + power
Multi-Effect Distillation (MED)	Medium	High	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Robust and reliable 3. can use low-grade heat 3. Less pre-treatment required. 4. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. High specific heat consumption 2. Low recovery ratio, when cooling water is accounted for. 	2	Heat + power
Thermal Vapour Compression (TVC)							
Mechanical Vapour Compression (MVC)	Medium to high	High	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Robust 3. Compact 4. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. High scaling potential under variable conditions. 2. Mechanical compressor requires skilled O&M 	4	Power
Reverse Osmosis	Medium	Low	Medium	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Reliable 3. Compact 4. High recovery ratio 5. Less start-up and shutdown time 6. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. Pre-treatment requires careful design. 2. Susceptible to various types' membrane fouling. 3. Variability in operating conditions and/or frequent start-up/shutdown cycles shorten membrane life 	3	Power
Electro-dialysis (ED & EDR)	Low	Low	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Reliable 3. Compact 4. High recovery ratio 5. Less start-up and shutdown time 	<ol style="list-style-type: none"> 1. Suitable for TDS up to 3000 mg/l. 	3	Power

	High/medium	High	Low	6. Less pre-treatment required	2	Heat + minor power
Membrane distillation (MD)	High/medium	High	Low	<ol style="list-style-type: none"> 1. Ability to use low grade heat 2. Operates at low pressure 3. Compact 4. High recovery; needs less feed water for a given output. 5. Less pre-treatment required 6. Suitable for very high TDS feed 	2	Heat + minor power
Electro Dialysis (EDM)	High	High	NA	<ol style="list-style-type: none"> 1. Improved version of ED. 2. Recovery more than RO possible and can be used for zero discharge. 3. Compact 4. Less pre-treatment required. 	4	Power
Thermo-ionic TM Desalination	High	High	NA	<ol style="list-style-type: none"> 1. Ability to use low grade heat 2. Compact 3. High recovery and needs less feed water for a given output. 4. Less pre-treatment required 	4	Power + Heat
Forward Osmosis	NA	Low (prospective)	NA	<ol style="list-style-type: none"> 1. Operates at low pressure and hence consumes less power. 2. Less pre-treatment required. 	4	Power (+heat in some cases)
Solar Stills	V. low	High	V. low	<ol style="list-style-type: none"> 1. Uses solar energy 2. Simple and easy to operate 	1	Solar (Heat)
Humidification/Dehumidification (HDH)	Medium	High	Low	<ol style="list-style-type: none"> 1. Can use low-grade thermal energy. 2. Simple design using cheap material 	3	Heat + power

NA: not available/ not established

2.2 Description of renewable energy technologies for desalination BATs

2.2.1 Solar energy

There are two main classes of solar energy technologies: solar thermal energy and solar photovoltaic (PV). As the name implies, solar thermal technologies capture the heat from solar radiation, either for direct use in a particular heat-driven process, or for power generation through a steam power cycle, and subsequent use of the generated power in a mechanically or electrically driven process. Solar photovoltaic (PV) technology is based on the direct conversion of energy from solar radiation into DC electrical power using panels of semi-conductors.

Because of the relatively low temperatures required in thermal desalination, non-concentrating collectors represent the more relevant class for coupling with thermally driven desalination processes. Concentrating collectors are mostly intended for power generation, a technology known collectively as Concentrating Solar Power (CSP), where attaining high temperatures in the working fluid is important for thermodynamic power cycle efficiency. CSP is a very promising area of technology for renewable desalination, but probably more so for the medium to large capacity ranges of desalination plants. The relative sophistication of CSP plants make them less suitable for autonomous desalination units in remote and rural areas.

Another type of solar thermal technology is *solar ponds*. A solar pond utilizes a salinity gradient over the depth of a pond or lake as a means of trapping incoming solar energy.

An attractive feature of solar ponds is that they combine the functions of a solar collector and a thermal storage system together [6].

One of the main advantages of solar thermal energy is that it is more amenable to storage than solar PV. It is easier and less costly to store thermal energy than it is to store electricity.

Solar photovoltaic (PV) technology is based on the direct conversion of energy from solar radiation into DC electrical power using panels of semi-conductors. This conversion is based on the photovoltaic effect; a property that some semi-conductors have in which light photons excite the electrons of the semi-conductor in to a higher energy state, leading to the creation of a DC voltage or current. Multiple PV cells are connected together to form solar panels. Connecting solar panels in series is used to increase the generated voltage, while connection in parallel can be used to increase the current. QuadraSolar claims that they have achieved 30% PV and 35% thermal efficiency.

2.2.2 Wind energy

Wind turbines are used to convert part of the kinetic energy in the wind into shaft power, which can either be used to drive an electric generator, or directly coupled to a mechanically driven process. The theoretical maximum efficiency of this conversion is 59.3%, while the efficiency actually achieved by real turbines is in the range of 35-48% [2]. This is only the efficiency of extraction of kinetic energy from the wind and conversion to shaft power; it does not account for other losses further down the line, such as losses in mechanical drive train and electric generator losses.

Wind turbines can be classified into horizontal axis wind turbines (HAWT), and vertical axis wind turbines (VAWT). The horizontal type (figure 18) is the more common type. In this arrangement (HAWT), the rotor shaft and electric generator are housed at the top of the turbine tower. HAWTs must be directed towards the wind to be effective. The MagLev VAWT is a magnetically-levitated low-RPM high-torque power output turbine, virtually silent and vibration-free. It is virtually maintenance-free because it is frictionless and can be mounted on building top. There

are no transmission gears necessary for the conversion of the kinetic energy into electricity. With their magnetically-levitated low-RPM high-torque power output and virtually maintenance-free operation, the MagLev Wind™ Turbines (figure 17) are perfectly suited to satisfy the demand for a cost-effective sustainable energy source on many roof tops. MagLev Wind™ Turbines are currently available with outputs ranging from 2.5kW up to 50kW. 1 MW MagLev Wind™ Turbine is being designed for larger commercial and industrial buildings

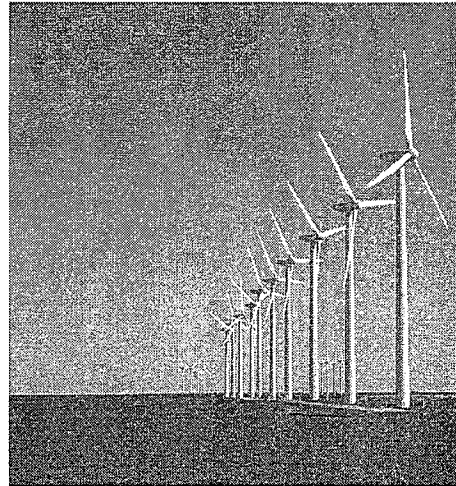
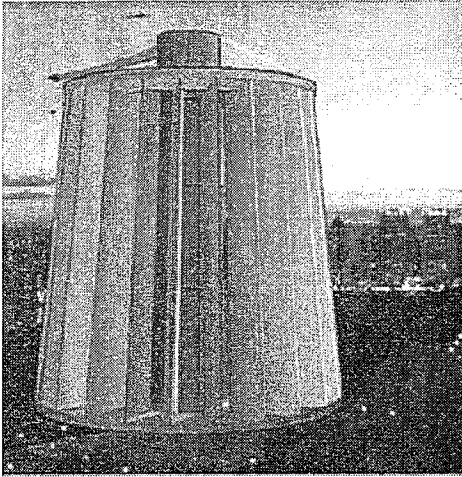


Figure 17: MagLev Vertical Axis Wind Turbine Figure 18: Horizontal Axis Wind Turbine Farm

2.2.3 Geothermal

Geothermal energy is thermal energy that originates from the Earth's interior. The source of this energy is mostly from the decay of radioactive matter in the Earth's core.

Geothermal energy sources at accessible depths vary in nature based on their temperature, which can range from 20 deg C to more than 300 deg C, and the state in which the water is available, which can be liquid or steam. High temperature geothermal sources, above 150degC, are used for power generation using a Rankine cycle, which can in principle be used to drive power-driven desalination processes. Lower temperature sources are best suited for direct coupling to thermal desalination processes. When high pressure steam is available, it can be used to directly drive a turbine for power generation or in direct coupling with a mechanically-driven desalination process [6], [16].

It is believed by some investigators that geothermal energy is one the most promising options for renewable energy desalination [16]. Geothermal reservoirs provide a continuous supply of thermal energy at fixed conditions throughout the day and year. This is highly desirable from the point of view of the desalination process, for which variability causes various difficulties and complications that need to be addressed in system design. Energy storage is not required, for example, as it might be with other resources. However, the disadvantages of geothermal energy are hazardous gases and minerals. They can come up from underground along with the steam. One of the most common substances to be released is hydrogen sulfide, which is extremely difficult to dispose of safely. Other minerals that can be troublesome are arsenic, mercury, and ammonia. A number of barriers for the adoption of geothermal energy for desalination have been identified in the literature [16]. These include:

- The technology has not yet been developed commercially, primarily because the associated cost of desalinated water by this means is not competitive with more established approaches.

- The very site-specific nature of geothermal energy resources makes it difficult to prescribe standard or modularised designs. This factor drives up the cost of developing such projects compared to some of the other, modular options available.

2.2.4 Waste Heat Availability

Even though not strictly a renewable energy, the possibility of waste heat availability in some situations must not be overlooked. This can be from a local off-grid power generation unit such as a gas turbine or a diesel engine. In such case, a number of thermally driven desalination processes can be set up to take advantage of this wasted resource without significantly increasing the demand on the locally generated power. An example of such a set-up is the 5000 l/d MD plant in the island of Pantelleria, Italy, which derives 80% of its required power from the waste heat of a diesel power plant, and the remaining 20% from solar collectors [17].

2.3 Process/RE resource combinations

Considering the various desalination technologies, and the various renewable energy technologies presented above, a wide variety of combinations is possible. It is unlikely that a single pair can be identified as being superior in all situations, and a rational choice of technologies will depend on many factors. In this section, some of the main combinations that are commonly adopted or which have been considered are presented. One of the difficulties and barriers for desalination by renewable energies is that the two elements: RES technology, and desalination technology have generally been developed separately, this has an impact on the reliability and modularity on the overall system and the ease of deployment[14].

2.3.1 Solar thermal-MED

The MED process is a mature thermal process that possesses many attractive features that favour its selection in combination with solar thermal energy. Compared to MSF, the fact that the same GOR can be achieved with fewer effects leads its relative simplicity and easier scalability. This makes the MED process more suitable for small-scale autonomous systems than the MSF process. In addition, as was previously mentioned, the power consumption of MED for pumping and auxiliary systems is lower than that of MSF, which is especially important when the source is solar thermal energy because a separate means of providing the required electric power is necessary.

A notable variant of the MED configuration is the Multiple Effect Stack (MES). Figure (15) shows a schematic of a four-effect MES plant. Seawater is introduced at the top of the stack and sprayed on the evaporator tube bundle forming a thin film. The heat input to the process is in the form of steam flowing inside the tubes of the first effect, giving up its latent heat to the evaporating film of seawater outside the tubes as it condenses. The process carries on at progressively lower pressures, in the same way described previously for the basic MED process.

The MES configuration is remarkably stable in operation and has the ability to adjust automatically even to sudden changes in the input steam conditions[2]. This feature makes it particularly attractive for pairing with a variable energy source such solar thermal. Moreover, being a once-through process where the highest seawater temperature coincides with the lowest seawater/brine salinity minimises the risk of scale formation without excessive anti-scalant requirements. Product water quality is typically is less than 5 ppm TDS throughout the life of the plant. Therefore, the MES variant of the MED process appears to be the most suitable for use with solar energy[2].

A 14-effect vertically stacked MED plant with a nominal capacity of 72m³/d was installed at the Plataforma Solar de Almería in Spain during the 1990's. The plant derived its input from parabolic trough collectors (PTC) with one-axis

solar tracking having a total area of 2762 m², and included a 155 m³ thermocline thermal oil energy storage tank. The heat transfer medium was synthetic oil, serving both to transfer heat from the collectors and to store energy. The heat was used to generate low-pressure steam at a temperature of 70degC. A performance ratio (in this case define as kg distillate per 2330 kJ thermal energy input) that varied slightly around 10 was achieved [2], [14].

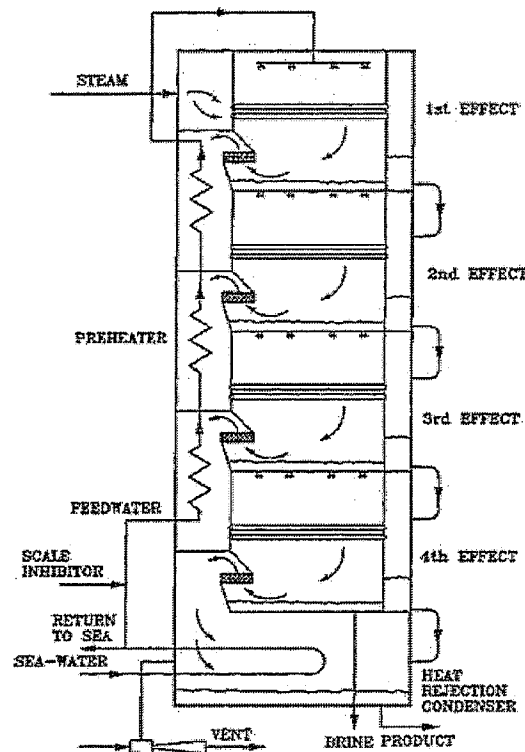


Figure 19: Schematic diagram of the Multiple Effect Stack (MES) flow configuration

2.3.2 Solar thermal-HDH

The HDH process is a good choice for application with solar thermal energy when a simple and relatively cheap option is desired. The cost of water produced is estimated to be in the range of 2-5 €/m³. The HDH process is more efficient than a solar still, and produces more output water per unit area of collector, in the range of 20-30 l/m²/d. Thus, it can more easily be scaled up to around 100 m³/d capacity. With the application of multiple-staging, the thermal energy consumption can be brought down to the range of 100 kWh/m³[14]. It also has the feature that the humidification process opens up the possibility for green house application, which can be desirable for some rural communities [16], [18–20]. Refer figure 15 for Simplified process schematics of HDH. A 1 m³/d multiple effect HDH unit in Oman is shown in figure 20.

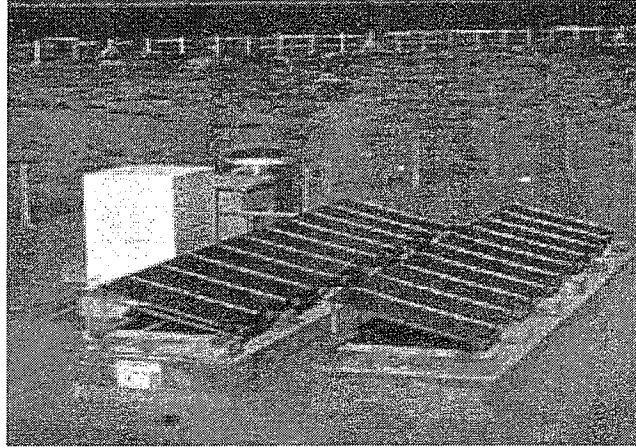


Figure 20: A 1 m³/d multiple effect HDH unit in Oman

2.3.3 Solar thermal-MD

The Solar-MD combination has some advantages for small-scale autonomous units up to about 10 m³/d. Among these advantages is the ability of MD to operate using low-grade thermal energy as low as 60-70degC (of course higher temperatures increase unit productivity). The process also adjusts continuously to variable input conditions and does not require a fixed operating point. The hydrophobic nature of MD membranes makes them substantially less prone to fouling and scaling than RO. The process does not use expensive metallic heat transfer surfaces, and the low operating pressures involved mean that expensive high-pressure piping is not needed. Such factors are expected to aid in bringing down the cost of MD-based systems when the problem of high-energy consumption can be effectively tackled. There seems to be some good progress achievable soon in this area with the multiple effect configuration (V-MEMD) developed by Memsys (presented earlier), making possible GORs in the range of 10, as in MED, but with substantially cheaper materials of construction.

The Fraunhofer Institute for Solar Energy Systems and its spin-off company SolarSpring GmbH have been developing since 2001 autonomous solar thermal driven Membrane Distillations units intended for remote areas. Two different system designs are available: the Oryx 150, a simple direct-couple (no energy storage) system with a nominal capacity of 150 l/d; and a larger two-loop system rated at 1-1.6 m³/d. The energy storage in the two-loop system allows 24-hour operation, thus achieving a higher specific output capacity.

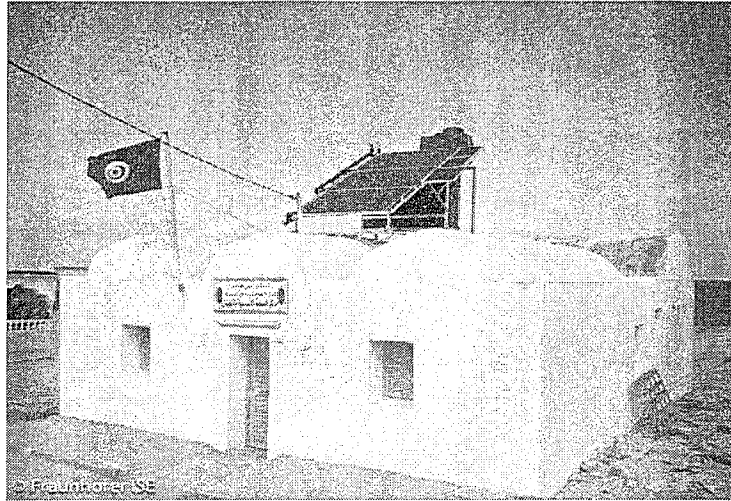


Figure 21: The Solar Spring Oryx 150 unit installed on the rooftop of a health centre in a rural area of Tunisia.

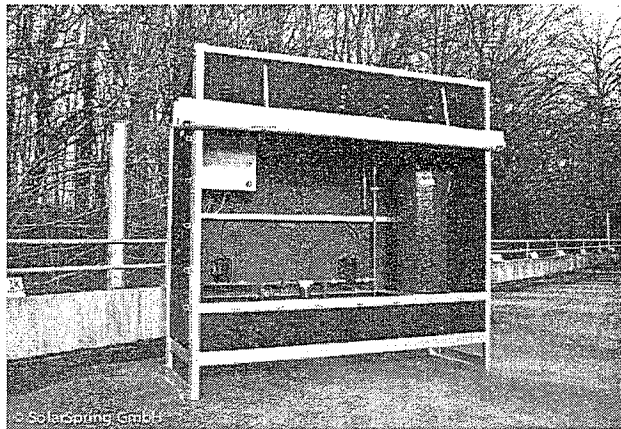


Figure 22: A view from the backside of the Oryx 150 unit. The spiral-wound MD module is the blue vessel on the right.

2.3.4 PV-RO

Due the maturity of both technologies involved – reverse osmosis and PV panels, the PV-RO combination is probably the most common and matured renewable energy desalination combination. The PV-RO system consists of a photovoltaic field that supplies electricity to the desalination unit. Since PV panels supply DC power, while RO pumps require AC power input, a DC/AC converter is required.

The specific cost of water produced in PV-RO plants is in the range of 3.5 –7 €/m³ for brackish and 9 –12 €/m³ for seawater RO units [14]. Notably, as the ProDes Roadmap [14] points out, water cost is disproportionately higher for systems with capacities lower than 5 m³/day. However, for higher capacities the water production cost should come down considerably. Both being matured technology, and RO being one of the lowest power consuming processes this should be easily achievable.

The fact that RO and PV are both mature technologies it means that there are a large number of suppliers for each of these technologies in many countries, and it should be easy to reliably source the necessary subsystems.



Figure 23: A 2.1 m³/h nominal capacity brackish water PV-RO plant in Tunisia, installed by the Canary Island Institute of Technology, Spain.

Ghermandi et al. [21] have pointed out that despite the lack of a standard design, the most commonly employed design consists of the following subsystems:

1. Solar sub-unit (PV panels)
2. Water extraction unit
3. Pre-treatment unit
4. High-pressure system (pump, motor and Energy recovery device)
5. RO membranes
6. AC/DC converter
7. Electrical storage

2.3.5 PV-ED

At present there is little experience using ED systems with renewable energy (RE) [14]. Only a few pilot units for R&D purposes are in operation. According to the ProDes Roadmap, the main barriers for this system are the limited availability of small-sized commercial EDR units and that they can only be used for brackish water desalination.

It is worth noting however that ED is a mature technology that is well suited for brackish water desalination, and it is relatively robust compared to RO (in terms of fouling resistance), which suggests that there might be some potential prospects for this technology when considering a brackish water plant.

2.3.6 Wind-RO

Wind-powered RO is a common renewable energy desalination combination, since both are mature technologies. Due to the highly fluctuating nature of wind energy, even more than PV, an energy buffer in the form of a battery set and a dedicated control system are required to stabilize the energy supply.

The cost of water produced by this technology combination is in the range of 3-7 €/m³ for small RO plants up to around 100 m³/day. For medium capacity RO plants in the range of 1000-2500 m³/day, the estimated cost is in the range of 1.50-3 €/m³.

2.3.7 Wind-MVC

Wind-driven MVC units have been considered [22], but have presented some problems and require further development before they can be applied commercially. One of the main difficulties is that the MVC process is usually designed to operate at a fixed point, and requires substantial time to reach the design point, which makes it difficult to couple with a variable energy supply. Furthermore, the frequent starting and stopping were found to cause severe scaling and total jamming-up of the system [22].

2.3.8 Geothermal MED

The relative advantages of MED, a thermally driven process, as mentioned in Section 2.1.2, makes it a natural choice for pairing with a geothermal energy source. A number of such projects are reported in the literature.

An 80m³/day pilot geothermal desalination plant based on the MED process has been installed in Kimolos Island, Greece [23]. Geothermal water at a temperature of 61-62degC from a 188m well is used to drive a 2 effect vertical tube MED plant from Alfa Laval. The estimated water cost was reported to be 1.6€/m³[23].

Another reference [24] reports on a project in Milos Island, Greece, aiming to construct a dual-purpose geothermal plant for generating 470kW electric power and producing 1800-1900 m³/day of distilled water. The planned desalination process was MED-TVC. The report describes extensive geothermal exploration studies and a detailed design plan, but it is not clear if the plant was actually constructed and what the current status of the project is.

A more recent prototype geothermal desalination system intended to take advantage of the abundant geothermal energy in Mexico is described in [25]. The system described uses a novel distillation system that resembles the MED process but with some modifications.

2.3.9 Geothermal HDH and other thermal processes

Although the MED process, including its variants, is the one most frequently considered process for pairing with low temperature geothermal energy, other potential combinations are possible. An experimental investigation combining a geothermal source with the HDH process is described in [18], [26]. The HDH process can be linked to the operation of a greenhouse, a very attractive combination for agricultural use in small communities located in arid regions. A case study examining the possibility of applying this solution in Algeria is reported in [19].

Another interesting combination that is not adequately explored is the direct desalination of low to medium temperature (60-90degC) high-salinity groundwater using membrane distillation.

3. Decisions, data and information before considering technologies for implementation of a desalination project

Desalination should be considered as part of a holistic approach for the overall sustainable development of rural and remote areas and only after less expensive technically efficient alternatives have been ruled out. Desalination projects require high level of technology, high capital cost, high-energy demand and high operating costs. The total production costs (including capital, energy and operational costs plus taxes if any) compared to conventional water resources is generally high and it is required that these costs must be paid by the water consumers, or through subsidies. Therefore, before deciding on the technology to be adopted and with which type of renewable energy source will be combined a number of studies must be carried out which will justify the implementation of the desalination project, will justify the size of the proposed desalination plant, the quality of the product water, site availability etc? For these studies, the following are outlined.

3.1 Integrated Water Resource Management Plan or diagnostic study

Water shortage in rural and remote areas could be the result of real water scarcity or a result of many other reasons such as drought, bad water management, structural deficiency, water demand increase due to change of inhabitants habits, population growth, wasteful use of water, inefficient water use, system losses not accounted, and in many cases due to non rational water resources management plans.

The decision to embark on desalination for the supply of water in remote or rural areas must be taken within the framework of an Integrated Water Resources Management Plan, in which all possible options for the supply of water to the remote rural area were examined. The Integrated Water Resources Management Plan should consider the nature of water demand, the efficiency of water consumed, the efficiency of water use, whether the water demand is justified or can be reduced by water demand methods, the water supply systems capabilities (capacity and efficiency of each system such as reservoirs, pipelines conveyance capacity, pumps and water distribution systems), the water available of the system and how this is allocated to the various consumers. All available options for the supply of the justified quantities of water to the remote or rural areas from existing systems should be examined, including desalination as an alternative option. If an Integrated Water Resources Management Plan is not available or the area is a remote area without connection to any nearby water supply system, a diagnostic study should be carried out to identify the real water problem of the area. The major question to be answered following conclusion of the diagnostic study is whether the water demand cannot be reduced and not supplied from renewable or other water resources and that the only option is the production of desalination water to satisfy in a satisfactory manner the water demand.

3.2 Capacities of Desalination Plants

3.2.1 Definitions

The Desalination Plant Capacity is defined as the quantity of water produced on an hourly, daily, monthly and annual plant capacity. For each capacity, the following is defined.

- ⊗ **Hourly Production:** This is the plants maximum capacity depending fully on the structural plant capabilities. Hourly production may vary depending on the seawater temperature and other parameters. This parameter is largely the decisive parameter for defining the capital cost. Of course the desalinated water cost is not exclusively decided by the Capital cost but also by the operation and energy cost parameters and for minimizing this cost an optimization of the hourly production against total production cost of desalinated water must be carried out taking into account hours of daily production, power costs under a certain power supply pattern etc.
- ⊗ **Daily Production:** The Maximum daily production is the product of the hourly production multiplied by the number of hours the plant will be in operation at full power supply. In case of Solar energy supply the daily production will be the product of the hourly production multiplied by the number of hours of power supply from the solar system. A Plant with an hourly production of 10 m³/hr supplied with power supply from a grid will most probably have a daily production of 240 m³/day, where when the supply is from a solar power system the daily production will be around 80-100 m³ assuming that the solar system will supply power during the daytime. In case the desalination plant is provided with energy from solar system in daytime and grid energy at night may increase its production considerably.
- ⊗ **Monthly Production:** This is the sum of daily productions calculated for each day. Daily production may be different for different days depending on seawater temperature, or due to plant stoppage for maintenance purposes, or due to power supply restrictions or relaxations.
- ⊗ **Yearly Production:** The annual production is the sum of the monthly productions and this give the annual quantity of desalinated water produced. The annual quantity is used to calculate the capital cost of water, which is one of the components of the desalinated water cost.

3.2.2 Desalination Plant Capacity

The desalination plant capacity in remote rural areas will be required to make up the difference between the daily, monthly and annual water demand and the daily, monthly and annual water availability of the existing water supply system. In the decision of the Desalination Plant capacity, the planners must take into account the marginal capital cost of each additional m³/day they add to the plant hourly capacity and how much quantity of desalinated water this additional hourly capacity will produce per year. It must be remembered that the hourly capacity of the plant will also set the renewable energy capacity and if this very high, the cost may be prohibitive. The Desalination Plant hourly production is definitely a very serious parameter for setting the cost of the Project and the planners must carry out optimization studies taking into accounts all the parameters that affect the capacity, mainly the hours of plant operation per day and energy cost. The desalination plants combined with renewable energy resources will constitute an optimization challenge for any water resources engineer for minimizing the cost of both the desalination Plant and that of the renewable energy source.

3.3. Desalinated water quality

Water quality characteristics are related to health, aesthetics and taste parameters and these are set by the requirements of the users. The Product Water to be used for drinking purposes must have the characteristics of a drinking water specified in the relevant national or international directives or standards. Similarly, if water will be used for irrigation then the water quality must have those characteristics that do not affect the crops to be irrigated as are defined in every irrigation manual. Water that will be used initially for drinking purpose and the waste produced will be treated and recycled for irrigation purposes the desalinated water quality characteristics must be such that it does not contain any toxic ions such as boron.

3.4 Demographic and socio-cultural considerations

The following demographic and sociocultural considerations should be taken into account before and after taking the decision to implement the Desalination Plant in a remote or rural area.

- a. **The Socio-technical-institutional interdependence:** Interaction between Three elements: people, technologies & organizations must be fully understood & accounted for. The desalination technology must be explained to the people to enable them to understand that it is similar to a physical process that takes place in the environment or in other words, it is part of the water cycle. They must also be explained how this technology and the project be implemented, such as from where the raw water will be supplied (seawater or brackish), where the brine will be disposed, how much energy will be used, the capital, operational and energy costs, how much the water will cost and who will construct and who will operate it, their role in the decision making and their role in the construction and operation and what is expected from them too. It must be emphasized that the project will be a success only if they will really support it.
- b. **Involvement of beneficiaries:** The organization/people that would operate a desalination plant should origin from the same local community served by the plant. If possible, they should be involved even from the planning phase of the plant, but it would be also necessary to participate at least from the construction up to the operation of the plant.
- c. **Involvement of adversely affected people:** Usually objections for the implementation of desalination plants are coming from people adversely affected, such as the owners of the land on which the plant will be constructed or even worse neighbours whose properties may suffer devaluation before of the project or even fishermen who think that the fish will be affected by the brine discharge and the seawater abstraction. All these concerns must be analysed and discussed with the interested persons within the framework of the Environmental Impact affected study and must be taken into consideration when compensating for the appropriation of the lands.
- d. **Learning:** Opportunities for learning, raising awareness & training need to be provided from the earliest stages of a project to maximize benefits. On the job training of operators is a very significant aspect of the project's sustainability.
- e. **Independence & autonomy:** Technological solutions, however clever & innovative they might be in the eyes of the decision-makers, must not be imposed on a community that finds them objectionable.
- f. **Sustainability:** Average income per family, poverty levels, affordability, willingness to pay for desalinated water & government subsidies, play a major role in sustainability. If actual income of the locals does not justify the implementation of the project the state' must make a contribution which must secure the project implementation with the locals undertaking the O&M Costs. The best system for subsidy must be implemented for securing the best scenario for project implementation and sustainability.
- g. **Flexibility & Process orientation:** The general conditions for water supply in rural areas can change relatively quickly, and are generally very site-specific. These conditions must be taken into account during the calculation of the water demand and any flexibility must be included in the design of the desalination Plant.
- h. **Realism:** Project objectives & expectations must be realistic & feasible to avoid failure. Project objectives must be agreed with the consumers and those preparing the planning of the project together with the project sponsors.

3.5 Cultural, religious & gender related issues:

- a. Often a new technology introduced into a community for the first time is perceived as an alien intrusion that is incompatible with long-standing traditions, social structures and responsibilities of the community. The technology should be explained in simple terms so the community will understand and accept it as a simple physical process.

- b. Despite the important role women play, men take charge of decision-making & women are often left out. This should be stopped and women should be included in the decision-making when it comes to water policies development.

3.6 Raw water resource availability & quality

- a. Raw water resources availability is a highly technical problem. Seawater abstraction should be made from a point where quality is good and steady and in sufficient quantities to satisfy the project requirements. In case of using well water as raw water source for desalination, detailed hydrological study/tests shall be conducted to ensure the draw down in the well and sustainability for the planned capacity throughout the period of operation. For this purpose, a detailed hydro geological study must be carried out to verify that only seawater or brackish water is abstracted from the wells and that the fresh water aquifer upstream are not adversely affected. Raw water quality must be steady within reasonable range so that the pre-treatment process to be selected to be able to treat satisfactorily the water before desalination in all cases and under any conditions.

Seawater beach wells may be used as a feed water source for seawater systems if there is a good hydro geological connection between the sea and the seashore. In such cases, the wells are quite shallow and can be as regular wells or Ranney wells or as a combination of both. For small desalination plants, regular wells will be satisfactory and much cheaper.

Open seawater intakes should be located at depths of 10-15 meters water depth, even during low tide with the water level inlet at 6 meters above sea floor to avoid abstraction of seabed load and at least 4 meters below the seawater surface at minimum tide. Abstraction velocities should be very low less than 0.30 m/s to avoid abstraction of fish swimming around the intake.

- b. Detailed physical, chemical and biological analyses of raw water at intake are fundamental for the design and operation of desalination systems for determination of the pre-treatment process and to avoid scaling and/or fouling of membranes and evaporators. Water originating from properly designed and operated well field has very low concentration of suspended solids and the treatment process will include only cartridge filters by omitting any media filtration. In case of open seawater intakes, a full pre-treatment process will be required.

3.7 Brine discharge location

Brine discharge (whose salt concentration is much higher than the raw water) would be preferably discharged to the sea but in case this is not feasible, it can be discharged in inland wells or evaporation ponds. In case of discharge to the sea, the location of the discharge point(s) should be positioned at a sufficient distance from the sea intake and at such orientation that the high salinity brine water would not be abstracted by the intake. This will require further consideration of the "excess salinity decaying profile" (excess water salinity is diluted within a distance of 12-15 meters from the point of discharge with a discharge velocity of 6.0 m/sec and concentration of brine 5.8% and seawater 3.5%) and the direction of seawater currents in the discharge location.

Brine discharge to inland is discussed in detail in section 4.8 of this report.

3.8 Pricing structures & financing schemes (Affordability)

- a. A successful desalination project in a rural or remote area should manage to recover its running costs & depreciation. This necessitates that the water tariff reflects the real costs of water supply. On the other hand, access to safe drinking should be available & affordable for all.
- b. The main challenges facing desalination in rural communities are identified as follow:
 - i. The low income dominating in the rural communities.
 - ii. Limited capital and financial resources.

- iii. High investment costs required for such projects.
- c. In response to these difficulties, a number of support mechanisms that do not distort the market function are possible, such as:
 - i. Direct financing of the infrastructure.
 - ii. Provision of financial incentives for the operators.
 - iii. Enabling private sector involvement.
 - iv. Adopting the “life-line rate”, where a progressive pricing structure is applied based on the volume of water used in order to assure social justice among the users. Israel reported that “Urban centres subsidize water delivered to rural and remote communities”.

Also given the prevailing poverty in rural & remote areas and accepting the principle that access to safe drinking should be available & affordable for all, subsidizing the capital & operational costs of desalination by central government is unavoidable. Based on that, it is suggested that the PCs should consider funding of desalination projects in rural or remote areas, as part of their national strategy on water supplies within their national IWRM framework. It must be emphasized that sustainability of desalination using RES in rural and remote communities should be an integral part of the overall sustainable development plan of the community using a holistic approach and if desalination plant is proved necessary, this should represent a trigger for further sustainable socio-economic and environmental development to reduce poverty and unemployment while developing markets. Many of the development plans can take stocks from local heritage, history, nature, ecology, indigenous culture, arts, and/or architecture.

Examples from some countries in the Mediterranean area confirm that only central governments can afford construction of desalination projects in rural and remote areas, either by funding them or by undertaking the responsibility through guarantees imposed to the contractors (via BOT/BOOT/PPP contract schemes). In other countries (Israel) the development of IWRM was based on the holistic approach, incorporating the cities, the rural and remote areas, the environment, development, tourism, etc. which contributed to keep the rural population in their area. On the other hand it is true that in some other countries this did not refrained people from rural and remote communities, such is the case in Algeria, from migrating towards urban centres for better quality of life and employment opportunities, which means that the holistic approach must meet the peoples expectations.

3.9 Institutional and regulatory factors

3.9.1 Institutional Factors

The institutional factors that are required for the promotion of the desalination project are the same that promote any water resource structure in the PC's and include the following:

- a. **National decision-making level:** This typically includes ministries & other high-level government entities that are involved in setting water policy and planning.
- b. **Executive level:** This is usually the role of government departments and organizations that operate under the top-level decision making bodies and they are responsible for the implementation of the decisions taken by the policy makers. The people from this level will be responsible to promote studies, investigations, issue tenders, evaluate tender, award tenders, coordinate execution of the project, commission the project, organize its operation, buy water from desalination project owners and sell desalinated water to the local community.

- c. **Stakeholders' level:** This can be the local communities that undertake the actual operation & maintenance of water supply facilities, also being the beneficiaries. Close relationship between the stakeholders and the Executive level responsible for the project implementation and the national decision making organizations (responsible for the projects funding) are very crucial.

3.9.2 Regulatory Factors

The implementation of desalination projects is a very complex procedure requiring the issue of a number of permits such as water abstraction permit, brine disposal permit, off-shore and on shore works permits, renewable energy installations, all after a thorough Environmental Impact Assessment Study. Following is a description of the EIAS.

3.9.2.1 Environmental Impact Assessment Study

The preparation of an Environmental Impact Assessment Study (EIAS) is a requirement for the promotion of a desalination project. The study will include among others the following.

- a) Disturbance on the Marine environment including sand suspension during construction phase taking into account the machinery and methods of construction. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects.
- b) Disturbance on the marine environment during the process of abstracting seawater, drifting and sweeping by Suction head or depletion and destruction of brackish and fresh water aquifers during abstraction of brackish water from on land aquifers including impingement of marine life on screens at the intakes. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects.
- c) Disturbance to the coastal environment including dust content in the air environment during the construction phase. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects.
- d) The impact on the marine environment from the use of chemicals during the pre-treatment, desalination and post treatment processes. The EIAS should include mitigation measures for diminishing or abolishing any adverse effects including the reduction of their amounts in the discharge stream (residual chlorine, iron, trace metals, anti-scalants, anti-foaming agents, thermal discharges, phosphorous, suspended solids and organic compounds), the leakage control and prevention of leakage of chemicals of seawater, brine backwater etc to the land and marine environment. The brine dispersion system should be evaluated and mitigation measure may be proposed for minimizing adverse impacts on the marine environment.
- e) The impact to the environment in general (green house emissions to atmosphere) from the energy consumption in case of non-renewable energy and the savings from the use of renewable energy.
- f) Disturbance to the environment from disposal of excess excavated materials. These could be used in the construction of roads or embankments etc.
- g) Noise and light generation during the construction phase and during the operation phase, disturbance to the environment and measures to reduction of noise and light pollution.
- h) General disturbance to the land, air and groundwater, from the materials to be used the emissions and by products during the construction, operation and maintenance of the project.
- i) Aesthetics considerations with regard to the appearance of the Facility and vegetation.
- j) Any other environmental aspect.
- k) MED POL Pollution Monitoring Program for Marine environment affected by the Land based Sources: Since MED-POL Program (the marine pollution assessment and control component of the Mediterranean Action Plan), which is responsible for the follow up work related to the implementation of the Land Based Sources LBS) Protocol, the Protocol for the Protection of the Mediterranean Sea against pollution from LBS and Activities and of the dumping and Hazardous Protocols, MED POL should be requested to assist in

the formulation and implementation of a monitoring program of the marine environment affected by the discharge of the brine and other land base sources such as backwash wastewater. Such programs are proposed in the EIAS and the implementation is carried out by the national environmental authorities in cooperation with the polluter.

The EIAS will be carried out according to the national policies and guided by the national legislations and the internationally recognized criteria, principles and procedures. This will be executed for a number of sites and each EIAS shall be examined further during the preparation of the feasibility study, for deciding which is the recommended site from the point of view of techno-economic and environmental impacts.

3.10 Desalination Project systems

A desalination project is made usually of the following systems:

- (a) **Feed raw-water system:** The source may be "well water" either from brackish aquifer or from the sea through an open intake. In case of supply of water from well the feed system provides the wells equipped with pumps and the feed water pipelines for conveyance of the feed water from the wells to the pre-treatment plant. In case the feed water is from the sea through an open intake the system includes the intake heads, the raw seawater marine pipelines from the intake heads to the intake pit, the pumping station in the pit and the on land seawater pipelines from the pit to the pre-treatment plant. The Intake heads should be located at a suitable head for avoiding abstraction of floating or bed load materials thus securing sufficient supplies of seawater.
- (b) **Pre-treatment system:** The objective of the pre-treatment is to treat the raw water through filtering to the required quality for passage of water through the desalination system without any problems to the desalination unit. The level of treatment is different for the different technologies (membranes, thermal and others). The concentration of suspended solids in surface water sources is usually much higher than the well water sources. Pre-treatment for surface water source may include a conventional filtration plant or a membrane filtration system.
- (c) **Desalination system:** This is the system that removes the salts from the raw water (brackish or seawater). This system may be a "Membrane system", a "thermal system" or "other system" as given in detail in chapter 2. The selection of the best desalination technology shall depend on the physical, environmental, maturity of the technology, the raw water and product water quality, the availability of the technologies, the energy for operating the plant available (including the renewable energies), the capacity of the operators to operate the specific technology, the costs etc.
- (d) **Post Treatment system:** This system provides the treatment of the permeate by the addition of the required minerals and chlorination to make the water suitable for the purpose it will be used.
- (e) **Brine discharge system:** The brine is the wastewater from the desalination plant and its concentration in salts is around twice the seawater in case of seawater reverse osmosis technology and other concentrations higher than the raw water depending on the recovery rates.
- (f) **Auxiliary systems:** This includes the chemical dosing systems, the Backwash wastewater treatment systems, the electrical supply systems, the instrumentation and control systems etc.
- (g) **Power Supply substation system:** This system secures the power supply to the plant. It can be a substation receiving power from the Grid or from a renewable energy source.
- (h) **Power supply system:** This supplies the power to the plant. The source may be a renewable energy supply system (solar, wind power or geothermal) or an Independent power production plant. In all other cases except the Grid supply, the energy source (renewable or independent power production plant or a combination of two) the plant must have its own system for its independent power supply.

3.11 Selection of the site of the desalination plant

It is considered that desalination plants under the Sustainable Water Integrated Management-support mechanism is for desalination processes combined with Renewable Energy Systems. One of the most important parameters apart from the selection of the desalination technology is the selection of the site for the desalination plant. The Project Site is usually made from three sub-areas as follow; (a) the marine works sub-area which will include the seawater open intake and the marine pipelines, (b) the on shore works area which will accommodate the onshore boreholes equipped with boreholes or the intake pit and the intake pumping station and the onshore seawater and brine pipelines (c) the Main Plant area which will accommodate the pre-treatment, the RO process, the Post treatment and all accessories and (d) the Renewable energy plant area.

Desalination Plant Site selection is very vital for the design, financing construction and operation of Desalination Plants. The Site, comprised of inland and offshore parts must fulfil the following requirements.

- (i) Must be located in a place where access and interconnections to the power supply grid or to the Independent Power Production or to the renewable energy source and to the water supply networks are technically and economically feasible,
- (ii) The area extent and shape (size and geometry) must be the appropriate so that the marine intake head structures, the marine pipelines, the inland pit the seawater pumping station, the inland pipelines, the main facility structures, the post treatment system, the product delivery sub-system, and the power supply system (IPP or national grid substation) are adequately accommodated and optimally located so that civil, electrical, piping interconnections and other works costs are minimized,
- (iii) Be suitably located in a marine environment where adequate quantity of feed water with a reasonable good, uniform and steady quality of feed seawater is abstracted at a reasonable cost,
- (iv) Be at a location where the brine, backwash wastewater and other wastes are disposed with minimum environmental adverse effects,
- (v) The geology and topography are suitable for the construction and erection of the various structures at reasonable costs,
- (vi) The environmental, town planning and rural planning regulations, law requirements and restrictions are met,
- (vii) The desalination plant is socially accepted by the neighbouring communities and other authorities and,
- (viii) The local taxes are not prohibitive and the existing infrastructure shall make easier and cheaper the project implementation.

Usually in the site selection more than one site are selected and after carrying out preliminary layout, design and costing studies together with environmental studies the most appropriate techno-economical site is selected.

3.12 Budgeting and implementation costs including total cost of water

The implementation of desalination projects requires a budget, which is made of the following costs.

- a) **Capital costs:** These include all the expenditures associated with the implementation of the project from the time of inception to commissioning. The capital costs are made of two components,
 - the development or indirect costs, which are associated with the administrative and financing efforts including engineering, permits issue and to secure the EPC Contractor for the construction and commissioning of the Project during the development and construction phase and to secure the O&M

contractor for the operation of the project during the Commercial Operation Phase. These costs vary from 5% to 30% depending on the size of the project.

- ✳ the Construction costs or direct costs or the EPC Price, associated with detailed design, management of the EPC Contractor, procurement of materials, pipes and equipment, Installation of equipment, materials and pipes, civil works execution, Marine works execution, testing and commissioning of the project. The direct cost of the project represents 70-95% of the total capital costs.

The direct costs are calculated using the project design, the construction drawings, the bill of quantities, the construction processes and machinery and the workers hours required to execute the projects and the material costs rates, machinery cost rates and the labour's and technical staff cost rates. Included in the direct cost is a contingency amount, which provides for non-accounted items and risks, involved during construction phase. These direct costs are given as the EPC Costs in monetary units (Euros or US\$).

The indirect costs calculations are based on the needs for administrative, legal, financing, engineering and management staff salaries, travelling, accommodation, housing etc for the preparation of the implementation of the project, financing of the project and supervision during the construction phase.

b) **Operation and Maintenance costs:** These include the operation and maintenance cost to be paid to the project operator on a monthly or bimonthly and yearly base and include the management and administration staff cost the labour costs, the chemicals costs, the consumables and replacement parts required in the maintenance of the project. These can be divided into two categories;

- ✳ the fixed O&M costs which are independent of the quantities produced i.e. labour and staff cost, insurance costs, environmental monitoring costs permits costs, administrative costs, lighting, air conditioning, cost for equipment maintenance etc and
- ✳ The variable O&M costs which are typically proportional to the quantity of desalinated water such as chemicals, replacement of desalination equipment etc. These costs are expressed in monetary units in US\$/m³ or US\$ per year.

c) **The Energy component cost:** This is the cost of the energy required to operate the desalination plant, to produce steam and power the pumps in thermal desalination units and to operate the pumps in reverse osmosis plants. In both cases, the energy cost is typically proportional to the quantity of desalinated water produced.

d) **Total Cost of desalinated water:** The total cost of the desalinated water is expressed in monetary units US\$/m³ or Euros/m³ and it is equal to the calculation resulting from the sum of the annual capital cost, plus the annual O&M cost, plus the Annual Energy cost all expressed in monetary units per year (US\$/year or Euros/year) divided by the volume of desalinated water produced in one year. The annual capital cost is the amortized capital cost over the economic life of the project, using the capital loan rate of interest.

e) **Key factors affecting project costs:** Key factors affecting the various costs components (capital cost, O&M cost and power cost).

- ✳ Economy of Scale. The larger the project the smaller the unit cost of water.
- ✳ Project Availability coefficient: The larger the project availability coefficient (defined as the percentage of hours of the total annual the project is operational or the percentage of desalinated water produced per year to the average maximum annual production. Obviously in the event of desalination projects combined with renewable energy source (solar without energy storage), the project availability will be very small around 40-45%, which increases the capital cost component. Due to this and in order to reduce the unit capital cost and unit the energy supply could be provided from the renewable energy sources at day time (for solar) and from the grid at night time.

- **Product water quality:** The higher the quality of desalinated water required the higher the cost. Boron removal further to other parameters requires additional process increasing capital, O&M and energy costs.
- **Raw water Quality:** The raw water quality has an effect on the desalinated water costs especially when using the Reverse Osmosis technology (TDS, temperature, Organic content, nutrients, boron silica, etc).
- **Raw water Intake and Brine water disposal methods:** The raw water intake and brine disposal are site dependent and the cost can be decrease by selecting the most suitable site.
- **Project risks:** There is a number of risks, which are not fully dependent on the project owner but are dependent on others, such as permitting, site availability, power supply risks, construction risks, source water risks, technology risks (associated with the technology maturity), regulatory risks (changes in water quality requirements on power supply tariffs, on wastewater discharge etc), operational risks, desalinated water demand risks and financial risks. All these have to be taken into consideration during preparation of capital costs and operational costs and in formulating the desalinated water price structure.

Preliminary capital cost (direct and indirect), which will include contingencies for environmental mitigation measures costs could be made from preliminary drawings for the preparation of the preliminary bill of quantities for each system and using suppliers and contractors cost rates. The O&M costs could be made using the requirements contained in the O&M Manual concerning the operation and maintenance requirements, where the energy cost will be calculated using the specific energy consumption* to be guaranteed by the designer.

* Specific Energy consumption: This is the total energy required by the plant including pumping energy, lighting, heating and air conditioning consumption in the plant for the production of one cubic meter of desalinated water.

f) Calculation of hourly, monthly and annual production of desalination project: For the calculation of the unit cost of desalinated water the total annual cost must be known (calculated as defined above) and the annual water production must be known. The annual desalinated water produced shall be calculated by using the hourly production multiplied by the Plant Availability**.

** Plant Availability is the result of the division of the total number of hours the plant could be operational divided by the total average number of hours available for operation per year. The average plant availability, for a plant supplied with non-renewable energy sources, is around 90 to 95 percent, where plants depending fully of the renewable solar system will have availability around 40-45%

4. Guidelines to screen and assess BAT options for desalination with focus on rural areas

This section aims to present the most important factors that need to be considered for screening and selecting the best technologies for renewable energy desalination for rural and remote communities.

4.1 Evaluation of available water resources and demand characteristics

A rational approach to the process of screening and selecting the best technologies out of the available technology candidates must begin with a comprehensive evaluation of the available water resources, as well as an evaluation of the water demand characteristics at the proposed site. (See previous chapter) This information has a direct influence on the selection of the best technology option to be implemented. Considering the relatively high cost of the desalination option for water supply, a thorough evaluation of the available water resources in terms of quantity and quality, combined with detailed knowledge of water demand, is essential for establishing the

opportunity cost of the various technology options under consideration. For instance, the availability of brackish water in sufficient quantities at location near the sea makes seawater desalination a less desirable option. Similarly, the lack of conventional water resources or brackish water can make the high cost of seawater desalination justifiable. The knowledge thus gained provides the first major factor for a rational selection process. Furthermore, these two elements – available resources and water demand – are needed to reveal the options available for an integrated water management approach. Besides the obvious implication on required plant size, detailed knowledge of water demand and its variation over time is also essential to understand the likely mismatches between water supply and demand, and between energy source and demand. This will clearly have an impact on design and technology specification, as well as storage requirements. One important class or type of remote location where desalination is commonly applied is the multitude of islands and seaside villages around the Mediterranean, which have significant seasonal influxes of tourists. This is an economically important class of desalination end-user for the respective countries, since they represent an important contribution to the local economy. In general, the seasonal variation of the population at a candidate site and its reflection on the water demand needs to be well understood.

4.2 Evaluation of available renewable energy sources and grid connectivity

The next major step in the process is to carry out an extensive study of the available energy resources, particularly focussing on renewable energy sources, if electric power supply is not available. At this stage, a thorough understanding of the available RESs and their qualitative and quantitative characteristics is required. The intensity and degree of variability of the considered sources needs to be taken into account in order to measure the relative merits of the available options.

Achieving the goal of better environmental sustainability dictates that consideration of the type of renewable energy source available should proceed, and be a driver for, selection of the desalination technology. Low temperature thermal energy sources, for example, favour the selection of thermal desalination processes over RO, even though the energy consumption of SWRO is lower. However, if brackish water is available the cost economics between thermal desalination and RO needs to be studied.

Thus, one might arrive at one conclusion when considering the desalination process in isolation; and arrive at another when one considers the type of energy source available. To give a more concrete example, if it is decided based on studying available water resources and local demand that there is a need for installing a seawater desalination plant, a cost comparison of the competing processes focussing exclusively on the processes might lead to the conclusion that RO is the best option. If, however, there is a low temperature geothermal reservoir available and the site is not connected to the power grid, it may be more desirable to opt for a thermally driven process instead.

A number of different RESs might be available at a given site. It is common in coastal areas on the Mediterranean to have a good amount of sunny days as well as reasonable wind speeds allowing the use of wind turbines for power generation. In such cases, it is necessary to carry out an economic analysis of the available options that takes into account the site-specific characteristics of the sources. That being said, it is also not advisable to select the energy source out of a list of available candidates in isolation of the desalination process either. A preliminary list of possible technology pairs should be compiled for the purpose of comparison. At the very least, one should try at this stage to decide on the broad type of energy source, i.e. whether to provide thermal energy or power. A hybrid approach combining two sources of the same type (e.g. solar PV and wind) can also be adopted as a means of partially overcoming the inherent variability of each single source.

Finally, results of the evaluation of available energy resources may establish the need for a backup power source, such as a diesel generator, to cover periods of low energy availability. The need and type of energy storage is linked closely to the type of process and should therefore be addressed at a later stage, after short-listing the desalination processes.

4.3 Short listing of candidate desalination processes based on available RES

The previous step of identifying, characterizing and selecting the RES should allow the elimination of all desalination processes that are not suited to the type of energy source chosen. The decision to adopt a shaft or electric power RES eliminates thermal processes and shortlists: RO, ED, and MVC. Among these options, RO is the most economical for seawater desalination. The MVC process is has higher power consumption, but is generally more robust than RO, requiring minimal pre-treatment in comparison. RO membranes are prone to fouling and scaling, and are less forgiving of operator errors. For brackish water plants in remote areas, the ED process is very attractive, since it is also more robust than RO, and is well suited to small-scale minimal maintenance plants in remote areas.

If, on the other hand, a low temperature thermal RES is chosen, the previous three processes are no longer relevant, and the potential candidates are MSF, MED, TVC, MD, HDH, and solar stills. The last three processes are generally suited for small-scale systems, up to around 5m³/d.

4.4 Maturity and level of deployment of the processes

The maturity of the selected process will reflect on the level of risk associated with project. Novel processes may possess attractive features, open up new possibilities, and occasionally introduce remarkable improvements in performance; but they are particularly difficult to recommend for remote and rural applications. The nature of rural and remote sites preclude easy access to technical support and highly qualified plant supervisors and operators. This factor tends to strongly favour proven and well-tested technologies for reliable solutions to pressing water demands in rural and remote areas. Nevertheless, local governments and decision makers should be aware of potential developments in technology and the possibilities they introduce. It is thus recommended that decision makers adopt a policy of encouraging and allocating funds for pilot testing of promising new technologies to establish their reliability, understand their maintenance requirement, and to gain confidence in their applicability to the local conditions.

In summary, the following factors are to be considered.

- Reliability of a desalination process is of a highest priority even from the total unit cost of the process, when desalination projects aim to provide drinking water.
- Desalination technology is witnessing fast development and it is recommended to keep up with progress on proven state-of-the-art desalination processes.
- A process can be considered matured/proven if it has been commercially operated for ≥ 3 years with success and recommended by water practitioners who used it.
- In all cases and in order to increase reliability of any proven desalination process, a plant should be design with at least two parallel lines, of 50% capacity each, in order to reduce the risk of total plant shutdown.
- Novel processes may possess attractive features, open up new possibilities & occasionally introduce remarkable improvements in performance; but difficult to recommend for rural applications awaiting maturity. In order to forward novel processes, the investment should be contracted as BOT or BOOT, so that the risk is carried by the investor. The investors are more willing to invest in plants serving rural and

remote areas rather than in cities, since the risk in investing in small plants is minimized as opposed to large and mega-plants.

- To reduce the risk of innovative and immature technologies in rural areas, a different mature & tested technology can be considered side-by-side to the new technology. This will reduce the risks of total dependability on the innovative technology. The provider of the new technology will grant the needed guarantees of proper operation & compensation in case of failure.

4.5 Pre-treatment requirements

Desalination processes differ in the level of feed pre-treatment they require for stable operation and long plant life. Membrane processes are generally more sensitive than thermal processes, and among the membrane processes, RO tends to be the most sensitive to feed quality specifically with respect to iron, silica, Fluoride, organics, etc. in feed water. RO plants drawing their feed from open intakes require thorough pre-treatment systems, typically consisting of chemical dosing and filtration. In addition, periodic cleaning of the membranes is required based on observed plant performance, as well as frequent backwashing of the filters and intermittent disinfection of the intake system. It is clear that a good degree of skill is required for trouble-free operation of RO plants. When the local geology of the site permits the use of beach wells as the intake system of a SWRO plant, the pre-treatment requirements can be significantly less demanding, and this option is preferable whenever possible. Recent experience at several SWRO plants operated or supervised by WESCO in Saudi Arabia has shown that often much of the chemical dosing, including coagulants, chlorination and acid dosing, can be reduced or eliminated without any negative effect on the RO plant, while reducing the impact on the environment and lowering operating costs. This of course can only be established on a case-by-case basis, and the possibility needs to be investigated at each plant. High recovery brackish plants are often designed to exceed the solubility limits of some of the sparingly soluble salts present in the feed water, and in such cases the use of an anti-scalant is likely to be a mandatory requirement. Recent technological innovations include SWRO or Brackish RO plants without any chemical in the pre-treatment process, which is both environmentally, and economically friendly and must easier to operate.

The ED process is generally more robust than RO, requiring less stringent feed pre-treatment. This makes it an attractive option for brackish plants in remote and rural areas with little access to technical support or skilled operators. Membrane distillation, due to the hydrophobic nature of its membranes is quite resistant to fouling compared to RO, and thus has very little pre-treatment requirements; however, more care is required during the start-up of the plant.

The Volume of product water and the availability of the renewable energy sources are the most important factors in the selection of the combination of the desalination technology and the renewable energy source. The volume of product water defines the size of the desalination plant and the power required. Obviously, for large desalination plants the energy requirements are very large, which make the marriage of the desalination plant with renewable energy sources (since both the desalination plant and renewable energy source plant will be very large) not economically feasible. For limiting the size of the desalination plant and that of the renewable energy plant use of energy from the grid at night could be made.

4.6 Operational skill level required

A related issue to technology maturity & pre-treatment requirements that is important factor in selecting & recommending a technology is the relative ease of plant operation compared to the level of skill available in rural communities. However, since the desalination plants in rural and remote areas are usually selected to be small and simple to operate the need for sophisticated technical capacity to operate such small plants is minimum.

Nevertheless, appropriate training of the local community can be given from the commissioning stage (even from the design of the plant if possible) and at regular periods after the plant start-up, in managing, operating and routine maintenance. This capacity development should be on the job with familiarization on the design and concepts of the desalination technology and associated RES. Furthermore, support from the service provider and/or designer should be assured especially for irregular conditions (e.g. break down of high-pressure piping or pumps etc). Alternatively, efficient support for irregular and major failures could be provided by a more centralized technical centres that can be called in whenever needs arise.

The minimum suggested staff in such projects to assure efficient and uninterrupted operation of the plants should include

- Plant Operator, with the minimum training for the day-to-day operation of the plant
- Maintenance experts (small team of 1-2 persons at central level to operate on call for a number of DES plants)
- Specialized experts at Central level including, High Pressure Pumps Expert, IT expert for automations, Chemist and Material Science Expert.

It was also suggested in case of lack of competence of the local people a PPP scheme could be chosen to operate the desalination plant and eventually increase the capacity of locals.

4.7 Energy storage vs Water storage options

Desalination plants are almost invariably designed to operate at fixed or slowly (seasonally) changing operating points, drawing fixed energy input at fixed rates. This contrasts sharply with the nature of many RESs, such as solar and wind, which are marked by instantaneous, diurnal, and seasonal variation. This introduces the need for energy storage and buffering. Energy buffering refers to a small amount of energy storage intended to smooth and filter out instantaneous and short-lived variations in the energy source. Longer interruptions in energy, such as the absence of solar energy during the night, cannot be handled by buffering and require a larger scale of storage. The evaluation of available RESs, mentioned above, should establish a clear picture of the degree of variability of the proposed sources over various time scales. Long and frequent short-term intermittencies in the rate of energy supply from the RES increase the buffer storage requirements.

Since the storage of electricity is not practical based on current technology, while water storage during the RES occurrence can be more effective especially at rural or remote areas where the water supplies are rather small and thus the water storage requirements entail low investment costs. On the other hand since the storage of thermal energy, is more economical, this will tip the balance towards favouring a thermal energy type of RES and a thermal process combination.

Notably, geothermal energy supplies energy at virtually constant rate and operating conditions, which has the advantage of eliminating energy storage.

Taking into account the total cost of the desalination plant and the RES plant for operation only during RES availability it can be said that both will be double or more than the required daily capacity. The Plant capacity and the RES plant sizes can be reduced tremendously if a hybrid power supply is possible by utilizing RES during their intense occurrence (e.g. solar power during the day) and fuel (diesel) power or grid power (if available) as a substitute during their low occurrence. This solution must be fully analyzed to prove that it is more cost effective.

4.8 Brine disposal

4.8.1 Brine Disposal methods and comparison

In coastal areas, brine can be disposed by dispersing it in to the sea. Brine disposal is a critical and utmost important factor, particularly for inland brackish water desalination plant, that needs to be considered while deciding the location for the plant and the desalination technology. The desalination technology that enables very low recovery will result in comparatively large volume of brine to be disposed. RO scores over ED, MSF and MED processes when brine disposal is a problem. In inland desalination plants, brine can be disposed by any one of the following techniques:

- ☒ Zero Liquid discharge techniques by Thermal Method.
- ☒ VSEP Treatment.
- ☒ Brine injection.
- ☒ Evaporation pond.
- ☒ Using brine to produce agriculture and aquaculture products
- ☒ Evaporation pond using enhanced Evaporation Mechanisms.

a. Brine Concentrators (Disposal of Brine Water Using Zero Liquid discharge techniques by Thermal Method):

The generated brine from the desalination plant can be further concentrated using brine concentrators or evaporators to produce almost a zero discharge. Though this option would be ideal for brine disposal, this option has not been recommended due to very huge investment, associated high O&M cost and need for skilled staff.

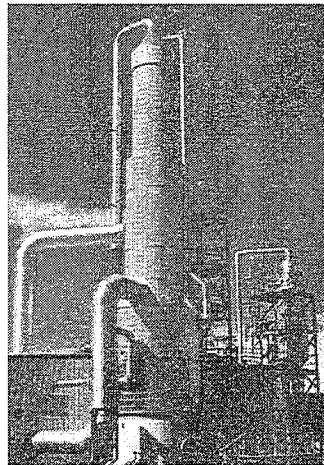
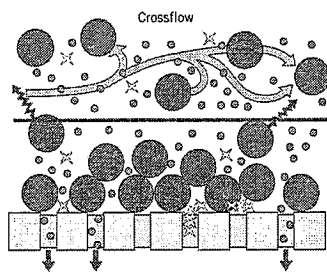


Figure 24: Ionics` brine concentrator & crystallizer at the AES Ironwood power plant

b. Brine Concentrators (Disposal of Brine Water by VSEP Treatment):

New Logic Research, Emeryville California has developed a new proprietary vibrating membrane filtration system that is not limited by solubility of sparingly soluble salts unlike conventional reverse osmosis membrane technology and is capable of extremely high recoveries of treated water from brine. The process is called Vibration Shear Enhanced Process (VSEP). VSEP employs torsional vibration of the membrane surface, which creates high shear energy at the surface of the membrane. The result is that colloidal fouling and polarization of the membrane

due to concentration of brine are greatly reduced. In addition through put rates of VSEP are 5 to 15 times higher in terms of GFD (gallons per square foot area of membrane surface) when compared other conventional RO membranes. The sinusoidal shear waves propagating from the membrane surface act to hold suspended particles above membrane surface allowing free transportation of liquid media through the membrane.



Fluid Dynamics Comparison between VSEP and Conventional Crossflow Filtration

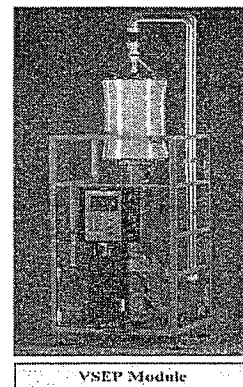
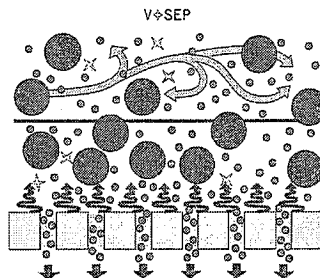


Figure 26: VSEP Module

Figure 25: VSEP Fluid Dynamics Comparison

New Logic has conducted pilot testing of several projects and supplied few commercial VSEP plants where the objective was to reduce the volume of reject from RO membrane system. The results have shown that it is possible to recover 99% from brine leaving behind 1% for disposal. However, for a 99% recovery a two-stage VSEP system will be required which is very expensive. VSEP system is not recommended for rural desalination plant brine disposal, as this calls for huge investment, associated O&M cost and skilled staff.

c. Brine injection:

Brine disposal by injection into wells is one of the possible methods of brine disposal at cheaper cost. However, brine disposal by injection into aquifer has been cautioned to be risky by the hydro geologist as the Injection of brine may destroy the aquifer in which is being pumped and may prevent its exploitation forever. Risk of contaminating the over lying aquifer in future will always be there since prevention of leakage cannot be guaranteed due to many reasons, one of which is the fractures that could be developed by tectonic activities. Decision on brine disposal by injection well needs to be taken after detailed hydro-geological investigation.

d. Disposal of Brine Water in Evaporation pond:

Solar evaporation is a well-established method for removing water from brine water. Evaporation ponds for brine wastewater disposal are used all over world especially in regions having a relatively warm, dry climate with high evaporation rates, level terrain, and low land costs. Solar evaporation ponds are being used in big desalination plants (Salbook & Bouyeb) of 60,000 m³/day capacity in the Riyadh region (KSA).

Hence, for rural desalination where access to dispose brine to sea is not there, evaporation ponds are more suitable due to following reasons:

- They are relatively easy and straightforward to construct.

- Properly constructed evaporation ponds are of low maintenance and require little operator attention compared to mechanical equipment.
- Except for pumps to convey the brine wastewater to the pond, no mechanical equipment is required.
- For smaller volume flows, evaporation ponds are frequently the least costly means of disposal, especially in areas with high evaporation rates and low land costs.

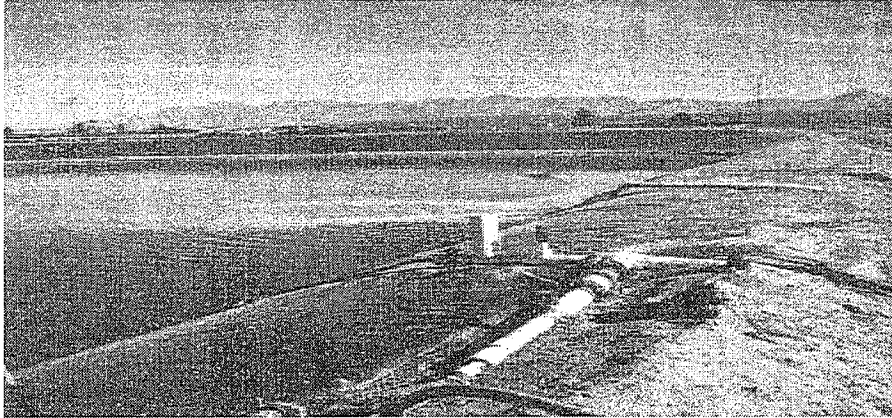


Figure 27: Evaporation pond with double synthetic liner and leak detection system in New Mexico.

Despite the inherent advantages of evaporation ponds, they are not without disadvantages that can limit their application, as described in the following list:

- They can require large tracts of land if they are located where the evaporation rate is low or the disposal rate is high.
- Requirement of impervious liners of clay or synthetic liners such as PVC or HDPE substantially increases the costs of evaporation ponds.
- Seepage from poorly constructed evaporation ponds can contaminate underlying potable water aquifers.
- There is little economy of scale for this land-intensive disposal option.

e. Using brine to produce agriculture and aquaculture products:

One of the alternatives for disposing brine is utilizing it for agriculture or aqua culture purposes. This technique involves addition of downstream facilities, which can be considered as a separate project of the main plant itself. This option, if implemented properly, will generate more job opportunities to the local people, business and profits opportunity to the potential investors and will serve as a good model for brine disposal of inland desalination plants.

The technique involves either some or all of the following:

- Construction of an algae farm
- Construction of a fish farm
- Plantation of halophytes such as blue panic

Ideally, the brine from the desalination plant should be first routed to an algae farm, where good quality algae can be produced and harvested on daily basis. The algae can be used as feed for fishes, animals or can be used to produce green urea. The overflow of water from the algae farm can then flow to a fish farm, where variety of fish such as Tilapia could be grown. Finally, the enriched brine from the fish farm could be used to irrigate salt tolerant plants (halophytes) such as blue panic. It is estimated that harvesting could be done frequently several time a year. These blue panic plants can be used as forage and has good proteins. Seepage from farms/ponds can contaminate underlying potable water aquifers.

However, a separate detailed feasibility study needs to be carried out on this.

f. Disposal of Brine Water in Evaporation pond using enhanced Evaporation Mechanisms:

Size of the evaporation pond is a function of the rate at which reject brine is evaporated from it. If it were possible to increase/enhance the natural evaporation rate, it would be possible to reduce the size of evaporation ponds. Such a reduction would result in substantial savings in the construction costs of ponds.

Methods to enhance natural evaporation from evaporation ponds include:

- ▣ spray evaporation
- ▣ creating turbulence in the pond;
- ▣ allowing brine to pass over inclined rough surfaces;
- ▣ creating an air flow over the pond

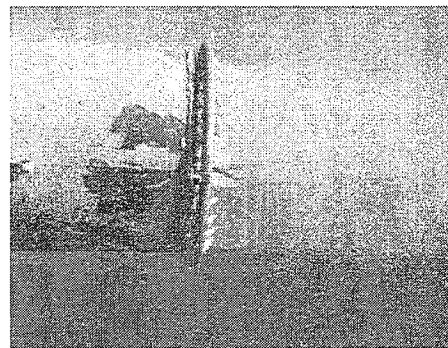
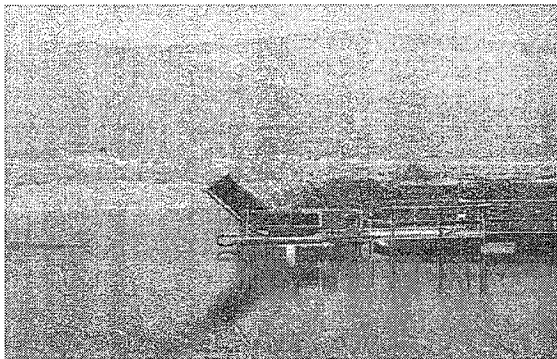


Figure 28 & Figure 29 Turbo-Mist evaporator in operation

Spray evaporation has been found to be effective in reducing the evaporation pond size to one sixth. However, this technique requires power for continuous operation of the turbo-mist evaporator and is suitable where the land is high. Also the carryover of spray due to wind may result in salt deposit in areas around the evaporation pond causing a potential environmental concern.

g. Comparison table for brine disposal in inland plants: The table below shows the available options for brine disposal.

Description	Capital cost	O&M cost	O&M Skill requirement	Environmental impact	Preference
Zero Liquid discharge (Thermal)	V.High	V.High	High	Moderate	Sixth
VSEP Treatment	High	High	High	V.Less	Fifth
Brine injection	Less	less	Nil	Less/Moderate	Second
Evaporation pond	Less	less	Nil	V.Less	First
Produce agriculture and	Moderate	Moderate	Moderate	High	Third

aquaculture products					
Evaporation pond using enhanced Evaporation Mechanisms	Moderate	Moderate	Less	Less	Fourth

4.8.2 General on Brine disposal

From experience, the most appropriate method for brine disposal from desalination plants operating in rural and remote inland areas is the use of evaporation ponds, due to the limited brine production (this was based on the assumption that in most rural and remote areas, desalination is produced from brackish water, which has a recovery of up to 90% of the volume of feed water. Therefore, only 10% of the feed water is lost as brine. The relatively ease in land availability in rural and remote areas and the low investment cost compared to the other disposal methods tends to make this option the most feasible one.

Brine injection although technically feasible and cost effective in areas with limited area for ponds it requires extensive hydro geological investigations and studies to prove that the brine will be confined and will not cause any damage to the freshwater aquifers. In view of the high level of hydro geological studies required and the high risk of polluting fresh water aquifers the brine injection should be considered after all other methods are ruled out and the risk of fresh water aquifers is very small or non existing.

Another brine disposal approach that could be considered for local community development is the reuse of brine in agricultural and aquaculture. A big disadvantage of this is the fact that the use of brine in agriculture would degrade the quality of the soil and it would need 3-4 times the volume of brine for washing the soil from salts.

In the coastal areas, the most cost efficient method of brine disposal is the discharge to the sea using carefully designed outfalls equipped with diffusers to help in the dispersion of brine in the near shore marine environment with minimum environmental impacts. In the design of the brine discharge systems the MED-POL program requirements must be taken into account, through an Environmental Impact Assessment Study. The MEDPOL programme (the marine pollution assessment and control component of MAP) is responsible for the follow up of work related to the implementation of the Land Base Sources Protocol, the Protocol for the protection of the Mediterranean Sea against Pollution from Land Based Sources and activities (1980, as amended in 1996) and of the dumping and hazardous waste protocols. MED-POL assists Mediterranean countries in the formulation and implementation of pollution monitoring programmes, including pollution control measures and the drafting of action plans aiming to eliminate pollution from land based sources.

According to the MED-POL representative, many countries refused to ratify the new Protocol. On the other hand, the international experts explained that the discharge of brine to the sea (from seawater desalination) affects only the near shore marine environment within a radius of approx. 100 m from the diffusers. Brine discharge of carefully situated and designed seawater desalination plants will have limited environmental impacts on the near-shore marine environment. According to the CDG, discharge of brine (particularly when mixed with cooling waters) through outfalls extended to the open sea where eddy currents disperse and dilute the brine to the open sea were found to be of very limited environmental impacts.

A solid recommendation culminated from the CDG discussions indicated that once it is decided to implement a desalination project, its environmental impacts should be assessed in accordance to the national EIA policies and guided by the internationally recognized criteria & methodologies (see section 3.9.2.1)

4.9. Other practical site characteristics

In addition to the above factors, a number of additional factors relating to the characteristics of the proposed site will also have a bearing on technology selection. Factors such as land topography and access, the availability and quality of roads and transportation considerations, and other infrastructure are all factors that need to be considered during the planning and screening stage to ensure adequacy for the proposed technologies. For more details on the criteria for selecting the site for the desalination plant are given in section 3.11.

4.10 Capital and operating costs of the total proposed solution (See also section 3.12)

After all other factors are duly considered and appropriately weighed-in, the ultimate deciding factor for selecting the best solution out of a number of equally acceptable technical solutions is the total cost. This ordering emphasizes that cost alone cannot be the deciding factor when considering the provision of a precious life-sustaining resource such as water to remote or disadvantaged local communities, and a number of important particularities of such cases need to be considered. After ensuring the relevant particularities are taken into consideration and have appropriately guided the selection process, it is then fair and reasonable to base the final selection among the remaining candidate technologies on the basis of total life cycle cost. Details on classification of costs and budgeting of costs are contained in section 3.12. Social and environmental cost to the community (ies) affected must also be accounted.

5. Modality for assessing community needs

5.1 Geographical considerations

The comprehensive geographic profile of a proposed site plays a central role in setting and modifying the requirements and local community needs for BAT in desalination. Such factors include the physical geography of the location which influences the type of soil and terrain, earthquakes and volcanic activity, surface topography, geothermal reservoir activity, and other geologic factors. These factors will have an immediate influence on site construction practices and civil engineering, including relevant construction codes and standards. In addition, the surface topography will have a significant influence on the quality of renewable energy resources available, or the ability to extract it efficiently.

Another critical aspect of the total geographic profile of a particular community is the local hydrology of the site. This includes the movement, distribution and quality of water at the location, and the portfolio of water resources available such as rivers and lakes (fresh water bodies) in addition to groundwater aquifers, sustainable extraction rates, drainage basins and flood plains, and other aspects of the total hydrological profile.

Establishment of the water balance of the region, with its three main components: precipitation, runoff, and evapo-transpiration, allows better management of water resources and a clear understanding of shortages, as well as the time-scales associated with various components of the water balance. Collectively, the various aspects of the hydrological profile of a location or region can be thought of as the inherent "supply-side" characteristics of water supply at the location. The "demand-side" characteristics are the subject of the next section. The mismatch in quantity, time, or location between the supply and demand gives shape and definition to the problem that the BAT desalination solution seeks to fully or partially alleviate.

Another aspect of the geographical profile of a community that must be taken into consideration is the possible historical and archaeological heritage of a site. Care must be taken to preserve such heritage from possible damage caused by digging and site construction and other civil works. Care must also be taken to protect heritage sites from the much more subtle aesthetical damage that can be caused by unsightly plant installations. To cite an example, some societies and individuals find the sight of wind turbines and wind farms to be objectionable. Thus the perceived visual impact of the technology on a site is important consideration, especially so for historical sites. Care shall also be taken to avoid the locations of wildlife habitat to protect them.

5.2 The human factor: demographic and socio-cultural considerations

It cannot be overstressed how important social, cultural, and demographic factors are to the success of a remote or rural desalination project. Basic statistics need to be gathered and analysed at the level of the community or village, as well as at a regional level. These include percentage of rural versus urban population in a region, the population density, average income per family, level of literacy and education and percentage grid connectivity. In addition, qualitative assessments of cultural perspectives and social aspects related to water usage and consumption need to be carried out. Social aspects often do not receive the attention they require and deserve in project planning. The ADIRA project [28] outlines a number of basic principles related to the social aspects of an autonomous desalination project. These are listed below with some slight adaptation:

1. The Socio-technical approach

This principle emphasizes the interdependency and interaction between three elements: people, technologies, and organizations. This interdependency must be fully understood and accounted for in order to improve the chances of success of a project.

2. Focus on people

The people affected by the project must be included in all stages, and their input must be taken into account. In addition, their values and cultural perspective need to be recognized and respected.

3. Learning

The target group, particularly in rural communities, need to learn in order to maximize their benefit from a new project. Opportunities for learning, raising awareness, and training need to be provided from the earliest stages of a project.

4. Independence and autonomy

The willingness of community members and target groups to participate and engage with a project depends largely on the level of independence and autonomy they are afforded. This means that community members need to be able to make their own decisions about proposed actions that will potentially affect their lives. Technological solutions, however clever and innovative they might be in the eyes of the designers or the decision-makers, must not be imposed on a community that finds them objectionable.

5. Flexibility and Process orientation

The general conditions and circumstances for water supply in rural areas can change relatively quickly, and are generally very site-specific. This dictates the adoption of a flexible process-oriented approach to projects that is able to easily react and adapt to changes. Inflexible approaches or fixed solution templates are inadequate for handling the large degree of variation between different projects, and even within a single project over time.

6. Sustainability

In this context, sustainability refers to the continuous support of the project by the authorities and other stakeholders after its completion, and the continuous service and operation of the installed systems. Even though sustainability, by this meaning, can only be verified over relatively long stretches of time, many of

the factors that influence sustainability can be identified from the earliest stages of a project. Sustainability criteria need to be compiled and documented during the planning stages to provide a reference and guide for later project activities, in the interest of improving the chances of achieving sustainability. Average income per family, poverty levels, affordability, willingness to pay for the water produced by the desalination plant and government subsidies, play a major role in sustainability.

7. Realism

Project plans, objectives and expectations must be realistic and feasible. Unrealistic or excessively demanding plans are bound to result in disappointment and/or failure. A good assessment and understanding of the real environmental context and particularities of a project is essential for insuring that project plans are feasible and firmly grounded in reality, rather than being driven solely by desires.

Cultural, religious and gender related issues

All too frequently, socio-cultural and religious causes are found to lie at the heart of failed community water projects[14]. Cultural and religious nuances vary widely between cultures and communities, and therefore a conscious and organized effort to understand such aspects needs to be made from outset. In this regards social science methods are the most appropriate means[28]. Often a new technology introduced into a community for the first time is perceived as an alien intrusion that is incompatible with long-standing traditions, social structures and responsibilities of the community[14].

In most societies and cultures, the responsibility for water management, sanitation and health at the household level lies with women[29]. While this role has allowed women to acquire much wisdom on matters of hygiene, sanitation and water management, often they are exposed to vulnerabilities associated with walking long distances to fetch water, such as harassment, and inability to attend school. To cite an example:

“In *Morocco*, the Rural Water Supply and Sanitation Project of the World Bank aimed to reduce the burden of girls “who were traditionally involved in fetching water”, in order to improve their school attendance. In the six provinces where the project is based, it was found that girls’ school attendance increased by 20 % in four years, attributed in part to the fact that girls spent less time fetching water. It was also found that convenient access to safe water reduced the time spent fetching water by women and young girls by 50 to 90 %.”[29]

Despite the important role women play in management and preservation of household water resources, in many societies, men take charge of decision-making and political issues and women are often left out. Women often end up having very little say in determining the kind of services and support they need to facilitate their roles.

“Gender considerations are at the heart of providing, managing and conserving our finite water resources and safeguarding health through proper sanitation and hygiene. The importance of involving both women and men in the management of water and sanitation has been recognized at the global level, at least since the 1977 United Nations Water Conference at Mardel Plata and during the International Drinking Water Supply and Sanitation Decade, 1981-1990. The Dublin principles, endorsed at the International Conference on Water and the Environment in 1992, recognized that “Women play a central part in the provision, management and safeguarding of water.” The statement called for recognition of the contributions of women as providers and users of water and guardians of the living environment in institutional arrangements for the development and management of water resources.” [29]

Capacity building

Successful project planning, implementation and sustainability require comprehensive and carefully planned capacity building. Ideally, this should target all the various stakeholders in a project, including consumers, technicians, decision makers, designers, contractors and suppliers. The most important of these groups are consumers and technicians at the village or site level, and the decision makers. Training programs need to be designed and delivered to develop the necessary human resources in the PCs in the following areas:

- Water supply management, technology evaluation, and flexible project planning. This aspect mainly targets planners and decision-makers in the PCs.
- Design of BAT desalination systems using RES in rural and remote areas. This can be introduced into the national engineering curricula of the PCs or offered as intensive training programs to practicing engineers.
- Installation and commissioning of relevant technologies. This should target local engineering and contracting companies and can be done in partnership with the technology manufacturers and system integrators.
- Operation and maintenance: In addition to engineering and contracting companies, this element should focus on training the local workforce available at the village or remote location in order to achieve the skill level required for the continued sustainability of the project. This can be viewed as being complimentary to the rational selection of the technologies that are suitable for the available operators. One aspect does not eliminate the need for the other. Technology selection must reasonably match the available skill level, while training must still be provided to ensure that the skill level is adequate for the technologies adopted.

5.3 Water resource availability

As mentioned previously, an extensive survey of the water resources in the vicinity of the proposed site needs to be carried out. The total quantity and quality water needs to be determined, in addition to analyses of well and/or seawater. Detailed water chemical analyses of raw water sample are required for the design of desalination systems to avoid scaling and/or fouling. In case of using well water as raw water source for desalination, detailed hydrological study/tests shall be conducted to ensure the draw down in the well, sustainability of the well for the current capacity plant throughout the period of operation of desalination plant. Aquifer recharging also needs to be considered, if study reveals that it is essential for the capacity of the plant considered. Another important aspect is the degree of proximity of the water sources to proposed site, which can have an impact on the water cost.

5.4 Pricing structures and financing schemes

A successful desalination project in rural or remote area should at least manage to recover its running costs and its depreciation [28]. This necessitates that the water pricing reflects the real costs of water supply. On the other hand, access to safe drinking water is a basic right for all humans, and consequently the basic human requirements for water should be available and affordable for all. Subsidies are usually needed to ensure water supply in rural communities. However, subsidies applied to conventional water resources distort the market and make alternative resources such as desalination and RES less attractive. Therefore subsidies need to be applied in a consistent way that allows the market to select the most efficient water supply method [14].

The main difficulties facing the implementation of desalination by RES in rural communities are:

1. The low income of the rural population.
2. Limited financial resources within rural communities.

3. High investment costs required for such projects.

In response to these difficulties, a number of support mechanisms that do not distort the market function are possible, such as [28][14]:

- ☒ Direct financing of the infrastructure.
- ☒ Providing financial incentives for the operators.
- ☒ Encouraging private sector involvement.
- ☒ Adopting the “life-line rate”, where a variable pricing structure is applied based on the volume of water used. The first tier of consumption, representing essential human needs, would be affordable to all, while the following tiers of consumption are priced at increasingly higher rates.

The life-line rate scheme has a number of advantages: 1) the minimum water requirement is affordable to all; 2) the average price of the consumption tiers can be set to reflect the actual cost; and 3) there is an incentive for users to conserve water.

The main financing models possible, in the order of increasing capital investment by the system provider and decreasing investment by the end-users, are listed below:

- ☒ Cash sales: Users buy and own the complete system upfront. The end-user thus owns the system from the outset and is responsible for operation and maintenance.
- ☒ Consumer credits: Users buy the system from the manufacturer or system provider in instalments, where the credit is granted by the system provider.
- ☒ Credit institutions: Users buy the system in instalments, where credit is provided by a third party credit institution.
- ☒ Lease: The User does not buy the system, but rather leases it from the company or financial intermediary, with the option of buying it after the end of the lease period. In this case, the ownership of the system is retained by the system provider or the financial intermediary, and is usually responsible for maintenance and repair.
- ☒ Fee for service: A company or public water supplier owns the system and sells the product (water) to the end users. The company is responsible for operation, maintenance and repairs.

5.5 Institutional and regulatory factors

The distribution of responsibilities in the water sector can generally be divided into three levels [28], [30]:

1. Decision making level

This typically includes ministries and other high-level government entities that are involved in setting water policy and planning. The main responsibility usually lies within one ministry that has the overall control over the water sector. However, there are typically other ministries that are also involved in water policy to various degrees, such as Environment, Agriculture, Development, Finance and other ministries.

2. Executive level

This is usually the role of government organizations that operate under the top-level decision making bodies.

3. User level

This can be either government or non-governmental organizations (NGOs) that undertake the actual operation and maintenance of water supply facilities. The user level is usually different for urban and rural areas. While cities have many favourable features such as large demand and high geographic concentration that allow economies of

scale, rural areas present various economic and technical challenges. This often means that subsidies are required to enable the provision of essential water resources to rural communities.

While there are no specific regulations directly targeted at desalination projects, a host of licenses are likely to be required for desalination projects in rural and remote areas. The specific licenses required are specific to each country, but generally the following items can be expected[28]:

- Borehole drilling and seawater withdrawal.
- Brine disposal (often in the form of liquid waste disposal regulations).
- Coastal zone construction.
- Drinking water quality.
- Renewable energy installations or electric power supply approval.

5.6 Additional Guidelines to Screen and assessment of Desalination BAT using RES

This section contains in brief some additional guidelines in screening and assessing the Best Available Technology using RES. This section contains the recommendations of the international and national experts as agreed during the Athens meeting 11 & 12 of June 12. The guidelines are given as steps 1 to 4 as follow.

Step 1: Evaluation of available water resources & demand characteristics: The international and national experts agreed to the need for a comprehensive evaluation of the available water resources, as well as an evaluation of the water demand characteristics at the proposed site to be the first step, with a purpose to ensure that all options are exhausted prior to deciding on desalination.

In order to evaluate and establish the needs of a rural or remote community for desalination projects, the real need for the community has to be examined within an overall assessment of water resources available to the community. Introduction of desalination, if decided, into a community should be within an IWRM context and should be considered by central and local authorities as a first milestone towards the overall sustainable development of the community. Accordingly, a detailed opportunity cost analysis should be elaborated before deciding on desalination. Factors to be taken into consideration in the opportunity cost analysis should include but not limited to alternative water resources, reuse of wastewater, production cost of desalination at the point of use, environmental externalities, savings from reduction of non revenue water (minimisation of leakages and illegal withdrawals), reallocation of water from irrigation with its socio-economic impacts, re-evaluation of crop development in agriculture policies etc.

A capacity development workshops need to be planned to train water officials on the principles of opportunity cost analysis for desalination shall be considered within the capacity building WP of SWIM program. It will be implemented "parallel but separate" to the tasks of SWIM-SM.

The recommended activities need to be implemented in synergy with other EU or Mediterranean projects such as NED-POL and H2020; donors and stakeholders to avoid duplication and to pool resources.

Step 2: Evaluation of available RES & grid connectivity: According to the experts, the next major step in the process is to carry out an extensive study of the available energy resources, with a particular focus on renewable energy sources, in case electric power grid or supply is not available. A thorough understanding of the available

RESs, their qualitative & quantitative characteristics are required. At this point, it was suggested that a Risk Analysis of the RES availability should be considered when evaluating desalination projects.

In addition to that, a capacity development programme is considered necessary to orient water policy makers in SWIM countries of the new developments and state-of-the-art aspects (technical, advantages, economics, limitations, etc.) of RES compatible with small-scale desalination.

Step 3: Short listing of candidate desalination processes based on available RES: The previous steps of identifying, characterizing and selecting the RES should allow the elimination of all desalination processes that are not suited to the type of energy source chosen within the socio-economic, environmental and cultural specificities of the community in need for desalination.

Step 4: Environmental Impact Assessment of DES-BAT & RES projects: Once the implementation of a desalination plant is decided based on exhaustive elimination of alternatives using opportunity cost analysis tools, an EIA has to be undertaken to identify, avoid and/or mitigate any potential environmental impacts according to national EIA policies. The cumulative environmental impacts (primarily from the discharge of brine to the sea or its reuse in agriculture) resulting from the operation of the desalination plant will be given adequate weight in the EIA studies.

Based on the CDG discussions with the national consultants, they agreed to the following:

1. SWIM-SM should consider the development of a comprehensive tool-box (guidelines) to support policy makers decide on desalination after exhausting all other options. The tool box should follow a logic sequence, simple and friendly to use. The tool-box shall include the economic and environmental instruments needed to decide on desalination while avoiding its environmental impacts.
2. SWIM to ensure the incorporation of EIA as a fundamental step in the structure and context of the proposed DES-BAT & RES guidelines.
3. A succinct plan for the development of the proposed guidelines (tool-box) need to be developed & discussed with the CDG, electronically shared with PCs, developed, electronically shared & then discussed in an enlarged regional consultative meeting with the involvement of national water & environment experts from PCs in collaboration with UNEP-MAP.

6. Recommendation of integration into National IWRM plans

Water was recognized since the antiquities as the "blood of the Earth", as the prerequisite for life in our planet and as one of the most vulnerable and scarce natural resources. Growing water-stress in south Mediterranean countries poses threat to the economic development and human live hoods, mainly among the poor and most vulnerable populations living in arid rural areas. Agriculture uses 70 to 85% [35] of the renewable water resources. Irrigation systems are often scattered across vast rural areas, with poor efficiency and lack of managerial control. UN Secretary General pointed out in the Millennium Conference (2000): "We need a Blue Revolution in agriculture that focuses on increasing productivity per unit of water – more crops per drop. Urbanisation, pollution, over-exploitation of natural resources pressures Mediterranean aquatic ecosystem biodiversity. The region has lost more than 50% of its wetlands.

The need for careful and wise management of water resources was recognized in Stockholm, in 1972. Increasing demands in water, deterioration of water quality and quantity and mismanagement of natural resources make water an even vulnerable and finite resource. The latter is more evident in the Mediterranean region where the sectoral approaches in water management are still prevailing in many countries [35] and cannot meet the contemporary needs for a sustainable resources management.

Over the past few decades there has been an increasing and recurring realization on one hand of the vital role that water plays for sustainable development, and on the other hand of the interdependence and competing demands of the various water use sectors on this finite resource. This has led to a new paradigm in the management and planning of water resources that is collectively called Integrated Water Resources Management (IWRM). The Global Water Partnership (GWP) defines IWRM as 'a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems'.

Water cycle is the "integrated water resources model" of nature. A sustainable management practice of water resources must not only take into account but also respect the fragile balance between the components of the water cycle. Rainwater, terrestrial water (lakes, rivers, etc.), coastal and marine water, wetlands: all must be managed in a holistic manner that is based on their particularities and implications, using all the available tools and methods. A modified water cycle recommended is illustrated below.

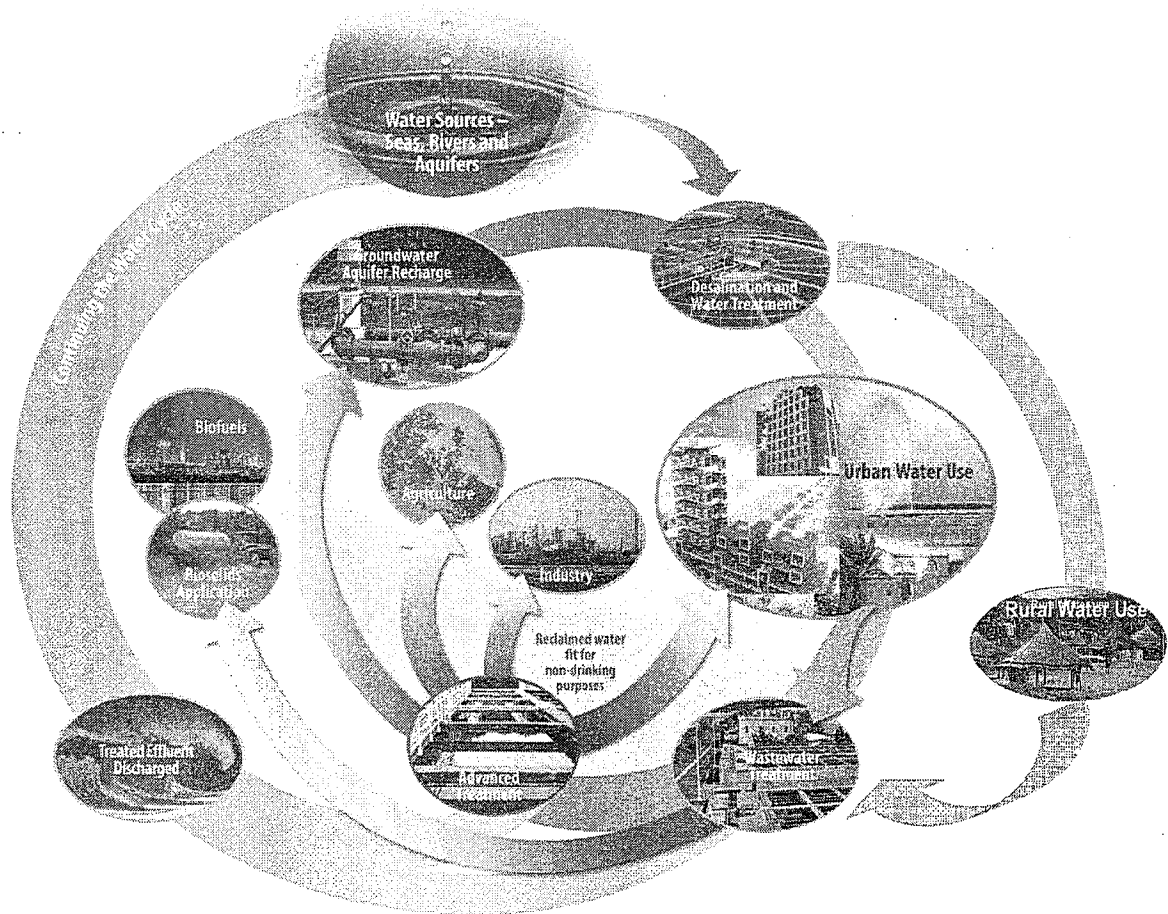


Figure 30: Recommended water cycle

The application of IWRM requires:

1. An enabling environment of appropriate policies and laws, where the governing authority acts as an enabler rather than a top-down manager.
2. Institutional roles and frame work, represented by all organizations and agencies across water-use sectors. It is essential of these institutional roles to discuss, plan, and act in coordination, realizing the participatory nature of the IWRM paradigm.
3. A set of management instruments, which are the practical tools through which the IWRM plans can be implemented. These include water resource assessments, development of River Basin Organisations (RBOs), incorporation of the stakeholders in decision-making, communication and information dissemination, ensuring financial sustainability, resource allocation and conflict resolution, regulatory instruments, and technology.

With this brief background in mind, while planning desalination projects for rural areas the following are to be considered.

- ☒ Desalination being a fairly costly source of fresh water, it is clear that consideration of desalination as an alternative source of water supply from the outset should be part of a comprehensive National IWRM plan. Desalination should only be considered after ensuring that good water management practices are followed on a national level, and properly managed conventional water resources are found to be insufficient. Contemplating construction of desalination plant to supply drinking water to a remote community that is exhausting its fresh groundwater resources on irrigation with low economic return shall be seriously reviewed with respect reallocation. Having said that, it is not uncommon in the case of arid rural and remote areas for the cost of water supply and transportation from conventional resources to be more expensive than desalination [14].
- ☒ Rational selection of desalination technology, whose operation during its life time is sustainable.
- ☒ While computing the life cycle fresh water production cost from desalination plants, other than desalination plant installation, operation and maintenance costs, the cost associated with raw water supply, pre-treatment, post treatment, brine disposal meeting Environmental Mitigation Plan (EMP) shall be taken in to account.
- ☒ Evaluation of the feasibility for rural and remote area desalination shall constitute a part of an integral approach that considers the specifics of each region and location in order to recommend the optimal approach or combination of approaches for each case. Thus, the opportunity cost of any proposed solution must be well understood and considered before a decision is made one way or the other. Moreover, the high cost involved in producing desalinated water, should encourage society and decision-makers to view the resulting wastewater as a valuable resource that should be recovered and re-used wherever possible.
- ☒ Water transportation is another area that should be carefully considered along with desalination, particularly if points of use are at higher altitude compared to points of production. Authorities need to consider the pumping cost.
- ☒ Thorough and rigorous EIAs are likely to prescribe several measures for mitigation of environmental impacts of desalination, such as a longer intake pipeline route with very low inlet velocity at the intake head and longer brine discharge pipeline route along with dilution and dispersion of brine in sea, chosen to avoid damage to a sensitive marine eco-system, to cite few examples. Potential environmental impacts are present in every phase of a desalination project [31]. Notably, the practice of IWRM offers the right opportunity and context for national and regional scale EIAs associated with increased desalination
- ☒ Considering the rapid pace of technology development, decision makers should also frequently perform updated evaluations and appraisals of the technologies that aim to extract value from desalination brine

streams. These include the extraction of valuable minerals, salt and the generation of power through electrochemical means or through available osmotic pressure differential.

- # Though not specific only to desalinated water supply, priority to be given to arrest network leakages to conserve the water loss and make true assessment of available resources.

An ideal IWRM water policy should exhaust all opportunities to rearrange the bundles of water endowments among different users to attain “win-win” outcomes. For instance, a policy of re-cycling wastewater for irrigation could potentially leave both farmers and households better off and allow adequate water for the local wetlands and thus, be a "win-win" policy. Integrated water management can also open up possibilities for positive synergies between desalination and wastewater treatment. A good example of this is the Japanese *Water Plaza* project[32], which combines tertiary treated wastewater streams with SWRO feed to reduce the RO feed salinity, thereby reducing the energy required, as well as taking advantage of the availability of treated wastewater to reduce the size of the required SWRO pre-treatment system. A 30% improvement in energy efficiency is reported to have been achieved by this approach.

Finally, it should be highlighted that although the concept and principles of integrated water management are common, the strategies and tools may vary widely, even within the South Mediterranean region, according to the diverse socio-cultural, economic and environmental conditions of the involved countries.

References

- [1] ADIRA, "ADIRA Handbook - A guide to autonomous desalination system concepts," 2008.
- [2] S. Kalogirou, "Seawater desalination using renewable energy sources," *Progress in Energy and Combustion Science*, vol. 31, no. 3, pp. 242-281, 2005.
- [3] B.-H. Jeong et al., "Interfacial polymerization of thin film nanocomposites: A new concept for reverse osmosis membranes," *Journal of Membrane Science*, vol. 294, no. 1-2, pp. 1-7, May 2007.
- [4] C. Kurth, R. L. Burk, and J. Green, "Improving Seawater Desalination With Nanocomposite Membranes," *IDA Journal on Desalination and Water Reuse*, no. Third Quarter, pp. 26-31, 2010.
- [5] LLNL, "Nanotube Membranes Offer Possibility of Cheaper Desalination," 2006. [Online]. Available: <https://www.llnl.gov/news/newsreleases/2006/NR-06-05-06.html>.
- [6] A. Al-Karaghoul, "Renewable Energy Opportunities in Water Desalination," in *Desalination, Trends and Technologies*, M. Schorr, Ed. InTech, 2011.
- [7] C. Alh eriti rea, W. R. Ernst, and T. A. Davis, "Metathesis of magnesium and sodium salt systems by electrodialysis," *Desalination*, vol. 7, pp. 189-198, 1998.
- [8] T. A. Davis and S. C. Rayman, "Pilot Testing of Zero-Discharge Seawater Desalination – Application to Selenium Removal from Irrigation Drainage," 2008.
- [9] M. Elbourawi, Z. Ding, R. Ma, M. Khayet, and M. S. El-Bourawi, "A framework for better understanding membrane distillation separation process," *Journal of Membrane Science*, vol. 285, no. 1-2, pp. 4-29, Nov. 2006.
- [10] W. Heinzl, S. B uttner, and G. Lange, "Industrialized modules for MED Desalination with polymer surfaces," in *International Workshop on Membrane Distillation and Related Technologies*, 2011, pp. 110-115.
- [11] GWI, "Memsys secures a second pilot study," *Global Water Intelligence*, 2011. [Online]. Available: <http://www.globalwaterintel.com/archive/12/1/general/memsys-secures-second-pilot-study.html>. [Accessed: 31-Mar-2012].
- [12] J. L. McCutcheon, R. L. McGinnis, and M. Elimelech, "The Ammonia-Carbon Dioxide Forward Osmosis Desalination Process," *Water Conditioning & Purification*, 2006.
- [13] R. L. McGinnis and M. Elimelech, "Energy requirements of ammonia-carbon dioxide forward osmosis desalination," *Desalination*, vol. 207, no. 1-3, pp. 370-382, Mar. 2007.
- [14] ProDes, "Roadmap for the development of desalination powered by renewable energy," 2010.
- [15] "MAGE Watermanagement: MAGE Solar Desalination." [Online]. Available: <http://www.mage-watermanagement.com/>. [Accessed: 22-Mar-2012].
- [16] M. Goosen, H. Mahmoudi, and N. Ghaffour, "Water Desalination Using Geothermal Energy," *Energies*, vol. 3, no. 8, pp. 1423-1442, Aug. 2010.
- [17] Mediras, "Multi-module two loop system in Italy: Mediras - Membrane Distillation in Remote Areas." [Online]. Available: <http://www.mediras.eu/index.php?id=121>. [Accessed: 22-Mar-2012].

- [18] K. Bourouni and M. Chaibi, "Water desalination by humidification and dehumidification of air: state of the art," *Desalination*, vol. 137, pp. 167-176, 2001.
- [19] H. Mahmoudi, N. Spahis, M. F. Goosen, N. Ghaffour, N. Drouiche, and A. Ouagued, "Application of geothermal energy for heating and fresh water production in a brackish water greenhouse desalination unit: A case study from Algeria," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 1, pp. 512-517, Jan. 2010.
- [20] M. Goosen, H. Mahmoudi, N. Ghaffour, and S. S. Sablani, "Application of Renewable Energies for Water Desalination," in *Desalination, Trends and Technologies*, M. Schor, Ed. InTech, 2010, pp. 89-118.
- [21] A. Ghermandi and R. Messalem, "Solar-driven desalination with reverse osmosis: the state of the art," *Desalination and Water Treatment*, vol. 7, no. November 2008, pp. 285-296, Jul. 2009.
- [22] V. Subiela and J. Carta, "The SDAWES project: lessons learnt from an innovative project," *Desalination*, vol. 168, pp. 39-47, 2004.
- [23] EGEC, "Geothermal Desalination," 2007.
- [24] G. R. Constantine Karytsasas, Dimitrios Mendrinou, "The Current Geothermal Exploration And Development Of The Geothermal Field Of Milos Island In Greece," *GHC Bulletin*, no. June, 2004.
- [25] H. Gutiérrez and S. Espíndola, "Using Low Enthalpy Geothermal Resources to Desalinate Sea Water and Electricity Production on Desert Areas in Mexico," *GHC Bulletin*, pp. 19-24, 2010.
- [26] K. Bourouni, R. Martin, L. Tadrist, and M. T. Chaibi, "Heat transfer and evaporation in geothermal desalination units," *Applied Energy*, vol. 64, no. 1-4, pp. 129-147, Sep. 1999.
- [27] J. Andrienne and F. Alardin, "Desalination site selection on North-African coasts," *Desalination*, vol. 165, pp. 231-239, Aug. 2004.
- [28] ADIRA, *ADIRA HANDBOOK: A guide to autonomous desalination concepts*. 2008.
- [29] IANGWE, "A Gender Perspective on Water Resources and Sanitation," no. 2. New York, 2005.
- [30] M. Papapetrou et al., "Market analysis for Autonomous Desalination Systems powered by renewable energy in southern Mediterranean countries. Case study on Turkey," *Desalination*, vol. 183, no. 1-3, pp. 29-40, Nov. 2005.
- [31] UNEP, *Desalination Resource and Guidance Manual for Environmental Impact Assessments*. 2008.
- [32] GWSTA, "Water Plaza." [Online]. Available: <http://waterplaza.jp/en/>. [Accessed: 29-Mar-2012].
- [33] Desalination Markets 2010 Global forecast and analysis by Global Water Intelligence.
- [34] Sparrow, B. and Zoshi, J. "A Breakthrough Low Electricity Thermo-ionic Desalination Process: Background, Piloting and Economics", 2009 IDA World Congress, Dubai.
- [35] Scoullou M., Malotidi V., Spirou S. and Constantianos V., "Integrated Water Resources Management in the Mediterranean", GWP-Med & MIO-ECSDE, Athens, 2002
- [36] Nicos X. TSIOURTIS, "Framework for Action of the Mediterranean Islands." The Hague WATER FORUM March 1999.
- [37] Nicos X. TSIOURTIS, "Desalination and the Environment " Key Note Speech Contribution to the European Desalination Conference, Limassol May 2001. *Desalination* 141 (2001) 223-236.

- [38] Nicos X. TSIOURTIS, "Criteria and Procedure for selecting site for a desalination Plant" Desalination 221 (2008) 114 124
- [39] Nicos X. TSIOURTIS, "Bankability of Desalination Projects" Desalination –Visions for the Future Israel Desalination Society Neaman Institute, Technion City, Technion IIT, Haifa ISRAEL 12th Annual Conference.
- [40] Nicos X. TSIOURTIS, "Small Islands water resources development –a holistic approach" A paper presented to the Symposium in Paros island on "Aegean Sea-Water Sustainable Development " 6-7 July 2001.
- [41] Nicos X. TSIOURTIS. "The role of non conventional and lower quality water for the satisfaction for the satisfaction of the domestic needs in drought management plans" 2007.



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ECONOMIC CONSIDERATIONS FOR SUPPLYING WATER THROUGH DESALINATION IN SOUTH MEDITERRANEAN COUNTRIES

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Acronyms and Abbreviations

AFED	Arab Forum for Environment and Development
BAU	Business as Usual
BOOT	Build own operate transfer
BWRO	Brackish water Reverse Osmosis
CASES	Cost Assessment for Sustainable Energy System
DBOO	Design Build Own Operate
ED	Electro dialysis
EPA	Environmental Protection Agency
EPA	Environmental Protection Act
FAO	Food and Agriculture Organisation
GCC	Gulf Cooperation Countries
GDP	Gross Domestic Product
IDA	International Desalination Association
IPCC	International panel on Climate Change
kW/h	Kilowatt per hour
MDG	Millennium Development Goals
MED	Multiple effect distillation
MENA	Middle East and North Africa
MSF	Multi-stage flash distillation
m ³	Cubic meter
NEI	Nuclear Energy Institute
NPV	Net present Value
OECD	Organisation for Economic Co-operation and Development
PES	Payment for Ecosystem Services
PPP	Polluter Pays Principle
PPP	Public Private Partnerships
R&D	Research and Development
RO	Reverse Osmosis
SMCs	South Mediterranean Countries
SWRO	Seawater Reverse Osmosis
TEEB	The Economics of Ecosystem and Biodiversity
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UPC	Unit product cost
UPP	User pays principle
VC	Vapour compression
WHO	World Health Organisation
WTA	Willingness to Accept
WTP	Willingness to pay

Contents

Acronyms and Abbreviations	1
Contents	2
Preface	4
Executive Summary	5
I. Introduction	8
II: Identification and analysis of socio-economic and environmental costs of supplying water through desalination	9
Capital and operating costs	10
Environmental Impacts of desalination plants	12
Country experiences	14
III. Identification and analysis of socio-economic and environmental costs of alternatives under technical efficiency and allocative efficiency	16
Cost of alternative water systems	16
Assessing cost of alternative water systems	16
Cost of supplying freshwater	18
Water Reuse	20
Cost of reused Water	21
Technical and allocative Efficiency	22
Policy reforms and Governance	22
Improving compliance and enforcement with water legislation	23
Use of economic instruments, application of full service cost recovery and through allocative efficiency	23
Investing in innovation and technology development	23
Education and public awareness	23
Service cost recovery	24
Water conservation measures for households	24
Water conservation measures for irrigation	25
Investing in ecosystem services	25
Investing in freshwater supply and sanitation	25
Accessing new (non-traditional) sources of water	26
Producing more food and energy with less water	26

Water and Energy.....	26
Reduction in virtual water exports (rice, cotton, sugar cane, etc.).....	26
IV. Examination of opportunity cost analysis of desalination versus technical efficiency and allocative efficiency	27
Cost of providing water by desalination.....	27
Costs and Benefits of Water Supply through Technical and Allocative Efficiency	29
V. Guidelines on performing opportunity cost analysis for desalination	33
Cost and benefits of supplying water through desalination	33
Cost and benefits of good governance and regulatory framework	35
Cost of administering, monitoring, and ensuring compliance to regulations.....	35
Use of economic instruments, application of full service cost recovery and through allocative efficiency	36
Cost for the construction and operation of a wastewater treatment plant	36
Benefits resulting from increased competitiveness and trade	36
Benefits resulting from improved access to education and productive activities	36
Increased land and property values as a result of a better environment.....	36
Benefits resulting from improved health	37
Social benefits in the form of additional number of jobs created	37
Reduced cost of supplying freshwater	37
Benefits of water conservation measures in the agriculture sector	37
Benefits resulting from saving in the use of virtual water	37
Financial flows generate income for the government and can therefore provide a good source for funding water and sanitation projects.....	38
Benefits of water conservation in the household sector	38
Benefits in the reduction of energy use	38
Benefits resulting from investing in ecosystems.....	38
Access the costs and benefits of new (non-traditional) sources of water	38
Estimate the costs and benefits of investing in water infrastructure	38
Economic values of the environment.....	39
VI. Recommendations	45
References.....	46

Preface

This study is prepared to assist the South Mediterranean Countries (SMCs) - Jordan, Syria, Lebanon, Israel, the Occupied Palestinian Territory, Egypt, Tunisia Algeria, and Morocco - examine the costs and benefits of supplying water through desalination as opposed to technical and allocative efficiency. It provides an analysis for the opportunity cost of supplying desalinated water. In doing so it considers the different measures that can be taken to achieve technical and allocative efficiency before resorting to the more expensive option of supplying water through desalination and provides an analysis of the costs and benefits associated with this option. It also provides a set of guidelines and recommendations for performing opportunity cost analysis for supplying water through desalination.

The main target audience for the study is policy and decision makers and practitioners in the SMCs. It aims at providing a guidance tool for policy and decision makers in to enable them take an informed decision with respect to investment in the water sector.

Executive Summary

Water Security is one of the main priorities in South Mediterranean Countries (SMCs) with water consumption per capita being 1000m^3 well below the world average of 6000m^3 and still declining. Water scarcity in SMCs is further exacerbated by population growth, the inefficient use of water in both rural and urban areas, and by climate change. It is therefore essential for countries in this sub region to consider the different options available for addressing current water shortages and future water needs.

Desalination of seawater represents a potential solution for addressing water scarcity and future water needs in SMC's. Since seawater desalination is an expensive alternative for supplying water, it is essential to carefully examine the opportunity cost of desalination versus technical and allocative efficiency.

The main objective of this study is to undertake a socio-economic and environmental cost analysis of supplying water through desalination, and of alternative solutions under technical and allocative efficiency. Based on this analysis, the study examines the opportunity cost of desalination versus technical and allocative efficiency, and provides guidelines for performing opportunity cost analysis for supplying water through desalination. It also concludes by highlighting a set of suggested recommendations to be taken into account in performing such an analysis.

For the purpose of this study it is assumed that the new hypothetical community for which $20,000\text{m}^3/\text{day}$ water is to be supplied is located close to a larger community of a population of say 500,000 inhabitants. In order to supply the new community with $20,000\text{m}^3$ of freshwater, the study proposes the construction of a decentralized wastewater treatment plant to supply water for irrigation thus releasing freshwater originally supplied for agricultural purposes to supply households for the new community with freshwater.

In estimating the stream of costs and benefits for supplying water through desalination a period of 20 years is used applying a social discount rate of 3.5%.

Desalination of seawater and brackish water offers one solution to meet water shortages. Cost of supplying desalinated water is higher than through conventional means, thus representing an increased financial burden on governments and users. Moreover, since in most of the SMCs, water supply is subsidized, with increased cost of desalinated water, subsidies provided by government will considerably increase. While cost of supplying freshwater is about US\$ $0.2/\text{m}^3$, it ranges between US\$ $0.5/\text{m}^3$ and US\$ $0.8/\text{m}^3$ for desalinated water.

In order to calculate the costs of desalination initial capital cost and operating costs are calculated for seawater reverse osmosis (SWRO) and brackish water reverse osmosis (BWRO) and are estimated at US\$ 5.1 million and US\$ 1.8 million, respectively. Capital cost for building the plant is estimated at US\$ 30 million for seawater desalination and US\$ 12 million for brackish water desalination plant based on a study by Wittholz providing the costing of desalination water plants worldwide.

Since a large share of the operating cost is attributed to energy, direct costs as well as environmental costs resulting from CO_2 emissions are calculated to derive at the total cost of supplying water through desalination. Other environmental implications aside from the source of energy used, is from the discharge of brine in the sea.

One major factor contributing to the cost of supplying water through desalination is energy. Different costs are calculated for the different sources of energy based on direct costs and environmental damage from the different sources of energy. Not only does this represent a direct fiscal cost, but also an indirect environmental cost represented in increased CO_2 emissions. Apart from the negative impacts of CO_2 emissions on health, it contributes to climate change with its negative impacts on sea level rise, coastal and marine life, impacts on wetlands, mangroves, forests and biodiversity, and desertification. SWRO plants discharge brine into the sea. The high salinity of the brine in calm water

with low current has proven to be detrimental to marine biodiversity. Environmental damages resulting from supplying water through desalination are considered in the analysis.

Total cost (NPV using a discount rate of 3.5% over a 20 years period) of supplying 20,000m³/day of desalinated water for the hypothetical community is estimated at US\$ 203.5 million using fuel as the main source of energy and US\$ 91 million using coal for SWRO. For BWRO the figures are US\$ 167 million and US\$ 55 million for fuel and coal respectively. These estimates are calculated on the basis of US prices for energy.

Given the high cost and potential environmental degradation of supplying water through desalination, it is essential to fully exhaust the potential of supplying water through technical and allocative efficiency before resorting to desalination.

Socio-economic costs and benefits of technical and allocative efficiency include a range of measures and policies. Costs and benefits for each policy measure are calculated based on estimates of costs involved and potential benefits using the benefit transfer approach. Measures for achieving technical and allocative efficiency include policies related to good governance, regulatory reforms, and market-based incentives. Physical measures include investing in wastewater treatment, investing in ecosystem conservation, water capture and storage, water conservation programmes, and water saving irrigation techniques.

It is estimated that cost of the plant will range between US\$ 4 million – US\$ 6 million. Operating cost is estimated to be between US\$ 0.10 - US\$ 0.19 m³ depending on the type of technology used. US\$ 0.2 is used in the calculations in order to take into account expected increased cost of labour and energy.

Cost of water conservation programmes including installing equipment and systems in buildings (US\$ 475 million), as well as irrigation efficient and saving equipment (US\$ 311 million) are estimated and captured in the cost. Savings resulting from water conservations in buildings and in agriculture are estimated to result in water savings of between 10%-20% and between 40%-80% respectively. These are estimated to result in annual gains of about US\$ 17 million and US\$ 66 million respectively. These savings in water are captured as benefits resulting from technical and allocated efficiency.

It is estimated that generally about 15% of total energy consumption is allocated to the water sector. Efficiency in the use of water should result in energy savings. Between 5%-10% per m³ of water produced goes to energy. A saving of 5% in energy consumption could result in savings of US\$ 5.5 million annually.

Other benefits include increased productivity and yields in the agriculture sector of between 20%-30% estimated at US\$ 80 million annually. Investment in infrastructure to capture water and recharge natural aquifers, and maintenance of pipelines are estimated and included in the analysis. For the purpose of this study an estimated figure was calculated based on the 20% of the estimated cost of supplying freshwater, which amounts to about US\$ 22 million. It is assumed that these measures may result in about 15% increase in water supply and are captured as benefits in the tune of US\$ 17 million annually-

Cost of governance and the introduction of regulatory framework are calculated based on human hours required for the development of regulations and the upgrading of institutional and working arrangements. Efficiency in the use and allocation of water resources due to better governance and a regulatory framework is expected to result in 10% savings in water consumption estimated at US\$ 11 million annually.

Empirical evidence indicates that improved quality of water and sanitation result in about 2% increase in GDP. This is mainly due to increased productivity of the labour force, more time devoted to productive activity due to less time spent on fetching water, reduced incidence of disease, medical cost, and reduced mortality rate. Using the average GDP for SMCs will yield a benefit of US\$ 77 million annually.

Savings in the amount of water allocated for agriculture due to the selection of water saving crops is captured in estimating the benefits from technical and allocative efficiency. This is represented in quantity of water saved in growing the low water content crop and the import of high water content crop estimated at US\$ 208 million annually.

Total cost (NPV using a discount rate of 3.5% over a 20 years period) of supplying 20,000m³/day of water through technical and allocative efficiency for the hypothetical community is estimated at US\$ 1.6 38 billion. Total benefits are estimated at US\$ 5.760 billion.

The analysis of the opportunity cost of desalination versus technical and allocative efficiency therefore reveals that it is cost effective and yields far more benefits to initially opt for technical and allocative efficiency for supplying water. Supplying water through desalination should only be resorted to after technical and allocative efficiency have been achieved.

The guidelines on performing opportunity cost analysis for desalination section provides an outline of the steps to be taken into account in order to calculate the opportunity cost of supplying water through this option. The guidelines identify and propose means of calculating the cost of foregone benefits and costs of opting for desalination as opposed to technical and allocative efficiency.

The recommendations section highlights factors to be taken into consideration in accounting for costs and benefits on performing opportunity cost analysis for supplying water through desalination. Apart from initial capital and operating cost of supplying water, health and environmental impacts of desalination as well as for technical and allocative efficiency should be estimated and accounted for. Other factors should include costing for storage and recycling facilities, water saving measures in the agriculture and household sector; benefits resulting from the efficient use of water resulting from growing water saving crops and importing high content water crops; jobs created as a result from efficient use of water and its allocation to support economic activities should also be considered as benefits accruing from technical and allocative efficiency.

I. Introduction

South Mediterranean countries (SMC's) fall into an arid zone and are marked by scarce water resources. They can be considered as one of the lowest group of countries in water availability in the world. It is estimated that these countries have less than 1% of the globe's renewable freshwater. Water reserves in the region are declining at a fast pace. It is estimated that it has declined by one third of the 1960's levels and will be halved by 2050 with the current consumption patterns and existing water policies. These estimates though do not take into account potential reduction in rainfall due to climate change. Average annual available water per capita in most of these countries is estimated at about 1000 m³. This figure is below the United Nations definition of water scarcity. It is expected that by the year 2023 this figure will reach 460 m³. (Tolba, M. and Saab, N. 2008).

Moreover, a number of these countries such as Egypt, Jordan, the Palestinian Territories, and Syria rely on water beyond their territories (Jägerskog, 2007). The severe water scarcity in these countries and their dependence on water beyond their boundaries would require regional cooperation to better manage this scarce resource.

What is exacerbating the water problem in these countries is the rate of population growth, which is one of the highest in the world. Climate change is also impacting negatively on water resource availability. Moreover, current development models and production and consumption patterns have a negative impact on water resources. Current development models adopted by most of the SMCs are not geared towards the efficient use of resources, particularly water and energy. The main activity in most of these countries is agriculture, which in many instances consumes more than 80% of water and yet is marked by inefficiency in the use of the resource. Moreover, the tourism sector is another sector where water is not being judiciously used (Moustakbal, 2009). Service cost recovery for water in SMCs does not include the full recovery cost of supplying water. The result is the miss allocation and the inefficient use of the resource. It also does not encourage conservation and the provision of efficient water infrastructure projects. Moreover, the water sector in these countries is characterized by having weak institutions, and governance structures (Jägerskog, 2007).

In order to address this shortage in water, alternative means of supplying water are sought. These are either through desalination, or through increased technical and allocative efficiency, and through the tapping of previously unfamiliar sources of water.

These include the following:

- Wastewater resulting from domestic use or what is referred to as grey water can, in some instances, be reused.
- Reclaimed water is wastewater that has been treated from solids and can mainly be used for irrigation. It can also be used for drinking if properly treated and used after being discharged into a water body.

Though reused water is a fast growing market, desalination currently captures a larger market share. Reused water capacity is expected to increase from 19.4 million m³/d in 2005 to 54.4 million m³/d in 2015. Seimens estimates that both reused and desalinated water will increase from 48 million m³/day in 2006 to 158m³/day million in 2016 (Seimens, 2008).

Efficiency in the use and allocation of water resources due to better governance and regulatory framework is expected to result in more freshwater being made available. These measures involve the use of a strict system of monitoring, compliance and penalties that support this legal framework. Emphasis should be laid on demand side rather than supply side of water. Measures that provide incentives for improved efficiency and reduction in wastage of water should be promoted. Emphasis should be laid on the efficient use of water in the agriculture sector since more than 75% of water available in SMCs is used by this sector. Use of water saving irrigation systems and growing low water content crops can effectively contribute to the efficient use of water by the agriculture sector and significantly result in water saving.

Desalination is growing in the region. Algeria, Egypt and Israel are one of the largest users of desalinated water from the SMCs selected in this review. Over the next decade desalinated water in the region is expected to represent an increasing share of supplied water. The construction of sixteen mega-plants that vary in capacity from 100,000m³/day to 500,000m³/day have made the desalination in Algeria one of the world's fastest growing markets. Algeria aims to have a total of 2,570,000 m³/day in the production of fresh water from SWRO.

In general the costs for operating either a SWRO or BWRO plants are predominantly in the electrical power. It is estimated that 44 % of the costs for a RO plant are in energy (Semiat, 2001), since desalinated water is energy intensive, the carbon footprint is the main concern associated with this industry. Desalination plants are therefore energy intensive resulting in a high level of emission. Depending on the type of energy used to power a desalination plant so too does the environmental damage. Also, for SWRO plants one main concern is the negative impacts on marine biodiversity due to the release of brine in seawater, especially in waters with low currents.

It should be emphasized that supplying water through desalination should only be considered if all other means for supplying water are exhausted. Reason being, desalination is costly and of potential negative impacts to the environment.

Desalination is an old concept and has been used for nearly a century; its importance however has never been graver. It is important though that if this option is finally resorted to that it is considered with a long-term goal in mind. That is to cut costs, reduce heavy reliance on fossil fuels as the main source of energy, and avoid any potential environmental damage resulting from desalination. These factors should, therefore, be seriously considered, designed and costed before resorting to the more expensive alternative of providing water through desalination.

In order to decide on the most cost effective and viable solution for supplying water, an opportunity cost analysis covering the socio-economic and environmental implications of supplying water through desalination should be performed. To conduct this analysis, the socio-economic and environmental costs of supplying water through technical and allocative efficiency will need to be undertaken and examined against the first option. Based on an extensive review of literature and experience of countries throughout the world, factors to be considered in the analysis were enumerated and costed.

The guidelines on performing opportunity cost analysis for desalination provides policy and decision makers as well as practitioners with a tool to perform opportunity cost analysis and accordingly make an informed decision of the best option to select.

II: Identification and analysis of socio-economic and environmental costs of supplying water through desalination

Globally, desalinated water represents a very small percentage of the total water supply. It is however, becoming increasingly recognized as an important means of supplying water, especially for countries relying mainly on rainfall as is the case for most of the SMCs. Changes in climatic conditions have led to unprecedented droughts and created the need for innovative means of supplying water. Over 15,000 desalination plants exist globally to date and are supplying fresh drinking water for urban centres as well as the rural sector.

This section is intended to identify the potential socio-economic and environmental costs of supplying water through desalination based on available data, previous studies, and country experiences. Information derived in this section will be used to estimate socio-economic and environmental costs for supplying 20,000 m³/day for a hypothetical community being considered in this study in section IV.

There are several factors that contribute to the cost of a desalination plant. The first part of this section will highlight the capital and operational costs of a desalination plant, as well as maintenance through the use of a cost database of previous plants, which will take into consideration location and

labour costs. The next part will examine energy costs and environmental externalities associated with the use of fossil fuels for the powering of desalination plants as opposed to renewable energies such as solar and nuclear. The last part of the section will provide a brief review of country experiences with desalination.

Capital and operating costs

In order to estimate costs associated with the construction and operation of a desalination plant a database extending over a 35 year period covering capital and operating costs, preliminary and feasibility design and tenders from around the world was considered. Data include information on plant location, technology used, plant capacity, and type of water being treated. Capital costs include the plant and land costs, civil works as well as amortization. Operating costs include costs of chemicals, energy requirements, spare parts and maintenance, and labour. The database includes 331 plants of varying technologies and a harmonized cost analysis especially from plants that reported different costs by different researchers. Also, considering that the database covers the period from 1970 to 2005, present value calculations were made and the currencies adjusted to match the 2005 US\$ value.

The unit product cost for a desalination plant (UPC) can be calculated using the formula below. Assuming a twenty-year longevity the equation is as follows:

$$\frac{\text{Capital cost}}{\text{Plant life}} + \frac{\text{Annual operating cost}}{\text{Plant capacity} \times \text{Plant Availability}}$$

Empirical data indicates that cost of desalination has been decreasing during the last three decades. In 1980 UPC was between \$4.5 and \$1.5, whereas in 2005 it was between \$2.0 and \$0.5 per m³. This trend has continued where current unit prices are now between \$1 and \$0.5. If we assume an average UPC of US\$ 0.7/m³ then for our hypothetical community, the initial capital cost should be US\$ 5.1 million. However, in most instances this may not be the case. Capital costs vary widely regardless of the operating costs. Plants using the same technology, feed water type and size can still have different capital costs ranging from US\$72 million to US\$307 million (Wittholz, 2007).

To help determine which technology is the cheapest to use, several studies were undertaken that factored the average costs for fixed and operating costs of a plant. Operating costs for both BWRO and SWRO were slightly higher than for thermal processes in desalination. On the other hand though, energy costs for Multi-stage Flash Distillation (MSF) and Multiple Effect Distillation (MED) were significantly higher. For RO, studies have shown that out of the entire cost factors, 63 % were operating costs of which at most 44% were for energy cost. Research indicates that the cheapest seawater process was SWRO and for inland BWRO (Wittholz 2007).

Table 1: Summary of costs for different technologies for 4 different capacities

	Capacity (m ³ /d)	Capital cost (US\$×10 ⁶)	UPC (US\$)
SWRO	10,000	20.1	0.95
	50,000	74.0	0.70
	275,000	293.0	0.50
	500,000	476.7	0.45
BWRO	10,000	8.1	0.38
	50,000	26.5	0.25
	275,000	93.5	0.16
	500,000	145.4	0.14
Source (Wittholz, 2007)			
MSF	10,000	48.0	1.97
	50,000	149.5	1.23
	275,000	498.1	0.74
	500,000	759.6	0.62
MED	10,000	28.5	1.17
	50,000	108.4	0.89
	275,000	446.7	0.67
	500,000	734.0	0.60

Capital and UPC for the varying capacities of plants with differing technologies is highlighted in table 1. These were calculated using the correlations and cost breakdown for each plant.

The cost of replacing existing water supply with desalinated water is approximately US\$ 0.45 ± US\$ 0.23 (Wittholz, 2007). One of the main concerns regarding supplying water through desalination is the high-energy requirement associated with it. An increase in the cost of electricity for example from US\$ 0.10/kWh to US\$ 0.15/kWh could potentially increase the UPC by 17.5%.

The following part of the section examines the different energy sources used for desalination plants and their environmental and social impacts.

In general the costs for operating either SWRO or BWRO plants are predominantly in the electrical power. As earlier indicated, it is estimated that 44 % of the costs for a RO plant are in energy (Semiat, 2001), other estimates go as far as 87% (Zhou, 2004). Cost breakdown are largely dependent on the features of each individual plant making it difficult to develop a generic model. The percentage share of energy costs related to the overall costs of production is examined in a study done by Wilf, where he estimates the UPC of energy in RO plants. Doubling the cost of electricity could increase the UPC by up to 50 % for an RO plant, whereas another could show a different UPC altogether. This simply means that even if the energy needed for operating two different desalination plants are the same, different energy costs will change the UPC of each plant only highlighting the difficulty in determining a clear generic model (Wilf, 2001).

Another factor that should be considered for the initial costing of a desalination plant is its location. Not only does vicinity with both the water source and the destination zone for the water, be it a city or an industrial area, matter but so do land and labour costs. A country where both land and labour are cheap should produce significantly cheaper water as opposed to a country where the factors of production are higher. However a study conducted by Park et al. shows that plant location had very little observable effect on the cost of water. This implies that cost data from around the world can be applied to any location without a huge variance in the outcome (Wittholz, 2007). This is due to the relative costs and weights attributed to energy and capital as opposed to land and labour.

Another cost implication associated with supplying water through desalination is the increased amount of subsidies that governments would have to pay if it were to maintain the same level of water charges. Average cost of supplying water for the SMCs goes as low as US\$ 0.1/m³ rendering the US\$ 0.7/m³ from desalination very expensive.

Environmental Impacts of desalination plants

Apart from high initial capital and operating cost represented in the high share of energy consumption in the desalination process, one main concern is the excessive levels of CO₂ emissions resulting from the burning of fossil fuel. Costs involved in increased CO₂ emissions include negative impacts on the climate represented in global warming and variations in climatic conditions, causing sea level rise, affecting coastal areas of most of the SMCs, and the inundation of low level areas such as the Delta in Egypt. Apart from damage to the environment, social implications include the resettlement of communities, loss of jobs, and negative health impacts. Economic implications include impacts on economic activities such as agricultural crops, fisheries, and tourism.

Since desalinated water is energy intensive, the carbon footprint is the main concern associated with this industry. The carbon footprint for cogeneration plants for MSF plants is between 10-20 kg CO₂/m³ and for MED is between 11.2-19.6 kg CO₂/m³. For single purpose thermal plants, the footprint is much higher if waste heat is not properly managed. For power generation plants, the footprint is between 0.5-0.8kg CO₂/kwh depending on the kind of fuel used (Sommariva, 2010).

The high-energy needs for desalination plants make the choice of source of energy used important. If fossil fuels are used as the primary energy source then both greenhouse gases such as CO₂ and acid rain gases such as NO_x and SO_x are emitted into the atmosphere. Table 2 shows estimated CO₂ emissions and cost of energy by source calculated on the basis of average energy needs of 6.09 kWh/m³ for a desalination plant. This figure was derived from a database containing energy requirements of around 330 desalination plants. Energy consumptions ranged from 3 – 36 kWh/m³.

Table 2: Energy needs and emissions for an RO desalination plant

	Coal	Oil	Natural Gas	Nuclear	Solar	Wind
Energy need/ m ³	6.09 kWh/m ³	6.09 kWh/m ³	6.09 kWh/m ³	6.09 kWh/m ³	6.09 kWh/m ³	6.09 kWh/m ³
CO ₂ emissions/ m ³	5481 g	3775 g	2253 g	18 g	0g	0g
Costs/m ³ *	3.23	21.56	4.51	2.19	15	8.7

*(US prices 2011 NEI)

As earlier stated, the most significant impact on the environment is through greenhouse gas emissions of fossil fuel powering the plant. In Israel for example, the average plant requires 3.7 to 4.5 kWh per m³ of electricity making the relative environmental externality lower than the average of 6.09kWh/m³. In order to assess the cost of the harmful output of NO_x and SO₂, the European Cost Assessment for Sustainable Energy Systems (CASES) are used for the purpose of this study, as it is the only available reliable data. This study provides pollution costs measured in terms of tons of emissions for each country in the European Union as well as other neighbouring countries (Becker et al., 2010). Costs include simulations on climate, population density and epidemiological studies, which link pollutant concentrations to morbidity and mortality rates.

Resorting to desalination plants to satisfy freshwater needs has to be carefully weighed against the negative impacts associated with CO₂ emissions. That is why it is essential that alternative means for supplying water through technical and allocative efficiency have to be fully exhausted before embarking on desalination plants using fossil fuel as the main source of energy.

Capturing the full environmental implications as a result of supplying 20,000m³/day of freshwater for the hypothetical community would be rather difficult to estimate in precise terms as the plant is not location specific. Moreover, figures arrived at by the CASES study do not consider the entire negative externality as it only accounts for air pollution.

Table 3: Air pollution externalities of desalination

	Pollution costs /ton emitted (\$/ton)	Average emissions during electricity generation (gram/kWh)	Emission costs/kWh generation (cents/kWh)	Emissions costs/m ³ of desalinated water (cents/m ³)
SO ₂	6.468	1.6	1.03	4.40
NO _x	3.746	1.7	0.64	2.71
PM ₁₀	9.232	0.05	0.05	0.20
CO ₂	19.39	707	1.37	5.83
Total				13.13

Source, (Becker et al., 2010)

Table 3 shows air pollution externalities of desalination for each pollutant calculated in US cents. Total cost was estimated at about US\$0.13 per m³. This figure reflects environmental costs using CASES and should be added to the UPC of desalination in order to internalize environmental externalities (Becker et al., 2010).

Air pollution and consequently CO₂ being the main environmental implications of desalination plants do not account for brine discharge both in SWRO and BWRO processes. Even though the environmental implications from wastewater resulting from desalination plants have not been adequately studied, it is however, recognized that brine discharge has a negative impact on marine life. In the 2007 World Bank report, it has been noted that there has been a negative impact of the discharge of brine, chlorine, trace metals, volatile hydrocarbons, and anti foaming and anti-scaling agents on the marine environment. RO processes allow for gases for the evaporation of brine in flashing chambers, which increases the CO₂ resulting in the release of other atmospheric gases such as O₂ and N₂. The more enclosed the sea or the less current flow is available the more detrimental the environmental impacts are. Build-up of brine in enclosed sea areas can damage the ecosystem. In the case of brackish water, the brine discharge is either spread over land, or allowed to drain back into the ground, or it is pumped into solar ponds in order to evaporate. These options are not sustainable. The excess salt or salinity disrupts the ecosystem and creates more arid zones in the case of the inland desalination plants. These externalities need to be internalized in order to account for the actual cost of a desalination plant. This can be addressed through price adjustments or the use of renewable energy sources which are less damaging to the environment. This requires the internalization of external costs in order to reflect the actual UPC of a desalination plant.

As can be seen from table 4, factors affecting the environment are not limited to emissions and brine discharge. For RO plants noise pollution is considered to be high. Other factors such as microelements, industrial risk and toxic material need to be considered for their environmental implications.

Another aspect to be taken into account is the number of jobs generated as a result of constructing a desalination plant. As will be seen below, the plant in Australia for example,

Qualitative Overview of Environmental Impacts of Three Desalination Technologies

Effect/type of plant	RO	MSF	E.D.
Noise	H	M	L
Water effluent	M	H	M
Microelements	L	H	L
Toxic material	M	H	M
Air pollution	L	H	M
Industrial risk	L	H	M

Note: H = high, M = medium, L = low.

Source World Bank, 2009 - Table 4

provided about 1700 building workers with average wages much higher than elsewhere in the country. The construction of a desalination plant as with any structure will primarily lead to increased employment in the construction sector and also in operating the plant. It will also result in increased employment in other sectors due to the increased availability of water that can be used in supporting activities in other sectors such as agriculture, industry, and tourism. Moreover, increased economic activity will generate incomes and contribute to GDP growth.

Country experiences

A number of desalination plants have been built in the SMCs. Israel is one of the countries in the region that has experienced several drought seasons in the last couple of decades, which led to water shortages reaching levels of about 520 million m³/year. Water shortages in Israel have mainly been met through desalination. Israel's total production of desalinated water is approximately 300 million m³ annually. These are supplied by using either natural gas or coal, resulting in negative environmental consequences. Several desalination plants were constructed in Israel one of which is in Tel Aviv. Costs associated with the construction of the plant are broken down in table 5 below.

Table 5: Test case for Tel Aviv

Volume, Mm ³	100
Investment, US\$ mil	300
Capital, US\$/m ³	0.17
Energy, US\$/m ³	0.26
O&M, US\$/m ³	0.20
Total, US\$/m ³	0.63

Source: (Moatty, 2000)

The US\$ 0.63/m³ in the table represents the cost of supplying water through desalination in 2003 (Moatty, 2000). In 2012 the cost of supplying desalinated water has fallen to around US \$0.5/m³.

Capital costs are included in UPC based on a 50 million-m³/year plant with a 20-year amortization and a 7% interest rate.

In 2005 Israel constructed a plant in Ashkelon, which had an output of 100 million m³ a year. Along with the plant in Palmachim they provide about 8% of the total water in the country. This percentage is expected to increase to 30% in 2020. The coastal city of Hadera will host a plant, which will produce 127 million m³ per year or about 347 thousand m³ a day. This large plant will supply the drought ridden Israel with approximately 20% of its household needs. The estimated cost of the plant is US\$ 425 million, with a unit cost of US\$ 0.57 per m³ while requiring 450 Giga watts annually to operate it (Rabinovitch, 2011).

Desalination projects are large in number but mostly small in size. Very few large-scale desalination plants actually exist and those that do exist adopt the more efficient but energy consuming technique of RO. One such example is found in Algeria. The construction of sixteen mega-plants that vary in capacity from 100,000m³/day to 500,000m³/day have made desalination in Algeria one of the world's fastest growing markets. Algeria aims to supply a total of 2,570,000 m³/day of fresh water from SWRO. The actual current desalination capacity is about 1,462,000 m³/day, which includes SWRO and BWRO as well as the use of MSF, vapour compression (VC) and electro dialysis (ED) technologies (Drouiche et al., 2011).

As indicated above, one main concern related to desalination plants is their high-energy requirement. For example, a desalination plant at Kwinana provides about 17% of Australia's water needs, while requiring about 50% more energy as compared to conventional water treatment plants (Knights, 2006). This becomes increasingly problematic with over 85% of Australia's energy needs being met through coal-fired power stations. The rest is either through gas or hydropower (Knights, 2006). This has raised a number of concerns with the development of desalination plants. In order to address this problem, renewable means of energy generation are being sought. Plans are being made to construct desalination plants powered by either solar, wind or geothermal energy (Heimbuch, 2009).

Increased greenhouse gas emissions are not the only negative externality caused by desalination plants. Both inland and coastline plants carry their own environmental drawbacks. Heavy consideration for the ecosystem and the society must be taken into account before any plant can be constructed. In Australia, under the Environmental Protection Act (EPA), due consideration is made before any structure is built. The coastline plants impose a heavy burden on the marine wildlife if not constructed following strict guidelines to avoid environmental damage to the marine ecosystem. Guidelines and restrictions as set out by the Australian EPA appear to be all encompassing. They even accounted for labour migrations and compensations for landowners. Landowners whose lands are being used for inland desalination plants have been compensated and new jobs and livelihoods were created (State Government Victoria, Department of Sustainability and Environment).

Given the high socio-economic and environmental costs of supplying water through desalination, a number of measures, should first be considered before resorting to this option. These measures are examined in more detail in section III and include the following:

- ❑ Undertake the necessary measures to reduce leakage from the water network.
- ❑ Measures should be introduced to reduce the life cycle cost of water.
- ❑ Introduce incentive and regulatory measures that encourage savings and efficient use of water.
- ❑ Enhance the role of private sector in the desalination industry.
- ❑ Shift the role of government to focus on regulating water supply than on operation.
- ❑ Invest in R&D with focus on innovation and technology development.
- ❑ Calculate the cost of larger plants in distant locations with increased cost of transportation, storage, and distribution compared to smaller ones close to urban areas.
- ❑ In many instances, smaller decentralized desalination plants are a more feasible option due to reduced costs of transportation and leakage, implementation schedules are shorter, and

water security is ensured by having a number of small plants, with the latter being more efficient to manage.

- ☒ Since desalination is energy intensive, solar power should be considered for desalination projects. Benefits derived include reducing CO₂ emissions and the resulting positive impacts on human health and the environment.
- ☒ Provide incentives for local entrepreneurs to invest in the production of key components of the desalination industry. One way of achieving this is requesting contractors providing the plants to manufacture the technology locally.

Desalination is an old concept, and has been used for nearly a century. It is important though to consider this option only after all potential alternative options have been examined and exhausted and with a long-term goal in mind. If it is ultimately to be resorted to and after all other options have been exhausted, costs will have to be cut down, as well as heavy reliance on fossil fuels as the main source of energy. Environmental damage resulting from desalination has to be avoided.

III. Identification and analysis of socio-economic and environmental costs of alternatives under technical efficiency and allocative efficiency

This section is intended to identify the potential socio-economic and environmental costs of supplying water through technical and allocative efficiency based on available data, previous studies, and country experiences. Information derived in this section will be used to estimate socio-economic and environmental costs of supplying 20,000 m³/day for the hypothetical community being considered in this study in section IV.

Cost of alternative water systems

In general, cost of supplying water is expected to be reduced due to technological advancement, improved management of information and consequently performance and energy efficiency. Green technologies, natural engineered systems that use vegetation and soil to capture and purify water, and integrated water management and payment for ecosystem services can contribute to better allocation and efficient use of water, thus avoiding the construction of new infrastructure and treatment facilities.

Mismanagement can result in unnecessary high cost due to inappropriate location of the water plant thus requiring the transport of water over long distances, increased use of energy and the corresponding costs. It can also result in the depletion of ground water and degrading its quality, which in turn forces governments to subsidize its operations.

Assessing cost of alternative water systems

According to an analysis done by Marsden Jacob Associates (2006) for Australian cities, it was found that favourable locations to the alternative water supply systems had the lowest cost. In unfavourable locations it was as high as US\$ 3.00/km, where water has to be distributed over long distances cost of pipelines and pumping increases. For wastewater reuse, the distance over which water has to be distributed affects the total cost of supplying water, it is more cost effective to provide the wastewater treatment facilities close to potential users, whether that is domestic, agricultural, or industrial.

It is estimated that the cost of collection systems is 80% or more of the total system costs. That is why it is essential that economies of scale should be achieved in these systems. It is therefore more expensive to have treatment plants at a central location. According to Marsden Jacob Associates (2006), treatment plants distantly located may cost the same or may even be more expensive than

desalination plants. According to Rocky Mountain Institute (2004), decentralized treatment plants do not require major investment, thus reducing the financial burden for users. However, in case of decentralized systems, transaction costs are higher. Also being riskier undertaking for lenders, the cost of capital may be higher than in the case of centralized plants.

Separate infrastructure and retrofitting are required for reclaimed water. It is estimated that the cost of providing this network in France is about Euros 20,000 for a public building. This cost is lower for an individual house. Other costs involve maintenance, operating, and monitoring costs. Benefits of this alternative are that it is less damaging to the environment since it reduces the discharge of wastewater in land and water bodies. As far as pay back period for the initial investment is concerned, according to Michel Le Sommer in France, where the average price of water is about Euros 3/m³, is between 15 and 20 years.

Regulations affect the payback period, which is dependent on the kind of the specifications of water quality standards the regulator sets. It also depends on the level of water prices and the extent to which environmental externalities are reflected in fees for wastewater discharges.

Hiessl (2005) compares the costs for three options in two German cities up to 2050. The three options were the centralized system, municipal reuse, and recycling. Innovative technologies as well as organizational and institutional aspects were accounted in the analysis. The first alternative was the centralized option, whilst the second and third options were the decentralized option. The three alternatives were evaluated according to 44 criteria covering ecological, social, and economic aspects. The outcome indicated that the recycling option was the best.

The specific location in which water services are being provided will determine whether it is more cost effective to opt for a decentralized or a centralized water facility. It has been generally accepted that in large urban areas a centralized option is preferred. For suburban or industrial centres decentralized water facilities were found to be more viable (Freedman and Hotchkies, 2007).

Table 6 shows the pros and cons of supplying water through a centralized and decentralized water facility.

Table 6: Some Pros and Cons of a variety of ways of providing water

	Freshwater	Alternative Sources of Water
Central infrastructure	<p>Pros</p> <ul style="list-style-type: none"> · Scale effects · Provides consistent services · Financial solidarity at municipal level <p>Cons:</p> <ul style="list-style-type: none"> · A number of negative externalities (environmental, financial) · Capital intensive and fails to attract private capital 	<p>Pros</p> <ul style="list-style-type: none"> · Positive environmental externalities (resource, wastewater discharge) · Financial solidarity at municipal level <p>Cons</p> <ul style="list-style-type: none"> · Costly (several networks) · Energy intensive
Decentralized infrastructure	<p>Pros</p> <ul style="list-style-type: none"> · Less water leakage in mains and less energy used to transport water · Reduced energy use · Flexible and resilient · Deferred and reduced investment costs <p>Cons</p> <ul style="list-style-type: none"> · Additional connections are needed for reliable sourcing 	<p>Pros</p> <ul style="list-style-type: none"> · Positive environmental externalities (resource, wastewater discharge) · Reduced energy use · Flexible and resilient · Deferred and reduced investment costs · May harness new sources of finance <p>Cons</p> <ul style="list-style-type: none"> · Health issues related to potable reuse · Questions about relevance when

Freshwater	Alternative Sources of Water
<ul style="list-style-type: none"> · Unequal service provision in the municipality · Inadequate monitoring systems 	<ul style="list-style-type: none"> central infrastructure is in place · Scale effect · Unequal service provision in the municipality · Inadequate monitoring and regulatory systems

Alternative ways of supplying water appear in light blue.

Source: Alternative Ways of Providing Water, Emerging Options and Their Policy Implications, OECD, 2007-2008.

It should be emphasized that public involvement is essential when deciding on the different options for water supply. It is important that the public accepts using recycled water. In many instances experience indicates that there has been resentment to this option. This has gradually changed, where in countries such as Australia, Singapore, the United States of America (USA) and generally in Europe, indirect potable reuse fed into a water body and then supplied through the drinking water system has been used (Marsdon Jacob Associates, 2006). Direct use is generally not accepted even if stringent quality measures are applied, as is the case in Singapore.

Water service recovery can encourage alternative water system markets. Full cost recovery for water supply and taxing wastewater discharge to reflect the actual cost involved or capping quantities to be discharged and pollution levels can shorten the payback for alternative options (OECD, 2008).

The extent to which wastewater is used depends on the price set for reclaimed as well as freshwater. The higher the cost of reclaimed wastewater the lower is the potential for wastewater reuse. And the lower the price of freshwater the lower is the potential for reuse of reclaimed water (Yang, 2007).

Cost of supplying freshwater

In calculating the cost of supplying water through centralized and decentralized water systems, socio-economic as well as environmental considerations should be taken into account. These costs will vary from one country to the other depending on labour cost, availability of local skills and expertise, and the extent of environmental damage. The following section provides a brief review of the situation in a number of countries.

Table 7 shows the average user tariff in a number of cities across the world.

Table 7: Average User Tariff (US\$/m3)

London	Philadelphia	Istanbul	Johannesburg	Japan	Singapore
3.2	1.9	1.8	0.7	2.5	1.3
Damascus	Jeddah	Tunisia	Egypt	Brazil Campinas	Mexico Guanajuato
0.08	0.01	0.7	0.9	0.3	0.4

Sources: Local Public Enterprise Database (March 2006, Ministry of Internal Affairs and Communication, Japan); Tunisia, London, Berlin, Damascus, and Jeddah (country reports); Singapore (estimate by the PUB website tariff table); Other Countries (Water Supply and Sanitation Working Notes No. 9, May 2006).

Notes: The average tariff of Singapore is estimated on the tariff structure on the PUB website. The tariffs of Japanese water and wastewater are combined for international comparison with some assumptions.

In *Egypt*, expenditures on water services, including investment and maintenance costs are borne by the government. Recovery cost for water services are below international standards, thus highly indebting the sector. During the last two decades the percentage of funding devoted to new

investments as opposed to operation and maintenance and debt services has been on the increase. In order to enable the financing of water services in Egypt, the government has identified a number of options. The first is to increase water charges. The second is to reduce transaction and operating costs through decentralization and efficiency. The third is to encourage the privatization of the water sector. The general trend in Egypt is that water corporations will be the main supplier of water.

Capital operation and management cost of supplying water in Egypt is between LE 0.8-1 per m³. Water users pay an average tariff of LE 0.15 which is 20% of the treatment and delivery cost. Water subsidies in Egypt are estimated to be between 3-4 billion LE annually.

Tunisia is one of the most scarce resource countries in the region. Per capita water consumption is 500m³ and is expected to drop to 360m³ by 2030. The Government builds dams and storage facilities to manage water resources including underground water. These are unevenly distributed among different regions with about 81% concentrated in the north, 11% in the centre of Tunisia, while 8% in the south of the country. Some of its water resources are transboundary, where it shares a number of small rivers along the Algerian borders. The main underground water resource is located in Djeffara coastal basin shared with Libya, and the North West Sahara Aquifer shared with Algeria and Libya.

In order to face the water scarcity problem, Tunisia has been using alternative means for generating water. These included the reuse of treated wastewater, artificial recharging of underground water aquifers, and desalination of both brackish and salty water. Tunisia has been reusing treated wastewater for agricultural purposes since the 1970s. It also uses treated water to support an important wetland ecosystem. It is considered to have one of the highest rates of reuse in the world. However, the system is heavily subsidized.

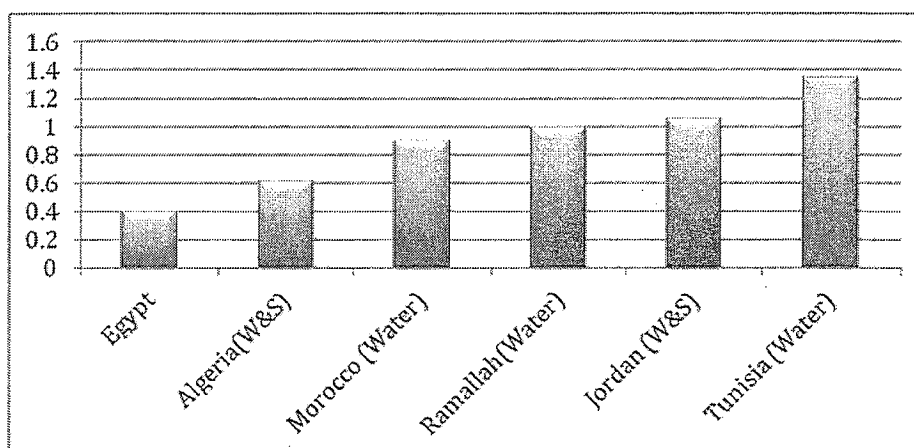
Desalination in Tunisia began in 1983 with the national authority providing 58,800 m³/day. The private sector is also involved in desalination mainly for tourism, industry, and high value agricultural crops. Main technology used is RO. The Government plans to increase its capacity to 50 million m³/day by 2030. This is in addition to recharging water aquifers artificially and the construction of dams to capture water in rainy periods, which is planned to increase water by 200 million m³ by 2030.

Moreover, since 1980 Tunisia has adopted water conservation measures in the agriculture sector. This has resulted in a decline in consumption per hectare from 6,200 m³/ha in 1990 to about 5,500 m³/ha in 2005. The National Programme of Irrigation Water Conservation was launched in 1995 to use water resources more efficiently and to maximize economic returns from the agriculture sector. Water efficient systems such as sprinklers, gravity irrigation, and drip irrigation systems have been introduced. This has necessitated the government to provide subsidies to farms amounting to between 40%-60% of the cost of the programme.

It is apparent that the country has to conserve its limited water resources and achieve maximum efficiency in the use and allocation of resources. Involving users in the management plans for conserving and using water resources is expected to enhance the effectiveness and efficiency of the proposed measures (Jagannathan, Mohamed, Kremer, 2009).

Figure 1 below shows the cost recovery for a number of countries in the region.

Figure 1: Water Supply and Sanitation: Cost recovery (%)



Source: World Bank Cross- Country data (2003-2004)

Water Reuse

Treated wastewater is increasingly being recognized as one potential means of supplying water. In addition to reducing the negative environmental impacts resulting from the discharging of wastewater in waterways, it provides an additional source of water, which can be used for irrigation. It reduces pressure on available water resources for domestic use and the need for resorting to more expensive solutions such as storage, transfer and desalination.

Table 8 shows the potential economic impacts of wastewater reuse.

Table 8: Economic impacts of Wastewater Reuse

Costs	Benefits
Value-added from displaced water (if any)	Value-added from reused wastewater (varies based on quality and reliability differences)
Opportunity cost of reused water (if any)	Alternative use of displaced water (if any)
Collection and treatment of wastewater, final disposal costs	Reduced environmental degradation
Conveyance/storage of reused water, including water losses (evaporation, leakage) and retrofitting costs for participating farmers	Aquifer recharge, or value of reduced aquifer depletion
Salinity-related impacts	Increase in property values
Other pollution (nitrates, heavy metals, toxic substances)	Increased crop yields
Health, odour, and nuisance costs	Savings in fertilizers
Ecological impacts (opportunity cost of reused water for minimum flow or other purposes)	Value of improvements or reform in the water sector due to water reuse.

Source: Water in the Arab World: Management Perspectives and Innovations: N. Vijay Jagannathan, Ahmed Shawky Mohamed, Alexander Kremer, 2009.

Moreover, cost implications of introducing reused water to farmers should be taken into account as it may involve reforming the pricing system to cover the cost of wastewater treatment. In several SMCs irrigation water is provided almost free of charge as it may be supplied directly from water bodies.

Table 9 shows cost of wastewater collection, treatment and reuse in the Arab world derived from a variety of sources.

Table 9: Cost of Wastewater Collection, Treatment, and Reuse

Component	Cost/m ³ (US\$)	Notes	Sources
Conveyance to treatment works	Highly variable*		
Non mechanical secondary treatment	0.10-0.22	Necessary for restricted reuse	WHO 2005, Shelef 1996, Haruvy 1997, Amami 2005
Aerated secondary treatment/activated sludge	0.22-0.27	Lower land requirement	Kamizoulis 2003, Shelef 1996, Shelef 1991 Haruvy 1997
Tertiary treatment (in addition to secondary)	0.07-0.18	Necessary for unrestricted reuse	Shelef 1996, Haruvy 1997, Shelef 1994
Distribution	0.05-0.36		Shelef 1994
Total	0.16-0.53		Shelef 1994, Lee 2001

- Costs come from a variety of sources and have not been standardized to a specific reference year.

Source: Water in the Arab World: Management Perspectives and Innovations: N. Vijay Jagannathan, Ahmed Shawky Mohamed, Alexander Kremer, 2009.

Cost of reused Water

This sub section will provide a brief account of the experience of selected countries in the SMCs with wastewater treatment.

In the current five years development plan of *Egypt*, about LE 5.55 billion are allocated for investment in the wastewater treatment sector. Egypt's wastewater treatment activities are part of a long-term programme to improve public health and environmental protection. One of its latest projects is stage II phase II of the Gabal El-Asfar wastewater treatment plant. The project aims at recycling an additional 500,000 m³/day of primary and secondary wastewater. The estimated cost of the project, located in the lower eastern part of Cairo is Euros 233.5 million, is expected to be completed by 2014. The new phase of the project will benefit an additional 2.5 million people over about 8 million people already benefiting from the exiting facility. The treatment plant, will improve water quality that will allow it to be used for irrigation rather than discharged directly in lake Manzala and the Mediterranean. (African Development Bank, Gabal El-Asfar Wastewater Treatment Plant- Stage II Phase II project, Country: Egypt, 2009).

Israel has resorted to wastewater treatment since almost three decades in an effort to meet water demand without resorting to desalination as being the costlier option. Currently, Israel has more than 400 wastewater treatment projects. The projects are mainly subsidized, with subsidies representing about 60% of infrastructure costs. Prices charged by the government for reused water is 20% lower than that provided by the National Water Carrier (Libhaber, 2007). More that 80% of wastewater in Israel is treated, which is the highest in the region. Given the experience the country has had with wastewater treatment, it has developed extensive expertise in this area.

As mentioned earlier, *Jordan* is one of the most water scarce countries in the region with about 150 m³/capita/year (FAO, 2006). It is also characterized by having the highest rates of depletion of

underground water. In spite of the challenging water scarcity in the country, reclaimed water represents 10% of total water supply in Jordan. There are three types of reused water in Jordan, direct use or planned, unplanned in the *Wadis*, indirect use after mixing with water supplies (McCornick et al., 2001). Regulations related to wastewater, which was instituted since 1998 has encouraged wastewater use. These included measures that prohibit the discharge of wastewater and considering it as part of the water resource to be reclaimed. It has also indicated that those using treated wastewater should be charged (Nazzal et al., 2000). One of the drawbacks is the negative impact of discharging large amounts of wastewater into surface waterways. This was the case in 1996 with the El-Samra treatment plant, which has caused salinity of the soil in the summer season. Another problem was overloading the plant, which has resulted in lowering the quality of treated water.

In *Tunisia* demand for reused wastewater has been lagging behind in spite of strong government support (Bahri, 2008b; Benabdallah, 2003; Shetty, 2004). In many instances farmers prefer to use underground water for irrigation even after reclaimed water has been made available to them. Concerns stem from the negative impacts in terms of increased soil salinity. Another problem is failure to meet demand when needed due to inadequate storage facilities. Moreover, it is not possible to use treated wastewater for high value crops (Bahri 2008b). This has forced the government in 1997 to set the charge for treated wastewater at US\$ 0.01/m³ below the freshwater charge of US\$ 0.08. This has still had little impact on the demand on reclaimed water (Shetty, 2004 and Bahri, 2008b). More efforts are therefore needed to be taken on the demand side of reclaimed water in Tunisia (Bahri 2008b).

A set of recommendations emanate from the experience of these countries:

- ❖ Wastewater treatment projects need to ensure that demand exists prior to construction to avoid idle capacity.
- ❖ Since full cost recovery is unlikely, it is important to ensure availability of funds to subsidize deficit.
- ❖ Since water conservation and demand management is the most cost effective, these measures should be introduced before embarking on waste treatment.
- ❖ Coordination between different relevant entities should be maintained. This includes apart from the water authority, sanitation, municipality, agriculture, and other potential users (Jagannathan, Mohamed, Kremer, 2009).

Technical and allocative Efficiency

The 2030 Water Resources Group in analysing water needs against supply have projected that by 2030 water demand will exceed water supply by 40%. Introducing water productivity measures is expected to close around 20% of the gap. Other measures such as the construction of dams and desalination projects, and increased recycling are expected to cover another 20% of the gap. The balance of 60% should come from increased in infrastructure investment, reforms in water policies and improved water efficiency.

This sub section will review the package of proposed measures proposed aimed at achieving technical and allocative efficiency in the water sector. Cost and benefits resulting from these interventions are estimated and accounted for in section IV providing an analysis of the opportunity cost of desalination versus technical efficiency and allocative efficiency.

Policy reforms and Governance

The 2030 Water Working Group (2010) estimates that with policy reforms and governance the global amount of funds needed to be invested in the water sector can be reduced by a factor of four. The absence of strong political support and strong governance structure represents an impediment for investment in the water sector (Global Water Partnership, 2009a). It is increasingly being recognized that effective governance structures offer the least cost solution for the efficient use and allocation of

water (Ménard and Saleth, 2010). Related to this, is the issue of land and water rights. Clear property right to land and water encourages investment in water infrastructure projects and the judicious use of water resources.

Improving compliance and enforcement with water legislation

Regulations are one of the main policy tools for regulating activities in the different sectors. Adequate water regulations need to be introduced to encourage the efficient use of water as well as the use of new non-conventional sources of water. In many instances for example, countries lack regulations that include reclaimed wastewater as a water resource (Jimenez and Asano, 2008). However, monitoring and ensuring compliance involves costs, and in many instances is difficult to administer, particularly in developing countries. This is even more so in countries with weak governance structures as is the case in most of the SMCs. It is one thing to institute legislations, but with weak institutions and governance structures, monitoring and compliance, and imposing penalties for non-compliant parties would be lacking.

Use of economic instruments, application of full service cost recovery and through allocative efficiency

There has been an increased recognition in the last two decades of the importance of using economic instruments to achieve environmental objectives. Though economic instruments can be used as a tool to generate income for governments, this should not be the main objective. Market-based incentives should be mainly used to alter behaviour, consumption and production patterns towards more sustainable patterns. They could be effective tools in operationalizing the polluter pays principle (PPP) and the user pays principle (UPP). While the former is intended to encourage polluters to avoid or at least reduce pollution resulting from their activities, the latter will lead to a full cost recovery of the supplied water. The use of economic instruments should be designed to eventually capture the full cost of producing water, including environmental and social externalities resulting from the full life cycle of producing water. Economic instruments should be designed to complement regulations and address environmental, social and economic considerations.

Economic instruments include taxes, subsidies, charges, and fees. Other instruments include payments for ecosystem services (PES), consumer-driven accreditation and certification schemes, trading of pollution permits and access rights to water. Payments for ecosystem services can either be government financed or financed by the user. Experience indicates that those financed and managed by water users are more efficient (Pagiola and Patais 2007).

Entitlement and allocation systems have also been used in several countries, which have resulted in the efficient use of water and in economic gains. Under a solid property rights system managers buy and sell entitlements for environmental purposes. In Oregon in the US, this practice has been in place since 1993 where the Water Trust has been buying water from farmers and using it to protect the watershed ecosystem (Neuman and Chapman 1999).

Investing in innovation and technology development

Most of the SMCs allocate meagre resources for R&D with the exception of Israel. Adequate financial resources should be allocated for research and development in the water sector to develop and improve water technologies and equipment. SMCs should gradually shift from primarily relying on outside water related technologies and equipment to locally developed ones. This will not only provide water-efficient technologies that are more appropriate for SMCs, and consequently cut costs, but can also create trade opportunities for countries of the region.

Education and public awareness

Education and public awareness campaigns have an important role in altering consumption patterns towards more sustainable practices. This applies to households, farmers, industrialists, and the public service sector itself. Efforts to promote efficiency in the allocation and use of water should be

accompanied by a long-term educational and public awareness campaign about the necessity of reducing the wasteful use of water and promoting more efficient practices. These campaigns should be designed to target the different stakeholders. This is necessary in order to gauge the interest of the different users, and encourage their involvement, and support in the implementation of policies and measures proposed by government aimed at maximizing the use of water resources for current and future generations. Integrating sustainable water management as in the education curricula will produce the necessary calibres needed at all levels to support the efficient and sustainable management of the water sector.

Service cost recovery

When setting a price for water, it is suggested that in situations where water is scarce this is done at the marginal cost of providing the next unit of water (Beato and Vives 2010). The most efficient charge is one where it equals the marginal cost i.e. the cost of producing the next unit of water. The unit cost declines with more water being provided. But the cost of providing the next unit of water is less than the average cost of supply. If water charges are fixed at the marginal cost, revenue collected will not be sufficient to cover average costs. In that case charges should be set above the average cost (Beato and Vives 2010).

Special considerations should be made when setting water charges to the poor and under privileged communities. Some countries use a cross subsidization system to provide water at affordable rates for the poor. On the other hand countries like Indonesia set different water charges for different income groups. It charges high income groups more than the cost of providing water and uses the difference to cover the cost of providing water to the poor (UNEP, 2011).

Water conservation measures for households

Water conservation measures are measures that result in the reduction in the use and loss of water. Such measures would also result in the preservation of water quality. This may be achieved through improved water management techniques and practices that result in the efficient use of water and the reduction or minimization of loss of water.

Goals for water conservation measures should be to ensure the following:

- Sustainability of water resources in terms of availability for current and future generations. Use and extraction of water should not exceed the pace of its replenishment.
- Energy conservation, since it is estimated that in some regions of the world over 15% of energy consumption is attributed to water management.
- Reduction in water consumption, thus reducing the need to build water infrastructure facilities.
- Preservation of the ecosystem and the services it provides as a habitat for indigenous populations and plant varieties.

Water management measures include using a metering system. In Canada for instance such a system is used to cover about 61% of Canadian homes (Environment Canada, 2005). According to the US Environmental Protection Agency, introducing a metering system reduces consumption by 20 to 40% (EPA, 2010). Other measures include water saving sanitary equipment for water taps, showers, and toilets. It is estimated for example, that using conventional showerheads uses about 100 litres in five minutes compared to 35 litres using a water efficient showerhead. Using water efficient faucets and taps can save up to 50% of water used during hand washing. Other measures to conserve water is using saline or recycled water for flushing toilets and watering gardens These measures can also be introduced in government buildings, including schools, hospitals, as well as public and private offices (AFED, 2010). The introduction of water saving equipment in the US was reported to have resulted in savings of between 6%-14% in water demand (Mysiak, Fo, 2012).

Water conservation measures for irrigation

However, since most of the water consumption is by the agricultural sector, water conservation measures should lay emphasis on that sector. This is particularly important as the SMCs are expected to increase their agricultural activities to meet increased demand for food. Efficiency in the use of water in agriculture means reducing evaporation, surface drainage without negatively impacting production and productivity. As a matter of fact improved and more efficient use of water should increase productivity. The predominant irrigation practice in the SMCs is flood irrigation. It is estimated that drip irrigation saves between 40%-80% in water consumption. However, without government support shifting to more efficient and water saving irrigation techniques will be difficult (AFED, 2010).

Apart from supplying the population with needed food, efficient and more sustainable practices in the agriculture sector will reduce the import bill as well as subsidies paid by most governments of the region for basic foodstuff. Making water supply in excess of human consumption will enable the channelling of water to support economic activities such as agriculture, industry and tourism.

It is essential that the right balance be made between selecting the crop that uses the least amount of water and the one that fetches the highest market value. This decision will be based on a number of factors, including the extent to which water prices reflect the cost of supplying it. Moreover, research indicates that the use of treated water for irrigation has far outweighed costs. Benefits are represented in reduced cost of pumping and quantity of freshwater saved (Mysiak, 2012). In most of the SMCs water for farmers is provided free of charge. This can be viewed as a subsidy for farmers, which results in inefficient and wasteful irrigation practices. Studies in Spain for example have indicated that benefits of using wastewater for agriculture have outweighed the cost by about Euros 9.5 million/year (Heinz, Salgot, Davila, J, 2011).

Investing in ecosystem services

As mentioned earlier, water ecosystems are rapidly being degraded in many parts of the world. A number of countries around the world are investing in river restorations and introducing measures to reduce their degradation. Table 10 below shows estimated returns on investments in ecosystems.

Table 10: Examples of estimated benefits and costs of restoration projects in different biomes

Biome/ecosystem	Typical cost of restoration (high-cost scenario)	Estimated annual benefits from restoration (avg. cost scenario)	Net present value of benefits over 40 years	Internal rate of return	Benefit/cost
		US\$/ha	US\$/ha	%	Ratio
Coastal	232,700	73,900	935,400	11%	4.4
Mangroves	2,880	4,290	86,900	40%	26.4
Inland wetlands	33,000	14,200	171,300	12%	5.4
Lake/rivers	4,000	3,800	69,700	27%	15.5

Source: Adapted from TEEB (2009a)

Investing in freshwater supply and sanitation

Cost of achieving the Millennium Development Goals (MDG) is estimated at US\$ 142 billion annually for sanitation and US\$ 42 billion annually for drinking water (Hutton and Bartram, 2008). In terms of

returns on investments, Sachs found that the average growth rate in developing countries where most of the poor have access to clean water and sanitation was 2.7% higher than countries that lacked those services (Sachs, 2001). Analysis undertaken by Tropp (2010), Ward et al. (2010), Grey and Sadoff (2007) indicates that investment in water infrastructure is necessary for development. As argued by Schreiner et al. (2010) providing small scale water projects such as storage facilities with the involvement of local communities are in many instances effective solutions for the provision of water.

Accessing new (non-traditional) sources of water

Rather than the construction of large dams for the provision of water, there are a number of less expensive solutions. These include water capture and storage of storm water, condensation of water from fog, inter-basin transfers, and transport of water through pipelines. Other solutions include recycling of sewage. In Singapore for example sewage is being recycled to a level allowing it to be used for drinking. However, there is much opposition by household to use recycled sewage (Dolnicar and Scahärer, 2006). It should be noted that some of these solutions are energy intensive thus increasing the cost of water produced per unit. They are still however less energy intensive as compared to desalination, as the latter is the most energy intensive solution consuming double that of sewage recycling. Though in both cases the RO technology is used (Coté et al., 2005). Given the cost of these solutions, it is cheaper to invest in demand control measures (Beato and Vives, 2010).

Producing more food and energy with less water

Given that agriculture consumes at least three quarters of water consumption, crop productivity should increase in order to meet increased demand on water and food. In many developing countries Maize yield is in the range of three tonnes per hectare. It can for example reach as high as eight tonnes with improved cultivation practices (UNEP, 2011). Moreover, the issue of virtual water should also be seriously considered in this context.

Water and Energy

There is a close relationship between water and energy. Water is needed as a coolant for power plants. In the USA for example about 40% of water used by the industry sector is used by power plants. It is expected that by 2030, 31% of water for industrial use will be needed for power plants.

Moreover, energy is also needed for the provision of water and sanitary services. As water is heavy, large amounts of energy is needed to lift and pump water over long distances. Cost of providing water for irrigation is relatively high compared to the financial returns from agricultural produce. It is therefore essential that water treatment and distribution systems provided for agricultural activities, particularly in developing countries can be provided at reasonable rates.

Reduction in virtual water exports (rice, cotton, sugar cane, etc.)

The water content of crops or virtual water has increasingly been given wider attention with increased concerns over water scarcity. The issue is being debated within the context of international trade and food security. As much as countries are concerned about food security and the need to satisfy increased demand, this should to be strategically decided upon based on the water content of crops. The same argument is true whether the crop is either exported or imported. The question then is what weights a country would give to the production of a staple food crop such as rice or wheat to ensure food security vis a vis importing these crops, thus reducing water consumption. It is estimated for example that one ton of rice uses about 4000m³ of water, and one ton of wheat uses about 1334 m³ of water, while one ton of potatoes uses about 255m³ (AFED, 2011). With increasing water shortages, countries in the region would have to optimize the allocation of available water resources against the different crops based on the water content of the crop and based on their preparedness to rely on imports. Growing low water content crops and importing high content ones contributes to the efficient use of water and increases water availability. Section IV provides estimates of savings resulting from growing a low water content crop such as potatoes vis a vis a high water content crop such as wheat.

Research so far undertaken reveals that there is no one simple solution to water scarcity. It is becoming evident that the responses to water challenges have to include a package of measures.

Increased economic activities due to water savings will result in job creation in the different sectors, thus absorbing an increased number of unemployed in the region. This will contribute to more social cohesion and integration of a larger segment of the population in economic activities. Social integration and justice are considered to be one of the main concerns and reasons that have sparked the uprisings in a number of SMCs. Creating jobs for the unemployed and lifting a larger percentage of the population from abject poverty will go a long way to providing a stable and more predictable environment for investment and development in the SMCs. Table 11 shows the projected changes in water supply based on a 2% of GDP investment in the water sector as well as the change in employment.

Table 11: 2% GDP invested in green sectors

	Unit	2030	2050
Additional investment in water sector	US\$ Bn/year	191	311
Additional water from desalination	Km ³	27	38
Water from efficiency improvements	Km ³	604	1,322
Total employment in water sector	Mn people	38	43
Change in total employment in water sector relative to BAU 2*	%	-13	-22

*BAU refers to the BAU scenario with an additional 2% of global GDP per year invested according to current patterns and trends.

IV. Examination of opportunity cost analysis of desalination versus technical efficiency and allocative efficiency

Cost of providing water by desalination

The cost of supplying desalinated water has been gradually decreasing as technologies advance. As earlier stated, the technology most used for desalination is RO. This is due to its efficiency and relative cost effectiveness. The average capital cost for a plant supplying 20,000m³/day is about US\$ 30 million for a seawater plant and about US\$ 12 million for a brackish water desalination plant. These figures are derived from a study by Wittholz, where cost for a SWRO plant with capacity 10,000m³/day and 50,000m³/day, were estimated at US\$ 20.1 million and US\$ 74 million respectively. Thus, US\$ 30 million is used as an approximation for a plant supplying 20,000m³ of water. Operating costs are estimated at about US\$ 5.1 million (0.7 x 20,000 x 365) and US\$1.8 million (0.25 x 20,000 x 365) for SWRO and BWRO respectively.

A large share of the operating cost is attributed to energy. This results in increased cost of operation as well as the cost of environmental damage resulting from CO₂ emissions. Estimates will be calculated on the basis of the different sources of energy used. Global average energy requirement

for a desalination plant of 6.09 kWh/m³ will be used (Wittholz, 2007). For each source of energy, a distinction is made between direct cost of energy and those resulting from the potential environmental damage. Prices used are those provided by the Nuclear Energy Institute (NEI) in the United States. In case of coal for example US\$ 0.032/ kWh is used resulting in about US\$ 1.42 million annually in terms of energy consumption (44,457,000 x 0.032; 44,457,00 = 20,000m³ x6.09kWh x365). Environmental costs are estimated using calculations by CASES for CO₂ emissions referred to earlier in the study. In case of coal, it is estimated that 5481 grams of CO₂ are emitted per m³ of water supplied. Using the estimated figure provided by Becker et al., (Table 3) cost of environmental damage of CO₂ per gram is estimated at US\$ 0.00001939 (US\$ 19.39/1,000,000)*. Using this figure will provide us with an annual environmental cost of operating a desalination plant with a capacity of 20,000m³ of US\$ 775,325 ((0.00001939 x 5481) x 20,000 x 365). Direct and indirect costs of the other sources of energy are shown in Table 12 and are calculated using the same rationale.

Another indirect cost to be considered is the increased level of subsidy that will need to be incurred by the government to make up for the increased cost of supplying desalinated water. In Egypt for example the cost of supplying water is US\$ 0.166 of which US\$ 0.133 is the amount of subsidy. Thus, at these prices, for a plant of 20,000m³ the subsidy is estimated at about US\$ 970,000 annually (0.133 x 20000x365). An increase in prices of at least US\$ 0.7 per m³ would lead to a total subsidy of about US\$ 4.8 million ((0.7-0.033) x 20000 x 365), an increase of about US\$ 3.9 million (4.8 – 0.9).

Table 12 shows the total direct and indirect costs for each source of energy, generating electricity needed for a desalination plant with a capacity of 20,000m³. Prices are subject to the prevailing prices in each country, but for the sake of the study, average prices from the US were used, as no data was available for the SMCs region.

Table 12: Direct and indirect energy costs in US\$

<i>Energy</i>	Coal	Natural gas	Fuel	Nuclear	Solar	Wind
44,570,000 (kW/year)	1,422,624	2,005,011	9,584,929	973,608	6,668,550	3,867,759
<i>Environmental effects</i>	775,325	318,702	\$534,000	2,546	-	-
<i>Total</i>	2,197,949	2,323,713	10,118,929	976,154	\$6,668,550	3,867,759

Table 13 below shows total cost of desalination plants using differed energy sources (cost of fossil fuels and nuclear between US\$ 0.5 to 0.8), as well as environmental costs. For wind and solar energy cost are in the range of US\$ 0.9 and US\$ 1.5 respectively.

Table 13: Cost of desalination plants by source of energy and environmental costs in US\$

	Coal	Oil	Natural Gas	Nuclear	Solar	Wind
Operating cost of a desalination plant	5,110,000	5,110,000	5,110,000	5,110,000	7,950,000	6,570,000
Energy Cost	1,422,624	9,584,929	2,005,011	973,608	6,668,550	3,867,750
Environmental	775,325	534,000	318,702	2,546	0	0

* US\$ 19.39 per ton was divided by 1,000,000 in order to have the cost per gram.

	Coal	Oil	Natural Gas	Nuclear	Solar	Wind
cost						
Total	5,885,325	5,644,000	5,428,000	5,112,546	7,950,000	6,570,000

Table 14 below shows the net present value of the stream of costs and benefits of supplying desalinated water (both seawater and brackish) over a 20 years period. A social discount rate of 3.5% was used in the calculations.

Table 14: Benefits and costs of supplying water through desalination

Measures	Costs US\$	NPV US\$
Capital Costs	30 million SWRO 12 million BWRO	60 million SWRO 24 million BWRO
Operating Costs	5.1 million SWRO 1.8 million BWRO	72 million SWRO 26 million BWRO
Energy	44,570,000 (kW/year)	
Coal	1,422,624	20 million
Natural gas	2,005,011	29 million
Fuel	9,584,929	136 million
Nuclear	973,608	14 million
Solar	6,668,550	95 million
Wind	3,867,759	55 million
Environmental impacts		
Coal	775,325	11 million
Natural gas	318,702	4.5 million
Fuel	534,000	7.5 million
Nuclear	2,546	36 thousand
Solar	-	
Wind	-	

Costs and Benefits of Water Supply through Technical and Allocative Efficiency

Based on available data, this section will provide a cost estimate in supplying 20,000 m³/day for a hypothetical community through technical and allocative efficiency.

If we were to use the annual average water consumption for the MENA region of 1000 m³/year, our hypothetical community will be around 7,300 inhabitants. Using world average water, annual water consumption of 6000 m³, we are then talking of a community comprising of about 1216 inhabitants. For the purpose of this study we will use the average water consumption for MENA rounded up to 3m³/day. We will also assume that the new community is being developed close to a larger community of a population of say about 500,000 inhabitants. Water needed for inhabitants of the new community is mainly for domestic use only. Introducing measures to enhance technical and allocative efficiency will involve costs as well as benefits accruing to the entire population living in the neighbouring city and the new community.

- § In order to supply the new community with 20,000m³/day of freshwater a decentralized wastewater plant is proposed. It is estimated that the cost of the plant will range between

US\$ 4 million – US\$ 6 million depending on the kind of technology used and quality of reclaimed water. Operating cost is estimated to be between US\$ 0.10-0.19 m³ depending on the type of technology used. A round figure of US\$ 0.2 will be used for the purpose of our calculations in order to take into account expected increased cost of labour and energy.

- ☒ For the purpose of this analysis US\$ 5 million for constructing a wastewater treatment plant to provide 20,000m³ daily for the hypothetical community will be used. Operating cost is estimated at US\$ 1.5 million/annually (US\$ 0.2 x 20,000m³ x 365).
- ☒ Improving water governance structure and institutions involved in the management of water supply system as well as introducing the necessary regulatory framework will involve costs represented in human hours spent. Time involved includes the development of regulations, work procedures that ensure transparency and accountability, monitoring, enforcement and compliance. In order to accomplish this task, it is assumed that about 10 staff members will be involved over a four months period. This will approximately cost US\$ 60,000 (4 months 10 staff members x US\$ 1,500). Functions preceding the initial activities related to the upgrading of the governance system should be performed by staff budgeted for by the national institutions.
- ☒ Efficiency in the use and allocation of water resources due to better governance and regulatory framework is expected to result in more freshwater being made available. If we assume an efficiency of at least 10% in water savings, it is estimated that around US\$ 11 million will be saved each year (3m³/day x 507,300 population x 10% savings in water x US\$ 0.2 x 365 days).
- ☒ In terms of improved health due to the provision of clean water and sanitation to the community, country experiences indicate an estimated increase of 2% in GDP. Savings due to improved health conditions of the inhabitants of the new community and the adjacent larger community of 500,000 was calculated based on the % share to the total population and GDP using the 2% estimate for the project countries. Taking the average GDP will give a rough estimate of US\$77 million annually.
- ☒ Efficiency in the supply of water will create employment in agriculture, industry and tourism. This is due to more water being made available offsetting the reduced labour in the water sector. If we assume that the additional water supply of treated water amounting to about 547,500,000m³ (500,000 inhabitants x 3m³/day x 365 days) is directed to the agriculture sector that should result in additional jobs created in that sector.
- ☒ The amount of water made available for agriculture can be used to grow 2,150,000 tons of potatoes (547,500,00 m³ ÷ 255 m³/ton). This quantity of water if used to cultivate wheat would only produce about 410,000 tons of wheat (547,500,00÷1,334m³/ton) (Chapagain and Hoekstra, 2004). World prices of potatoes range from US\$ 100- 200, while that for wheat is about US\$ 270 (World Bank, 2012,). While due to the relatively high cost wheat fetches in the market it is more profitable to grow potatoes rather than wheat.
- ☒ Now, assuming that the smaller community requires 7.3 million m³ of water annually (20,000m³ x 365) leaves approximately 540 million m³ to the larger community. This amount of water can produce 2,118,431 tons of potatoes (540,200,000÷255) resulting in about US\$ 318 million (2,118,431tons x US\$ 150) in revenue, an increase of about US\$ 208 million from using all of the water only for wheat. This figure is based on the estimated amount of agricultural land in the proposed new community and does not include agricultural land, which may also be available in the adjacent population centre. These calculations do not also capture the benefits accruing from savings in the use of pesticides due to improved irrigation methods.

- ☒ In case 410,000 tons of wheat was imported using revenue generated from the sale of potatoes, then US\$ 208 million will be generated in excess. This excess is equivalent to an increase in water content of 1.040 billion m³ (US\$ 208 million ÷ US\$ 0.2).
- ☒ Apart from influencing attitudes towards more sustainable consumption and production patterns, economic instrument should be designed to capture a higher percentage of the recover cost of supplying freshwater. They should also be designed in such a way that it does not result in increased burden for the poor and low-income groups, where water provided for this category of consumers would have to continue to be subsidized. However, higher water charges should be charged for high-income groups as well as sectors such as tourism and industry. An increase in water charges by 10% to the richest 20% of the economy could generate an additional cost recovery of US\$ 445,000 annually (3m³/d x 101,460{507,300 x 0.2} x US\$ 0.004{0.04 x 10%} x 365 days).
- ☒ Water conservation programmes include installing water conservation equipment and systems in buildings. It is estimated that the introduction of these equipment in buildings and houses in existing housing stock estimated at 126,825 units (507,300÷4 average family size) can cost between US\$ 2,500 to 5,000 per unit i.e. between US\$ 317 million and US\$ 634 billion. For the purpose of this analysis we will use the average cost of US\$ 475 million.
- ☒ Regarding irrigation efficient and saving equipment (drip irrigation system) this is estimated to cost US\$ 2,500 per hectare. Cost estimated to grow about 350,000 tons of potatoes is about US\$ 311 million (2,118,431 tons divided by 17 world average tonne/hectare x US\$ 2,500 cost/hectare of installing new equipment).
- ☒ Savings resulting from investing in water conservation programmes for municipalities is expected to result in reduction in water consumption for households estimated at between 10%-20% amounting to 83 million m³ (507,300 population x 3m³/d x 365 days x -15%). Thus resulting in savings amounting to US\$ 17 million annually.
- ☒ Savings resulting from investing in water conservation in the agriculture sector due to the installation of a drip irrigation system for example is expected to result in between 40%-80% of savings in water consumption. This could save between 220 million m³ and 440 million m³ i.e. between US\$ 44 million and US\$ 88 million annually. Using an average between the two figures gives us an approximate figure of US\$ 66 annually.
- ☒ It is estimated that generally about 15% total energy consumption is allocated to the water sector. Efficiency in the use of water should result in energy savings. Between 5%-10% per m³ of water produced goes to energy. A saving of 5% in energy consumption could result in savings of US\$ 5.5 million annually (3m³ x 507,300 x 365 days x 0.2 x 0.05). Water saved due to efficiency measures will be used to support activities in other sectors.
- ☒ Other expected benefits in the agriculture sector are improved productivity and yields. This will enhance competitiveness of crops and access to international markets thus resulting in an increase in foreign external earnings. Improved irrigation and production methods could result in an increase in productivity of between 20%-30% i.e. 530,000 additional tons of potatoes (2,118,431 tons of potatoes x 25%). Using world market prices of potatoes of US\$ 150/ton would result in US\$ 80 million annually.
- ☒ Investment in infrastructure to capture rainwater, recharging natural aquifers, and in the proper maintenance of pipeline networks will vary according to the number of dams close to natural aquifers and the length of the water pipelines. Costs involved may range between 15% -25% of cost of supplying freshwater of US\$ 0.2/m³. If we use an average figure of 20% of unit cost we get a total capital cost of US\$ 22 million (507,300m³ x 3m³ x 365 x 20% x US\$ 0.2) measures will result in an increase in water availability resulting from an increase in underground water, which could otherwise have been wasted as well as saved water due to reduced water leakages from the network. If we assume that this will result in about 15%

increase in water supply for the new community and the adjacent population centre, 83m³ million/annually (507,300 x 3m³ x 365 x 15%) i.e. about US\$ 17 million annually (83 million tons of water x US\$ 0.2/m³). It will also result in savings in terms of reduced cost of additional capacity of plants supplying freshwater, and in the reduction of energy needed to provide water.

- Reclaimed water provided by a new wastewater treatment plant will provide 20,000 m³ of treated water for irrigation, thus releasing the same amount of freshwater for domestic use. The entire amount of treated water could be used for irrigation purposes and freshwater needed for domestic use to be supplied through savings in water use resulting from technical and allocative efficiency.

Table 16 shows the estimated costs and benefits of supplying water through technical and allocative efficiency. A 3.5% social discount rate over a period of 20 years was used to arrive at the NPV.

Table 16: Estimated Benefits and Costs of Water Supply through Technical and Allocative Efficiency

Measures	Costs US\$	NPV of Costs US\$	Benefits (Annual) US\$	NPV of Benefits US\$
Capital cost of wastewater treatment plant	5 million	10 million		
Operational costs (Annual)	1.46 million	21 million		
Governance and regulatory framework	60,000	120 thousand		
Installing of conservation equipment and systems (households)	475 million	945 million	17million	240 million
Installing of drip irrigation using the assumptions in the study	311 million	618million	66 million	938 million
Capturing of rain water, recharging natural aquifers etc.	22 million	44 million	17 million	240 million
Energy Efficiency			5.5 million	80 million
Use of crops with lower virtual water content such as potatoes			208 million	3 billion
Increased productivity in agriculture (assuming 25%)			80 million	1.1 billion
Increase in water charges by 10% for high income or tourism			445 thousand	6.3 million
Annual saving through increased efficiency due to better governance			11 million	156 million

Measures	Costs US\$	NPV of Costs US\$	Benefits (Annual) US\$	NPV of Benefits US\$
Total	814 million		404 million	
Total NPV		1,638 million		5,760 million

Calculations reveal that supplying 20,000m³/day through technical and allocative efficiency result in net benefits over costs amounting to about US\$ 4.122 billion. Cost of supplying the same amount of water through desalination is estimated at US\$ 203.5 million using fuel as the main source of energy and US\$ 91 million using coal for SWRO. For BWRO the figures are US\$ 167 million and US\$ 55 million for fuel and coal respectively. These estimates are calculated on the basis of US prices for energy. Estimates for benefits resulting from improved health were not included in both cases.

V. Guidelines on performing opportunity cost analysis for desalination

This section provides an outline of steps to be followed when calculating the opportunity cost of a desalination plant. The analysis in this section will identify and estimate the costs of foregone benefits that may occur as a result for opting for supplying water through desalination. In doing so it will identify measures and policy interventions that are required to achieve technical and allocative efficiency and suggested means of estimating costs involved and potential benefits.

This section should be read in conjunction with sections II and III providing an analysis of the socioeconomic and environmental costs of desalination plants and of alternatives under technical and allocative efficiency respectively, as well as section IV examining the opportunity cost of desalination versus technical efficiency and allocative efficiency.

Cost and benefits of supplying water through desalination

The analysis made under section II provided the basis and rationale for estimating the direct and indirect costs, including socioeconomic and environmental costs involved in supplying water through desalination. Costs arrived at would be evaluated against the foregone benefits resulting from opting for desalination as opposed to technical and allocative efficiency.

In order to estimate the socioeconomic and environmental cost of desalination, the starting point is to identify the potential direct costs and benefits. Costs involved can be classified into capital and operating costs, and those will depend on the capacity of the plant, location, technology used, and type of energy used. As indicated earlier since desalination is energy intensive, the potential of using solar energy should be considered. Even though initial capital cost for solar may be higher, it results in long term benefits in the form of reduced energy cost, and environmental benefits derived from reduced CO₂ emissions and impacts on health and the environment.

Benefits resulting from satisfying freshwater needs generally include improved sanitation and health. This results in increased productivity of workers as well as number of days spent on productive activities, and reduced medical bill due to the reduced negative impacts on health. A brief account on the different tools and methodologies for the economic valuation of the environment are provided in this section.

Table 17 below lists the potential costs and benefits of supplying water through desalination.

Table 17: Benefits and Costs of providing desalinated water

<p>Capital and operating costs</p>	<p><i>Benefits</i></p> <p>Increased supply of freshwater to meet domestic demand</p> <p>Increased activity in other sector (agriculture, industry, tourism) due to increased availability of water</p> <p>Increased contribution to GDP</p> <p><i>Costs</i></p> <p>Cost of constructing the desalination plant, including cost of land</p> <p>Cost of operation, including cost of energy, labour cost, spare parts and maintenance</p> <p>Government subsidies</p>
<p>Environmental Implications</p>	<p><i>Costs</i></p> <p>Increased CO₂ emissions with negative impacts on climate</p> <p>Impacts on coastal and marine life, including impacts of discharge of brine in the sea</p> <p>Impacts on wetlands, mangroves, forests, and biodiversity</p> <p>Impacts on desertification</p> <p>Noise pollution</p>
<p>Social Implications</p>	<p><i>Costs</i></p> <p>Increased medical cost due to increased incidence of disease due to increased CO₂ emissions resulting from increased economic activities</p> <p><i>Benefits</i></p> <p>Increase in number of jobs created to build and operate the desalination plant</p> <p>Increased number of jobs in other productive sectors due to increased water availability in other sectors</p> <p>Improved health conditions due to availability of clean freshwater</p> <p>Increased productivity of labour force due to better access to water and sanitation</p>

Cost and benefits of good governance and regulatory framework

A necessary prerequisite to achieve technical and allocative efficiency is to ensure good governance and adequate regulatory frameworks involving the different sectors (water supply, agriculture, industry, tourism, municipalities, urban and physical planning). An assessment of current regulatory frameworks and governance structures should cover economic, environmental and social costs and benefits of existing regulatory an institutional setups. Regulatory frameworks targeting water should be designed to encourage the efficient use and allocation of water resources to the different sectors. They should be designed to maximize the use of water per unit of output, enhance economic activity in the different productive sectors, promote unsustainable patterns of consumption and production, encourage the use of treated wastewater for irrigation and industry, and restrict pollution of rivers, and the depletion of underground water and aquifers.

The socioeconomic and environmental implications of regulations should be identified and their implications fully assessed. Distributional and equity consideration should be taken into account in order to avoid placing an extra burden on the poor and lower income groups. A public consultation and participatory process should be adopted in the design of regulatory framework. This will ensure that the concerns and priorities of the different stakeholders are taken into account.

Good governance and efficient institutions are necessary to ensure the sound and sustainable management of water resources. This involves ensuring transparency and accountability in the functioning and operation of different institutions involved in management and use of water resources. Lines of command and responsibilities and coordination mechanisms should be clear and well established.

Costs involved will be country specific and will depend on the level and quality of institutions and regulatory frameworks available. It will depend on whether new institutions are required or current ones need to be restructured, and the level of intervention to provide efficient ones. Costs should include work days spent on the assessment of current institutions and regulatory frameworks, proposals for the types of institutions and regulatory frameworks needed, and their review and development.

Cost of administering, monitoring, and ensuring compliance to regulations

Key in overseeing the implementation of regulatory frameworks, monitoring, and ensuring compliance are qualified and well trained professionals. Strengthening national capacities and upgrading of staff may be needed depending on existing capacities. Estimates for the cost involved in conducting public consultations and awareness campaigns, monitoring, and compliance, and the strengthening of national capacities should be estimated.

Economic benefits resulting from regulations in terms of efficiency gains, and contribution to increased output of a product per unit of water input should also be estimated. This should cover the different sectors referred to above. This should be translated into savings in water use and increased contribution to GDP in terms of increased output per unit cost of water.

At least a 10% savings in water consumption can be captured from good governance and improved level of performance of institutions as a result of more efficient use and allocation of water resources. Estimated savings du to efficiency gains will depend on the level and quality of intervention and the effectiveness of the proposed regulatory frameworks and functioning of institutions.

Use of economic instruments, application of full service cost recovery and through allocative efficiency

Economic instruments are increasingly being used to support command and control mechanism to achieve environmental objectives. Well-designed and implemented economic instruments can be effective tools in promoting the allocation and use of water resources. As referred to in section III they can be used to operationalize the PPP and UPP hence influencing behaviour towards more sustainable consumption and production patterns of water. Internalizing externalities in water charges apart from promoting the judicial use of water will result in increased revenue for governments that can be channelled to support investment in the water infrastructure. Cost of designing, introducing, and monitoring the implementation of economic instruments should be captured. Benefits derived to be based on the extent to which the introduced measures are likely to result in efficiency gains in the use and allocation of water amongst competing uses. Governments may decide to increase the recovery rate of supplying water by 10% on certain users such as industry and tourism and high-income groups. It is essential that equity and distributional considerations be taken into account when setting water charges.

Cost for the construction and operation of a wastewater treatment plant

Freshwater is mainly provided from underground aquifers, precipitation, or water bodies. Underground aquifers could either be non-replenishable or the rate of extraction of water may be faster than the rate of replenishment. Rate of precipitation is affected by climate change, which also has an impact on increased rate of deforestation, desertification, and forest cover thus impacting water availability. It is therefore more rational to direct investment to wastewater treatment to maximize the use of available water resources. Capital cost of constructing a wastewater treatment plant as well as operating cost depends on the capacity of the plant. The larger the plant's capacity the lower is the unit cost of supplying water. In order to estimate cost of supplying water, the NPV of the capital and operational cost over a 20 years period may be calculated to obtain the current value for constructing and operating the plant. A social discount rate of 3.5% may be used to calculate the NPV.

Benefits resulting from increased competitiveness and trade

Efficient use of water reduces the overall costs of the final product. This results in increased competitiveness of final products, which opens up new market niches. Increased competitiveness results in a larger volume of trade and contributes to a positive balance of payments, creates employment opportunities, and contributes to GDP growth. Income expected to be generated from increased competitiveness and trade should be estimated and translated into financial gains, as well as projected increase in GDP calculated and included as part of the foregone benefits in investing in desalination. System dynamics models can be used to estimate impact of gains from efficient use of water on economic activities, employment, balance of payment, and GDP

Benefits resulting from improved access to education and productive activities

Less time spent on fetching clean water, particularly by women means more time that can be spent on education and productive activities. This in turn contributes to an increased percentage of the population receiving education and engaging in productive activities. The result is a positive impact on GDP. The percentage of the population affected by increased access to water and sanitation can be calculated based on the additional water supply to be made available. Based on that, the number of adults to be engaged in productive activities can be estimated and their contribution to GDP calculated based on national figures.

Increased land and property values as a result of a better environment

Regulations penalizing the dumping of industrial and domestic waste in water bodies results in clean rivers. Improved landscaping, and the provision of recreation areas, and space may also accompany this for pedestrians and cycling. This can result in increasing the value of properties and a source of

income for municipalities. Increase in land and home values will depend on a number of factors, including the quality and extent of development. Benefits resulting from an improved environment may accrue to individual owners or to the government.

Benefits resulting from improved health

Providing clean water and sanitation improves health conditions of the population, particularly for the poor and underprivileged communities lacking access to clean water and sanitation. Benefits are derived from increased productivity of the labour force, reduced incidence of disease, reduced cost of medical bill, cost of building hospitals, clinics, and medicine. Country experiences indicate that improved health due to better water and sanitation increases GDP by 2%.

Social benefits in the form of additional number of jobs created

Though efficiency in the management of water resources is likely to result in a reduction in labour requirements, it is also likely that additional jobs are created in other economic sectors due to additional water supply made available to these sectors. Regulations may entail changing production processes in the different sectors to promote efficient use of water, avoidance or reduction of wastage of water. It may also involve requirements for treatment and water recycling which results in direct job creation. Reduction in labour in the water sector due to increased efficiency in the sector is likely to be absorbed by jobs created in other sectors due to the availability of water. It is therefore useful to be aware of the composition and structure of the labour force, and requirements for the different sectors in order to predict the labour movement between sectors and the net effect resulting from water efficiency.

Reduced cost of supplying freshwater

Laws requiring farmers to use recycled treated water for irrigation will reduce pressure on freshwater. The result is reduced cost of supplying freshwater for domestic consumption, and other uses such as industry and tourism. In other words the opportunity cost in this case is the savings in freshwater that can be channelled for other uses. Moreover, using treated wastewater for agriculture reduces the need for fertilizers and increases crop yields. Cost of supplying freshwater should be calculated based on the amount of treated wastewater supplied and the unit cost of providing freshwater. Increased crop productivity may be captured when calculating efficiency gains in agriculture.

Benefits of water conservation measures in the agriculture sector

It is estimated that at least 70% of water consumption in the SMCs is used by the agricultural sector. In Egypt that percentage reaches up to 85% of the water supply in the country. Measures to conserve water include installing water meters for irrigation and the use of drip irrigation and centre-pivot irrigation equipment. It is estimated that these measures alone result in large savings in water consumption estimated at about 40% over conventional irrigation systems. Installing meters would also enable governments to measure the amount of water consumed and collect charges accordingly. Savings in water consumption and additional income accruing to the government from collecting charges are benefits resulting from conservation measures, which should be accounted for.

Benefits resulting from saving in the use of virtual water

Selecting the kind of crops to be cultivated for domestic consumption and trade is important in maximizing the utilization of water resources. The selection of crops should be decided upon based on the least intensive water consuming crop varieties. In other word, available water supply should be used prudently to maximize yields as well as value of end product. Cultivating low water intensity consuming crops and importing high intensity water consuming crops results in maximizing available water supply in the country. Strategically planned in a manner that does not compromise water and food security can result not only in savings in the use of water, but also in increasing the amount of water supply. Once a decision is made on the kind of crops that should be cultivated and those that

would need to be imported, the volume of water saved and important can be estimated and costs calculated. The associated savings in energy should also be calculated.

Financial flows generate income for the government and can therefore provide a good source for funding water and sanitation projects

Income generated due to the introduction of taxes, fees, and charges on water use as well as on polluting water bodies from the various sectors can be calculated and reflected as part of the opportunity cost for constructing a desalination plant. Cost of administering, monitoring, and collecting taxes, fees, and charges should be deducted from income generated and collected.

Benefits of water conservation in the household sector

It is estimated that about 8% of total water use is for domestic consumption. Introducing household equipment and devices is estimated to cut down on water consumption by that sector by 15%. Costs of installing water saving devices, which will vary according to the quality of devices and equipment installed, should also be calculated. These are one off initial costs, while the savings in water consumption are annual. Other measures in water savings are the use of recycled household wastewater for flushing and irrigating gardens. This involves the installing of the necessary piping systems in buildings.

Benefits in the reduction of energy use

It is estimated that roughly 15% out of the total energy use in most countries is used in water management projects. This percentage share will increase in case the predominant water supply facilities are desalinated plants. Efficient and improved management systems should result in energy savings. Efficient management systems and conservation measures may result in energy savings of about 5% out of the total estimated share of 15% of energy in water management projects. This cost will vary depending on the source of energy and the type of water technology used. The use of solar energy should be promoted as the main source of energy for supplying water. Factoring in the positive impacts of reduced energy use and CO₂ emissions is expected to offset the relative increase in initial capital cost for solar energy in the long run.

Benefits resulting from investing in ecosystems

Costs involved in ecosystem conservation vary depending on the biome in question. Different biome, which contribute to freshwater conservation in addition to rivers include wetlands and mangroves. Benefits derived will depend on the extent and effectiveness of the conservation project. Since ecosystems are an essential source of freshwater supply the proper conservation of these systems are vital in ensuring a sustained supply of freshwater. Benefits derived from such investment should therefore be captured in calculating the opportunity cost of water desalination. Economic valuation methods such as contingent valuation and WTP and WTA may be used to arrive at the benefits from investing in the ecosystem.

Access the costs and benefits of new (non-traditional) sources of water

Non-expensive solutions for the provision of water referred to earlier include water capture and storage of storm water, condensation of water from fog, inter-basin transfers, transport of water through pipelines or Medusa bags. Costs and benefits of these measures should be calculated and included in estimating the opportunity cost of desalinated water.

Estimate the costs and benefits of investing in water infrastructure

These include investment in rainwater capture infrastructure such as dams for the recharging of natural aquifers. It also includes the continuous maintenance of the pipeline network. Cost will depend on the number of dams and aquifers to be recharged and the length of the water pipelines.

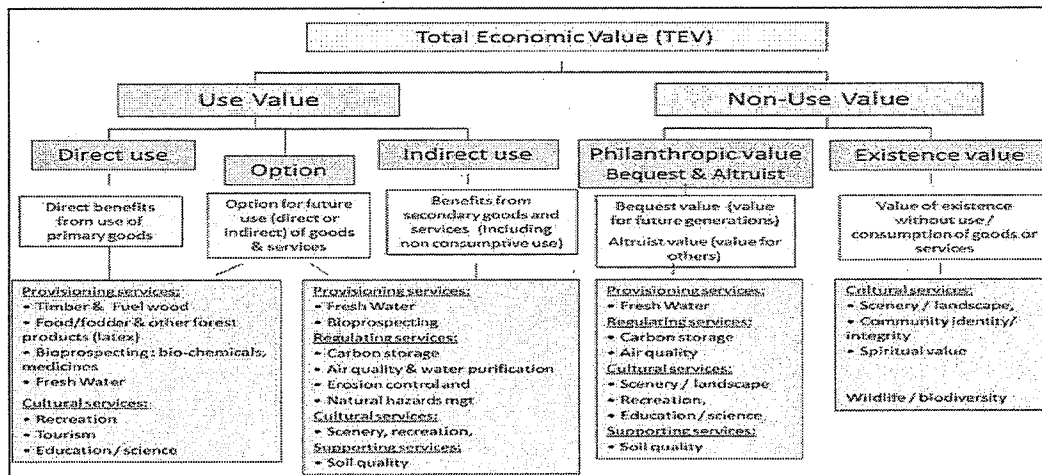
Regarding benefits, a percentage of at least 15% increase in water supply resulting from these investments may be used.

Economic values of the environment

Valuation methodologies have been used to estimate the cost and benefits of projects on the environment. The concept of economic valuation of the environment is grounded on the principle of welfare economics. It is based on the people's willingness to pay (WTP) or willingness to accept (WTA) (Hanemann, 1991; Shorgen and Hayes, 1997). Measuring economic values may be done on the basis of observed behaviour. These are divided into direct and indirect behaviour method. The former can use market prices, where the environmental impacts are on goods and services traded in the market. The indirect observed behaviour also uses observed behaviour but not for goods traded in the market. Valuation method used here is referred to as hedonic pricing method, which uses statistical techniques using implicit prices of the attribute of a product such as clean water, air and a travel cost method. The latter uses observed travel cost to reach a specific destination of value to the user. It also includes cost-based methods such as the replacement cost method, which values services provided based on cost of replacing it by the proposed project.

Another economic valuation technique is based on hypothetical behaviour. This includes direct hypothetical valuation called contingent valuation and indirect hypothetical measures of WTP and WTA. Benefit transfer is also used to value economic benefits of the environment. This method simply uses estimates derived in one context to estimate values in another context. Though such a tool has been controversial, it has been accepted as a reliable tool if carefully applied in case the contexts are close enough and in hypothetical situations where no observed practices are available (Silva, Pagiola, 2003). Figure 2 below shows the different economic valuation tools for the environment.

Figure 2: Economic valuation Tool



Source: White et al, 2011, adapted from Kettunen et al (2009), adapted from Pearce & Moran 1994

Table 18 below summarizes the different costs and benefits that need to be considered when estimating the opportunity cost of desalination water, which is also represented in Figure 3.

Table 18: Benefits and Costs of Technical Efficiency and Allocative Efficiency for Water Supply

Improved governance and institutions Improved regulatory frameworks	
<i>Costs</i>	<i>Benefits</i>
Cost of compliance, monitoring, and enforcement	Reduction in amount of funds required for investment in water supply plants by a factor of 4
Cost of developing procedures that ensures good governance, transparency, and accountability	Postponement of investment in more expensive water desalination projects
Cost of formulating regulatory frameworks that ensures coherence between regulations related to different sectors as well as market incentives	Reduced subsidies paid by government for supplied water
Cost of strengthening national capabilities to formulate regulator frameworks that promotes the efficient use and allocation of water resources, monitoring, and compliance	Improved health (savings estimated at about 2% of GDP)
	Employment generated in agriculture, industry and tourism due to more water being made available sufficient to offset reduced labour in water sector due to efficiency
Use of economic instruments	
<i>Costs</i>	<i>Benefits</i>
Cost of enhancing local capacities in the design and implementation of economic instruments for the efficient and sustainable use of water resources	Increase in rate of cost recovery from industry, tourism, and high-income families is expected to result in a 20% additional revenues being generated
	Influencing consumption patterns towards more sustainable water consumption practices resulting in water saving of between 15%-25%
Water conservation programmes for municipalities	
<i>Costs</i>	<i>Benefits</i>
Cost of installing water saving equipment and devices in government public buildings (offices, schools, hospitals, post offices, etc.,) private houses and buildings	Sustainability of water resources in terms of availability for current and future generations
	Reduces the need to build water infrastructure facilities
	Reduction in per capita water consumption that could result in savings between 10%-20% water savings for households
	Estimated reduction of at least 5% savings out of the total 15% of energy attributed to water

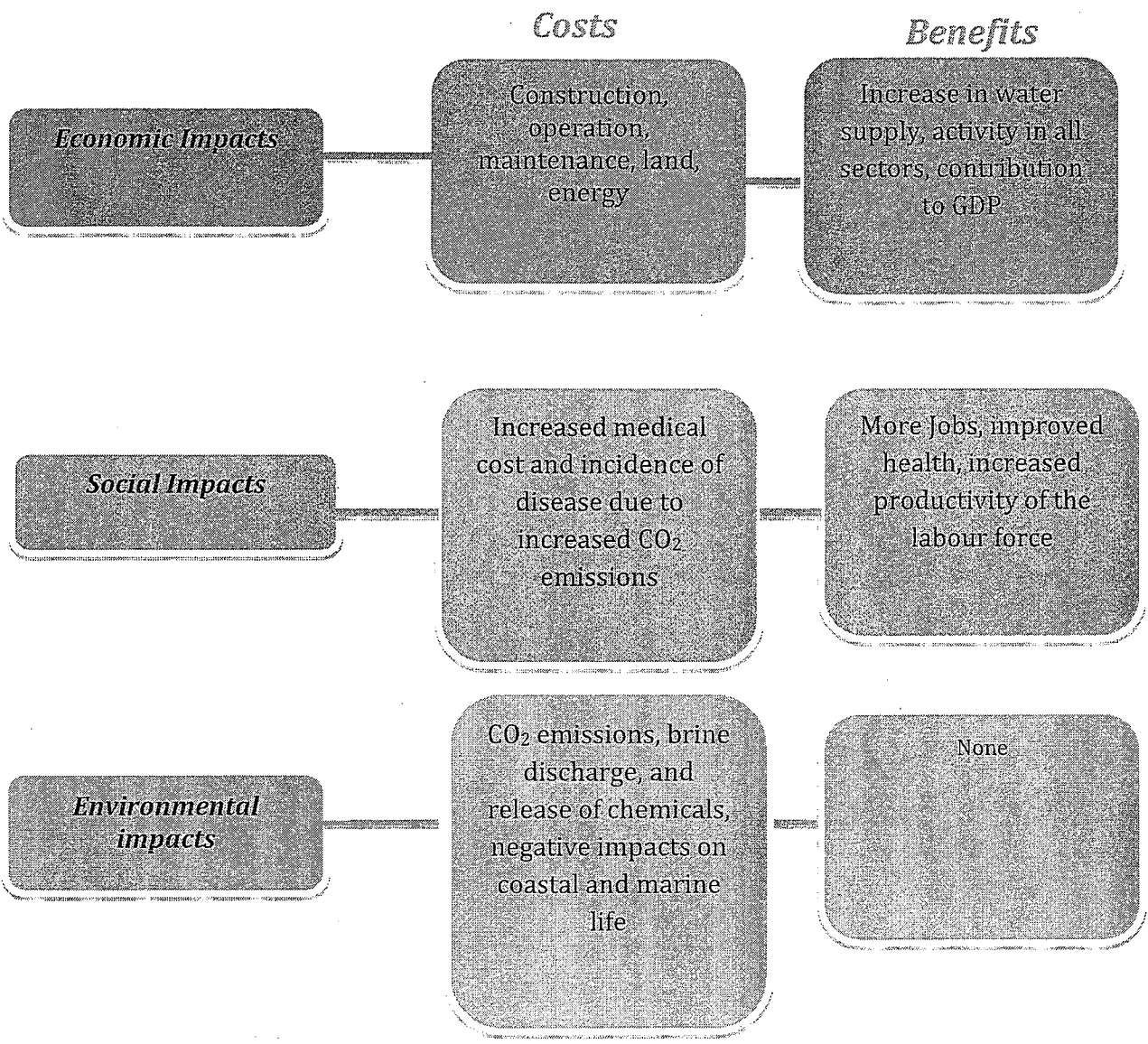
	management
Water conservation programmes in the agriculture sector	
<i>Costs</i>	<i>Benefits</i>
Cost of installing water saving irrigation equipment and devices	<p>Increased output per unit of water consumption</p> <p>Reduced cost of final product</p> <p>Improved crop productivity/yield</p> <p>Increased competitiveness of produced crops in international markets</p> <p>Reduction in per capita water consumption in the agriculture sector that could result in about 40% savings in water</p> <p>Reduced water content of traded crops (virtual water)</p> <p>Converting from high water content crops such as wheat to lower crops such as potatoes will save water</p> <p>Reduction in the use of pesticides due to reduced amount of weeds and other fungi resulting from flood irrigation and other wasteful uses of water</p>
Investment in ecosystems	
<i>Costs</i>	<i>Benefits</i>
Cost involved will vary according to the extent to which the government in question is committed to securing a continuous and sustainable supply of water for current and future generations.	<p>Reduction in the pollution of rivers</p> <p>Reduction in the rate of depletion of underground water</p> <p>Improved quantity and quality of freshwater</p> <p>Reduced environmental degradation</p> <p>Enhances the preservation of habitats for indigenous wildlife</p> <p>Ecosystem conservation contributes to the preservation of the ecosystem responsible for the continuous supply of water on a sustainable basis</p>
Water capture, storage of storm water, transport of water (pipelines/Medusa bags)	

<p><i>Costs</i></p> <p>Costs involve the construction of small dams to recharge water aquifers, installation and extension of water pipelines, continuous maintenance to avoid water leakages from the network. Cost will vary according to the number of dams and area covered by water supply</p>	<p><i>Benefits</i></p> <p><i>Benefits</i></p> <p>Increase in the supply of freshwater from storms that could have otherwise been wasted</p> <p>Reduction in the cost of providing water supply facilities</p> <p>Reduction in the use of energy used in the operation of water plants</p>
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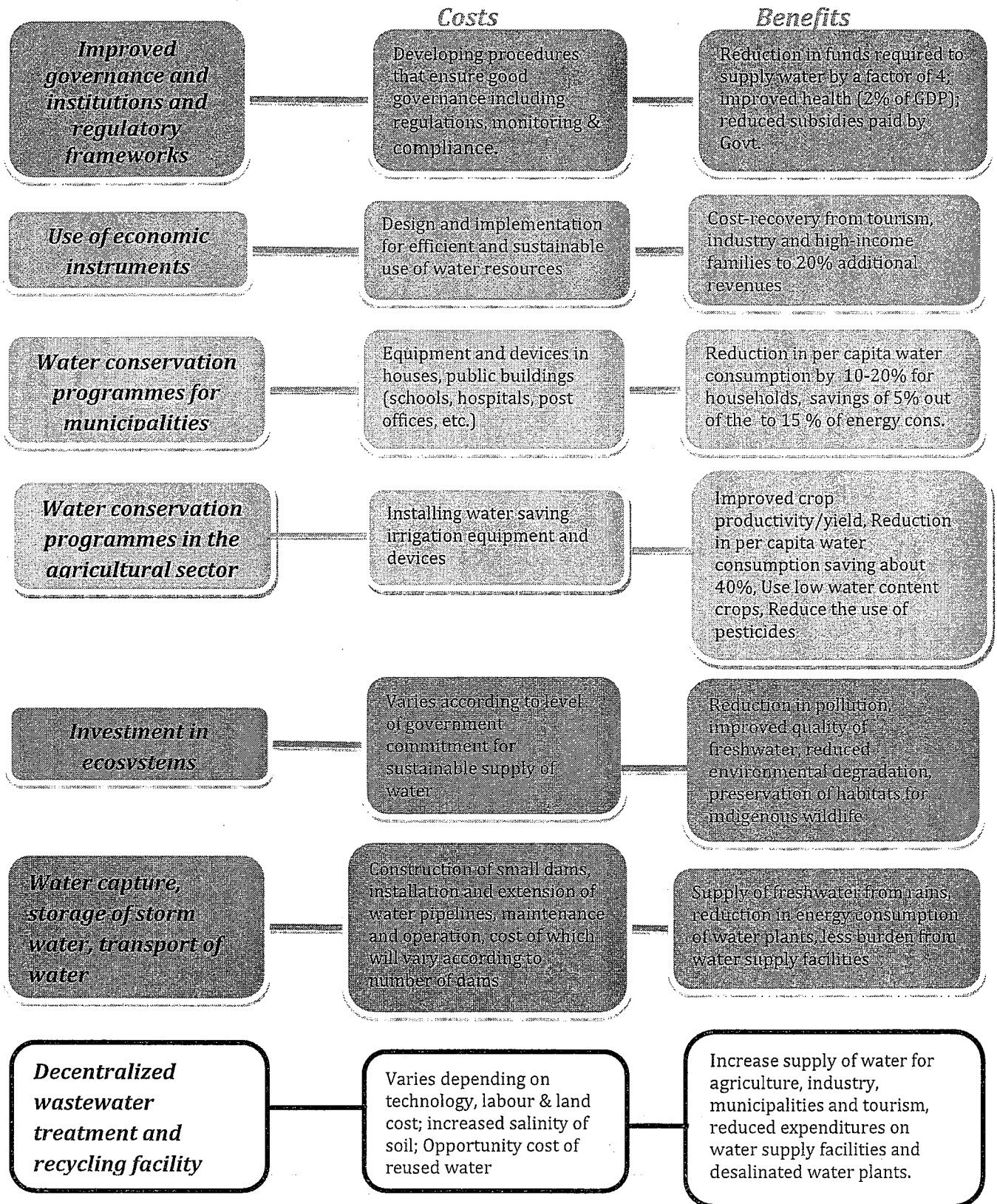
Decentralized wastewater treatment and recycling facility

<p><i>Costs</i></p> <p>Cost per cubic meter will depend on the type of technology used, labour cost, land cost, and distance to convey water to destinations an average cost of US\$.20 will be used and amortized over a 20 years period</p> <p>Increased salinity of soil</p> <p>Opportunity cost of reused water</p>	<p><i>Benefits</i></p> <p>Increased supply of water for irrigation and for some industrial use thus reducing pressure on freshwater for domestic use and by industry and tourism</p> <p>Reduced expenditures on water supply facilities and desalinated water plants</p> <p>Reclaimed water provided by a new wastewater treatment plant will provide 20,000 m³ of treated water for irrigation, thus releasing the same amount of freshwater for domestic use. The entire amount of treated water could be used for irrigation purposes and freshwater needed for domestic use to be supplied through savings in water use resulting from technical and allocative efficiency.</p>
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Cost and benefits of supplying water through desalination



Cost and benefits of technical and allocative efficiency



VI. Recommendations

Opportunity cost analysis provides a tool for policy and decision makers to enable them take the right decision with respect the best possible investment option. In order to undertake effective opportunity cost analysis it is recommended that the following should be taken into account:

- ☒ Socio-economic and environmental cost and benefits for supplying water through desalination should, include the health and environmental costs of CO₂ emissions due to the extensive energy component of desalinated water as well as the discharge of brine water.
- ☒ Opportunity cost for desalination plants or in other words foregone benefits for investing in desalination versus other options should be fully considered and accounted for. This includes the socio-economic and environmental costs and benefits of technical and allocative efficiency, which covers cost and benefits of good governance, legislative framework, incentive system, public awareness and human resource development.
- ☒ Other investments include investing in a decentralized wastewater treatment facility, investing in upgrading and improving the water network to reduce wastage. Other demand management water saving measures, include investing in storage and recycling facilities, new irrigation techniques, wastewater treatment, reuse and recycling, ecosystems that promote water conservation and provides purification services.
- ☒ In estimating socio-economic and environmental costs and benefits, benefit transfer method may be used. Other economic valuation methods that can be used are the contingent valuation method.
- ☒ Virtual water is an important element that should be fully taken into account in technical and allocative efficiency and in calculating the opportunity cost of supplying water through desalination. Selecting low water content products to grow locally and import high-content products maximizes the use of available water resources and increases water availability in the country.
- ☒ Job creation is an important component in any type of investment, this is particularly important to factor in when calculating the benefits of technical and allocative efficiency. This is due to the potential number of jobs that are likely to be created in the chain of activities associated with this option.
- ☒ In calculating the positive impacts on health, factors such as increase in productivity, reduced medical bill, improved life expectancy, and reduced mortality rate especially for children should be accounted for.
- ☒ Benefits accruing from the release of freshwater due to the allocation of treated wastewater for agricultural use should be carefully estimated and costed.
- ☒ In order to calculate the NPV of investment cost a 3.5% social discount rate may be used to calculate investment cost at present value.

References

- A. Poullikkas, Optimization algorithm for reverse osmosis desalination economics. *Desalination*, 133 (2001) 75–81.
- African Development Bank, Gabal El-Asfar Wastewater Treatment Plant- Stage II Phase II project, Country: Egypt, (2009).
- Alternative Ways of Providing Water, Emerging Options and Their Policy Implications, OECD, 2007-2008.
- Arab Environment 4, Green Economy, Sustainable Transition in a Changing World, 2011 Report of the Arab Forum for Environment and Development, Edited by Hussein Abaza, Najib Saab, Bashar Zeitoun
- Artim, Eniko, Ellen Baltazar, Joanna Fiedler, Dusan Sevic, and Ruslan Zhechkov. "Investing in the Environment as a Way to Stimulate Economic Growth and Employment." *How Environmental Projects Contribute to Achieving Lisbon Agenda Goals*. (2008): n. page. Web.
<<http://ec.europa.eu/environment/integration/pdf/LisbonReport.pdf>>.
- Bahri, A. "Water reuse in Middle Eastern and North African countries." *In Water Reuse: An international Survey of Current Practice, Issues and Needs* (eds. B. Jimenez and T. Asano). IWA Publishing, London. (2008b)
- Beato, P. and Vives, A. A primer on water economics. Vives, A. and Beato, P. 2010. A primer on water financing. 2010.
- Becker, N.I.R. "The Effect and Reform of Water Pricing: The Israeli Experience." *International Journal of Water Resources Development* 18 (2): 353–66. 2002
- Benabdallah, S. "La réutilisation des eaux usées traitées en Tunisie." *Etudes et rapports d'expertise II*. 2003
- Chapagain, A.K. and A.Y. Hoekstra. Virtual Water Trade: A Quantification of Virtual Water flow between Nations in Relation to International Trade of Livestock and Livestock Products, Value of Water Research Report, Series No 12, IHE Delft, February 2003
- Christopher Ward Consultant and Researcher Institute of Arab and Islamic Studies University of Exeter
wardcsward@aol.com
- Côté, P., Sivers, S., and Monti, S. "Comparison of membrane- based solutions for water reclamation and desalination." *Desalination* 182:251–257. 2005
- "CO2 Emissions from Fuel Combustion Highlights." *lea statistic*. International Energy Agency, 2011. Web. 30 Jun 2012. <<http://www.iea.org/co2highlights/CO2highlights.pdf>>.
- C. Sommariva and V.S.N. Syambabu, Increase in water production in UAE. *Desalination*, 138 (2001) 173–179.
- Dolnicar, S. and Schäfer, A.I. Public perception of desalinated versus recycled water in Australia. 2006. Available at <http://ro.uow.edu.au/commpapers/138>
- Drouiche, Nadjib, Noredine Ghaffour, Mohamed W. Naceur, Hacene Mahmoudi, and Tarik Ouslimane. "Reasons for the Fast Growing Seawater Desalination Capacity in Algeria." Springer Science Business Media B.V. 2011. (2011): n. page. Print.
- Engel, S., Pagiola, S., and Wunder, S. "Designing payments for environmental services in theory and practice: an overview of the issues." *Ecological Economics* 65:663–674. 2008
- Environment Canada (2005) Municipal Water Use, 2001 Statistics (Report)
- Freedman J., J.W. Hotchkies, presentation at the OECD expert meeting on Sustainable Financing for Affordable Water Services, November 2007 (available at <http://www.oecd.org/dataoecd/38/53/40015778.pdf>)
- Global Water Partnership. "Triggering change in water policies." Policy Brief 8. Global Water Partnership. 2009a. "Government Initiatives." *Desalination Background*. N.p., 20 Aug. 2010. Web. 21 June 2012.
<<http://www.water.vic.gov.au/initiatives/desalination/desalination>>.
- Grey, D., "The World Bank and Water Resources: Management and Development". Presentation at World Bank Water Week. 2004.
- Heimbuch, Jaymi. "New Australian Desalination Plant Will Use 100% Renewable Energy." TreeHugger. Treehugger, 10 July 2009. Web. 21 June 2012. <<http://www.treehugger.com/clean-water/new-australian-desalination-plant-will-use-100-renewable-energy.html>>
- Heinz, I., Salgot M., Mateo-Sagasta Davila, J. "Evaluating the costs and benefits of water exchange projects involving cities and farmers. *Water International*". 36 (2011): 455-466
- "How to Conserve Water and Use It Effectively." *Environmental protection agency*. United States Environmental Protection Agency, 2012. Web. 30 Jun 2012. <<http://water.epa.gov/polwaste/nps/chap3.cfm>>.
- Hutton, G. and Bartram, J. Regional and global costs of attaining the water supply and sanitation target (target 10) of the Millennium Development Goals. World Health Organisation. 2008a
http://www.who.int/water_sanitation_health/economic/cba_interventions/en/index.html

Jägerskog, Anders. "Mena Water Overview: Trans boundary Cooper action, I WRM and Opportunities for Swedish Engagement." *Stockholm International Water Institute*. (2007): n. page. Web. <http://www.siwi.org/documents/Resources/Papers/Paper12_MENA_Water_Overview_2007.pdf>.

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Knights, D., I. MacGill, and R. Passey. "The sustainability of desalination plants in Australia: is renewable energy the answer?." (2006): <http://www.ceem.unsw.edu.au/content/userdocs/ozwaterpaperimrp_000.pdf>

M. Wilf, Optimization of seawater RO systems design. *Desalination*, 138 (2001) 299–306.

Libhaber, M., and M. Michail. "Innovative Methods in Waste- water Treatment for Agricultural Reuse in Israel." In *Water Reuse Symposium IV*, Denver, CO. 1987

Marsden Jacob Associates; *Securing Australia's Urban Water Supplies: Opportunities and Impediments*. A discussion paper prepared for the Department of the Prime Minister and Cabinet (available at <http://www.environment.gov.au>)

McCornick, P.G., N. Haddadin, and R. Sabella. "Water Reuse Options in the Jordan Valley: Water Reuse Component." Ministry of Water and Irrigation, Jordan; USAID, Jordan and Vermont. 2001b

Ménard, C. and Saleth, R.M. The effectiveness of alternative water governance arrangements. 2010

Moatty, Nessim. "Water management and desalination in Israel." *Desalination*. (2001): 101-104. Print.

Moustakbal, Jawad. "Water resources and climate change in MENA region ." *Committee for the Abolition of Third World Debt*. (2009): n. page. Web. 30 Jun. 2012. <<http://www.cadm.org/Water-resources-and-climatechange,5080>>.

Nazzal, Y., M. Mansour, M. Al Najjar, and P.G. McCornick. "Wastewater Reuse Law and Standards in the Kingdom of Jordan." Ministry of Water and Irrigation, Amman. Amman–Zarqa Sources: Water Reuse Component." 2000

Neumann, J.E., Yohe, G., Nicholls, R., and Manion, M. "Sea-Level Rise & Global Climate Change: A Review of Impacts to U.S. Coasts." Prepared for the Pew Centre on Global Climate Change. 2000. C.F: <http://www.pewclimate.org> (accessed April 23, 2008)

Pagiola, S. G. Acharya, and J. Dixon. Forthcoming. *Economic Analysis of Environmental Impacts*. London: Earthscan

Pare, J.. "Energy Source Cost Comparisons." . N.p., 2007. Web. 30 Jun 2012. <http://des.nh.gov/organization/divisions/water/wmb/coastal/ocean_policy/documents/te_workshop_cost_compare.pdf>.

Rabinovitch, Ari. "Desalination plant could make Israel water exporter." Reuters. N.p., 2011. Web. 21 Jun 2012. <<http://www.reuters.com/article/2011/12/06/us-israel-desalination-idUSTRE7B50V520111206>>.

Sachs, J.D. *Macroeconomics and health: Investing in health for economic development*. Report of the Commission on Macroeconomics and Health prepared for WHO. 2001

Seimens, *Business Opportunities and Corporate Responsibility*, presentation at the IDA & GWI Conference Water Finance & Sustainability 2008, London, April 2008

Semiati R., *Desalination: present and future*, *Water International*, 25(1) (2000) 54–65.

Shetty, S. "Treated Wastewater Use in Tunisia: Lessons Learned and the Road Ahead." In *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities* (eds. C.A. Scott, N.I. Faruqui, and L. Raschid-Sally), CABI Publishing. 2004.

Silva, Patricia, and Stefano Pagiola. "A Review of the Valuation of Environmental Costs and Benefits in the World Bank Projects." *Environmental Economics Series* (2003): n.pag. *The international Bank for Reconstruction*. Web. 30 Jun 2012. <http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2004/06/17/000009486_20040617154708/Rendared/PDF/293490EDP010940Valuation01Public1.pdf>.

TEEB for National and International Policy Makers. Summary: Responding to the Value of Nature. TEEB – The Economics of Ecosystems and Biodiversity (2009), <<http://www.teebweb.org/LinkClick.aspx?fileticket=I4Y2nqqliCg%3d&tabid=1019&language=en-US>>

The Adaptive Water Resource Management Handbook Edited by Mysiak J., Henrikson H. J., Sullivan C., Bromley J. and Pahl-Wostl C. London • Sterling, VA First published by Earthscan in the UK and USA in 2010

Tolba, M., Saab, N., (editors), 'Arab Environment Future Challenges', 2008 Report of the Arab Forum for Environment and Development, 2008, available at <http://www.afedonline.org>.

Towards a Green economy, Pathways to Sustainable Development and Poverty Eradication, UNEP 2011

Tropp, H. and Jägerskog, A. "Meeting the Water Scarcity Challenges in the Middle East and North Africa" Prepared for the Human Development Report. Submitted to Journal of Human Development.

UNEP, Water Investing in Natural Capital, Green Economy, 2011 http://www.unep.org/greeneconomy/Portals/88/documents/ger/ger_final_dec_2011/4.0-WAT-Water.pdf

Vermont. McCornick, P.G., N. Haddadin, and R. Sabella. "Water Reuse Options in the Jordan Valley: Water Reuse Component." Water and Irrigation, Jordan; USAID, 2001b

Wangnick/GWI. 2005. 2004 Worldwide desalting plants inventory. Global Water Intelligence. Oxford, England. (Data provided to the Pacific Institute and used with permission.)

Water Efficiency Handbook, Identifying opportunities to increase water use efficiency in industry, buildings, and agriculture in the Arab World. AFED, 2010

Water in the Arab World: Management Perspectives and Innovations: Edited by N. Vijay Jagannathan, Ahmed Shawky Mohamed, Alexander Kremer, 2009.

Water tight 2012, The top issues in the global water sector, Deloitte, Global Services Limited, 2012 <http://www.deloitte.com/assets/Dcom-Global/Local%20Assets/Documents/Energy_Resources/dttl_er_WaterTight2012.pdf>.

Wittholz, Michelle K., Brian K. O'Neill, Chris B. Colby, and David Lewis. "Estimating the cost of desalination plants using a cost database." Desalination. (2007): 10-20. Print.

Yang H., K.C. Abbaspour, Analysis of Wastewater Reuse Potential in Beijing, Desalination, 212, pp.238-250. 2008

Y. Zhou and R.S.J. Tol, Implications of desalination for water resources in China — An economic perspective. Desalination, 164 (2004) 225–240.



**CORE DESALINATION GROUP MEETING – ASSESSMENT OF BEST
AVAILABLE TECHNOLOGIES FOR DESALINATION IN RURAL/LOCAL
AREAS IN THE SWIM-SM PROJECT COUNTRIES
SUMMARY OF MEETING RESULTS**

(WP1/ACTIVITY 1.1.3 B)

**Athens-Greece
(11-12 June 2012)**



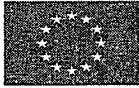
Contents

List of Abbreviations & Acronyms.....	3
1. Workshop Background, Objectives	4
1.1 Introduction	Error! Bookmark not defined.
1.2 Objectives and expected results.....	4
2. Meeting Methodology.....	5
3. Overview of the Workshop Agenda	5
4. Results of the Meeting	6
4.1 Technical Aspects of Desalination BAT Using RES	7
4.2 Assessing Community Needs for Desalination	11
I. Geographical & physical considerations.....	11
II. Demographic & socio-cultural considerations	11
III. Cultural, religious & gender related issues:	12
IV. Raw water resource availability & quality.....	12
V. Pricing structures & financing schemes (Affordability)	12
VI. Institutional and regulatory factors	13
4.3 Factors to be considered in Selecting the BAT	13
I. Factor 1: Maturity & level of deployment of the processes.....	13
II. Factor 2: Volume, Quality & Variations of Feed Water	14
III. Factor 3: Operational skill level required	14
IV. Factor 4: Energy vs Water Storage	15
V. Factor 5: Brine Disposal.....	15
VI. Factor 6: Other practical site characteristics.....	16
VII. Factor 7: Total Unit Cost.....	16
4.4 Guidelines to Screen and Assess Desalination BAT Using RES	17
I. Step 1: Evaluation of available water resources & demand characteristics.....	17
II. Step 2: Evaluation of available RES & grid connectivity.....	17
III. Step 3: Short listing of candidate desalination processes based on available RES	17
IV. Step 4: Environmental Impact Assessment of DES-BAT & RES projects.....	17
4.5 The way forward.....	Error! Bookmark not defined.
5. Workshop Agenda.....	20
6. List of Participants.....	22



List of Abbreviations & Acronyms

BAT	Best Available Technology
BOOT	Build, Own, Operate and Transfer
BOT	Build, Operate and Transfer
CDE	Core Desalination Experts
CDG	Core Desalination Group
DES	Desalination
EC	European Commission
ED or EDR	Electro-Dialysis
EIA	Environmental Impact Assessment
EU	European Union
FPs	Focal Points
HDH	Humidification/Dehumidification
IT	Information Technology
MAP	Mediterranean Action Plan
MD	Membrane Distillation
MED	Multi-Effect Distillation
MED-POL	Programme for the Assessment and Control of Marine Pollution in the Mediterranean Region
MSF	Multi-Stage Flash
MVC	Mechanical Vapour Compression
oPt	occupied Palestinian territory
PCs	Participating Countries
PPP	Public Private Partnership
PV	Photovoltaic cells
RES	Renewable Energy Sources
RO	Reverse Osmosis
SMCs	South Mediterranean Countries
SWIM-SM	Sustainable Water Integrated Management - Support Mechanism
TDS	Total Dissolved Solids
TL	Team Leader
TVC	Thermal Vapour Compression
UNEP	United Nations Environment Programme
WP	Working Package



1. WORKSHOP BACKGROUND, OBJECTIVES

The Sustainable Water Integrated Management – Support Mechanism (SWIM-SM) is an EC-funded Regional Technical Support Project that includes the following Partners Countries (PCs): Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, the occupied Palestinian territory (oPt), Syria and Tunisia. The project aims to promote actively the extensive dissemination of sustainable water management policies and practices in the region given the context of increasing water scarcity, combined pressure on water resources from a wide range of users and desertification processes, in connection with climate change.

Within this context, there is good potential for addressing the water scarcity problem in rural and remote areas through sustainable saline water desalination technologies, as seawater and brackish water desalination are well established industries comprising a wide variety of available technologies with decades of accumulated experience.

Based on the need expressed by SWIM PCs, SWIM-SM is implementing a set of activities to strengthen users' participation towards more effective local water governance and management with particular focus on the use of desalination processes in rural and remote areas. In this context a "Core Desalination Group Meeting" took place in Radisson Blue Park Hotel in Athens between 11 and 12 June 2012. Seventeen (17) international, regional and local experts from five project countries participated in the regional workshop. Furthermore, representatives from regional organisations and donors-assisted projects, as well as resource persons with relevant experiences in the region participated in the workshop. The detailed list of participants is included in Section 7.

1.2 Objectives and expected results

As part of its activities, SWIM-SM commissioned a report to provide a review of the Best Available Technologies (BAT) for desalination in rural and remote areas suitable for the PCs. The focus of the review is exclusively on sustainable desalination technologies in rural and remote countries in combination with renewable energy sources (RES) suitable for the PCs.

The main goal was to produce a report reviewing and compiling the BATs, which can then be catered to the specificity of the PCs to supplement water supplies to rural and remote communities, whether they are on coast or inland communities, taking into consideration the prevailing socio-economic, political, and cultural constraints.

The report aims to provide PCs and decision-makers with an overview and assessment of the BATs on desalination in remote areas

The meeting was held on the occasion of presenting the main results of the draft report and aimed at achieving the following objectives:

- 1) Review, discuss and validate with the Core Desalination Group (CDG) the findings of the Assessment on Desalination BATs in rural and remote areas (Day 1)
- 2) Establishment of a dialogue between the CDG and the national desalination experts from the PCs, towards the development of a regional orientation towards desalination as a non-conventional water resources option in South Mediterranean Countries (SMCs).



2. MEETING METHODOLOGY

The meeting was divided in two days. In the first day the Core Desalination Group (CDG) discussed the outcomes of the Assessment Report on Desalination BATs, so that their comments and recommendations would be incorporated in the findings of the report and then communicated to the national experts from SWIM PCs.

In the second day the overall conclusions of the report along with the recommendations of the international experts were presented and discussed with the national experts from SWIM PCs in order to exchange views between the PCs and the international experts, on the desalination element as part of their non-conventional water policies.

3. OVERVIEW OF THE WORKSHOP AGENDA

The workshop was held over two days (June 11th & 12th, 2012) as per the detailed Agenda in **Section 6** of this report.

The agenda during **Day 1** consisted of:

- 1) Introduction to the Group background, objectives and methodology, expected output and meeting rules.
- 2) briefing on the main findings of the assessment report on the BATs for the combination of desalination processes with the use of RES
- 3) Breakout sessions dedicated to discussion between the international experts on the findings of the report, especially in regard to the technical aspects of desalination BAT Using RES, the modalities for assessing local community needs for desalination, the factors for assessing and deciding on the optimum desalination option and to the guidelines to support decision makers in screening and assessing options for desalination.

Day 2: was dedicated to sessions for the:

- 1) Presentation of the outcomes and recommendations emanating from the first day CDG meeting.
- 2) Discussion between the international experts and the national experts from the PCs on the findings of the assessment report with the incorporated remarks and recommendations of Day 1;
- 3) Exchanging views and experiences between the participants on desalination as an element of the water resource management in the SMCs, to allow the determination of trends on desalination;
- 4) Discussions on the development of the guidelines to support decision makers in screening and assessing options for desalination ("Toolbox");
- 5) Validation of the findings of the assessment report and setting the way forward, with time schedule of the next actions of the CDG.



4. RESULTS OF THE MEETING

The results of the meeting are presented below point by point, as derived from the discussions between the SWIM-SM Programme Manager and the international CDG during the first day and contributions of national experts during the second day of the meeting.

The main conclusions and recommendations culminating from the discussions during both days can be summarized as follows:

1. Desalination should be considered as part of a holistic approach for the overall sustainable development of rural and remote areas and only after less expensive technical efficiency (demand management interventions) & allocative efficiency (efficiency with which society allocates its water resources among sectors for sustainable socio-economic development) are exhausted. Water demand management options such as water conservation, reallocation among sectors, inter-basin transfer, changing crop patterns, innovative irrigation techniques, reduction of Non Revenue Water (NRW), etc. should be considered first.
2. The niche for SWIM-SM work on desalination is for desalination processes combined with Renewable Energy Systems (RES) for the water supply in rural and remote communities. The selected niche doesn't exclude SWIM from addressing desalination issues of priority to the region including environmental aspects of the industry at different scales.
3. The potential cumulative environmental impacts of the proliferating mega desalination plants, around the shores lines of the Mediterranean, strongly emerged as a crucial issue and should be given adequate attention.
4. Opportunity cost analysis, including the socio-economic & environmental externalities, should be used as an analytical tool to select among alternatives prior to deciding on desalination.
5. In case desalination is decided, it has to be subject to an EIA study according to the national policies & guided by the national legislations and the internationally recognized criteria & procedures.
6. Desalination, if decided, should be addressed within an IWRM context and as a milestone and a trigger towards instigation of a holistic sustainable development plan that encompass self socio-economic and environmental development of the community.
7. SWIM-SM is to undertake several activities and parallel capacity development actions in support of SWIM PCs in the following areas:
 - ☒ Development of a tool box (guidelines) in collaboration with MED-POL to help water officials in SWIM-PCs decide on desalination option using a structured methodology that is based on exhaustion of all water demand management options prior to resorting to desalination. The tool box would include instruments such as opportunity costs analysis and environmental impact assessment methodologies catered for desalination.
 - ☒ Synergize with MED-POL in addressing the potential cumulative environmental impacts of mega desalination projects with particular focus on the near-shore marine environment around the Mediterranean coasts.
 - ☒ Organize and convene capacity development workshops on fundamentals of opportunity cost analysis among options to satisfy water demand in comparison with desalination. These opportunity cost analysis should encompass socio-economic aspects with emphasis on environmental externalities.



- Organize and convene capacity development workshops on the environmental aspects of desalination and their cumulative impacts with special emphasis on the state-of-the-art mitigation measures.
- Further develop table 1 of the Desalination BAT report into a folding flyer that can be disseminated to assist policy makers swiftly screen and compare among desalination options that are compatible with their local conditions.
- Organize and convene training workshops on the application of the tool-box jointly developed with MED-POL with emphasis on the implementation of EIA policies designed for desalination plants construction and operation.
- SWIM might recommend management systems for regular monitoring, inspecting and auditing for both the desalinated product water and for brine discharges to ensure compliance with nationally promulgated regulations.
- SWIM to devise a capacity development programme to orient water policy makers in SWIM countries on the new developments (technical aspects, advantages, economics, limitations, etc.) of RES compatible with small scale desalination.

The discussions on the first day of the meeting were focused on 4 main issues as follows:

- Technical Aspects of Desalination BAT Using RES
- Assessing Community Needs for Desalination
- Factors to be Considered in Selecting the BAT
- Guidelines to Screen and Assess Desalination BAT Using RES

On second day, the outcomes and recommendation culminating from the previous day regarding these 4 issues were discussed with the representatives of the PCs along with their policies and view on these subjects. The outcome is presented below.

4.1 Technical Aspects of Desalination BAT Using RES

The Assessment Report on Desalination BATs (DES-BATs) refers to a number of desalination processes that could be combined with RES in order to achieve water supply to rural and remote areas. These processes were presented by the Team Leader (TL) in the form of the table presented below. The desalination processes were compared in terms of their techno-economic feasibility and practicality for rural and remote communities. The CDG and national experts found the table very useful and expressed interest to further develop it as a simple preliminary screening tool for policy makers to develop an opinion prior to extensive investigations for deciding on the desalination BAT for rural and remote communities.

The RES taken into account for the combination with desalination processes include mainly the solar and wind power, the geothermal power (a promising RES with continuous supply of thermal energy at fixed conditions throughout the day and year) and the waste heat from other activities (both combined with thermal type desalination processes).

The main factors in narrowing down the combinations of DES-BATs and RES are the salinity of the feed water and the type of energy available at a given location.

The combinations between DES-BATs and RES that are suggested in the report focus on the utilisation of solar and/or geothermal power and/or waste heat in combination with Multi-Effect Distillation (MED) and Humidification/Dehumidification (HDH), of wind power combined with Mechanical Vapour Compression (MVC) and the use of Photovoltaic cells (PV) in combination with Reverse Osmosis (RO).



The participating experts reviewed table 1 of the report comparing among different BAT and compatible RES. The experts expressed real interest in disseminating this table to water policy makers to use it a screening tool.

Even though there can be a wide variety of combinations between DES-BATs and RES, no additional technological developments were suggested by the experts, as these should be mature and proven reliable before considering their implementation in rural and remote areas. It was highly recommended that financing of desalination plants should be either through BOT or BOOT with guarantees on the part of the contractor to supply consistent volume and quality of water as agreed in the contract.

Regarding the cost ranges given in the report for various DES-BATs and RES combinations and also the determination of applicable combinations in the PCs (based on the specificities of the area), the experts concluded that the production costs aspects are case specific and depends to great extent on the scale of the operation, technology used, water quality at the intake, targeted drinking water quality and brine water discharge technology.

Finally, in terms of capacity development needed to orient water engineers and administrators on the available mature desalination BAT and their compatible RES, it was agreed that a capacity building component would be prepared under the respective Work Package (WP) of SWIM-SM, part of which would be the development of the Toolbox discussed in these meetings (presented below).



Table 1: Comparison of desalination technologies in reference to rural areas

Process	Capital Cost	Energy consumption	Other O&M cost	Major merits	Major Weak Points	O&M Skill required (scale 1-5)	Type of energy required
Multi-Stage Flash (MSF)	High	High	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Robust and reliable 3. Less pre-treatment required. 4. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. High Feed water Requirement. 2. More brine to be disposed. 3. High specific energy consumption 	2	Heat + power
Multi-Effect Distillation (MED) Thermal Vapour Compression (TVC)	Medium	High	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Robust and reliable 3. can use low-grade heat 3. Less pre-treatment required. 4. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. High specific heat consumption 2. Low recovery ratio, when cooling water is accounted for. 	2	Heat + power
Mechanical Vapour Compression (MVC)	Medium to high	High	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Robust 3. Compact 4. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. High scaling potential under variable conditions. 2. Mechanical compressor requires skilled O&M 	4	Power
Reverse Osmosis	Medium	Low	Medium	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Reliable 3. Compact 4. High recovery ratio 5. Less start-up and shutdown time 6. Suitable for high TDS feed 	<ol style="list-style-type: none"> 1. Pre-treatment requires careful design. 2. Susceptible to various types membrane fouling. 3. Variability in operating conditions and/or frequent start-up/shutdown cycles shorten membrane life 	3	Power
Electro-dialysis (ED & EDR)	Low	Low	Low	<ol style="list-style-type: none"> 1. Mature and proven technology 2. Reliable 3. Compact 4. High recovery ratio 5. Less start-up and shutdown time 6. Less pre-treatment required 	<ol style="list-style-type: none"> 1. Suitable for TDS up to 3000 mg/l. 	3	Power



Membrane distillation (MD)	High/medium	High	Low	<ol style="list-style-type: none"> 1. Ability to use low grade heat 2. Operates at low pressure 3. Compact 4. High recovery; needs less feed water for a given output. 5. Less pre-treatment required 6. Suitable for very high TDS feed 	<ol style="list-style-type: none"> 1. Technology is still under development 2. High specific heat consumption. 	2	Heat + minor power req.
Electro Dialysis Metathesis (EDM)	High	High	NA	<ol style="list-style-type: none"> 1. Improved version of ED. 2. Recovery more than RO possible and can be used for zero discharge. 3. Compact 4. Less pre-treatment required. 	<ol style="list-style-type: none"> 1. Emerging technology. 	4	Power
Thermo-ionicTM Desalination	High	High	NA	<ol style="list-style-type: none"> 1. Ability to use low grade heat 2. Compact 3. High recovery and needs less feed water for a given output. 4. Less pre-treatment required 	<ol style="list-style-type: none"> 1. Emerging technology. 2. High specific heat consumption. 3. Proprietary design and information kept confidential 	4	Power + Heat
Forward Osmosis	NA	Low (prospective)	NA	<ol style="list-style-type: none"> 1. Operates at low pressure and hence consumes less power. 2. Less pre-treatment required. 	<ol style="list-style-type: none"> 1. Emerging technology. Process optimisation is going on 	4	Power (+heat in some cases)
Solar Stills	V. low	High	V. low	<ol style="list-style-type: none"> 1. Uses solar energy 2. Simple and easy to operate 	<ol style="list-style-type: none"> 1. Large area required. 2. Not practical for large capacity. 	1	Solar (Heat)
Humidification/ Dehumidification (HDH)	Medium	High	Low	<ol style="list-style-type: none"> 1. Can use low grade thermal energy. 2. Simple design using cheap material 	<ol style="list-style-type: none"> 1. Suitable only for small capacities. 2. Requires large area 	3	Heat + power



4.2 Assessing Community Needs for Desalination

Team Leader of SWIM-SM presented the main findings of the Assessment Report regarding the factors to be considered in order to assess the real needs and the feasibility of a desalination project for the water supply of a rural or remote area. These factors include the following:

I. Geographical & physical considerations

The CDG agreed to the fact that physical geography of the location, the type of soil & terrain, surface topography, geothermal reservoir activity and other geologic factors can all influence the type of desalination technology to be used. Also, local hydrology of the site including the movement, distribution & quality of water at the location, water resources available & other aspects of the total hydrological profile are significant aspects to be considered in combination with the water crop of the region (precipitation, runoff, and evapo-transpiration).

It was also concurred that possible cultural, historical and archaeological heritage of a site should be given adequate considerations to avoid damage caused by construction and other civil works, along with the aesthetical damage that can be caused by unsightly plant installations. Wind turbines and wind farms are considered objectionable especially so for historical sites.

Finally, areas reserved for wildlife habitat (Natural Reserves) should be avoided to protect them & evade potential impacts to bio-diversity.

II. Demographic & socio-cultural considerations

- a. **The Socio-technical-institutional interdependence:** Interaction between 3 elements: people, technologies & organizations must be fully understood & accounted for.
- b. **Involvement of beneficiaries:** The CDG agreed to the notion that people affected by the project must be included at all stages & their input must be taken into account.

The CDE suggested that the organization/people that would operate a desalination plant should originate from the same local community served by the plant. If possible, they should be involved even from the planning phase of the plant, but it would be also necessary to participate at least from the construction up to the operation of the plant.
- c. **Learning:** Opportunities for learning, raising awareness & training need to be provided from the earliest stages of a project to maximize benefits. On the job training of operators is a very significant aspect of the project's sustainability.
- d. **Independence & autonomy:** Technological solutions, however clever & innovative they might be in the eyes of the decision-makers, must not be imposed on a community that finds them objectionable.
- e. **Sustainability:** Average income per family, poverty levels, affordability, willingness to pay for desalinated water & government subsidies, play a major role in sustainability.

To this point, Mr. Tsiourtis noted that based on previous experiences, at the onset of a desalination project, local people do agree to pay for their water consumption. However, due to the poverty levels of the people in rural and remote areas, they later refrain from paying for the service due to un-affordability jeopardizing the whole project sustainability. For this reason he suggested that the Financing Aspect should be an additional factor in the Feasibility Studies for the assessment of such projects.

According to Dr. Bushnak, sustainability of the process should not necessarily rely on government funding but on self-sufficiency based on recovery of cost by tariffs determined by the local communities served and operating the plants.



- f. **Flexibility & Process orientation:** The general conditions for water supply in rural areas can change relatively quickly, and are generally very site-specific.
 - g. **Realism:** Project objectives & expectations must be realistic & feasible to avoid failure.
- III. **Cultural, religious & gender related issues:**
- a. Often a new technology introduced into a community for the first time is perceived as an alien intrusion that is incompatible with long-standing traditions, social structures and responsibilities of the community.
 - b. Despite the important role women play, men take charge of decision-making & women are often left out. This should be stopped and women should be included in the decision-making when it comes to water policies development.
- IV. **Raw water resource availability & quality**
- a. In case of using well water as raw water source for desalination, detailed hydrological study/tests shall be conducted to ensure the draw down in the well and sustainability for the planned capacity throughout the period of operation.
 - b. Detailed chemical analyses of raw water at intake are fundamental for the design and operation of desalination systems to avoid scaling and/or fouling.
- V. **Pricing structures & financing schemes (Affordability)**
- a. According to the CDG, a successful desalination project in a rural or remote area should manage to recover its running costs & depreciation. This necessitates that the water tariff reflects the real costs of water supply. On the other hand, access to safe drinking should be available & affordable for all.
 - b. The main challenges facing desalination in rural communities are identified as:
 - i. The low income dominating in the rural communities.
 - ii. Limited capital and financial resources.
 - iii. High investment costs required for such projects.
 - c. In response to these difficulties, it was agreed that a number of support mechanisms that do not distort the market function are possible, such as:
 - i. Direct financing of the infrastructure.
 - ii. Provision of financial incentives for the operators.
 - iii. Enabling private sector involvement.
 - iv. Adopting the "life-line rate", where a progressive pricing structure is applied based on the volume of water used in order to assure social justice among the users. Israel reported that "Urban centres subsidize water delivered to rural and remote communities".

During this discussion it was made clear that given the prevailing poverty in rural & remote areas, subsidizing the capital & operational costs of desalination by central government is unavoidable. Based on that, it was suggested that the PCs should consider funding of desalination projects in rural or remote areas, as part of their national strategy on water supplies within their national IWRM framework. In fact, it was over emphasized that sustainability of desalination using RES in rural and remote communities should be an integral part of the overall sustainable development plan of the community using a holistic approach. It was agreed that desalination plants, if proved necessary, should represent a trigger for further sustainable socio-economic and environmental development to reduce poverty and unemployment while developing markets. Many of the development plans can take stocks from local heritage, history, nature, ecology, indigenous culture, arts, and/or architecture.



The experience in Cyprus, as presented by the international expert, Mr Tsiourtis, confirms that only central governments can afford construction of desalination projects in rural and remote areas, either by funding them or by undertaking the responsibility through guarantees imposed to the contractors (via BOT/BOOT/PPP contract schemes).

Israel's representative stated that the country has developed IWRM based on the holistic approach, incorporating the cities, the rural and remote areas, the environment, development, tourism, etc. This approach has, nevertheless, not refrained people from rural and remote communities, such is the case in Algeria, from migrating towards urban centres for better quality of life and employment opportunities.

VI. Institutional and regulatory factors

The CDG agreed to the three levels of institutions that are required for the sustainability of a desalination project include the following:

1. **National decision making level:** This typically includes ministries & other high-level government entities that are involved in setting water policy and planning.
2. **Executive level:** This is usually the role of government organizations that operate under the top-level decision making bodies.
3. **Stakeholders' level:** This can be the local communities that undertake the actual operation & maintenance of water supply facilities, also being the beneficiaries. Close relationship between the stakeholders and the national decision making organizations (responsible for the projects funding) is very crucial.

Regarding regulatory aspects of desalination projects, it was clear that licensing procedures should be oriented to environmental aspects regulated by the formal EIA policy and to technical issues; the latter is expected to address the following:

1. Borehole drilling and/or seawater withdrawal.
2. Desalinated water quality.
3. Renewable energy installations and their associated electric power supply approval.

Since regulatory aspects of small scale desalination using RES are almost non-existent in most of the SWIM region, it has been deemed necessary to propose guidelines and criteria for PCs to license small scale desalination in rural and remote areas, within the framework of SWIM-SM.

4.3 Factors to be considered in Selecting the BAT

I. Factor 1: Maturity & level of deployment of the processes

The main results from the discussions on this factor are given below:

- ☒ Reliability of a desalination process is of a highest priority even from the total unit cost of the process, when desalination projects aim to provide drinking water.
- ☒ Desalination technology is witnessing fast development and it is recommended to keep up with progress on proven state-of-the-art desalination processes.
- ☒ A process can be considered matured/proven if it has been commercially operated for ≥ 3 years with success and recommended by water practitioners who used it.



- In all cases and in order to increase reliability of any proven desalination process, a plant should be design with at least 2 parallel lines, of 50% capacity each, in order to reduce the risk of total plant shutdown.
- Novel processes may possess attractive features, open up new possibilities & occasionally introduce remarkable improvements in performance; but difficult to recommend for rural applications awaiting maturity. In order to forward novel processes, the investment should be contracted as BOT or BOOT, so that the risk is carried by the investor. The investors are more willing to invest in plants serving rural and remote areas rather than in cities, since the risk in investing in small plants is minimized as opposed to large and mega-plants.
- To reduce the risk of innovative and immature technologies in rural areas, a different mature & tested technology can be considered side-by-side to the new technology. This will reduce the risks of total dependability on the innovative technology. The provider of the new technology will grant the needed guarantees of proper operation & compensation in case of failure.

II. Factor 2: Volume, Quality & Variations of Feed Water

This factor category was originally introduced as “Pre-treatment requirements” during Day 1, but after the discussions with the CDG, it was commonly agreed that the volume and quality of the feed water along with its variations (e.g. seasonal etc) are the inflow factors to consider when selecting a DES-BAT. It was also stated that regarding seasonal variations, different approach should be given to residents than to tourists, with primary focus on residents. Remote tourist resorts should be self sustained in terms of water supplies without any subsidies from the central government.

During second day discussions, it was concluded that in order to select the best combination of DES-BAT and RES the most important factors are the volume of product water and the available RES. The quality of feed water is an important factor for the design of the plant once the combination of DES-BAT & RES has been selected, as it reflects greatly on the pre-treatment requirements of the feed water upflow of the desalination plant. It is very difficult to identify the combination of DES-BAT and RES without adequate survey of

III. Factor 3: Operational skill level required

A related issue to technology maturity & pre-treatment requirements that is important factor in selecting & recommending a technology is the relative ease of plant operation compared to the level of skill available in rural communities. However, as noted by the Team Leader, the desalination plants in rural and remote areas are usually selected to be small and simple to operate, so there is minimum need for sophisticated technical capacity to operate.

Nevertheless, appropriate training of the local community can be given from the commissioning stage (even from the design of the plant if possible) and at regular periods after the plant start-up, in managing, operating and routine maintenance. This capacity development should be on the job with familiarization on the design and concepts of the desalination technology and associated RES. Furthermore, support from the service provider and/or designer should be assured especially for irregular conditions (e.g. break down of high pressure piping or pumps etc). Alternatively, efficient support for irregular and major failures could be provided by a more centralized technical centres that can be called in whenever needs arise.

The minimum suggested staff in such projects to assure efficient and uninterrupted operation of the plants should include

- Plant Operator, with the minimum training for the day-to-day operation of the plant



- ❖ Maintenance experts (small team of 1-2 persons at central level to operate on call for a number of DES plants)
- ❖ Specialized experts at Central level including, High Pressure Pumps Expert, IT expert for automations, Chemist and Material Science Expert.

It was also suggested in case of lack of competence of the local people a PPP scheme could be chosen to operate the desalination plant and eventually increase the capacity of locals.

IV. Factor 4: Energy vs Water Storage

Due to the fact that RES have variations (instantaneous, daily, & seasonal) in contrast to the desalination plants that are commonly designed to operate at fixed or slowly (seasonally) changing operating points (drawing fixed energy input at fixed rates), in order to combine the two technologies storage of energy is required.

However, as agreed among the participants, energy storage is not practical based on current technology, while water storage during the RES occurrence can be more cost effective, especially at rural or remote areas where the water supply needs are rather small and thus the water storage requirements entail low investment cost.

Alternatively, the CDG recommended hybrid design to utilize RES during their intense occurrence (e.g. solar power during the day) and fuel (diesel) power as a substitute for RES during their low occurrence can be more cost effective.

V. Factor 5: Brine Disposal

A set of available options were presented during the discussions of both days which is given in the table below:

Table 2: Comparison of brine disposal technologies

Description	Capital cost	O&M cost	O&M Skill requirement	Environmental impact	Preference
Zero Liquid discharge (Thermal)	V.High	V.High	High	Moderate	Sixth
VSEP Treatment	High	High	High	V.Less	Fifth
Brine injection	Less	less	Nil	Less/Moderate	Second
Evaporation pond	Less	less	Nil	V.Less	First
Produce agriculture and aquaculture products	Moderate	Moderate	Moderate	Hlgh	Third
Evaporation pond using enhanced Evaporation Mechanisms	Moderate	Moderate	Less	Less	Fourth

As resulted from first day discussions, the most appropriate method for brine disposal from desalination plants operating in rural and remote inland areas is the use of evaporation ponds, due to



the limited brine production (this was based on the assumption that in most rural and remote areas, desalination is produced from brackish water, which has an efficiency of up to 90% of the volume of feed water. Therefore, only 10% of the feed water is lost as brine. The relatively ease in land availability in rural and remote areas and the low investment cost compared to the other disposal methods tends to make this option the most feasible one.

In anticipation for expansion of desalination plants in the vicinity of urban centres and the relatively limited areas to be allocated for evaporation ponds, the Jordanian national expert expressed some interest to address brine ground injection. The outcome of the discussion with the international experts indicated that brine injection could be a cost efficient method for brine disposal from large plants at areas with limited land availability. However, it was agreed this is a very limited case that shouldn't be given a high priority by SWIM-SM to undertake a capacity development in hydro-geological investigation for brine injection, since evaporation ponds are the least expensive and most technically feasible option for rural and remote areas.

Another brine disposal approach that could be considered for local community development is the reuse of brine in agricultural and aquaculture. An objection was raised by the Jordanian representative, due to the fact that the use of brine in agriculture would degrade the quality of the soil and it would need 3-4 times the volume of brine for washing the soil from salts. At that point the Environmental Impact aspect of reusing brine to agriculture was raised by the SWIM-SM Team Leader and it was agreed that this would be incorporated in an option in toolbox to be developed (see below).

In the coastal areas, the most cost efficient method of brine disposal is the discharge to the sea using carefully designed outfalls equipped with diffusers to help in the dispersion of brine in the near shore marine environment with minimum environmental impacts. The Environmental Impacts of brine discharge to the sea was raised by the MED-POL Programme Officer. SWIM-SM Team Leader raised the issue of potential **cumulative environmental impacts** of the proliferating mega desalination plants around the coasts of the Mediterranean Sea. During the first day, the MED-POL Programme Officer informed the CDG that according to the **"New Protocol" brine dumping to the sea is not allowed anymore**. (A debate took place on the use of the term "dumping" rather than "discharge" to the sea. The MED-POL Programme Officer promised to advise the participants on the correct term).

According to the MED-POL representative, many countries refused to ratify the new Protocol. On the other hand, the international experts explained that the discharge of brine to the sea (from sea water desalination) affects only the near shore marine environment within a radius of approx. 100 m from the diffusers. Brine discharge of carefully situated and designed seawater desalination plants will have limited environmental impacts on the near-shore marine environment. According to the CDG, discharge of brine (particularly when mixed with cooling waters) through outfalls extended to the open sea where eddy currents disperse and dilute the brine to the open sea were found to be of very limited environmental impacts.

A solid recommendation culminated from the CDG discussions indicated that once it is decided to implement a desalination project, its environmental impacts should be assessed in accordance to the national EIA policies and guided by the internationally recognized criteria & methodologies.

VI. Factor 6: Other practical site characteristics

Land topography & access, the availability & quality of roads & transportation considerations, and other infrastructure are all factors that need to be considered.

VII. Factor 7: Total Unit Cost

After all other factors are duly considered & appropriately weighed-in, the ultimate deciding factor for selecting the best solution out of a number of equally acceptable technical solutions is the **total unit cost**.



The total unit cost should incorporate all externalities related to the desalination project, including the social and the environmental costs to the community.

4.4 Guidelines to Screen and Assess Desalination BAT Using RES

I. Step 1: Evaluation of available water resources & demand characteristics

The international and national experts agreed to the need for a comprehensive evaluation of the available water resources, as well as an evaluation of the water demand characteristics at the proposed site to be the first step, with a purpose to ensure that all options are exhausted prior to deciding on desalination.

In order to evaluate and establish the needs of a rural or remote community for desalination projects, the real need for the community has to be examined within an overall assessment of water resources available to the community. Introduction of desalination, if decided, into a community should be within an IWRM context and should be considered by central and local authorities as a first milestone towards the overall sustainable development of the community. Accordingly, a detailed opportunity cost analysis should be elaborated before deciding on desalination. Factors to be taken into consideration in the opportunity cost analysis should include but not limited to alternative water resources, reuse of wastewater, production cost of desalination at the point of use, environmental externalities, savings from reduction of non revenue water (minimisation of leakages and illegal withdrawals), reallocation of water from irrigation with its socio-economic impacts, re-evaluation of crop development in agriculture policies etc.

A capacity development workshops need to be planned to train water officials on the principles of opportunity cost analysis for desalination shall be considered within the capacity building WP of SWIM program. It will be implemented "parallel but separate" to the tasks of SWIM-SM.

The recommended activities need to be implemented in synergy with other EU or Mediterranean projects such as NED-POL and H2020; donors and stakeholders to avoid duplication and to pool resources.

II. Step 2: Evaluation of available RES & grid connectivity

According to the experts, the next major step in the process is to carry out an extensive study of the available energy resources, with a particular focus on renewable energy sources, in case electric power grid or supply is not available. A thorough understanding of the available RESs, their qualitative & quantitative characteristics is required. At this point it was suggested that a Risk Analysis of the RES availability should be considered when evaluating desalination projects.

In addition to that, a capacity development programme is considered necessary to orient water policy makers in SWIM countries of the new developments and state-of-the-art aspects (technical, advantages, economics, limitations, etc.) of RES compatible with small scale desalination.

III. Step 3: Short listing of candidate desalination processes based on available RES

The previous steps of identifying, characterizing and selecting the RES should allow the elimination of all desalination processes that are not suited to the type of energy source chosen within the socio-economic, environmental and cultural specificities of the community in need for desalination.

IV. Step 4: Environmental Impact Assessment of DES-BAT & RES projects

Once a desalination plant has been decided based on exhaustive elimination of alternatives using opportunity cost analysis tools, an EIA has to be under taken to identify, avoid and/or mitigate any potential environmental impacts according to national EIA policies. The cumulative environmental



impacts (primarily from the discharge of brine to the sea or its reuse in agriculture) resulting from the operation of the desalination plant will be given adequate weight in the EIA studies.

Based on the CDG discussions with the national consultants, they agreed to the following:

1. SWIM-SM should consider the development of a comprehensive tool-box (guidelines) to support policy makers decide on desalination after exhausting all other options. The tool box should follow a logic sequence, simple and friendly to use. The tool-box shall include the economic and environmental instruments needed to decide on desalination while avoiding its environmental impacts.
2. SWIM to ensure the incorporation of EIA as a fundamental step in the structure and context of the proposed DES-BAT & RES guidelines.
3. A succinct plan for the development of the proposed guidelines (tool-box) need to be developed & discussed with the CDG, electronically shared with PCs, developed, electronically shared & then discussed in an enlarged regional consultative meeting with the involvement of national water & environment experts from PCs in collaboration with UNEP-MAP.

4.5 The way forward:

Table 3, below is a summary of the steps agreed to be followed for the development of the guidelines (Toolbox), for the support of the decision makers to decide on desalination projects, to cover the water supply need of rural and remote areas in the PCs.

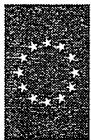


Table 3: Proposed steps forward by CDG under SWIM-SM

Task	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13
Finalization of the "Assessment of BAT for Desalination in Rural Areas.												
Preparation of a draft plan with structure, content and scope of the Toolbox.												
Electronically share the plan with CDG to reflect & approve the plan												
Engage an International consultant to develop the Toolbox												
Electronically share draft Toolbox with national FPs for comments & feedback												
Convene a Joint Regional Consultative meeting in collaboration with UNEP/MAP to reflect & approve Toolbox.												

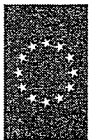


5. DETAILED WORKSHOP AGENDA

		Agenda - Day 1	Responsibility
From	To		
9:00	9:20	Session 1: Workshop Opening - Opening remarks (Project Director – SWIM-SM) - Orientation remarks (Programme Manager – SWIM-SM) - Introduction and orientation (Team Leader – SWIM-SM)	Project Director – SWIM-SM (Stavros Damianidis) Programme Manager – SWIM - SM (Alessandra Sensi) Team Leader – SWIM - SM (Hosny Khordagui)
9:20	11:00	Session II: Reflections and Comments on Desalination BAT: - Presentation on desalination BAT in rural areas. (20 minutes) - Round table discussion of the findings (80 minutes)	Team Leader – SWIM - SM (Hosny Khordagui) Desalination Expert – SWIM - SM (Adil Bushnak)
11:00	11:30	Coffee Break	
11:30	13:00	Session III: Modalities for assessing local community needs for desalination: - Round table discussions on factors to be considered in deciding on communities need for desalination as the appropriate choice.	Team Leader – SWIM - SM (Hosny Khordagui) International Desalination Experts SWIM - SM
13:00	14:00	Lunch Break	
14:00	15:30	Session IV: Factors for assessing and deciding on the optimum desalination option: - Round table discussions on factors to be considered by decision makers in assessing and selecting the best desalination option.	Team Leader – SWIM - SM (Hosny Khordagui) International Desalination Experts SWIM - SM
15:30	16:00	Coffee Break	
16:00	18:00	Session V: Guideline to support decision makers in screening and assessing options for desalination - Round table discussion on the necessity for the development of detailed guidelines to support desalination decision making. - Suggested structure and content of the proposed guidelines.	Team Leader – SWIM - SM (Hosny Khordagui) International Desalination Experts SWIM - SM



		Agenda - Day 2	Responsibility
From	To		
9:00	9:10	Welcoming remarks and briefing by SWIM-SM Technical Director	Programme Manager – SWIM - SM (Alessandra Sensi)
9:10	11:00	<p>Session VI: Presentation and discussions of 1st day outcomes.</p> <ul style="list-style-type: none"> - Power point presentation on the main outcomes of the first day discussions on desalination BAT for rural areas, assessment of communities for desalination and factors to be considered in deciding on desalination options. (20 Minutes) - Round table discussions on the major outcomes. (90 Minute) 	Team Leader – SWIM - SM (Hosny Khordagui) International Desalination Experts SWIM – SM National Focal Experts from PCs
11:00	11:30	Coffee Break	
11:30	13:00	<p>Session VII: Development of guidelines screen and assess the appropriate desalination option.</p> <ul style="list-style-type: none"> - Briefing on the core experts deliberations on the need and structure of guidelines to support desalination decision making. (15 Minutes) - Round table discussions on suggested structure, scope and content of the guidelines (75 Minutes) 	Team Leader – SWIM - SM (Hosny Khordagui) International Desalination Experts SWIM – SM National Focal Experts from PCs
13:00	14:30	Lunch Break	
14:30	16:00	<p>Session IIX: Development of a regional Orientation for desalination in SMCs</p> <ul style="list-style-type: none"> - Briefing on the outcomes of CDG deliberations on the necessity and scope of a regional orientation for desalination (15 Minutes) - Round table discussions on the suggested regional orientation (75 minutes) 	Team Leader – SWIM - SM (Hosny Khordagui) International Desalination Experts SWIM – SM National Focal Experts from PCs
16:00	17:00:	Session IX: The way forward, wrap up and closing remarks	Programme Manager – SWIM - SM (Alessandra Sensi) Team Leader – SWIM - SM (Hosny Khordagui)

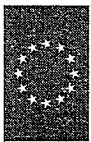


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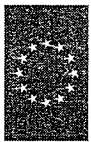


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