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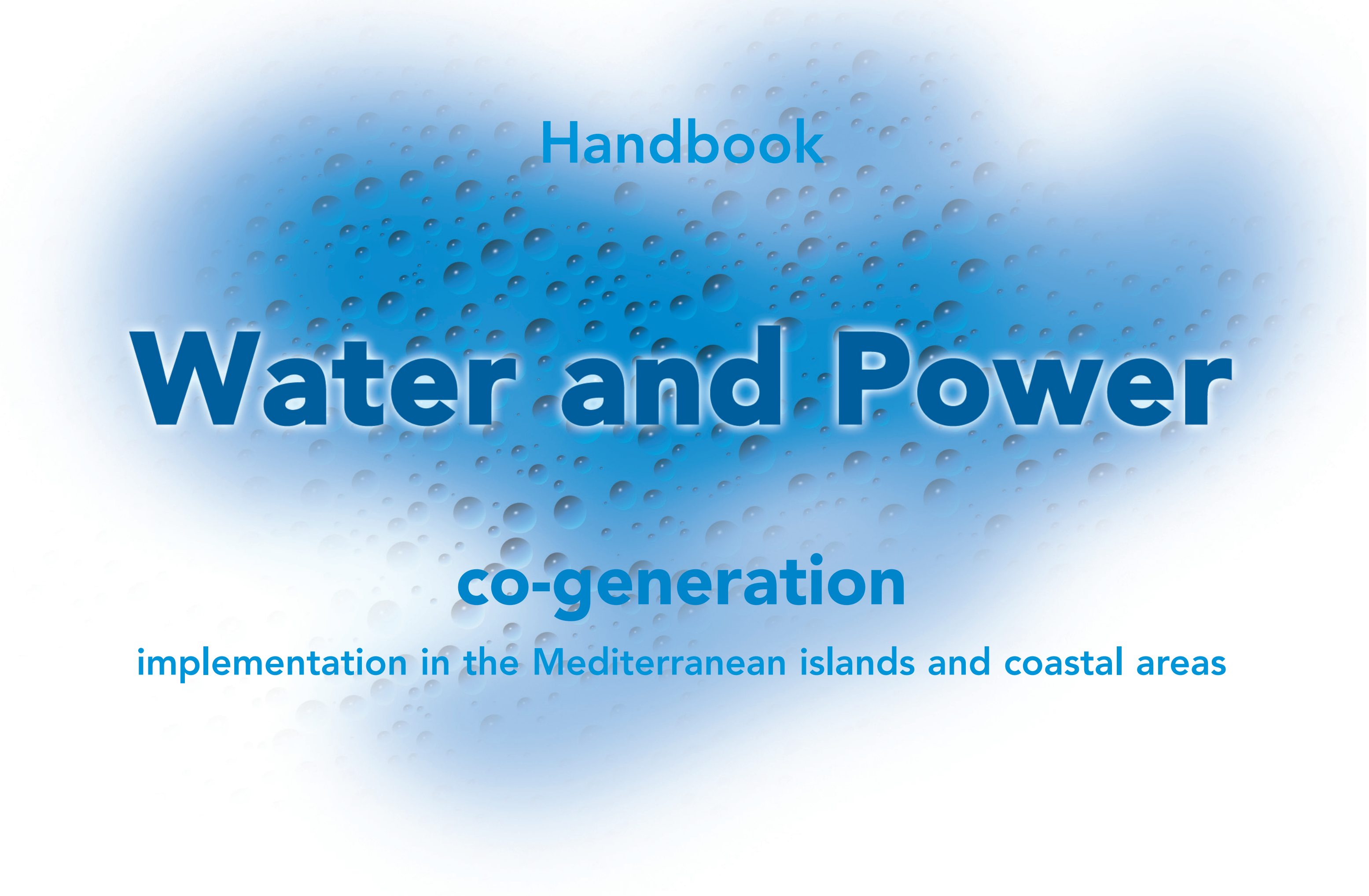

Handbook

Water and Power

co-generation

implementation in the Mediterranean islands and coastal areas

produced by

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Water and Power co-generation implementation in the Mediterranean islands and coastal areas

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Content

1. Introduction

Background

This handbook is the result of the EC-funded OPET Program “CO-OPET: Support Initiative for the Organisation for Promotion of Energy Technologies”. Its objective is to present opportunities of commercial desalination technologies exploiting waste heat from power plants and to assess the possibility of their implementation on small islands with limited fresh water resources.

Human communities living in hot and arid areas, or on islands in the sea, usually are in bad need for both water and power (electricity). Especially in hot climates, both these needs follow a similar demand curve, daily as well as seasonally. Both cooling and water demand reach their respective peaks during midday and during the hot summer season.

Conventional Cogeneration, namely Combined Heat and Power (CHP) is usually not very convenient in hot climates since there is no sufficient demand for the available waste heat. - So why not produce instead water and power by exploiting the otherwise wasted exhaust heat (or waste heat) from thermal power plants to drive thermal seawater desalination systems?

In large scale applications, such as in Saudi Arabia and in the Arab Gulf Emirates, this technology is already a common and well proven practice. Also large ships adopt similar seawater desalination systems exploiting the waste heat from the ship’s main propulsion systems. So why aren’t such technologies used for small scale stationary applications on islands or serving isolated communities on arid coasts?

The aim of this handbook is to assist decision makers on islands by providing an appropriate (and rapid) economic evaluation tool for possible seawater desalination applications, based on the present energy/water supply situation, and taking into account the specific constraints arising from the limited size of the examined “island systems”.

For more details on the presented technology options, please refer to the report “Study on technical and economic constraints and opportunities” prepared under the same project.

Application field

The present investigation focuses on the large majority of smaller islands in the Mediterranean sea, with resident (stable) inhabitants between 100 - 20.000 inhabitants, and which do not have an electrical under-sea cable connection to the continent, and rely therefore on local thermal power plants (usually diesel gensets) for their electricity supply, and which represent therefore the energy source potentially exploitable “for free”. Accordingly the following approximate power and water needs may be assumed for such islands:

Table 1 - Typical Mediterranean island parameters: inhabitants, tourists, power and water needs

Parameter			island size			unit
			small	average	large	
Number of inhabitants	resident (stable)		100	1.000	10.000	inhabitants
	tourists overnight (summer peak)		400	3.000	20.000	tourists
Water demand	annual		13.000	110.000	900.000	m^3/year
	daily (annual average)		50	400	3.000	m^3/day
	during peak month		4.000	27.000	200.000	m^3/month
Electrical system	Generation capacity installed		1	4	18	MW
	Power demand / production	overall annual	600	5.000	30.000	MWh/year
		during peak month	180	1.000	5.000	MWh/month
Waste heat availability	overall annual		420	4.250	30.000	MWh/year
	peak month		130	850	5.000	MWh/month
Temperature of waste heat	from cooling jacket		90°C			
	from exhaust gases (diesel)		300°C			

The following approximate per capita demands for power and water have been assumed:

- Electricity (power) consumption: 10kWh/day per inhabitant
- Water consumption (average): 200-300 Litre/day per inhabitant
- The installed power generation capacity varies typically between 1,5 kW/inhabitant (for larger islands) and 10 kW/inhabitant (for smaller islands).

Water supply costs on islands

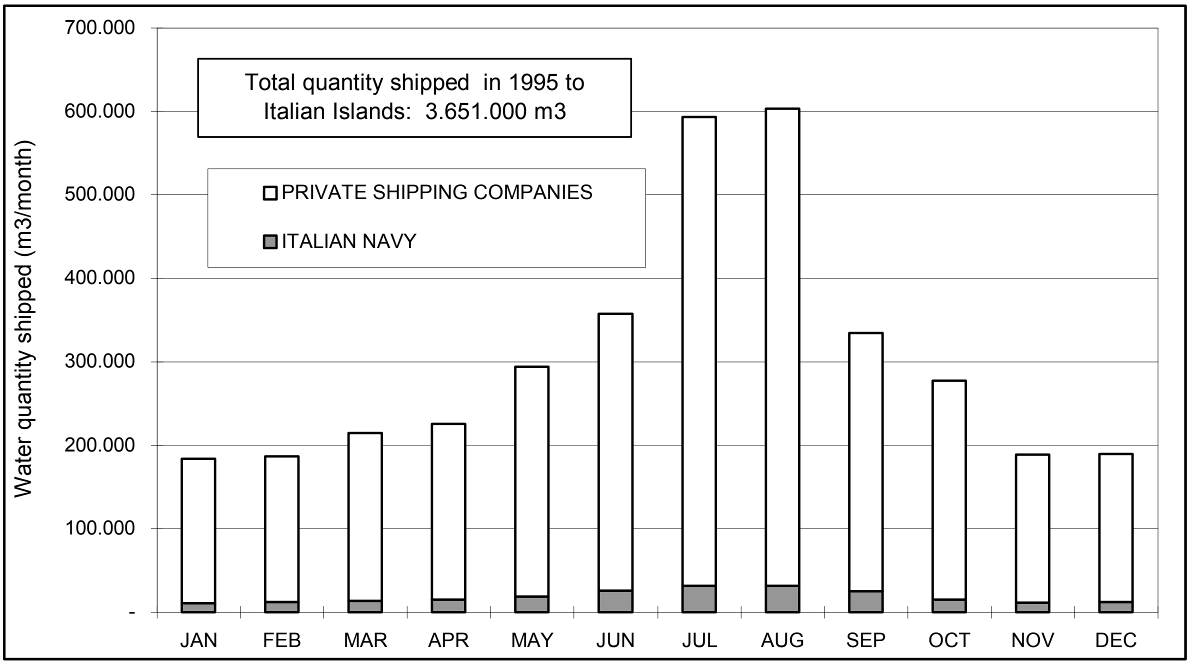
The majority of Mediterranean islands depend almost entirely on the continental mainland concerning the water supplies, which are mostly shipped by means of tanker ships (belonging to private companies or to the national Navy).

The costs of the sea freight are extremely high: from 7 €/m^3 up to 12 €/m^3; this is because the water supply on the islands and the relative costs are decided centrally by some national Ministry or the national government, and not by local authorities.

As example, the following Figure 1 illustrates how much water is presently transported by tanker ship to the Italian “minor islands”.

The Italian government spends annually more than 30 million € to transport via tanker shipping a total quantity of 3,7 million cubic metres of water to the Italian “isole minori”, i.e. at an average cost of 7,5 €/m^3

Figure 1 - Overall monthly water shipping to all Italian islands (1995)



Source: Final report ”Renewable Energies on Mediterranean Islands”, EC DG XII - APAS - RENA CT94-004 (1996)

The installation of desalination systems on the islands would allow to reduce the costs of water supplies on islands. Furthermore, these systems present other advantages, reported as follows:

- Independence from water supplies from the continent, allowing to ensure water availability to both tourists and the island inhabitants, and independent from meteorological conditions.
- Excellent water quality; in fact in this way the contamination by germs due to shipping is avoided
- Economic opportunities in terms of technical competences, qualified jobs, representing a model for sustainable tourism and development.

In the case of desalination plants using thermal processes of distillation, the best solution is to combine these plants with the power plants, in order to use the waste heat of the power plant to drive the desalination plant.

Electricity costs on islands

Usually, on the smaller islands in the Mediterranean Sea, the price paid by consumers for electricity does not reflect the real costs of their electricity supply.

The high cost of conventional (diesel) power on islands is in most cases hidden by subsidised consumer tariffs intended to alleviate the hardships of life of island populations. The gap between tariffs paid by consumers and the actual costs of energy (and of water) on islands is covered either by government subsidies (for example by the “Cassa Conguagli” in Italy) or else by the national utility (like PPC in Greece). In any case it is always the national (mainland) community as a whole to cover these costs.

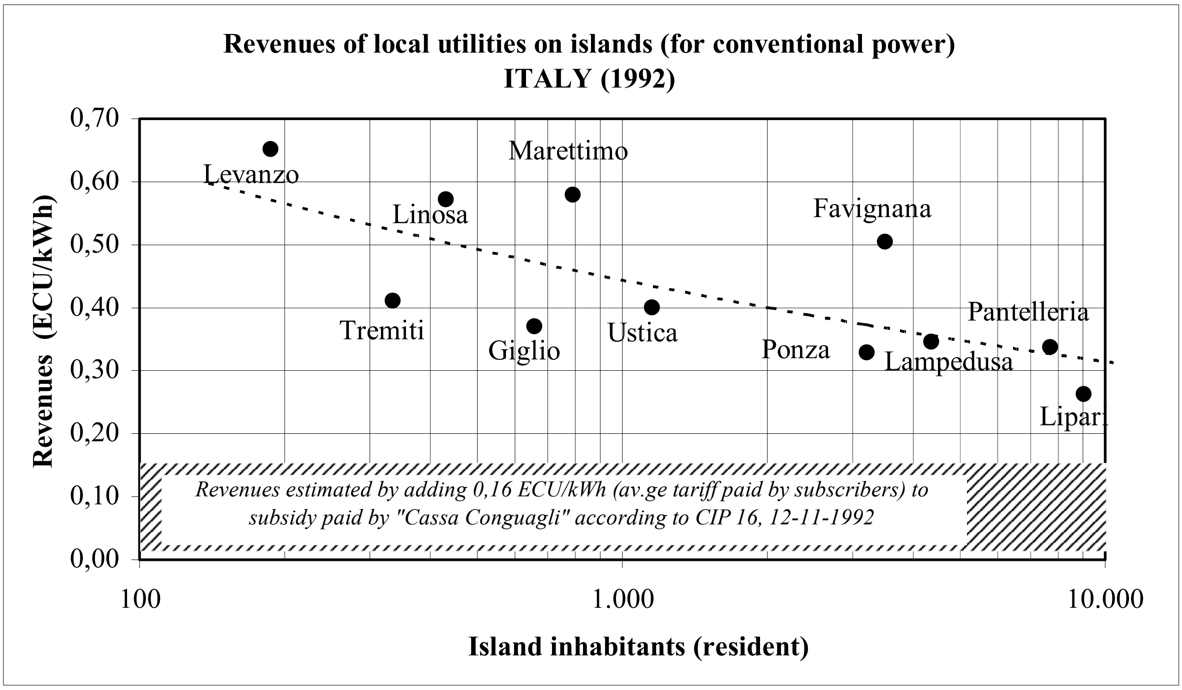
Subsidised consumer tariffs produce a market distortion giving new technologies, such as seawater desalination or renewable energy sources, no chance to win competition with conventional (subsidised) power and water supplies. If these new technologies would be permitted to compete under fair (equal) conditions, on the islands, they would frequently win.

Subsidised tariffs induce islanders not to save, but to boost consumptions, making the water and power supplies larger and more expensive. Furthermore they freeze the existing (conventional) water and power supply system on islands, since there is no economic interest to improve the system and to introduce innovations.

Unfortunately local operators are frequently reluctant to provide information, especially of economic type. As a result, frequently relevant data have to be gathered indirectly.

The following graph present the revenues of local island utilities for the Italian minor islands in 1992, and illustrates the relationship between electricity costs and the size of the served island community (population).

Figure 2 – Typical real costs of electricity on Italian minor islands



Source: Final report "Renewable Energies on Mediterranean Islands", EC DG XII - APAS - RENA CT94-004 (1996)

2. Desalination as an alternative solution

Desalination is the process of removing salt from saline water and producing fresh potable water. It provides an alternative option for drinking quality water and fosters development in arid or coastal regions with limited groundwater resources or located far from conventional water resources. Even if desalination technology is used solely for the production of non-drinking quality water, it helps preserve existing resources from over-exploitation and mismanagement.

Desalination technology has evolved considerably over the past 50 years and has proved its technical feasibility. The average price of desalinated seawater today is estimated to be only one-tenth of what it was twenty years ago, making it a viable solution for the supply of water to islands.

A large number of desalination plants have been installed throughout the world, the majority of which can be found in the Middle East and the Caribbean islands. Despite still being overall more expensive than conventional applications due to its intensive use of energy, desalination has proved in various cases to be more reliable and economic solution. In the case of transportation of water by marine vessels, desalination has emerged as a less expensive alternative.

The total worldwide desalination capacity in 1971 was reported to be around 1,5 million m^3/day. In 1996 this had risen to 20,3 million m^3/day, with approximately 11.000 installations spread in 120 countries all over the world (Source: Raphael Semiat). It is estimated that today, there are approximately 13,600 desalination units, which currently produce 26 million m^3/day of fresh water each day. Desalination capacity according to the U.S. Department of the Interior, Bureau of Reclamation, increases 12 % annually.

The Middle East region has approximately 50 % of the desalination capacity, with the Kingdom of Saudi Arabia accounting for 30 % of the total world percentage and hosting the largest plant capable of delivering close to one million m^3/day using the MSF technique. There are approximately 1,000 units installed in the United States, mostly based on the RO technology, which account for 15 % of the world's production.

The integration of desalination technologies into power plants makes possible the utilisation of waste heat usually discharged to the atmosphere for the production of potable water. Accordingly the combined production of power (electricity) and water reduces both the production costs of electricity and of water. Examples of such desalination co-generation plants can be found all over the world, and particularly in the Middle East.

General

Desalination, also called desalinization or desalting, refers to a water treatment process that removes salts from water. Desalination can be done in different ways, but the result is always the same: fresh water is produced from brackish (up to 10g/L) or sea water (up to 50g/L). Desalting devices essentially separate saline water into two streams: one with a low concentration of dissolved salts (the fresh water stream) and the other containing the remaining dissolved salts (the concentrate or brine stream) – (Buros, 1999).

Conceivably the most important characteristic with regard to the desalination process is the water salinity. Salinity refers to the concentration of dissolved minerals in water and it is often described as total dissolved solids (TDS). It is either expressed in ppm (parts per million) or in mg/Litre. The concentration of salts in natural water typically ranges between 1,000 and 30-35,000 ppm. The following table presents the salinity levels for various natural waters classified by their TDS concentration:

Table 2 - Salinity levels

Water	Concentration (TDS)
Fresh potable	500 ppm
Brackish water	1,000 to 35,000 ppm
Seawater	~ 30-35,000 ppm
Brine water	> 100,000 ppm

Desalination units are used to reduce the salinity of seawater, brackish groundwater, municipal or industrial wastewater according to different water quality demands. The generated product water can then be used as drinking water, or can be applied for municipal, industrial or irrigational needs.

Desalination technologies

General Classification

Desalination technology may be classified in three major categories:

1. Thermal processes: in which desalination takes place with phase change (thermal processes of distillation)
2. membrane processes: in which desalination takes place without any phase change (mechanical processes)
3. alternative processes (grouping which includes all other processes)

Thermal distillation processes

The three main processes based on the thermal separation technology are:

- Multi stage flash evaporation (MSF)
- Multi effect distillation (MED) and

- Vapour compression (VC) systems (either MVC or MED-TVC)

Membrane processes

The two main processes based on the membrane technology, consisting in the mechanical separation of total dissolved solids (TDS) from the pure water, are:

- Electro dialysis
- Reverse Osmosis

Compared to thermal separation techniques, no phase change is required making them less energy intensive. Membrane processes have emerged in the scene during the last four decades. Owing to the latest developments and the reduced costs in membrane technology, membrane separation processes are becoming increasingly popular and competitive and account for one third of the total world desalination capacity.

Advantages/disadvantages

Each of the most important processes for desalination has advantages and limitations, summarizing as follows.

Advantages of thermal distillation processes:

- Suitable to treat sea waters, because salts' content in the water to be desalinated doesn't meaningfully engrave on the process
- High reliability
- minimal pre-treatment requirements for feed sea-water
- Capability to exploit low enthalpy waste heat from power plants.
- Economical if a cheap heat source is available.

Disadvantages of thermal distillation :

- Amount of water production depends on operating temperature.
- Tube scaling, which occurs at high temperatures by $CaSO_4$. This introduces a limit to the top brine temperature (of 120°C), and consequently to the efficiency.

- The energy consumption of these processes is quite high and depends mainly on the temperature and GOR.

Advantages of Reverse Osmosis:

- Relatively low energy consumption (but only in terms of final energy use).
- Smaller and more compact.
- lower investment

Disadvantages of Reverse Osmosis:

- thermal stability limit of the membrane
- the sensitivity of membranes to fouling (erroneous operation can reduce the life of a membrane to less than one year)
- lower water quality as compared to thermal distillation
- need for expensive pre-treatment (feed water must pass through very narrow passages, suspended solids must be removed)
- Needs expensive electricity as main drive power
- High maintenance requirements
- High operating costs

The following table provides an overview of the available technologies and the form of energy required to drive the process.

Table 3 - Various desalination technologies

Desalination Technology		**Form of Energy used**
Thermal	Multi Stage flash Evaporation (MSF)	Heat
	Multi Effect Distillation (MED)	
	Vapour compression (VC)	Heat or mechanical energy
Membrane	Reverse Osmosis (RO)	Mechanical or Electrical Energy
	Electrodialysis (ED)	
Alternative	Ion exchange (IX), Freeze, Solar, nuclear, submarine desalination	Solar, nuclear, mechanical, thermal energy

For more details on the presented technologies, please refer to the report "Study on technical and economic constraints and opportunities" prepared under the same project.

The following table presents a summary of the available desalination processes and related typical process parameters.

Table 4 – Typical data of commercial desalination processes

Process			Sea-water	Maintenance requirements	Size range per production unit (m^3/day)		Specific energy consumptions													
							Electricity(*)		Thermal energy (heat)					Primary energy(**)						
							kWh/m^3		GOR		kWh/m^3		Temperature	electric (kWh/m^3)		Heat (kWh/m^3)		**Total (kWh/m^3)**	
					min	max	min	max	min	max	min	max	°C	min	max	min	max	**min**	**max**
Membrane processes	Electrodialysis Reversal	EDR	**NO**	↗	0	30.000	0,2	1,5	n/a					0,5	5	n/a		**0,5**	**5**
	Brackish Water Reverse Osmosis	BWRO	**NO**	↗	0	10.000	0,3	1,9	n/a					0,8	6	n/a		**0,8**	**6**
	Seawater Reverse Osmosis	SWRO	yes	↗	0	10.000	4,0	7,9	n/a					12	24	n/a		**12**	**24**
Thermal processes	Multiple Effect Distillation	MED	yes	↘	2.000	20.000	0,8	1,8	1	10	63	630	60-80°C	2,3	5	63	630	**65**	**635**
	Multiple Effect Distillation with thermo-compression	MED-TC	yes	↘	2.000	20.000	0,8	1,5	3	15	42	210	60-80°C	2,3	5	42	210	**44**	**215**
	Multiple Stage Flash - Brine recirculation	MSF-BR	yes	↘	4.000	75.000	2,6	4,0	4	12	52	160	90-120°C	8	12	52	160	**60**	**172**
	Mechanical Vapour Compression (all electric)	MVC	yes	↘	100	3.000	8,5	12,0	20	40	16	31	90-120°C	26	36	16	31	**41**	**67**

(*) Upstream feed-water intake and downstream distribution pumping not considered

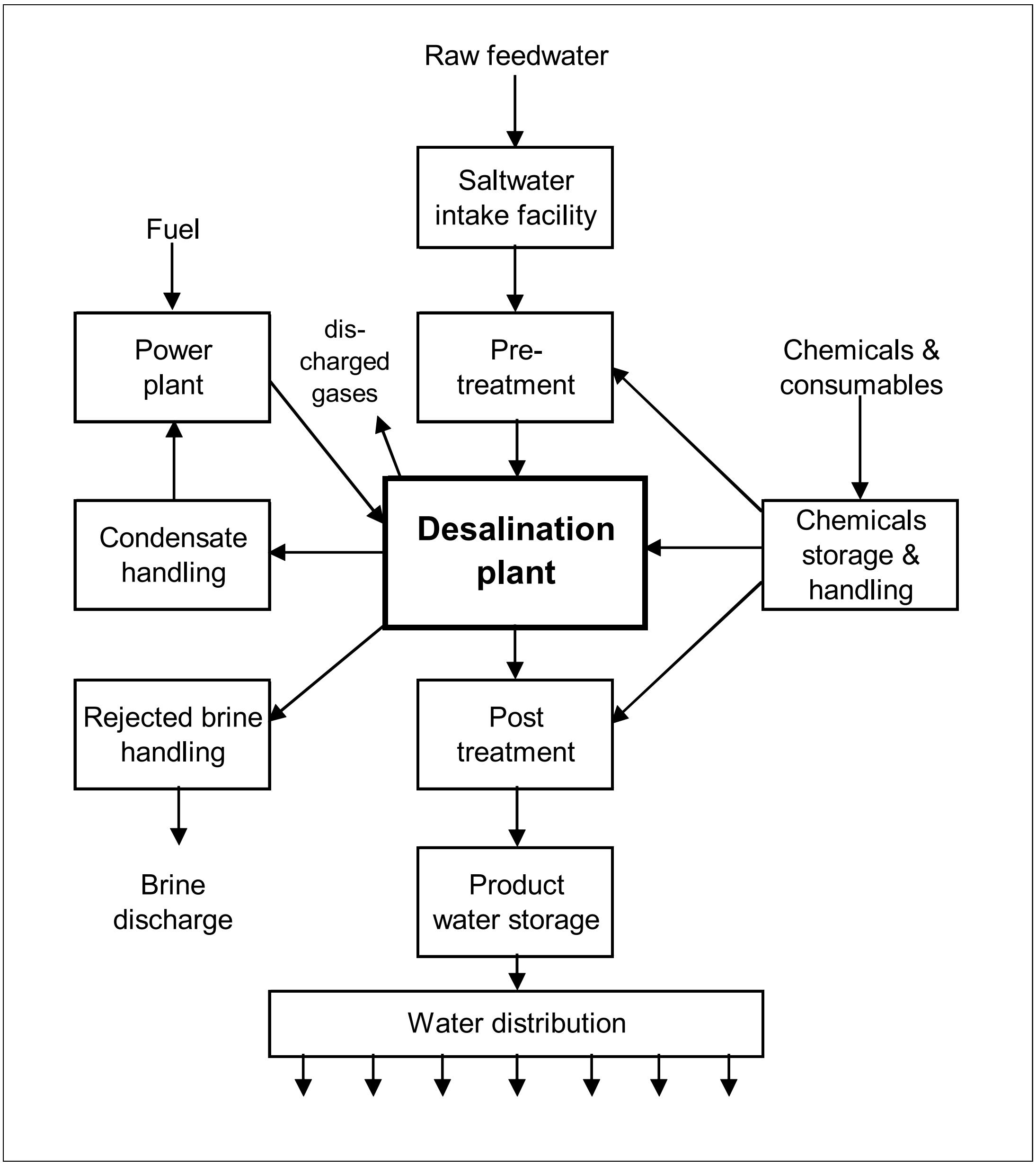
(**) Considering average specific fuel consumption of diesel generators = 260g/kWh

↗ = high ↘ = low n/a= not applicable

Common facilities

All processes used for desalting saline water have many common elements, as represented in Figure 3.

Figure 3 – Typical overall scheme of a desalination facility



As illustrated, the water needs some treatment before being sent to the desalination plant, where product water is produced; it depends on the feedwater composition, on the type of process and on downstream equipment.

Along with product water are produced few more streams, as concentrated reject brine but also gases and condensate.

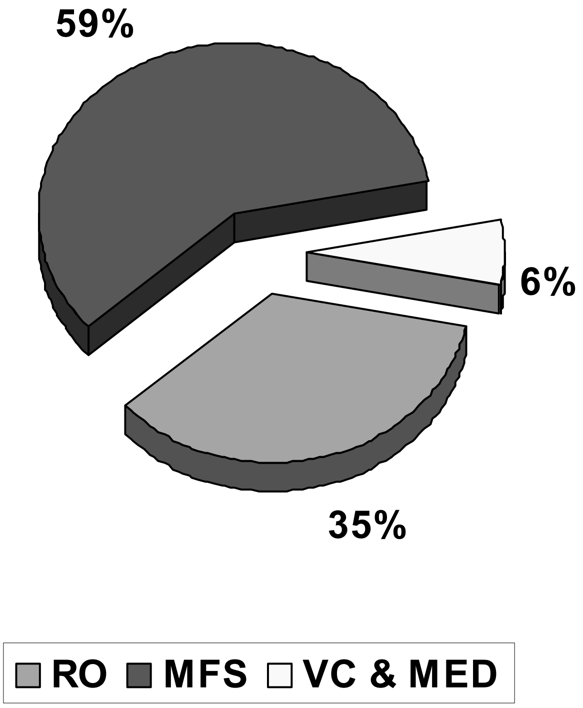
Desalinated product water is usually not suitable for consumption without some form of treatment, during which chemicals are added to make it potable and not corrosive for distribution pipes. At the end, treated water is pumped to storage tanks or sent directly into the distribution system.

Market share and trends

Thermal desalination processes account for approximately 65 % of the total desalination capacity, which is divided between Multi Stage flash (MSF) evaporation (representing 90 % of all world thermal desalination capacity), MED and VC, which both account for a modest 10 % of the world total. Reverse Osmosis holds the remaining world market share of 35 %. Together MSF and RO processes dominate the market for both brackish water and seawater desalination, with a total share of more than 90 %.

Reverse Osmosis currently represents the prime technology, with most newly commissioned or scheduled plants being based on this technology. However, it is expected that in the near future MED percentage will also rise as the old MSF plants will be gradually replaced or decommissioned.

Figure 4 –World market shares of desalination technologies



3. Cogeneration

Conventional Cogeneration - Combined Heat and Power (CHP)

Cogeneration, so-called combined heat and power (CHP) generation allows to obtain significant reductions in the consumptions of primary energy source and in emissions of gases responsible for climate change (CO_2).

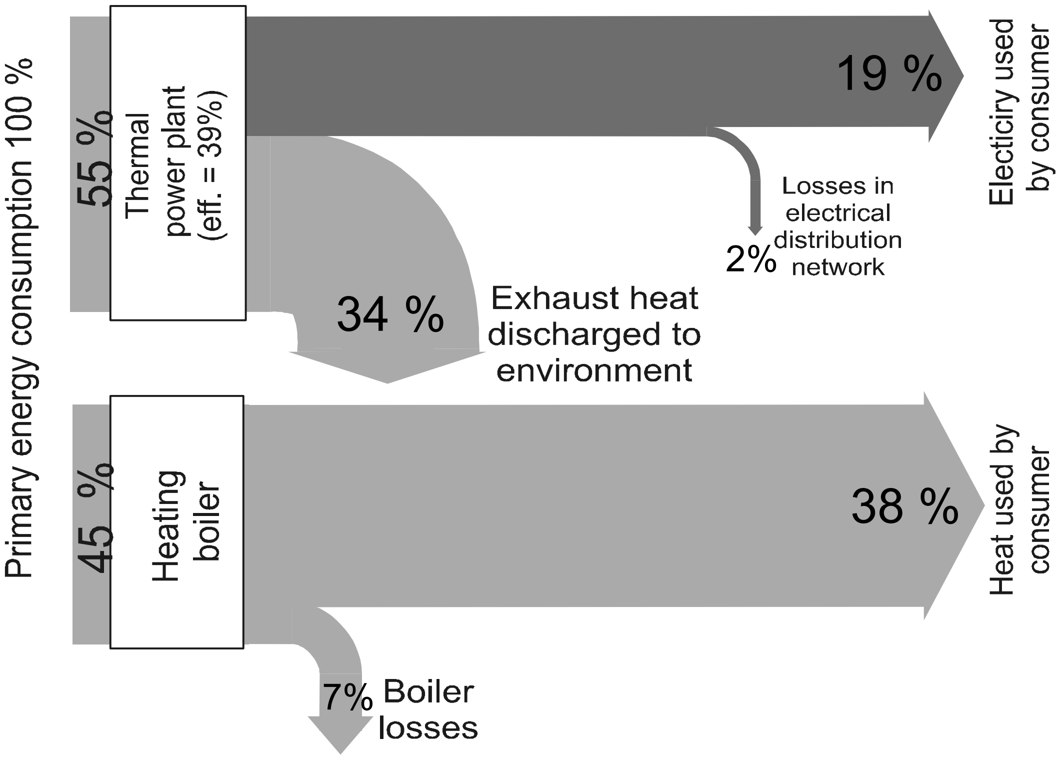
Generally electricity and heat are produced separately in different locations: Centralised thermal power plants usually consume fuel is to produce electricity by, while heat is produced in homes and elsewhere by means of domestic boilers. Co-generation, the combined production of Heat and Power (CHP) is instead able to produce both electricity and heat consuming fuel only once; in this way, compared to separate generation, co-generation allows to save approximate 30-40% of the otherwise required primary energy source.

As illustrated by Figure 5 in comparison to the separate generation of heat and electricity, co-generation allows to achieve substantial environmental and energy saving benefits; however, just because these advantages arise from a combined production, it’s necessary to use the produced thermal energy.

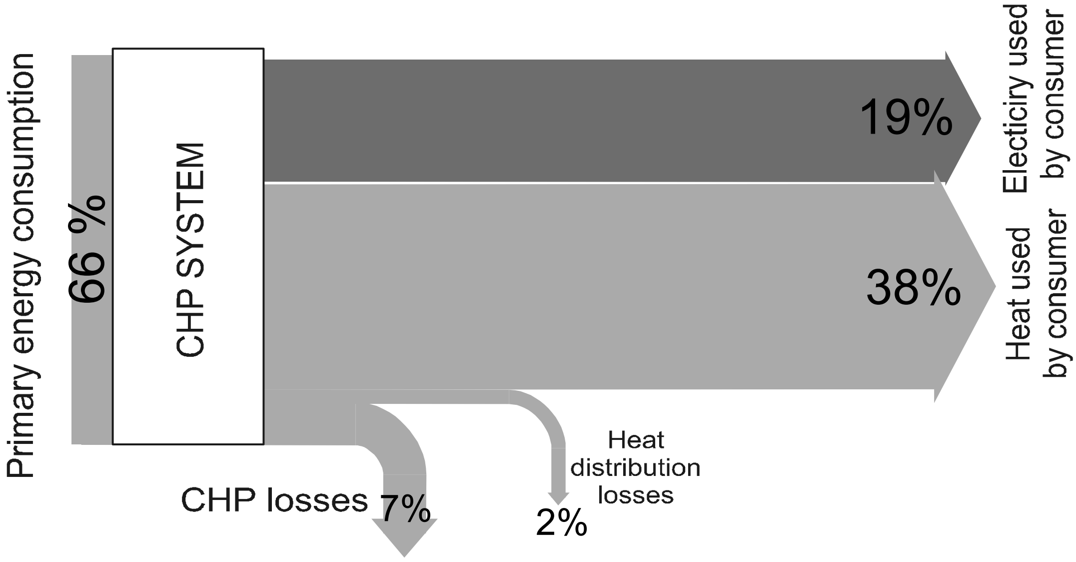
Moreover, since the load profiles (over daytime and seasonally) differ between electricity demand and heat demand, co-generation is convenient only if the electricity demand and the heat demand follow a similar profile.

Figure 5 – Comparison in terms of primary energy source consumption (supplying same end use energy to consumer) between:

a) CHP



b) separate heat and power production



Cogeneration of Power and Water

The heat made available by a CHP plant may be exploited to thermally distillate sea-water and to produce fresh-water for civil consumption. Actually, the best solution to desalinate great quantities of sea water consists in combining a desalination plant with another industrial plant or a thermal power plant generating waste heat which otherwise would be lost to the environment.

For the envisaged target application range on small islands in the Mediterranean sea, the local thermal power generation facility will usually be a diesel power plant. Accordingly the following considerations focus primarily on diesel systems to be exploited as waste heat source.

The typical electrical efficiency of a diesel engine ranges between 35-40 %. Theoretically the remaining 60-65 % of losses and waste heat provides a magnitude of the thermal energy potentially available since rejected from different systems in the diesel engine (exhaust gases, cylinder cooling jacket, oil cooler, turbocharger air cooler etc). Nevertheless, only a portion of this heat can be recovered at temperatures which can be effectively exploited to drive a desalination process.

Substantial quantities of heat are available in the exhaust gas from the engines. Nevertheless there are some limitations on the amount of heat which can be recovered from this source. In case that the consumed fuel contains sulphur, sulphur dioxide may be present in the exhaust. If the temperature of the exhaust gas is reduced to the dew point, sulphur dioxide will react with water vapour to form sulphuric acid which will result in corrosion in the exhaust system and stack. For this reason the exit temperature should be maintained above 180°C. This and other restrictions limits the amount of heat which can be effectively recovered from a diesel engine to about half of the theoretically available waste heat.

Accordingly, nearly the same amount of thermal energy (heat expressed in kWh) as the electric energy generated by a diesel power plant may be made available to drive a desalination system. Since no additional fuel is consumed for this purpose, de-facto this thermal energy (heat) is available at no additional cost, i.e. it is “for free”.

For the design of a desalination plant driven by the waste heat generated by a diesel engine, the heat output from the diesel power plant will come primarily from two specific heat sources:

1. Steam from the waste heat recovery boiler exploiting the hot exhaust gases of the diesel engine
2. Heat recovered from the cooling water jacket of the diesel engine and from the turbocharger air cooler.

4. Performance evaluation

General criteria

Desalination is a relatively sophisticated and expensive way to obtain fresh water. Related processes are quite complex and the degree of complexity is directly related to the size of the system. In order to evaluate, case by case, the most appropriate process for seawater desalination, the following factors should be taken into account.

Product water quality and quantity

Based on an initial estimate of the amount of water required, some processes may not be considered. For example, if we are considering desalinated sea-water to be supplied to an arid Middle East city, with no alternatively freshwater sources, the quantity of water required is massive and the only processes to consider are seawater distillation and seawater RO. The end use determines the product water quality; feed water contains many impurities, some of these may be removed during pre-treatment and other during the desalting process itself. The final product may still contain certain undesirable constituent and for this reason sometimes post-treatment is required. The type and extent of post-treatment required is determined by the product concentration desired.

Feedwater temperature

Feedwater temperature may affect process selection or the design of a particular process. It affects the heat economy of distillation processes, because at higher temperatures the overall temperature drop in the plant is reduced. In ED process, higher temperatures are beneficial, because, for a given current density, power consumption is decreased. Instead higher temperatures may have a negative effect on RO membranes.

Availability of cheap energy

Availability of cheap energy should be evaluated from all angles (type, source, availability, quality and cost). Higher efficiency plants are more complex in design and operation but they save fuel. If intermittent operation is required, a system with low capital and high operation cost is favoured. Where constant desalted water supply is required, the rate of energy consumption is of great importance. If both electricity and water are required the desalination and power plant may be integrated into a dual purpose plant, in fact, due to savings in fuel and common facilities, the economics may change appreciably.

Waste brine disposal

Provisions have to be made to dispose reject brine without causing adverse environmental impacts.

For plants located near the sea, reject lines can be channelled directly into the sea, but for inland desalination plants it is usually difficult to find areas where brine may safely disposed of. In general, disposal into the sea is cheaper and less hazardous compared to inland site disposal. Anyway, the solution of these problems adds to the product costs.

Location

The plant should be sited as close as possible to the feedwater source, in order to avoid excessive pumping and pipeline constrains. Moreover, the location should preferably be near both the energy source and the demand areas.

Process economics

The cost of desalting water needs to be accurately evaluated. Cost may be subdivided in two major components:

- **Capital costs:** include site development, desalting equipment, brine disposal, water treatment, steam supply, power supply, project management, etc
- **Operating costs**: include operating manpower, maintenance materials, chemicals, steam/fuel, electric power, etc.

Usually, these two cost factors behave inversely, i.e. the lower the capital cost, the higher will be the operating costs, and vice versa.

If the required drive energy (fuel and electricity) is expensive, a high performance ratio will be required to reduce energy requirements, and as a result the investment costs will have to be higher.

Instead, if the drive energy is cheap, the required performance ratio may be lower, and this in turns allows to reduce the investment cost.

Thermal versus membrane processes

The main differences between the two main desalination process classes, namely thermal distillation and membrane processes may be summarised as follows:

Energy consumption

Thermal distillation technologies are apparently an order of magnitude more energy intensive than membrane processes (in terms of energy quantity - kWh). This is the reason why, erroneously, thermal distillation processes are frequently considered less energy efficient.

Distillation processes do not need high exergy energy such as electricity, but only low enthalpy (low temperature => low exergy) heat of low value which is, from an energy efficiency point of view, not at all comparable to the highly valuable expensive electricity (or mechanical power) required to power membrane processes.

In fact, membrane systems cannot benefit from the utilisation of waste heat as an integrated unit within the power plant since they require mechanical or electrical energy to operate.

Distillation technologies can instead be powered by waste heat, which is frequently available "for free", reducing thereby the energy costs and making water production much more competitive.

The fact that they use a much larger amount of energy is thereby of secondary importance and more than compensated by their ability to exploit waste heat "for free", which otherwise would be discharged to the environment.

Scale economy

Distillation plants benefit much from scale economy. As a result, thermal plants generally tend to be larger and bulkier than membrane plants. For the same desalting capacity, thermal technologies require larger desalting surfaces which make them more expensive.

Thermal desalination systems have larger requirements for desalting surfaces. The cost of desalination unit are much more expensive since they are proportional to the heat exchange area.

Maintenance

Membrane technology has made significant progress and now can offer more efficient and cheaper membranes. Membrane lifetime spans usually from 3 to 5 years after which they must be replaced, a considerable cost parameter in the operation and the feasibility of a plant.

Membrane fouling after a few thousand hours of operation should be expected and requires membranes to be regularly cleaned and washed.

Distillation plants require maintenance mainly because of scaling and of corrosion as a result of too high temperatures.

Thermal distillation systems need expensive materials and plating in order to avoid corrosion.

Due to possible bacterial contamination, membrane-based plants need to shut down more often for routine cleaning and maintenance.

Feed-water pre-treatment requirements

Membrane-based units require extensive feed water pre-treatment. Despite the development of more efficient membranes, pre-treatment is necessary to avoid membrane fouling, which incurs a high cost in chemicals. Although new membranes have fewer pre-treatment requirements, the overall cost still remains significant.

The concentration of dissolved solids essentially determines the process cost in membrane-based technologies. Desalting seawater may cost about 2 to 5 times more than that of brackish water for the same plant capacity.
Thermal distillation processes present low pre-treatment requirements.

Rejected brine

Due to lower recovery rates, distillation plants produce much higher brine volumes that need to be disposed of.

On the other hand, the salt concentration of the rejected brine is lower and therefore less polluting.

Thermal systems require more complex brine disposal systems since higher temperature brine water needs to be cooled down before disposal.

Post-treatment requirements

Well designed distillation plants manage to remove all organic and inorganic impurities, Membrane technologies may require further post-treatment, especially due to the presence of bacteria. Due to possible bacterial contamination, membrane-based plants need to shut down more often for routine cleaning and maintenance.

Feed sea-water salinity

Salinity will determine the distillation cost only for membrane processes. Thermal distillation is not affected by this parameter.

Distillation processes can process feed water of lower quality than that of reverse osmosis plant facilities.

Membrane plants have higher recovery level than distillation plants but reduced salt removal capacity. As a result, water quality purified with RO or ED may not be of the highest quality.

Lifetime expectancy

Membrane life expectancy should be expected to be 3 to 5 years for saltwater environment or 5 to 7 years for brackish water, after which it should be changed. Membrane fouling after a few thousand hours of operation should be expected and requires them to be regularly cleaned and washed.

Thermal distillation plants present a typical lifetime of 20-30 years

5. Cost comparison

The following paragraphs and graphs give an approximate picture of the typical cost structure of the required investments, and ultimately of the produced water for the desalination technologies of major interest, namely for:

1. processes driven by waste heat coming from a nearby power plant:
    a) Multistage flash distillation (MSF)
    b) Multiple Effect Distillation (MED)

2. Seawater Reverse Osmosis (SWRO) as principle alternative solution typically adopted for same smaller applications, which however uses expensive electricity and cannot exploit waste heat

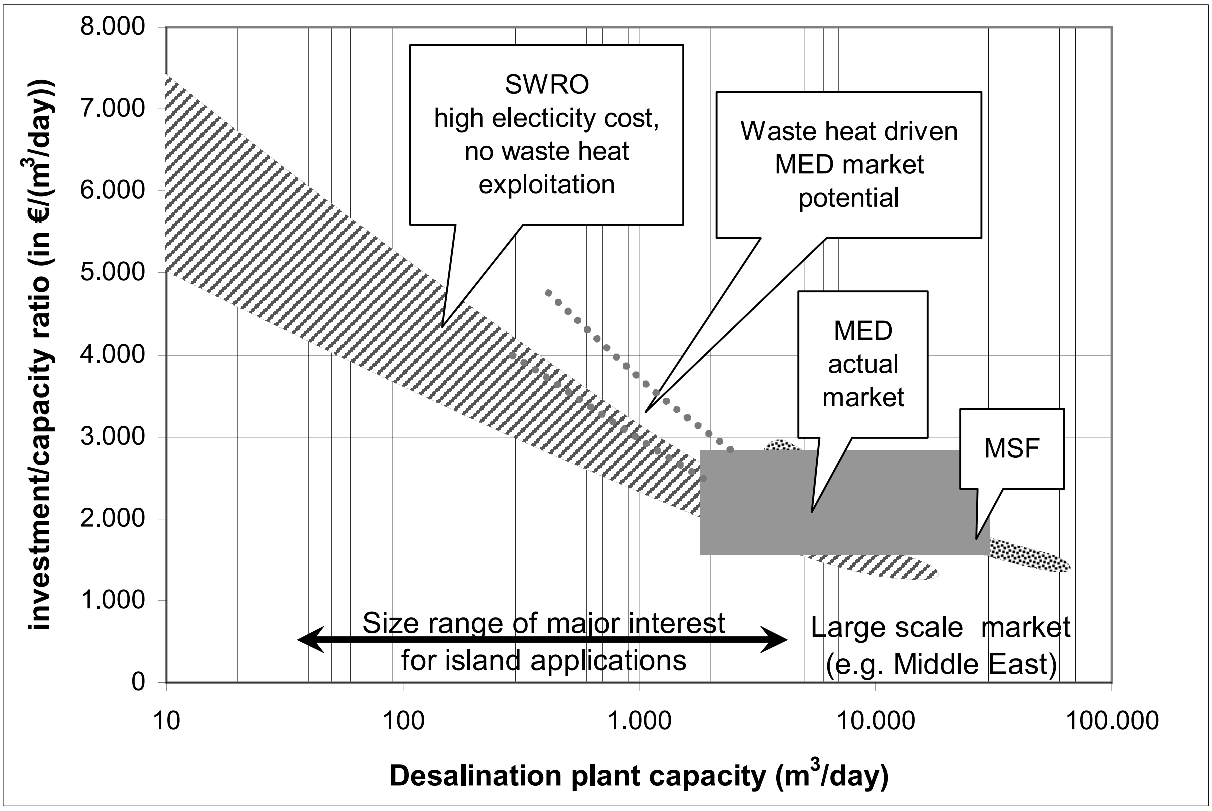
In all following graphs the X-axis is logarithmic in order to embrace the very wide size range from some few cubic metres of water daily, sufficient to satisfy the water needs of 10-20 families, up to 50.000 m^3/day, the presently largest commercially available desalination technology, corresponding to the water needs of a European city of approximately 200.000 inhabitants.

Furthermore this type of presentation allows to present the scale economy effect by means of nearly linear curves, and to take related effects into account for comparison.

Investment cost

The following graph presents an overview of the typical specific investment costs for the desalination technologies of major interest, namely Sea-Water Reverse Osmosis (SWRO), Multiple Effect Distillation (MED) and Multistage Flash Distillation (MSF).

Figure 6 – Typical specific investment costs for the desalination technologies of major interest, namely SWRO, MED and MSF



Note: each 1 m^3/day satisfies the potable water needs of 3-5 inhabitants (Europe)

The graph allows to estimate, on the basis of the required daily water production capacity, the probable investment required to build the plant.

For any desired daily water production capacity (given on the X-axis), the graph gives the value (on the Y-axis) for the specific investment/capacity ratio. This value multiplied by the capacity itself (expressed in m^3/day) allows to obtain the approximate investment (expressed in Euro) required to build the plant.

The graph makes evident that SWRO, wherever applicable, is usually the solution requiring lowest investments.

Among the two thermal desalination technologies, the MED process, wherever applicable, appears slightly less expensive that the traditional MSF alternative.

Furthermore the market potential for smaller waste heat driven MED systems is made evident, i.e. the size range which presently is not covered by this technology since considered too expensive in comparison to typical water costs on the continent whereas, if real costs of water on the islands is considered, this size range offers interesting market potentials.

Cost of Produced water

The following paragraphs and graphs give an approximate idea of the typical cost structure of the produced water for the envisaged desalination technologies of major interest. Cost calculations have been made considering an investment payback period of 10-12 years and the cost of the consumed waste heat to be zero.

Instead, as regards the required electricity, for each of the 3 discussed technologies, 2 different graphs are presented reflecting two different electricity cost scenarios, namely:

a) Considering the subsidised electricity tariff usually being adopted on islands, amounting to approximately 0,10 Euro/kWh
b) Considering the real cost of electricity on islands, estimated on the basis of the indications given by the project ”Renewable Energies on Mediterranean Islands”, EC DG XII - APAS - RENA CT94-004 (1996).

The figures given in the following paragraphs are to be interpreted as an approximate indication of the costs to be expected, since based on typical average performance and cost figures of the envisaged desalination technologies.

Multistage flash distillation: MSF + COGEN

The following 2 graphs present the typical cost structure for the produced water by means of a MSF plant exploiting waste heat from a nearby power plant.

Considering the subsidised electricity tariff scenario, and especially for the smaller size range, the investment payback reflects the main cost share.

Instead, considering the real cost of electricity on small islands, and again for the smaller size range, the electricity cost becomes the main cost share, followed by the investment payback cost.

MSF is a technology most appropriate for large-scale applications. Accordingly its application is recommended only for larger islands presenting an urban area of at least 20.000 permanent inhabitants.

Figure 7 – MSF + COGEN – Waste heat driven MSF - Typical cost structure of produced water considering a subsidised electricity tariff of 0,10Euro/kWh

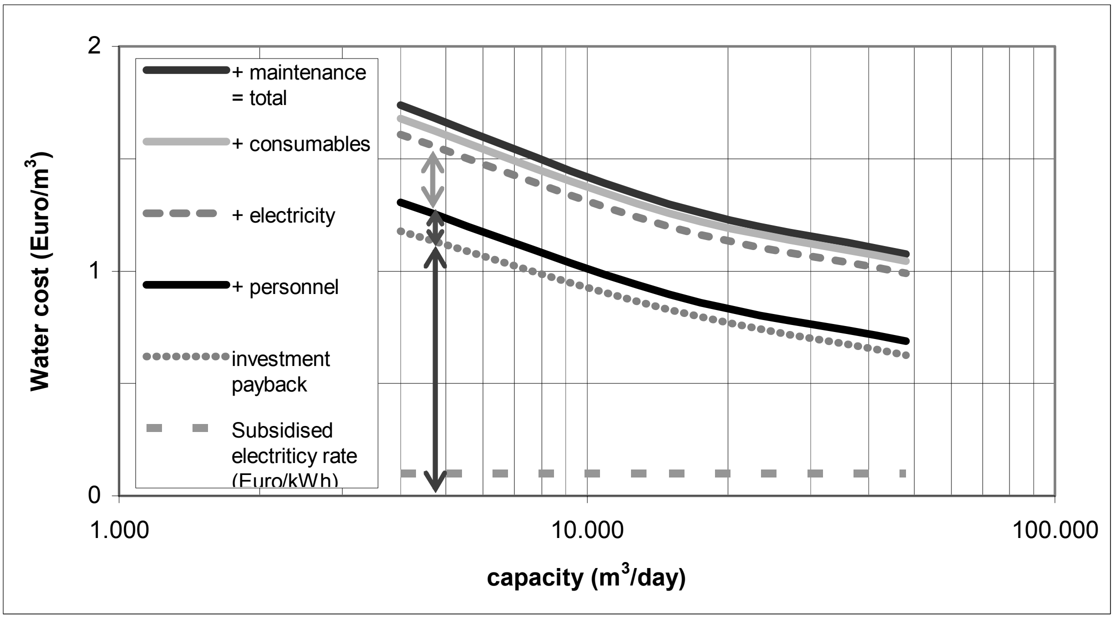
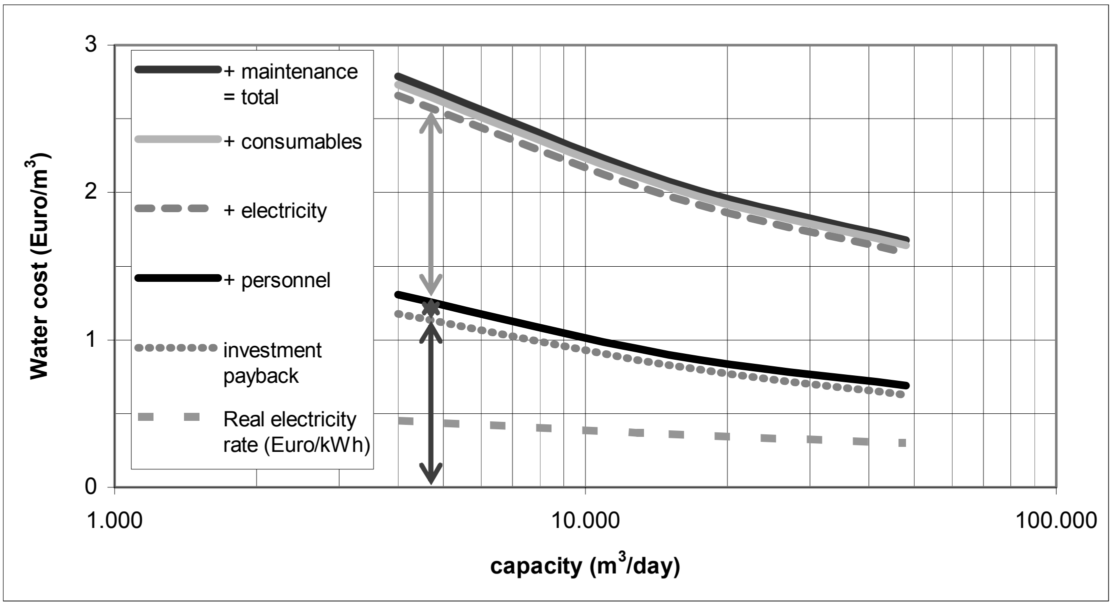


Figure 8 – MSF + COGEN – Waste heat driven MSF - Typical cost structure of produced water considering the real cost of electricity on small islands



Multiple Effect Distillation: MED + COGEN

The following 2 graphs present the typical cost structure for the produced water by means of a MED plant exploiting waste heat from a nearby power plant.

Considering the subsidised electricity tariff scenario, and especially for the smaller size range, the investment payback represents the main cost share, and the electricity cost is of minor importance.

Considering instead the real cost of electricity on small islands, the electricity cost becomes much more important, but the largest cost share still remains to be the investment payback cost.

MED is a technology most appropriate for medium-scale applications. Accordingly presently market available technologies allow applications on medium to large islands presenting an urban area of at least 10.000 permanent inhabitants.

Nevertheless the outcomes of this investigation indicate a market potential also for smaller applications serving an island population of at least 2000 permanent inhabitants.

Figure 9 – MED + COGEN – Waste heat driven MED - Typical cost structure of produced water considering a subsidised electricity tariff of 0,10Euro/kWh

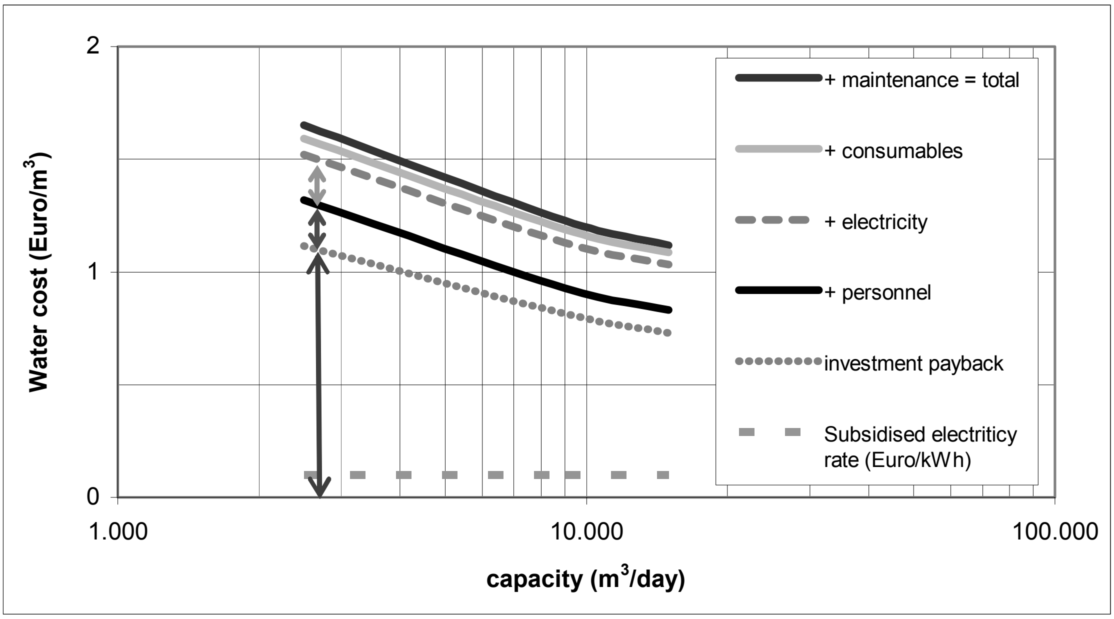
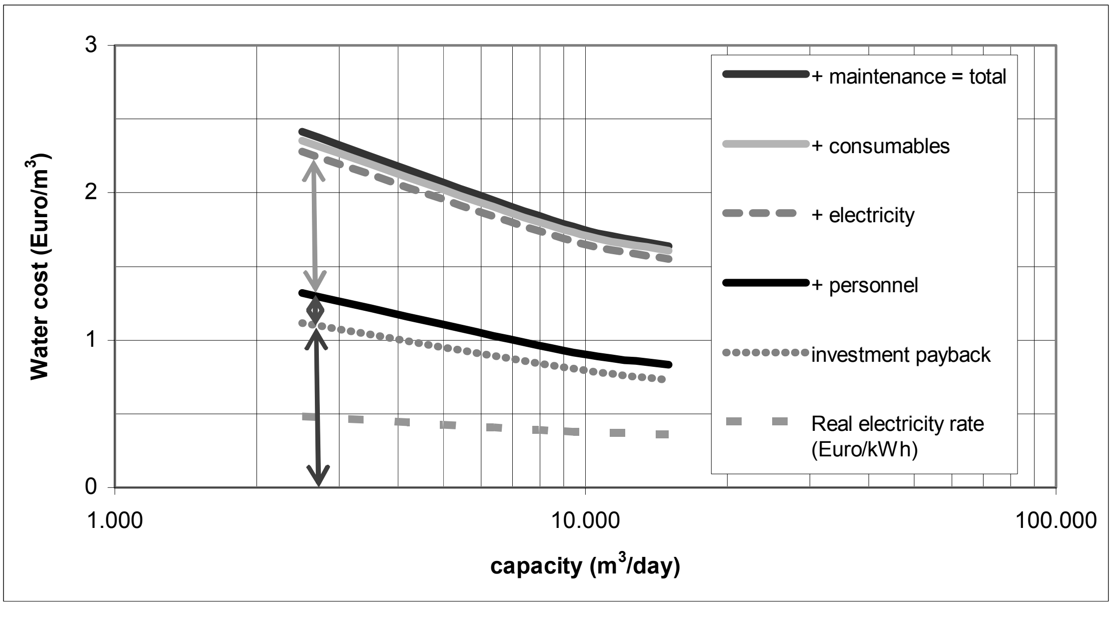


Figure 10 – MED + COGEN – Waste heat driven MED - Typical cost structure of produced water considering the real cost of electricity on small islands



Seawater Reverse Osmosis (SWRO)

The following 2 graphs present the typical cost structure for the produced water by means of a SWRO plant, which however **cannot exploit waste heat**. This option is presented here since considered the main competing alternative desalination technology usually being considered for installations on islands.

Considering the subsidised electricity tariff scenario, and especially for the smaller size range, the investment payback reflects the main cost share, followed by the cost of the personnel required to operate the plant.

Instead, considering the real cost of electricity on small islands, and again for the smaller size range, the electricity cost becomes the main cost share, followed by the investment payback cost and the personnel cost.

Operation personnel cost is usually a not very important issue for desalination. The graph presented in Figure 11 shows instead that, in case of smaller SWRO units, the impact of personnel cost grows to become a significant cost share.

SWRO is a technology most appropriate for small to medium-scale applications. Accordingly it is recommended for all smaller island applications where MED + COGEN cannot be adopted.

Figure 11 – SWRO – Typical cost structure of produced water considering a subsidised electricity tariff of 0,10Euro/kWh

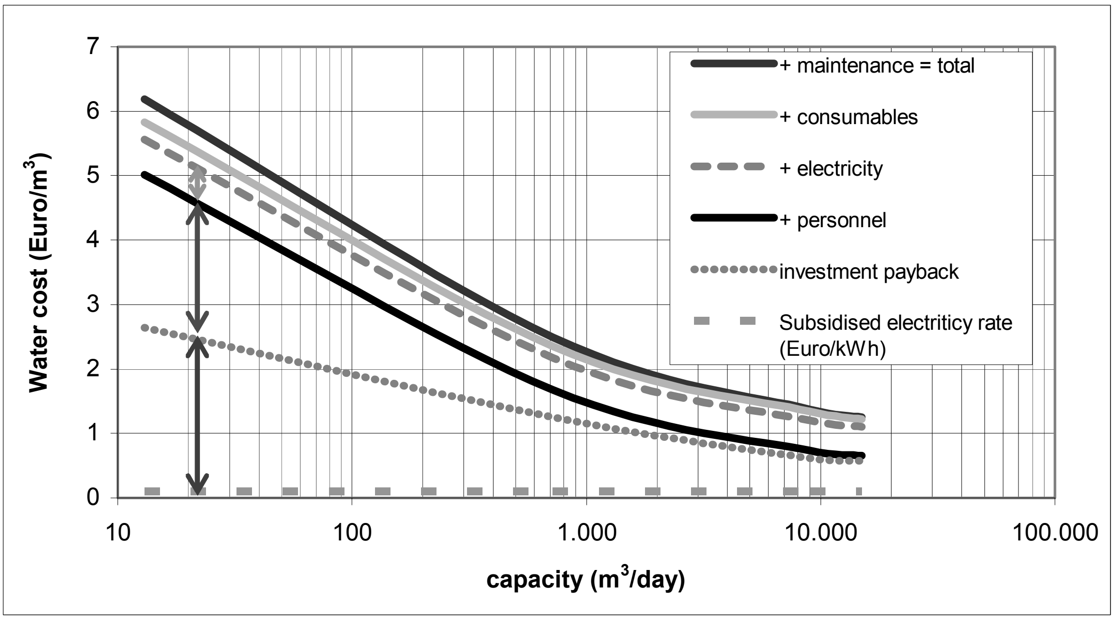
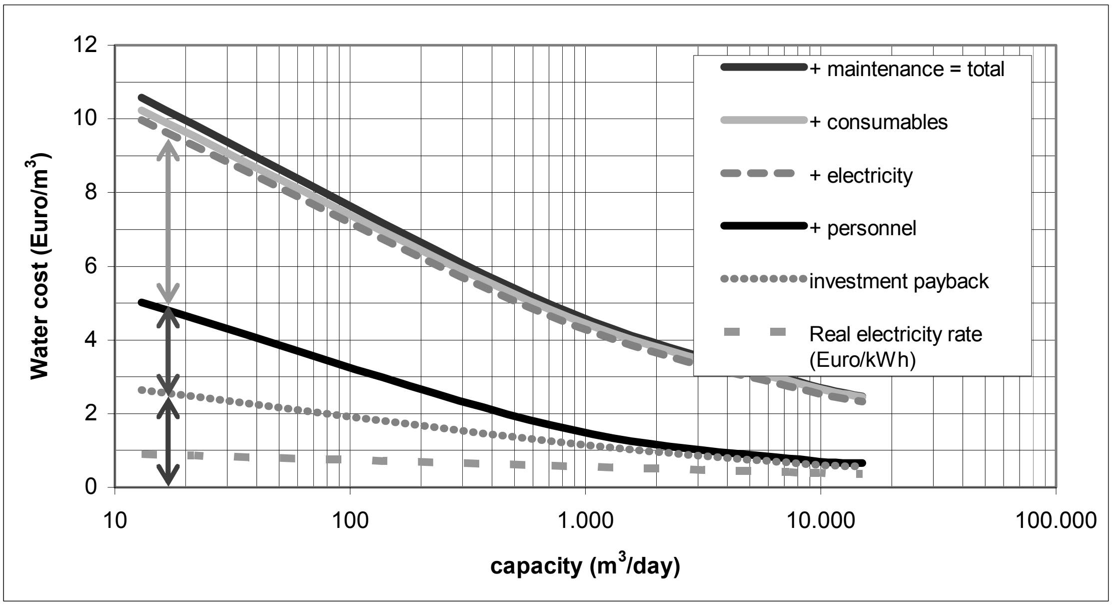


Figure 12 – SWRO – Typical cost structure of produced water considering the real cost of electricity on small islands



Overall cost comparison

The following 2 graphs present the results of the cost comparison between the overall cost of water produced by a SWRO plant without waste heat exploitation, and the two thermal distillation processes allowing to exploit the waste heat from a nearby power plant, namely MSF+COGEN and MED+COGEN.

The SWRO option is presented here since representing the main competing alternative desalination technology usually being considered for smaller installations and also on islands.

Taking into account the subsidised electricity tariff scenario usually being considered by consumers, there appears to be no substantial difference between the 3 presented technology options, i.e. all three follow a quite similar behaviour, depending mainly on the size (capacity) of the envisaged desalination facility. As a result, decision makers may tend to choose the less investment intensive technology, namely Seawater Reverse Osmosis (SWRO).

Instead, taking into account the real cost of electricity on small islands, the difference in overall produced water costs become quite significant, making the MED+COGEN option become by far the most convenient.

Figure 13 – Comparison between overall costs of produced water considering a subsidised electricity tariff of 0,10Euro/kWh

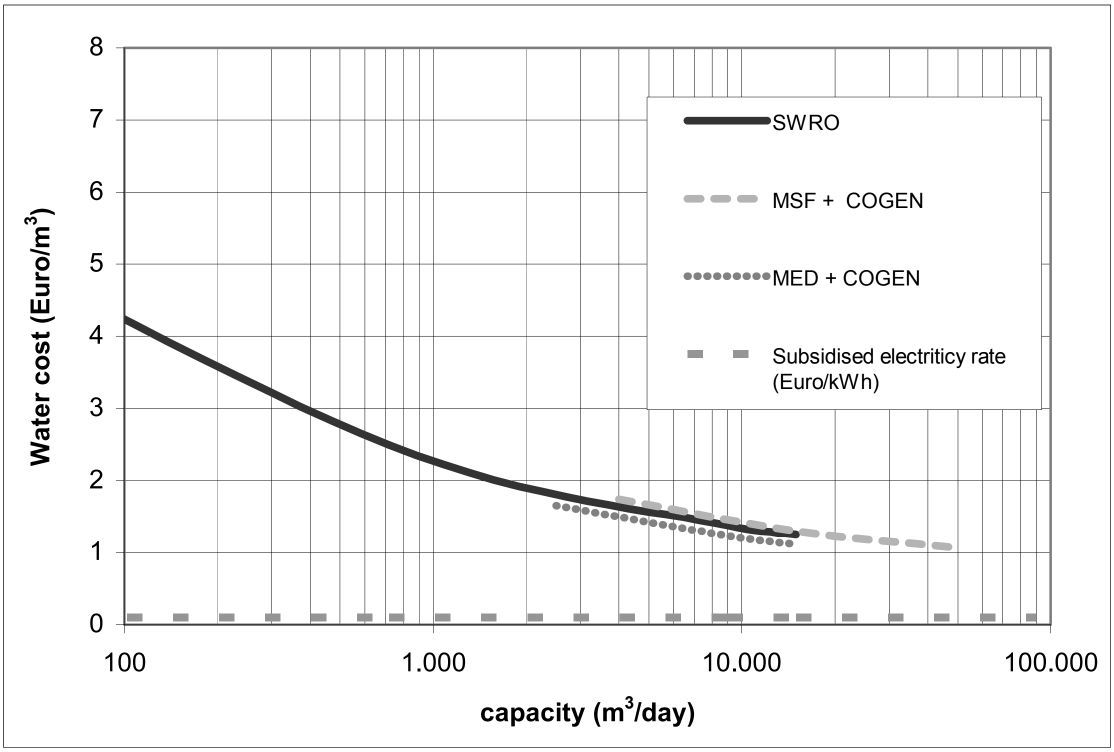
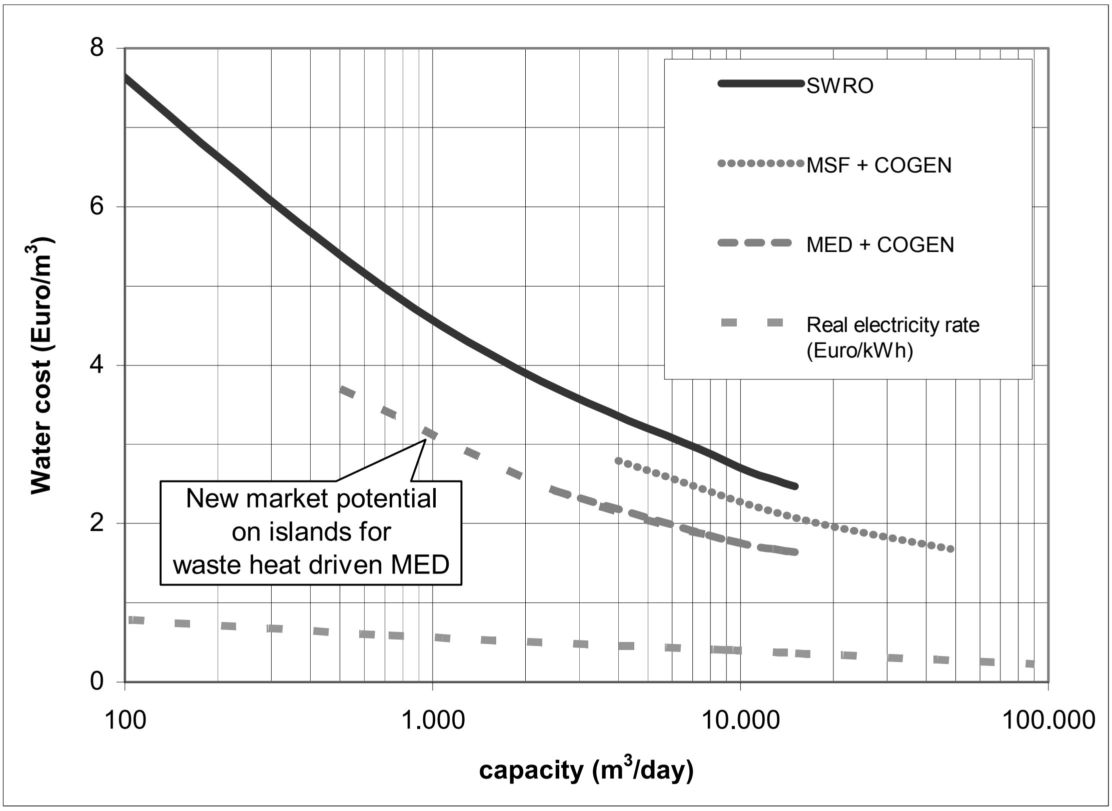


Figure 14 – Comparison between overall costs of produced water considering the real cost of electricity on small islands



Note: each 1m^3/day satisfies the water needs of 3-5 inhabitants (Europe)

6. Conclusions

Since based on typical average performance and cost figures, the cost graphs presented in the previous paragraph are to be considered only as a first approximate indication useful for rough estimates. Nevertheless costs calculation results allow to come to the following general considerations.

If real costs of power (electricity) and of water supplies by shipping from the continental mainland were considered, on many of the islands in the Mediterranean Sea, desalination would represent a viable solution and would be recognised as economically advantageous.

In most cases the **high cost** of isolated electricity production and of shipping of water to islands **is hidden** by national funding and **by subsidised tariffs** intended to alleviate the hardships of life of island populations. However, same subsidised consumer tariffs produce market distortions which end-up to freeze the present situation, giving efficiency improvements, new technologies and desalination frequently no chance to win competition against the status-quo situation, namely expensive shipping of water supplies from the continental mainland or from other nearby islands.

This handbook presents basic information on available technologies for desalination and specifically on those desalination processes able to exploit, practically for free, the waste heat generated by conventional diesel power plants. Specifically it describes market available technologies and the economic potentials of Co-generation of water and power on islands. Outcomes are tailored for use by regional decision makers, municipal authorities and island water & energy system planners.

Most evaluations and comparisons between conventional water supplies by shipping and desalination solutions neglect to consider the beneficiary effects of desalination on the local economy of islands, such as:

- Independence from external water supplies by shipping
- Improved water quality: desalination produces water of excellent quality, while today's shipping by tankers provokes germ contamination of the island aqueduct systems.
- Improved employment and training possibilities for islanders, allowing them to become qualified up-to-date water processing and desalination technicians (electronics, electrical engineering, desalination technologists, etc.).

If real costs of electricity production on islands is taken into account, on many Mediterranean islands, thermal desalination exploiting the waste heat from the local diesel power plant would be economically advantageous. The gap between tariffs paid by electricity and water consumers and the actual costs of relevant supplies on islands is covered by governmental subsidies, or by the national utility. In all cases it is always the national (mainland) community to cover these costs.

Subsidised consumer tariffs produce a market distortion giving innovation and desalination no chance to win competition with subsidised electricity and with water supplies by shipping. If desalination would be permitted to compete under fair (equal) conditions, on the islands, even smaller desalination systems would frequently win.

Thermal desalinations systems exploiting waste heat from a power plant are commonly adopted for large scale applications in the middle east. On islands instead there are only few inefficient MVC desalination systems using electricity, or else, like in Greece, only Reverse Osmosis (RO) systems. No thermal desalination systems using waste heat exist on islands, and this although the use of waste heat for seawater desalination produces marked advantages in terms of energy efficiency and economic savings. So why is this mature, commercial and more economic technology not applied on islands?

The answers lies in the difference between macro-economy and micro-economy.

Subsidised consumer tariffs produce market distortions giving innovation and desalination no chance to win competition against subsidised electricity and water supplies by shipping. If desalination would be permitted to compete under fair (equal) conditions, on the islands, even smaller desalination systems would frequently win.

Another important question for the social acceptance on islands is, who gains economic advantages, or suffers economic damage from the introduction of a new technology, whether it be desalination or other. In case of subsidised tariffs, it is the national economy and the subsidising institution to benefit economically from such change, and not the islanders and the local economy, since tariffs remain unchanged for consumers, while the local people working for the status-quo power and water supply system feel not prepared to deal with such change and fear that their income source might be endangered.

This handbook provides a guidance and answers technical and economic questions on how to solve the problems of water supplies on islands in the Mediterranean Sea. It shows that the introduction of combined water and power production by means of thermal desalination systems exploiting the waste heat of diesel power plants results in substantial economic savings for the national economy, since they allow to reduce the overall amount of money already being spent for subsidised conventional power and water supplies.

The OPET network

The Organisations for the Promotion of Energy Technologies (OPET) Network has embarked upon a new and challenging series of activities, aimed at promoting public awareness of current energy research results.

The activities are intended to further the deployment of innovative technologies and increase the pace of market uptake in respect of research that supports European Energy Policy priorities. By identifying key actors and disseminating information about new developments in the European Research Area, they provide an integrated and comprehensive view of on-going research in the following areas of work:

1. Buildings
2. Renewable energy sources
3. Co-generation and District Heating and Cooling
4. Clean Fossil Fuels
5. EMINENT
6. CO-OPET

Each of these activities are oriented towards providing solutions that are aimed at present market needs and that will assist in the promotion of new technologies, thereby stimulating knowledge flow between key market actors and related research bodies. In this way, the OPET Network further enables the smooth integration of EU policy priorities, new technological research, and market sustainability and competitiveness.

The OPET Network is an initiative of the European Commission that began its life in the late 1980s. Its aim is to promote the benefits of tomorrow's innovative energy technologies (with the exception of Nuclear energy).

The current initiative marks a new and challenging chapter in its history as it continues to disseminate knowledge and stimulate technology implementation, establishing itself as a cornerstone in the building of a European Energy Policy Research Area.

The Organisations for Promotion of Energy Technologies (OPET) Network aims to promote European energy technologies across the EU and global markets and thereby to reduce global warming.

In order to fulfil its mission, the OPET Network seeks to provide an efficient flow of knowledge between energy research an the European energy markets.

1. Transferring the results of European and member state energy RTD that supports European Policy priorities into successful technology deployment within the market, for the benefit of all European citizens
2. Translating European energy policy priorities into concrete actions at local, regional and European level
3. Accelerating the pace of innovation

The OPET Network currently incorporates 115 partner organisations extending accross 48 countries from within the European Union, candidate countries of Central and Eastern Europe, Cyprus and Associate States, Latin America, China, India, Southern Africa, ASEAN, Blacksea region and former CIS (Community of Independent States) countries

For further information, www.opet-network.net.