MSc Program
Renewable Energy in Central and Eastern Europe

Upgrading Exergy – from Electricity to Potable Water by REN-powered Desalination

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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17.11.2016, Linz

Affidavit

I, André Raffer, hereby declare

1. that I am the sole author of the present Master Thesis, "Upgrading Exergy – from Electricity to Potable Water by REN-powered Desalination ",

104 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Linz, 17.11.2016

Mag. André Raffer

Abstract

As investment analyst mainly in the area of securities and in the face of actual market situation (zero interest rates in developed world, bubble-like prices in nearly every asset class due to central bank intervention etc.), finding or developing investments in real assets like infrastructure seems to make more sense. Combined with two topics of intrinsic interest – renewable energy and growing water scarcity – educational steps have been taken to get into these topics.

This lead to the core question: is a combination of renewable energy and seawater desalination, enhanced by electrical energy storage, feasible and if not what may help to improve the financial situation?

Therefore desalination technologies have been researched concentrating on the mature and commercially developed 'reverse osmosis'. On the one side the investment should be acceptable for investors only looking for commercialized technologies; on the other side renewable energy forms producing electricity (not heat) are in focus, especially photovoltaics (PV) as water scarcity and irradiation highly correlate. Enlargement is done by adding electrical energy storage (EES) as support for photovoltaics to reach at least a majority of sustainable energy production. Then the status-quo of desalination on Mediterranean Island gets depicted; during the research a desalination project with inconvenient outcome has been found. The findings of technological and plant research has been combined and re-calculated to find out if that plant would be an acceptable investment based on this thesis' assumptions.

Three main and two sub-scenarios have been built and expressed as project and business finance calculations: the desalination plant; the plant with PV to supply 1/3 of energy demand; the plant with PV and EES to supply 2/3 of energy demand. Whereas the first two scenarios showed positive results along a spectrum of criteria, the last one ended negative due to immense investments in PV and EES. Here the two sub-scenarios come into play: support by 20% investment subsidy; support by lower EES investment costs and 20% investment subsidy. The former improved but is still not investable, the latter entered a kind of 'orange' zone as some parts reached slightly positive areas.

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1 Introduction

This thesis topic is to find out if two areas appreciated as one of the most important for the future of this planet – renewable energy and seawater desalination – deliver acceptable returns for institutional investors if combined in a way so that majority of energy for the desalination process comes from a sustainable source, supported additionally by energy storage.

As there are side spectra of technologies in the mentioned areas limitations are necessary. Therefore the concentration lies on reverse osmosis as mature and electricity-driven desalination form, on photovoltaics as supplier for renewable energy and battery storage as time shift support.

Chapter 2 describes the observations in detail which lead the author to this thesis' topic.

Chapter 3 gives an overview on desalination technologies and core criteria of reverse osmosis.

Chapter 4 goes into detail of reverse osmosis plant and its processes, from seawater intake to discharge of concentrate.

Chapter 5 delivers explanations for the complimentary systems photovoltaics and energy storage (here concentrating on batteries).

Chapter 6 shows planning considerations for desalination and project set-up; it also combines gathered knowledge into a risk matrix as one of the core project management tools; and finally the status-quo of Mediterranean water situation and desalination is depicted. During this screening a partly failed plant on Menorca was found and selected as base for calculations.

In chapter seven the Menorca plant gets combined and adapted with plant data from literature to calculate project and business financial data for three main scenarios:

- The plant as stand-alone
- The plant supported with PV for one third of yearly energy demand
- As above but for two thirds of yearly energy demand and supported by batteries

As the first two show positive results but the last one ends negative, two sub-scenarios for that one are added:

- Support by 20% investment subsidy
- Support by lower battery costs and 20% investment subsidy

The first alternative is still not feasible but the second enters partly in regions with positive results although not enough to get it through investor committees. Some additional improvements or changes of project design are still necessary.

Chapter 8 finally concludes the thesis.

2 Starting points and observations

2.1 Water stress

Widely known is the fact that only around 2-3% of earth's water is of drinking quality of which 1%-point is available for human use, the remaining is frozen in glaciers and on the poles. And as with nearly every resource on earth, this potable water too is unevenly distributed. Combined with earth's different climate zones (especially drought-prone zones along equatorial latitude) a structural water stress spectrum arises.

The situation gets enhanced by different economic and mankind factors, of which the UN in its latest Water Report (UNESCO/UN-Water, 2015: 10-12) lists the main ones as follows, embedded in common unsustainable developments and governance failures:

- Population growth as nominal influence on basic products and water
- Adapted living and consumption habits towards middle-class level
- Increasing demand for meat, homes, cars, electric devices etc.
- Therefore additional rising use of water in industry and agriculture
- Accompanied trend to urbanization, making municipalities the main water 'agents'
- Aggravated by polluting water resources and damaging natural water cycles

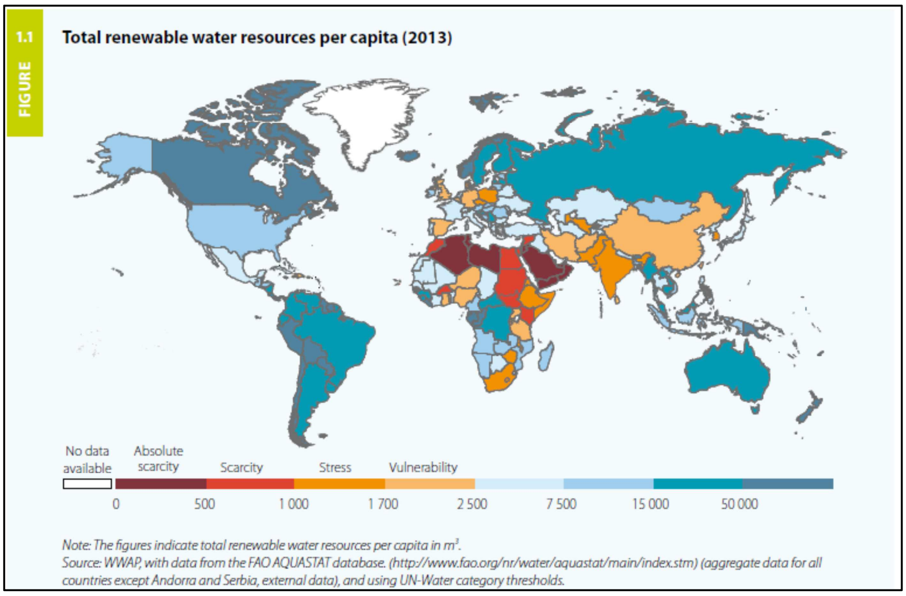
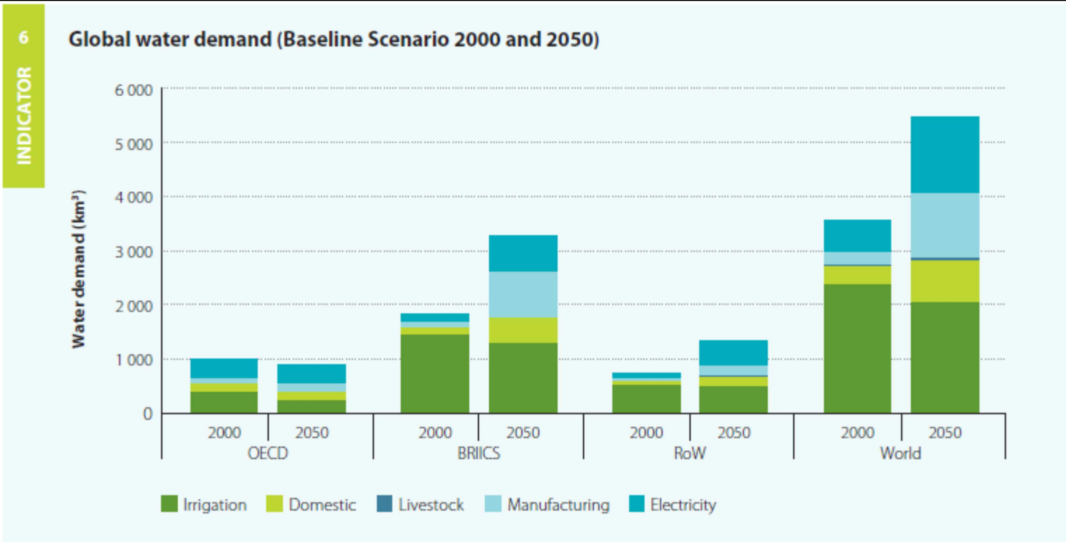


Figure 2-1: Water stress levels, Source: UNESCO (2015a)

The primary tool to overcome this situation is for sure saving water across all factors, like changing human behaviour, increasing industrial production and agricultural efficiency, investments in related infrastructures etc. Nevertheless the author believes that the sheer increase in population and its consequence spectrum cannot be solved solely by saving measures, at least not in the medium term.



Note: BRIICS (Brazil, Russia, India, Indonesia, China, South Africa); OECD (Organisation for Economic Co-operation and Development); RoW (rest of the world). This graph only measures 'blue water' demand and does not consider rainfed agriculture.
Source: OECD (2012, Fig. 5.4, p. 217, output from IMAGE). OECD Environmental Outlook to 2050 © OECD.
OECD (Organisation for Economic Co-operation and Development). 2012. OECD Environmental Outlook to 2050: The Consequences of Inaction. Paris, OECD. http://dx.doi.org/10.1787/9789264122246-en

Figure 2-2: Water demand scenarios 2010/2050, Source: UNESCO (2015b)

Instead, tapping literally into the vast pool of seawater resources seems more promising to overcome regional dependent water scarcity. Development of technologies and number of projects facilitate this thought. Details are bespoken in chapter 2.3.

2.2 Renewable energy

Already achieving global success in installed GWh and reaching efficiencies on different levels (equipment production, energy yield) these forms of energy source are still in growth status, although at different marginal rates, depending on necessity and political/financial support. But the focus in this thesis does not lie in the technologies itself, but in the development of specific related areas and the possible combination with desalination projects.

Especially the regression of subsidies or even penalization via taxes in different countries comes into one's mind; one the one hand due to worsening national budget situations, on the other due to protection of the electricity grid caused by fluctuations of solar and wind production time tables.

Subsidies and FiTs for PV in Europe are a good example of turnaround policies. To fulfil EU directives and reduce fossil fuels to reach GHG targets, generous support has been granted (non-recourse investment support and/or long-term contracts with fixed tariffs). Household-small and commercial-large projects have been implemented and combined with fast decreasing production costs of modules and equipment. Then many countries reduced or stopped the support: Bulgaria, the Czech Republic, Greece, Italy, Romania, Spain and also Austria and Germany, including adapting their laws. Different modifications occurred, some even retroactively: reduced FiTs, grid charges, income tax, quantity caps etc. Legal repercussions are obviously accepted by national legislatives; especially (foreign) investors may claim compensation for breaching contracts (Radjai & de Germiny: 2015).

Research from McKinsey analyse the PV sector in a wider range. A boom in solar industry due to subsidies followed by financial crisis in 2008-09, low natural gas prices and mainly deflationary inputs from Chinese producers with their low-cost advantages in capital and labour put pressure on this industry. The 'hard' costs (equipment) fell first, now to be followed by 'soft' costs (service and finance), which equalizes partly falling subsidies and help reaching 'grid parity' – therefore the still rising installation capacities. The industry gets mature, private and commercial users continue to install, latter to diversify their energy supply, to save costs and to convince their sustainability-appreciating customers. The financial industry follows by new financing structures and reliable contracts (Frankel D. et al, 2014).

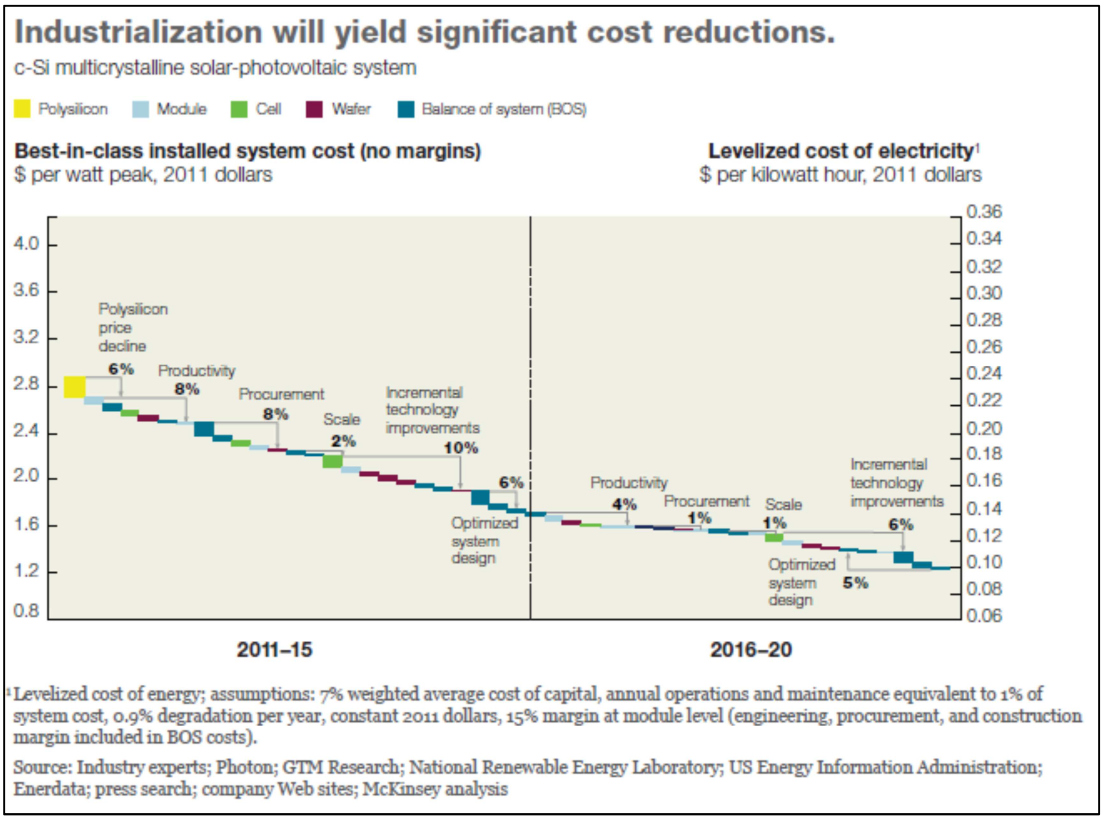


Figure 2-3: PV cost development and projection, Source: Aanesen, K. et al (2012)

They further worked out five non-supported segments which don't need to rely on subsidies but should be able to implement PV as energy source on a competitive cost basis (Aanesen, K. et al 2012: 6-8):

1. Off-grid areas (agricultural, telecommunication, industry)
2. Private/Commercial clients with variable electricity pricing (peak demand – a latent structural change in utility behaviour)

   as well as Private/Commercial clients with basically high electricity prices
3. Small grid systems
4. Developing markets setting up new grid networks
5. New large scale plants

Points 1, 3 and 5 are kind of linked to this thesis which will go one step further regarding the product established by the PV produced electricity.

2.3 Desalination

The IDA report on their website some data about this technology. As of June 30, 2015 it showed:

- Over 18,000 installed plants worldwide
- More than 87 million cubic meter produced water per day
- In over 150 countries
- Providing potable water to over 300 million people

Seawater desalination plays the main role, followed by brackish, river and waste water treatment.

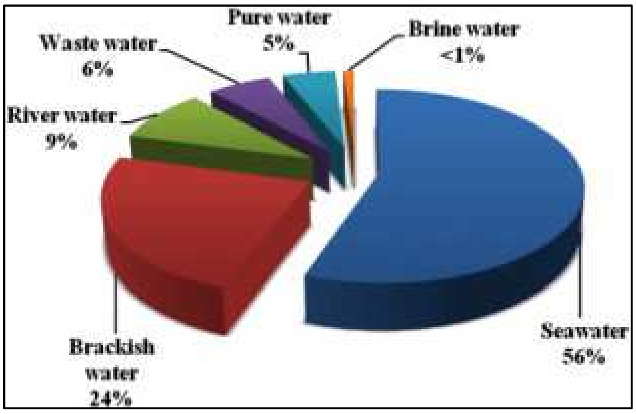


Figure 2-4: Source for global desalination in 2012, Source: yatesenvironmentalservices (2013)

Right now, the worldwide largest full running project is Sorek in Israel. It went operational in 2013 and actually runs up to full capacity of 627,000 m³/d fresh water which provides 20% of Israel's domestic water demand. Costs are roughly USD 500m, the water is sold for USD 0.58 per m³. Reverse osmosis is used as technology; to save energy and therefore costs, 16'' pressure tubes (instead of standard 8'') are used to reduce piping by 75%. Additional savings come from efficient pumps and energy recovery systems (Talbot: 2015). According to EIB, one of the financing partners, costs per m³ are around EUR 0.50 which are USD 0.55 at a rate of EUR/USD 1.11 at request date 07/06/2016 (EIB, 2016).

But also the industry (power plants, refineries etc.) is a demand driver, being since 2010 responsible for nearly half of new plants (WaterWorld, 2016).

2.4 Putting together the pieces

The core theme and idea of this thesis emerges by simply combining the observations above: to produce a highly valuable commodity – potable water – by using electricity from renewable energy which needs commercial income sources instead of market distorting subsidies. This idea is supported amongst others by these developments:

- Water is progressing to commodity status. Despite actual political comments to keep it at human-rights-level, the trend is already emerging. Worldwide different kinds of markets evolve (Zwick, 2015), even futures/forward trading platforms like in Australia (Curran, 2014 and www.waterfind.com.au).
- Water has definitely a high price, even if it is seen in humid parts of the world as ‘free’ – mainly because it is priced there very low.
- Renewable energy forms like wind power and PV are in mature status with falling costs but also suffer falling subsidies. The GHG emission reduction still favour them, but the fluctuations they introduce into the main grids are sometimes troublesome.
- Especially on PV the focus lies due to the simple fact, that the majority of dry areas are also the ones with the highest irradiation.

It therefore makes sense to develop an electricity-driven desalination plant to produce water for direct regional use or indirect global trade – i.e. drinking water or irrigation water for agriculture to export harvest or livestock. The project can even get enhanced by related areas like storage systems (batteries, pump storage towers). Depending on the projects’ and natural boundaries it should be possible to combine all available technological proven and mature options to profit from the investment by converting the exergy into a tradable commodity. The calculations in this thesis try to proof this respectively recommend adaptions to reach this goal.

3 Desalination

3.1 Technology overview

There are different treatments available, differing on one side in the kind of technology (meaning physical and/or chemical processes) and on the other in the practical and market status (from research lab over pilot testing to long-year usage and maturity level).

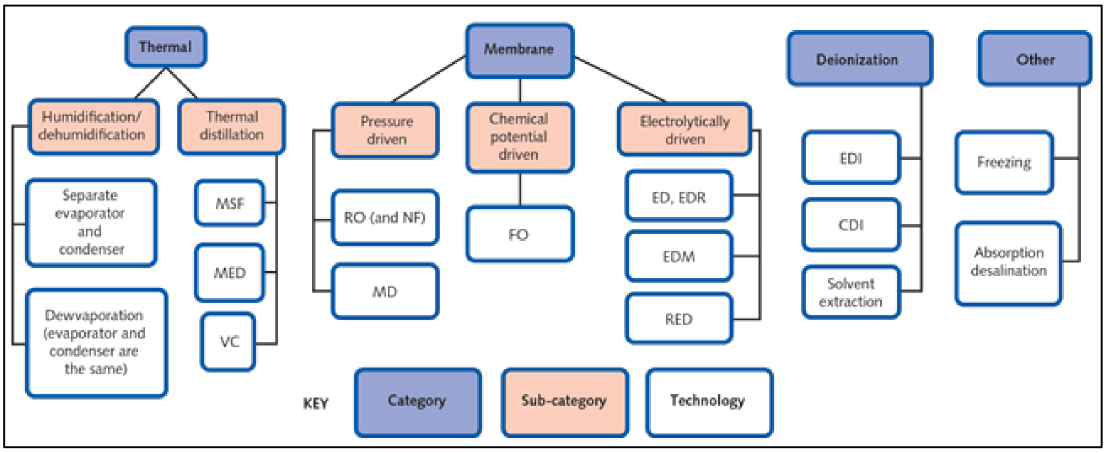


Figure 3-1: Desalination technologies overview, Source: O'Callaghan & Mickley (2016)

Following short descriptions of selected categories (AWWA Manual M61, 2011):

a) Thermal category

MSF – Multiple Stage Flash: water is heated in series of stages with each lower pressure and temperature; each lower pressure stage causes water to vaporize again, an effect called flashing.

MED – Multiple Effect Distillation: same process as in MSF, but the vapour stream is additionally used to heat the feed stream, thus saving energy.

VC – Vapor Compression: a one stage process, in which water vapour from distillation is compressed electrically or thermally to reuse it as heat source.

b) Membrane category

RO – Reverse Osmosis: as this is the technology chosen for base and business case, it is explained in details in the next chapter.

NF – Nanofiltration: like in RO a semi-permeable membrane and hydraulic pressure is used, but more to soften and remove DBP and DOM.

MD – Membrane Distillation: a combination of thermal and membrane technology; salt water is first evaporated and then goes through a hydrophobic membrane

FO – Forward Osmosis: also like in RO, but the other way around; instead of working against natural pressure from osmosis, an even higher salinity solution works with the natural pressure, freshwater is then generated from this solution by additional separation.

ED(R) – Electrodialysis (Reversal): whereas RO uses pressure to force water through membranes, this technology uses electrical potential (cathode/anode set-up) to achieve the effect of separating dissolved salts from feed water.

c) Deionization/Other

CDI – Capacitive Deionization: the mineral ions are adsorbed on electrodes running on low voltage.

Freezing: Here the less energy demanding phase change from liquid to solid (instead liquid to vapour) is used, as ice crystals exclude salt from their structure; key research here is driven by proper washing and separation without melting.

3.2 Reverse osmosis

This technology works against the natural process of osmosis, which is the "*movement of a solvent (as water) through a semipermeable membrane (as of a living cell) into a solution of higher solute concentration that tends to equalize the concentrations of solute on the two sides of the membrane*" (Merriam-Webster, 2016a).

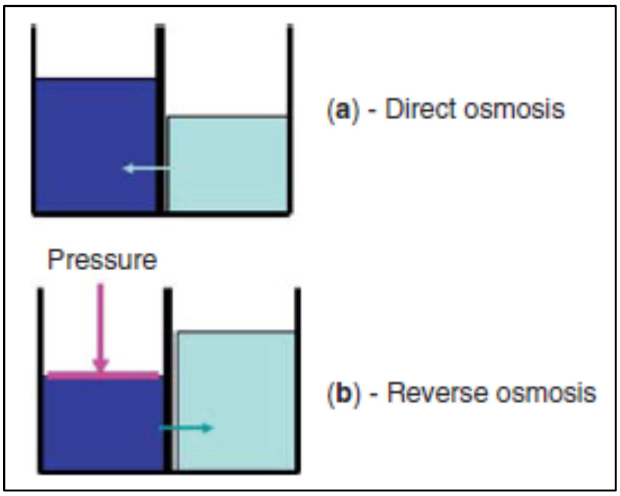


Figure 3-2: Illustrating Osmosis and RO, Source: Wilf, in Kucera et al. (2014)

To overcome this natural tendency respectively the occurring osmotic pressure, hydraulic pressure is used to reverse the process and further concentrate the solute solvent into so called brine, whereas desalted product water collects on the other side of the membrane. The osmotic pressure depends on the total dissolved salts (TDS, measured in ppm), a thumb rule defines 0.77 bar in a solvent with 1,000 ppm TDS (Wilf, in Kucera et al., 2014: 157).

3.2.1 Important parameters

Next are the most crucial factors listed and described which give an indication of different relationships and performances of RO:

Table 3-1: RO Parameter Overview (Wilf, in Kucera et al., 2014: 159-166)

Parameter	Description
Recovery Rate	Shows the % of feed water turned into product water (permeate)
Net Driving Pressure (NDP)	Driving force of water through membrane; applied in excess to osmotic pressure (and system pressure losses)
Water and Salt Transport	Rates of flow through the membrane; former is proportional to NDP, latter is proportional to concentration differential across membrane. The different mass transfer rates of these two result in salt rejection.
Salt passage and rejection	Former defined as concentration differential on both sides of membrane, an inverse function of applied pressure. Latter is the opposite and an important parameter of membrane application suitability.
Temperature	It influences the flow rate. As reference for RO membranes 25 C° are chosen. Per 1 C° increase, water and salt flow increase about 3%; this request lower applied pressure at higher feed water temperatures, but only up to 30 C°, thereafter the effect levels off with osmotic pressure.
Average Permeate Flux	Permeate flow by total membrane area.
Specific Water Permeability	Water flux driven by NDP (resistance of membrane to water flow).
Concentration Polarization	An increased salt concentration formed on a boundary layer of the membrane; this reduces water product flow rate and salt rejection.

3.2.2 Membrane basics and configurations

RO membranes consist in their structure of three layers:

- Ultrathin semipermeable film, giving the salt rejection characteristics
- Microporous support
- Reinforcing fabric

The first developed semipermeable film (late 1950s, UCLA) were made of cellulose acetate. It is nearly uncharged which has the advantage of low fouling possibility by cationic polymers; its smooth surface additionally avoids the collection of fouling particles on it. As disadvantage has to be mentioned its working ability only in a narrow range (4 to 6 pH) and temperatures below 35 C°. Membrane compaction and additional pre- and posttreatments have to be done. Besides, biochemical reactions may cause decrease of membrane integrity, and the higher density is responsible for higher head loss which makes higher working pressure and energy consumption necessary. Useful life is around 3-5 years.

At present, aromatic polyamide are used as state-of-the-art. They work at lower pressure, lower salt passage and higher productivity. They work in a wider range of pH making it easier to maintain and clean. Useful life there is 5-7 years. To mention is that there charges depend on pH value resulting in different salt rejection characteristics; also degradation due to oxidation is a common problem which makes dechlorinating obligatory in pre-treatment process.

UNIHA (2016): Module lifetime depend on source and treatment but 5 years are more realistic than 7. Chemical cleaning is the main cause of degradation.

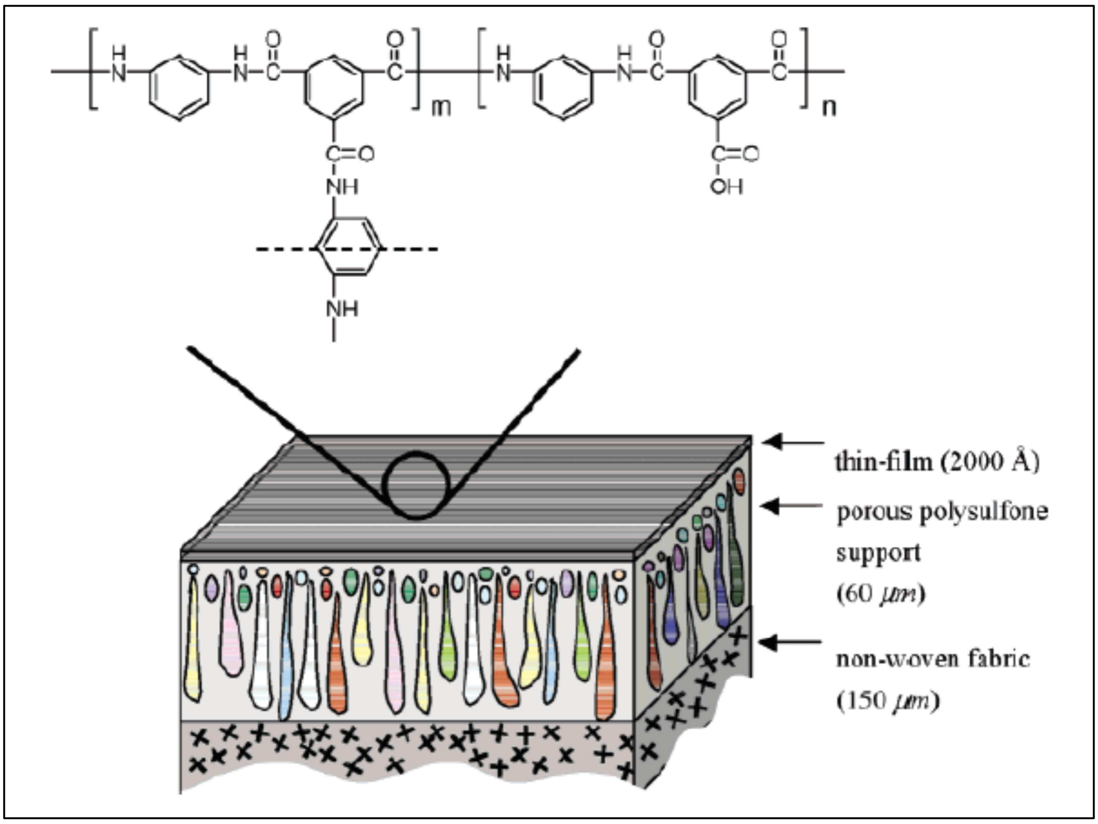


Figure 3-3: Schematic of thin-film-composite (TFC) RO membrane and the chemical structure of the aromatic polyamide thin-film layer, Source: Chaoyi (2010)

Thin-film nanocomposite are right now in research – their parameters are even better and promise to produce up to 20 times more permeate per unit surface than common membranes (Voutchkov, 2013: 45-49).

Regarding the configuration, membranes are commercially available in elements of different set-up: spiral-wound, hollow-fibre and flat sheet. They pack a large surface area in standardized size and performance. Spiral-wound elements took over marketplace since 1990 therefore they are bespoken here in detail.

In such elements, 40-42 RO membranes are rolled in standard 8 inch diameter spiral wound modules. This is done by building 20-21 membrane envelopes (each two membranes separated by a permeate spacer) which form a channel to allow the product water to evacuate. The envelopes itself are separated by feed spacer to facilitate feed water conveyance along the membranes. Pressurized feed water is applied on the outside of the envelopes, permeate collected at the centre of the module, running into a central product water collector connected to all modules; salts remain at the feed side and mix with rest of feed water, resulting in brine flow at the back end of the element. Several modules are then put and linked together into pressure vessel tubes. Multiple vessels together are assembled to so called skids or racks. All RO system parts together – feed pump, racks, piping, valves, energy recovery, instruments and controls are also called RO train. Typically, several RO trains work together but independently, each producing 10-20% of plant product water flow (Voutchkov, 2013: 49-54, 385-386).

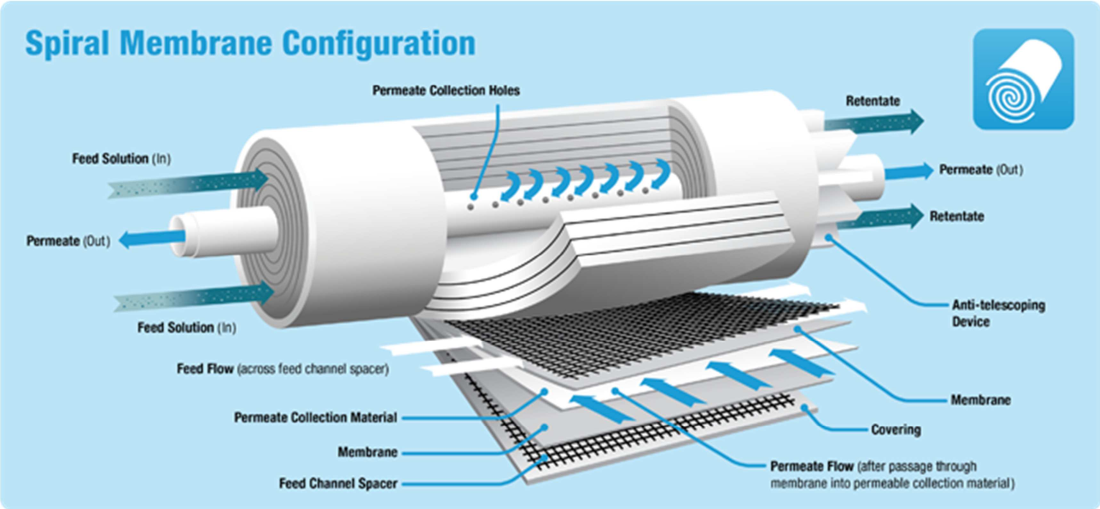


Figure 3-4: Spiral wound RO element, Source: www.kochmembrane.com (2016)

UNIHA (2016): Only spiral wound modules are in use for RO. Regarding the size, 8 inch is standard and mainly used. Only very large plants work with 16 inch and some have still to cope with technical challenges.

3.2.3 Membrane fouling

This factor needs special attention as it occurs for all water sources and membrane types and requests pretreatment and operational effort. It simple means that different forms of suspended or dissolved solids and organics precipitate on the membranes surface and reduce its performance; to ensure constant product water flow then, higher pressure hence more energy is necessary, at most up to the point on which the flow pressure gets too high and would cause physical damage on the system. Depending on source water quality and effectivity of pretreatment, elements have to be cleaned chemically on a regular schedule, or in extreme cases, need to be replaced. Two forms occur:

External Fouling – meaning accumulations on membrane's surface like scaling (from minerals), cake formation (from rejected in-/organic matter) and biofilm formation (from microorganisms). Appearance possible in any combination and at any time.

Internal Fouling – meaning damages on membrane's polymers by physical compaction (long-term exposure to higher-than-build-for process pressure or temperatures) or chemical compaction (exposure to damaging oxidants, acids etc.).

The former can be repaired by regular cleaning; the latter is often irreversible and forces replacement (Voutchkov, 2013: 69-70).

4 Desalination plant components

In this chapter the core and peripheral components of a desalination plant are bespoken, including influencing risks and factors, to deliver all inputs for creating a base case plant. Figure 4.1 gives an introducing picture from an example in Australia:

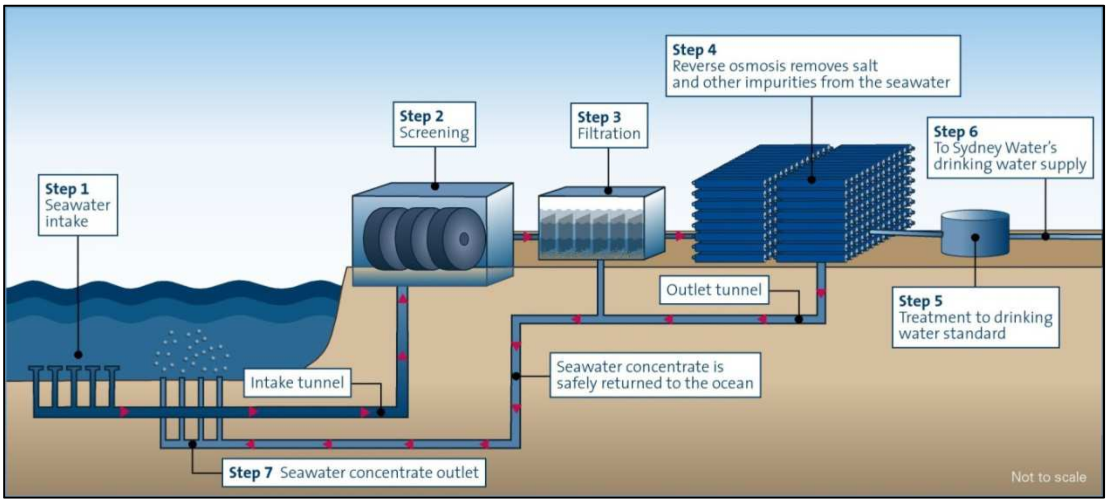


Figure 4-1: Desalination plant main facilities, Source: Sydneydesal (2016)

4.0 Feed water quality

Before discussing the different components the raw material processed has to be analysed, a step at the very beginning of every such project – thus marked as sub-chapter '0'. There exist four categories of sea water constituents (concentrating here only on open intake, not on deep well or brackish qualities): **dissolved minerals and gases, colloids and suspended solids, organics, microorganisms**. Temperature is another key factor as warmer water has lower viscosity meaning it has lower density, therefore increasing production rate of RO.

4.0.1 Minerals and gases

The main task of desalination is to remove the ions from feed water, of which **sodium and chloride** build the majority (NaCl, commonly named 'salt'); others are **calcium, magnesium, sulfate** etc. An ion is '*an atom or group of atoms that carries* *a positive or negative electric charge as a result of having lost or gained one or more electrons'* (Merriam-Webster, 2016b). The measurement unit is total dissolved solids (TDS) or salinity, expressed in ppm or milligrams per liter (mg/L) or milliequivalents per liter (meq/L) to ensure accuracy regarding electrical state of ions – anions are negatively and cations positively charged. TDS is the most crucial factor for RO planning, as it shows the osmotic pressure and therefore RO pressure and energy needed to overcome it. 100 mg/L TDS creates approx. 0.07 bar OP bringing TDS of 35,000 mg/L to around 24.5 bar. Beside that it indicates the product water quality. Gases like **oxygen, carbon dioxide**, ammonia etc. cannot be removed by RO membranes. Ocean water and its product mainly content oxygen (Voutchkov, 2013: 16-20). Figure 4.2 shows TDS levels for different main locations.

	Typical Seawater	Eastern Mediterranean	Arabian Gulf at Kuwait	Red Sea at Jeddah
Chloride (Cl^-)	18.980	21.200	23.000	22.219
Sodium (Na^+)	10.556	11.800	15.850	14.255
Sulfate (SO_4^{2-})	2.649	2.950	3.200	3.078
Magnesium (Mg^{2+})	1.262	1.403	1.765	742
Calcium (Ca^{2+})	400	423	500	225
Potassium (K^+)	380	463	460	210
Bicarbonate(HCO_3^-)	140	-	142	146
Strontium (Sr^{2+})	13	-	-	-
Bromide (Br^-)	65	155	80	72
Borate (BO_3^{3-})	26	72	-	-
Fluoride (F^-)	1	-	-	-
Silicate (SiO_3^{2-})	1	-	1,5	-
Iodide (I^-)	<1	2	-	-
Others	-	-	-	-
Total dissolved solids (TDS)	**34.483**	**38.600**	**45.000**	**41.000**

Figure 4-2: Major ion composition of seawater (mg/L), Source: www.lenntech.com (2016)

4.0.2 Colloids and suspended solids

They are of organic or inorganic nature and basically suspended until they reach the RO membrane where they concentrate and precipitate, reducing its flux. Mostly **iron, manganese, copper, zinc and aluminium** fall into this category but open seawater contains low levels, so if they are part of fouling, the reasons are overdosing of coagulant in pretreatment or corrosion in pipelines upstream (Voutchkov, 2013: 24-25).

4.0.3 Organics

These are man-made compounds or aquatic microorganisms of large size, rejected by RO membranes. Anyway they can create foulants on membrane surface also called cake layer or biofouling (if it is made out of aquatic organisms). Another factor is natural organic matter (NOM) produced by algae and aquatic flora and fauna: **proteins, carbohydrates, oils, pigments and humic and fulvic substances (acids)**. They discolour water and react with disinfection media, nevertheless not occurring in high levels in non-algal-bloom conditions. The latter may be a seasonal problem (also called ‘red tide’) or nearby river outfalls. These substances can additionally be pretreated in UF/MF or removed during membrane cleaning (Voutchkov, 2013: 29-30).

4.0.4 Microorganisms

These aquatic lifeforms and their excrements also cause biofilms on membranes: **bacteria, fungi, algae and protozoa**. They especially occur in warmer water like in the Middle East and challenge the RO operations. Bacteria, setting the majority, favour environmental conditions like them in algal bloom seasons and enhance fouling and cake layer building. Low velocities help them to precipitate, so if flux exceeds a threshold they begin to form. To avoid this, reducing RR is done to increase flow on feed side hence increasing velocity. The overall backlash with low RR is obvious, so disinfection in pretreatment is practically preferred. Here, chlorination is a double edged sword as it destroys the bacteria and algal cells and release the contained organic compounds, delivering food for remaining microorganisms – so instead of continuous chlorination, intermittent and random (‘shock’) chlorination is done instead. Pretreatment by high pressure and MF/UF do the same to algal cells, so gravity granular media filtration are of advantage where this factor is important (Voutchkov, N. 2013: 34-37).

4.0.5 Measurements and considerations

Table 4-1 gives an overview of ranges, typical values and considerations of source water contents and parameters, on which RO design has to be oriented to avoid complications. Recommended is an analysis of water quality over a timeframe of 12 months with regular (monthly) sampling to gather a complete picture with seasonal fluctuations.

UNIHA (2016): A one year water analysis is necessary but in real life some come clients only have a single sample, some even with unclear measurement conditions and time frames.

Table 4-1: Water quality criteria details, Source: Voutchov (2013)

Parameter	Measures	Contents	Measures not	Unit	possible Range	Base Level	Practical Level	Considerations
TDS	mineral content/ion composition	sodium, chloride, calcium, magnesium …		mg/L	35-45.000	35.000	see chapter 4.0.1	
Turbidity	particulate foulants	debris, silt, suspended organic matter, microorganisms	type and size, dissolved foulants	NTU	0.1-100+	0.5-2.0	0.1-1.0	Levels above 0.1 mg/L are indicative of a high potential for fouling. Spikes above 50 NTU for more than 1 h would require sedimentation or dissolved air flotation treatment prior to filtration.
SDI	particulate foulants potential	-	small size particles	SDI	2.0-5.0	2	2	Source seawater levels consistently below 2 all year round indicate that no pretreatment is needed. An SDI greater than 4 indicates that pretreatment is necessary.
TSS	total weight of solid residuals	-	dissolved solids	mg/L	3.0-50.0	3.0-5.0	3.0-5.0	Needed to assess the amount of residuals generated during pretreatment. It does not correlate well with turbidity beyond 5 NTU
Chlorophyll a	algae with green pigmentation	-	-	µg/L	0.5-10	0.5	0.5	Indicative of algal bloom occurrence. If water contains more 0.5 µg/L, the source water may be in an algal bloom condition.
Algal count	number of algal particles per unit water			x/mL	1-60000	2000	1000	Indicative of algal bloom occurrence. If water contains more than 2000 cells per milliliter, the source water is in an algal bloom condition.
Particle distribution profile	number of solids for size ranges			µm	1-50+	20	02.Okt	
Collodials	by laboratory tests	iron, manganese, silicia, hydrocarbons			-	-	-	
LSI	potential of mineral scaling (calcium carbonate)	pH, calcium, alkalinity, temperature, TDS	other scalants	LSI	neg.-1+	0.2	0.2	
TOC	organic content (NOM etc.)	-	-	mg/L	<0.2-12	<0.2	<0.2	If this parameter is below 0.5 mg/L, biofouling is unlikely. Above 2 mg/L, biofouling is verly likely.
BFR	accumulation of biomass	-	-	pg-ATP	1-120	1	1	
Iron				mg/L				If iron is in reduced form, RO membranes can tolerate up to 2 mg/L. If iron is in oxidized form, a concentration of more than 0.05 mg/L will cause accelerated fouling.
Manganese				mg/L				If manganese is in reduced form, RO membranes can tolerate up to 0.1 mg/L. If manganese is in oxidized form, a concentration of more than 0.02 mg/L will cause accelerated fouling.
Silicia				mg/l				Concentrations higher than 100 mg/L in concentrate may cause accelerated fouling.
Total hydrocarbons				mg/l				Concentrations higher than 0.02 mg/L will cause accelerated fouling.

UNIHA (2016): TDS is the most important parameter (including detailed ion composition), followed by metals and TOC. For drinking water and especially irrigation purposes boron has to be controlled (following WHO recommendation of 2.4 mg/L). Out of that data scaling potential is calculated using SDI as indicator – a value of max. 2 is required, some RO membrane producer guarantee useful functioning only up to a value of 3.

4.1 Feed water intake & Pump station

This regards to the methods collecting the source water. Main separation criteria are open/surface and subsurface intakes. Depending on plant size, geology, economics and source water quality, the best fitting solutions will be chosen.

4.1.1 Onshore open intake

Used mainly for large and thermal/hybrid plants (sometimes with power-plant co-location), this type of collection uses large and deep canals and artificial concrete forebays at the shore including filter screens and pumps. They are the cheapest version but also the one collecting the worst quality of feed water as they work in the so called surf zone in which the breaking waves lift particles from the bottom, causing high levels of turbidity, algae, silt, organics etc.; not to speak of beach erosion and damages from wave action. This low quality makes it difficult to use the source in membrane desalination (Voutchkov, 2013: 194 & 198).

4.1.2 Beach wells

Vertical ones are most common for small plant sizes up to 10,000 m^3/day if geologically possible. The aquifer soils filter the seawater slowly which results in source water of better quality. Beach erosion may endanger soil support and integrity forcing costly refurbishment; the structures on the beach may also cause aesthetic concerns which make architectural measures necessary to integrate them into landscape (Voutchkov, 2013: 86-89).

4.1.3 Offshore open intake

This system uses velocity-cap-type inlets away from shore, conduit-connected (pipes, tunnels) with onshore filters, intake chamber and pump stations. The inlets are up to several hundred meters away from shore, 4-20 meters below water surface and 4-10 meters above water floor, collecting seawater with typical TDS content (Voutchkov, 2013: 194-195).

Analysis of intake and pipeline route should consist of (Voutchkov, 2013: 201-202):

- Bathymetric Profile – topographic profile of water floor
- Geotechnical Survey – determining formations, seismic faults, seabed conditions (flat sandy = pipeline on bottom or trench; rocky = under bottom)
- Wave and tide survey – evaluation of horizontal currents and its effects on intake and sediment as well as tidal fluctuation to define submergence of intake
- Underwater current survey – impacts on water quality, intake location and possibility of using wedgewire screens
- Biological/ecological survey – identifying sensitive habitats for maritime species
- Source water quality profile – taken at several optional locations, regularly over at least a year and during extreme events (storms, algal blooms etc.)

Based on the mentioned surveys the location delivering the relative best water quality should be chosen, including worst-case scenarios. Depth recommendations between 8-20 meters for the intake velocity cap consider factors like water quality, costs of deeper installations and their negative impact of lower water temperatures (high viscosity, therefore higher energy demand for pumps and separation process). At the entrance of the intake, inlet coarse bar screens are applied with specific through-screen velocity, which is not too high (0.10-0.15 m/s) to avoid jellyfish suction; after 18-24 months other content like debris or shellfish collect on the screen which then have to be cleaned by divers. Single or multiple inlets/conduits are possible, designed with 20-30% overcapacity of annual intake flow to account for accumulation of silt, debris and biomaterials; multiple inlets are used whenever possible, as the cleaning can be done consecutive and no full shutdown of plant is forced. Depending on the plant size and set-up, simple pipelines per intake or concrete tunnels are used to convey the feed water to pre-treatment facility (Voutchkov, 2013: 202-205).

UNIHA (2016): Beach wells are preferred for small to medium plant sizes (max. 30,000 m³ product flow per day). They provide pre-filter and buffer capabilities, especially the former is desired as it supports the pretreatment process (e.g. algae) and protects the RO by blocking scalants. On the other side geological and economic issues cap the quantity of possible wells and intake volume – above that level offshore intakes make more sense.

4.1.4 Intake pump station

Wet-Well Pump Stations – most commonly used in desalination due to its simplicity and low cost structure. Vertical turbine pumps are submerged in used wells, which highlight the main disadvantage: exposure to corrosion, regarding a ventilation system for minimization. Additionally maintenance is difficult (crane construction, not accessible for service).

Dry-Well Pump Stations – in a separate structure and accessible for maintenance, but higher construction costs for separation of pumps and suction header.

Canned Pump Stations – a metal suction surround the pumping unit, which gives the limit of volume processed; on the other side, it is as efficient as the other mentioned stations but needs much less space, which reduces the costs.

UNIHA (2016): Wet-well systems are common as they combine well and pump – on the other side these pumps respectively their maximum volume limit the wells intake flow. Dry pumps are more expensive. Nowadays intermediate solutions are possible where the pump is in a separated dry area directly aside the wet well connected through a wall.

Stations should be located such that flooding causes no damage to motors, and downstream of the coarse and fine screening systems to avoid damage. To reach capacity factors of +96%, the unit design should engage duty and standby pumps to be flexible, enhanced by variable-frequency drives (Voutchkov, 2013: 225-228).

UNIHA (2016): Frequency control is standard for today's pumps to protect the system in starting phases and regulate daily production.

4.2 Pretreatment

For this thesis, the topic pretreatment includes all preparations regarding feed water before reaching RO trains. Figure 4-3 shows water contents based on their size:

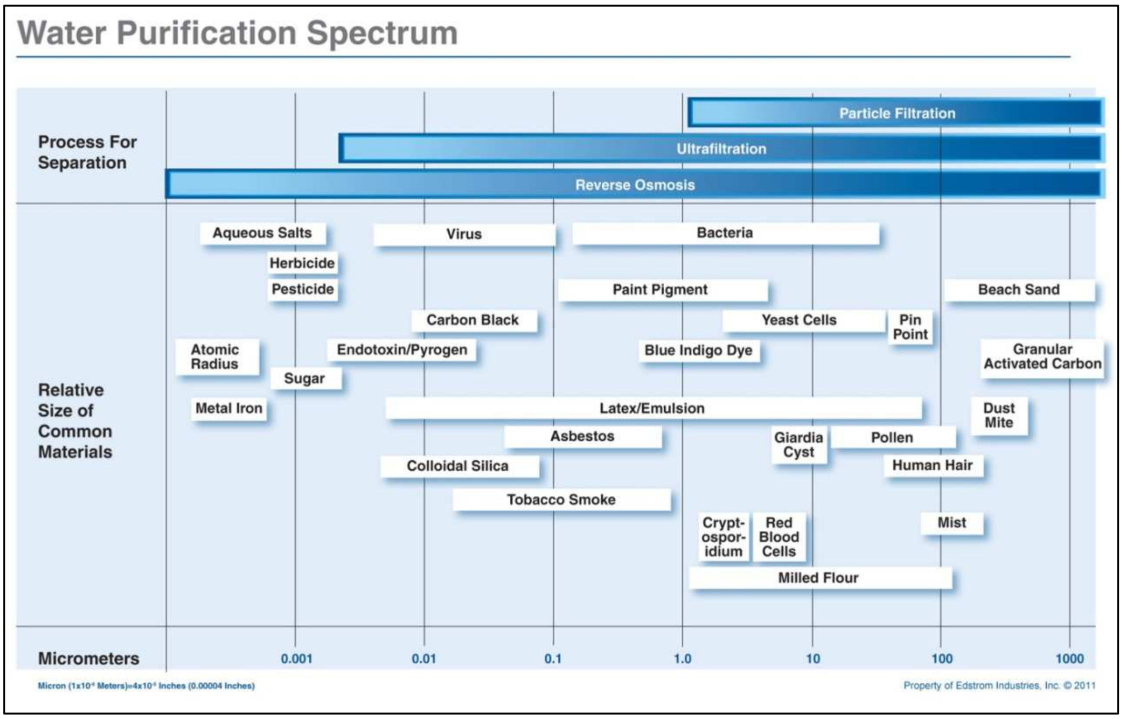


Figure 4-3: Water contents and sizes, Source: Aqualose (2016)

There are different ways (physical, chemical), positions (up- and downstream of the process steps) and necessities to reach requested source quality, described and ranked differently in literature. What can be said for sure is that the main criteria for choosing pretreatment methods come from source water analysis, followed by target product water parameters. Therefore the pretreatment tools are listed here neutrally with pros and cons, following the main order of appliance upstream.

4.2.1 Screening

As the first step of treatment, the different screens prevent all size of debris and marine organisms from entering the RO train. The main systems are (Voutchkov, 2013: 235-250):

Coarse bar screens (50-300 mm) – already describe in chapter 4.1.3 they are used in offshore inlet systems to avoid larger debris and aquatic life entering the intake. Designed for low velocities they minimize impingement and account for loss of filter surface with time when shellfish and sediment accumulation increase, which makes cleaning by divers necessary every few years.

Fine screens (3-10 mm) – applied after the coarse bars they further filter particles mainly to protect the intake pumps. They rotate based on pressure analysis from debris accumulation and can be in the form of bands (for small and medium plants) or drums (for large plants).

Wedgewire screens (0.5-10 mm) – special passive screens, no mechanical part, at the suction end of intake pump and hence eliminating need for other screens. Running on low flow velocity they minimize impingement and entrainment but only working well in suitable ambient cross-flow currents, therefore not often usable although advantageous.

Microscreens (80-400 microns) are necessary, when the ‘core’ pretreatment is of membrane type (see chapter 4.2.4) because the so far describe ones are not sufficient in removing such small particles which may cause damage in related membranes.

Cartridge filters (1-25 µm) are somewhere in between the described screens, used often as the only filter system when source water quality is high or as RO membrane protection when granular media filtration is used as ‘core’ pretreatment (see chapter 4.2.4).

Cleaning of the screens is done manually or by backwash systems, in which filtered permeate (and air) is used in a process reversing the filter flow direction and therefore removing accumulated material from the screen surface.

4.2.2 Additional physical treatment

There are further methods removing coarse material which act as support for different pretreatment steps (Voutchkov, 2013: 271-277):

Sand removal – not so common with offshore intakes, sometimes a well-intake problem. The low sand content in well-designed plants can be removed by sedimentation or filters.

Sedimentation – necessary when the source water turbidity and SDI are in upper areas; basins are positioned before 'core' pretreatment facilities, which use coagulants and flocculation (see chapter 4.2.3) to reduce turbidity and SDI in feed water.

Dissolved air flotation – this method comes into play in case of particulates not removable by sedimentation or filtration, namely floating material like **algal cells, oil, grease** etc. In a DAF tank small air bubbles are created which float the material at the top and can be skimmed off for disposal. Compared to sedimentation, this process needs only 1/10 of surface loading and its residuals end up in higher density. On the other side, it is more complex and costlier.

4.2.3 Conditioning

Besides the physical screening a chemical treatment at different process steps may be or is necessary. These are described next, in order of process position (Voutchkov, 2013: 255-267):

a) Ahead of pretreatment

Coagulation – depending on pH value and temperature, chemicals like iron salt or ferric sulfate are used to neutralize the negative charge of small seawater particles and to agglomerate them into larger flocs (in special tanks). Especially for source water with high turbidity caused by resuspension of bottom sediments it is obligatory. Overdosing should be strictly avoided as it enhances filter and RO fouling.

Flocculation – this is an additional treatment with polymers to increase flocculation tendency, but it can also cause fouling and the benefits may get negated.

UNIHA (2016): Coagulation is done usually, flocculation is to be avoided. In case of algae bloom potential DAF is the preferred additional method. If algae occur whole pretreatment and RO systems can be destroyed.

Oxidants – also called biocides, reduce growth of organisms along streams and facilities and biofouling on RO membranes. The most known and used chemical is **chlorine**, a toxicant for (aquatic) organisms. But it’s not an absolute barrier, and released intracellular material from destroyed bacteria cells serve as food for bacteria already colonized on membranes. Besides ‘shock’ chlorination at random schedule is useful to avoid resistance on organism level. Additionally it has to be removed (using oxidant scavengers) before reaching RO membranes as it destroys their polymeric structure. Not so strong but effective alternatives like chlorine dioxide or chloramines promise easier application, depending on specific conditions.

UNIHA (2016): Chlorination is induced already at intake point to protect the whole piping and pretreatment steps from bio growth. Direct at RO entry, source water is dechlorinated and scale inhibitors get added.

b) After pretreatment filtration

Scale inhibitors – mineral deposits (scaling) is beside biofilms the most common kind of fouling on RO membranes. Low-solubility salts exceed their threshold (with increasing recovery) and form crystals on membrane surface, reducing flux and productivity. Special suppliers deliver antiscalants (i.e. acids) and recommend dosages depending on source water analysis.

4.2.4 ‘Core’ pretreatments

a) Granular Media Filtration

This is the most common technique for RO plants (beside cartridge filters). Source water runs through layer(s) like anthracite, sand and garnet in a one or two stage process, depending on turbidity. 90-99% of solids and silts gets removed, also some aquatic microorganisms. If the solids retained in pores of filters cause a predefined level of hydraulic loss, the backwash process begins in which filtered water or concentrate flows upward the media and removes the collected solids and transports it to discharge. Sometimes backwash is combined with air to increase turbulence. The whole cycle takes 24-48 hours and reduces the media surface which has to be accounted in building and maintenance.

Filter cells are design following practicable filter bed size, remaining capacities of filters when one is in backwash and design of RO systems i.e. trains. The filter media is commonly dual (two layers) with different specialisations based on source water content and temperature.

As driving force for flow, gravity and pressure is available, each with different advantages. The latter is mainly used in small and medium plants.

UNIHA (2016): Pressure dual media filters are first choice because of footprint. A pressure pump (up to 4 bar) delivers source water to pressure chambers which can process more than gravity filters per unit of area – hence higher cost are acceptable.

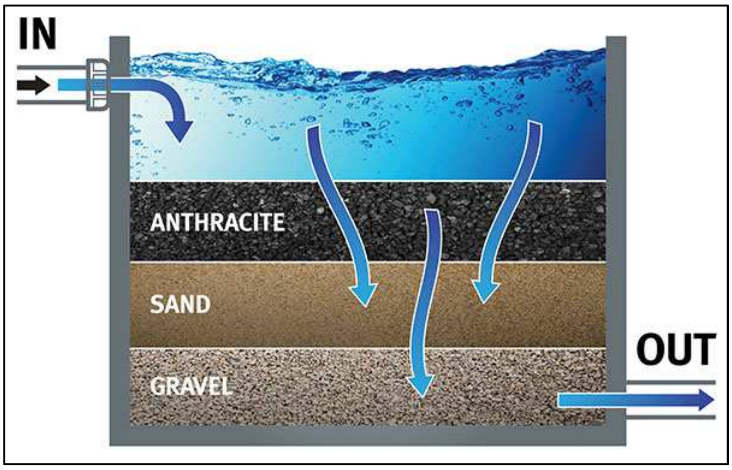


Figure 4-4: Gravity dual media filtration process (Source: carlsbaddesal.com, 2016)

Coagulation/Flocculation is required before granular filtration, also sedimentation or DAF may be necessary to enable or enhance its effects. Regarding organics its removal rate is low; microorganisms like algae may make third media layer necessary, bacteria/viruses are retained on a quite high level (Voutchkov, 2013: 285-299).

UNIHA (2016): A standard setup with offshore intake would consist of coarse bars, fine bars drum screens, dual media pressure filters, and cartridge filters directly before RO to protect it if some particles got through former steps. In case of membrane pretreatment (UF/MF) cartridges are not necessary.

b) Membrane Filtration

Like with RO process, membranes are used in pretreatment to remove particulates, colloidal and organic foulants – microfiltration and ultrafiltration are the common methods. Therefore more other treatments for coarse and fine contents as upstream steps are necessary. These methods are not as long in practical use as granular or cartridge filtration so they are still at short vintage level and not that proven.

Requested are more steps than with granular media: additional to filter process and backwash, cleaning and integrity testing are necessary. Backwashing happens every 30-120 min and takes a few seconds. As this is not enough, chemical enhanced backwashing (CEB) is obligatory up to two times a day, using e.g. chlorine. Not securing membrane fouling protection completely, additional cleaning has to be done every 1-3 months for 8-24 hours by using a combination of low and high pH solutions. Integrity testing is required to find membrane damages.

Membrane configuration can be done like in RO – pressure vessels – or submerged which means the membrane are installed in open tanks (Voutchkov, 2013: 311-321)

UNIHA (2016): Dual media filters are more robust and practical than UF/MF. The latter are also membranes which provide an additional step with fouling potential making chemical cleaning obligatory. Also in the media and articles UF/MF is not seen very positive.

4.3 Reverse osmosis unit

It represents the centre technology and main purpose of a desalination plant – the separation of dissolved solids (remaining after pretreatment), mainly minerals, from feed water. The widest definition of so called RO trains consist of feed pumps, membrane modules in pressure vessels, energy recovery devices, pipes, manifolds for stream flows, instrument panels and sometimes sampling panels for permeate. Components and design are described next.

4.3.1 Filtered water and high pressure pumps

Two schemes are possible to deliver pretreated source water to RO system's high pressure pumps: direct flow-through in which the intake and pretreatment is designed to cope with the high pressure requirement, or interim transfer where an additional pump boosts filtered water to required pressure levels. Actual SWRO design enhances these systems with VFDs to combine filtered water and RO pressure control to adapt on seasonal changes in source water like temperature or salinity and therefore safe costs and energy.

UNIHA (2016): RO racks are always assembled with separate high pressure pumps. The pressure differences between pretreatment and RO steps are very high, the level of the latter (70 bar) would compel strong and expensive structures for the former to withstand.

The high pressure pumps provide 55-70 bars for SWRO to perform membrane separation. Here as well, although costlier, VFDs can be installed to adjust pump motor speed for optimum efficiency. Beside temperature and salinity, membrane fouling is a crucial adjustment factor: RO systems lose 8-15% productivity over 3-5 years causing pressure increases to maintain product flow until reaching damage threshold.

For small size plants reciprocating (piston) pipes are used which have high efficiencies of 90-95% and a flat pump curve which means the feed flow rate stays nearly constant with changing pressure by keeping efficiency; disadvantageous is the pulsation flow (min and max flow with every stroke) depending on number of pistons – the more of the latter the less pulsation. Centrifugal pumps are used for all plant sizes but bear the disadvantage of a non-flat pump curve, so VFDs have to be installed to keep efficiency stable with variable operating pressure, or they have to be designed as multistage, as the curve flattens with number of pump stages. Medium and large size SWRO therefore uses multistage centrifugal pumps with efficiencies of 80-88%. They can be horizontal or radial split-case type whereas the latter are smaller, easier to maintain and water-lubricated. Two alternatives for small and medium size plants are segmental-ring multistage and high-pressure single-stage pumps, depending on costs, efficiency requirements and energy recovery device type (Voutchkov, 2013: 360-369).

4.3.2 Pressure vessels

As indicated in chapter 3.2.2 membrane elements (modules) are installed together in pressure vessels, industry standard now is eight elements due to more cost effectiveness (fewer vessels, lower equipment costs). Such design also brings higher flow velocities and lower recovery rates which reduces concentration polarization factor and fouling potential – but with the downside of higher pressure differential from first to last element within one vessel, making correct selection and implementing of modules critical.

Vessels can be differentiated by pressure (for SWRO classes of 42-105 bar are in use), diameter (actual industry standard is 8 inch/200 mm), by materials (most common is fiberglass-reinforced plastic) and by the feed port location. Regarding the latter, standard applications feed on one end and collect permeate and concentrate on the opposite end. Side entries shorten the piping and ease maintaining. Even further go multi-port vessels which have several ports for feed and concentrate, which brings uniform flow distribution and further piping reductions and cost savings.

Basically all elements are identical which leads to the following uneven flow pattern: product water flux and feed pressure decreases in flow direction, first two elements produce 35-40% of total flow, these entry elements work under full pressure and productivity. Along the vessel, permeate is removed (and with it pressure energy) but concentrate remains until the last element, this increases salinity and osmotic pressure and finally reduces productivity for the last element into regions of 6-8%. To overcome these drawbacks, hybrid configurations are available in which the first element is of low permeability/high salt rejection type (reducing yield to 14-18%), the second a standard element and the rest high permeability/low salt rejection types – evening out flow and saving energy in the areas of 5-15% alongside reducing fouling potential.

4.3.3 System design variations

Based on feed water source and product water requirements different set-ups and arrangement of RO pressure vessels are possible (Lanxess, 2012: 3-4):

Figure 4-5 shows a standard configuration which achieves around 50% RR; higher ones are possible if concentrate is partly recycled back into feed circulation. This scheme applies to single modules/vessels as well as single stage systems where two or more vessels work in parallel.

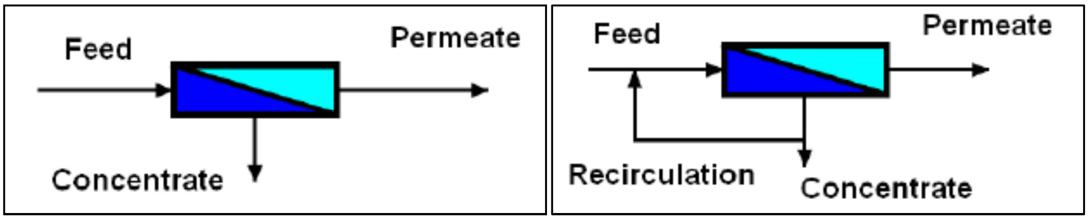


Figure 4-5: Standard RO configuration (left) and with concentrate recirculation (right), Source: Lanxess (2012)

To increase the systems' RR to 75-80%, stages are linked serially so that subsequent modules treat the concentrate of the former ones. In respect of the decreasing feed flow the number of subsequents is reduced (ratio 2:1). If an even higher purity is required (>90%), a two pass design where the subsequent modules treat the permeate of the former ones, can be designed (recirculation the subsequents' concentrate as it is already of high quality).

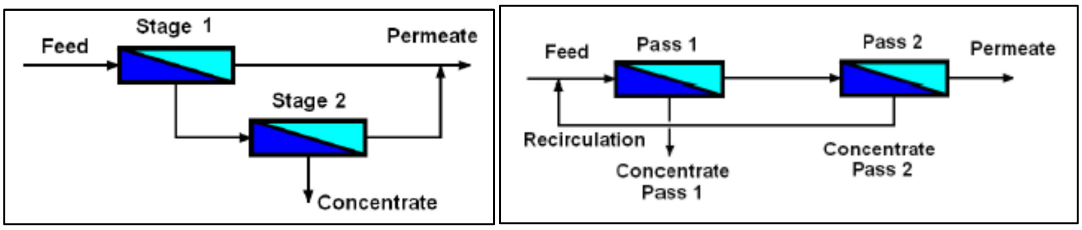


Figure 4-6: Two stage RO (left) and Two pass RO (right), Source: Lanxess (2012)

There are special cases with further steps like permeate blending – product is used as drinking water which request specific salinity levels – and permeate recirculation – adopted when feed temperature differs seasonally to stabilize pressure variations and product quality.

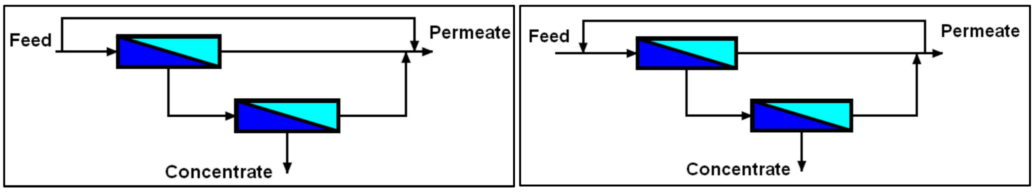


Figure 4-7: Permeate blending (left) and Permeate recirculation (right), Source: Lanxess (2012)

UNIHA (2016): Single pass and stage is sufficient; double pass is designed if boron levels are too high (e.g. in Israeli plants). Regarding module type combination, different modules in one track is not common right now but the RO producers go an intermediate way and combine vessels with different characteristic to achieve better results.

4.3.4 Energy recovery devices

A crucial aspect to increase the whole plants efficiency is reuse of energy contained in the high pressure flow within RO system (as the high pressure pumps use the most of all energy). The permeate's flow is 'lost' but the concentrate with energy content nearly the opposite of RR (40-50%) can be recovered to support feed flow pumping. Two main technologies are used to reuse the concentrate pressure (Voutchkov, 2013: 386-392):

a) **Centrifugal ERD**

Concentrate pressure is applied to different kind of **impellers/wheels producing rotational energy** which supports high pressure pumps. Pelton wheels, working with high-velocity nozzles and spoon-shaped buckets, are shaft-connected directly to feed pumps. With 80-90% conversion efficiency the concentrate leaves the ERD with gravity conditions. The maximum Pelton wheel size/volume is also the RO skid boundary (at present 21,000 m³/day) and more costly as well as less efficient than turbochargers – on the other side it's simple, compact and less costly than isobaric systems.

Turbochargers consist of a shaft-connected centrifugal pump and a turbine and are applied in series with medium pressure pumps, therefore splitting the task of reaching necessary feed pressure before the RO system. Having 90-92%

conversion efficiency, the whole pump system reaches up to 80%. As pump efficiency is reversely proportional to delivered pressure, a higher overall efficiency can be reached for small sized pumps, being also less costly and space saving. It is not so useful for large sizes and very sensitive to RR and flow/pressure fluctuations. A Francis turbine works similar to Pelton wheels but differ in flow-path. It is not only sensitive to flow/pressure but also starts turning late at design level (40% of flow).

b) Isobaric ERD

In opposite of separated recovery and pump units the **pressure-exchange principle** is at work here where energy of concentrate directly pumps new feed water to RO (45-50% of feed flow, the rest comes from standard high pressure pumps). Efficiency of 93-96% reduce electricity need strongly and have the main advantage of being not coupled to the high pressure system, so not restricting its size, supporting the trend of large RO sizes and fewer trains. Implementations showed power cost reductions of 10-15%.

UNIHA (2016): Isobaric pressure exchangers are state-of-the-art and highly efficient up to 98% recovery of concentrate pressure. Pelton-wheel systems have been used in older plants.

4.3.5 Membrane flushing and cleaning system

As already bespoken in previous chapters RO systems get water-flushed regularly and in lesser intervals cleaned with chemicals (every 4-6 months on average) to remove foulants of all kinds. The latter needs a unit also call CIP with tanks, pumps, filters, piping and control. Size depends on system set-up (stages) and is based on a full cleaning cycle of the largest train. A typical sequence shows these steps (Voutchkov, 2013: 395-397):

1. Train flushing
2. Membrane disinfection, removal of iron and calcium
3. High pH cleaning, flushing, evaluation
4. Low pH cleaning, flushing
5. Final disinfection
6. Final flushing and evaluation cleaning effect

UNIHA (2016): Pure flushing with water is the main cleaning purpose to remove light forms of scale. The better the source water and/or the pretreatment the longer chemical cleaning can be avoided. One should also put attention on the fact that deadlock times cause more fouling than production so after deadlocks chemical cleaning is always done. As indicators pressure level and energy demand are used – a 5% limit is usual then chemistry gets applied.

4.3.6 Instrumentation and controls

This part ranges from simple manual control and automatic shutdowns to complex applications. The operator can overview the whole RO system units and their performances and gets warned by alarms; shutdowns of whole ore individual parts are down manually or automatically to protect the plant. Instruments mainly used to monitor flows of all kinds are magnetic flow meters for large plants or simple and low-cost rotameters for small ones. Critical pressure locations use electronic pressure transmitters, water quality is measured by conductivity/pH/temperature analyzers (Voutchkov, 2013: 397-403).

4.4 Post-Treatment

Frankly speaking, desalinated water is ‘too clean’ regarding specific minerals as with RO not only salt is removed but many other mineral contents like calcium or magnesium (resulting in low ‘hardness’); also the carbonate alkalinity is reduced which in sum makes the product water unstable and variable regarding pH values leading to corrosive behaviour – the inability to form or protect calcium carbonate ($CaCO_3$) films on pipe walls etc. which at the end damages water distribution systems. Additionally colour, taste and quality of product water gets unacceptable or even unhealthy, known also as ‘red or black water’. Different values and indexes exist to measure corrosion potential, a selection listed below (Voutchkov, 2013: 445-450):

- LSI – based on difference of pH of unconditioned and treated product water at calcium carbonate saturation point; negative value indicates undersaturation; of limited suitability

- CCPP – quantifies calcium carbonate itself; negative value indicates undersaturation; most accurate indicator
- LR – based on chloride and sulfate ions; values below 5 minimize corrosion
- Alkalinity – the buffering capacity of water meaning the concentration of acid or base necessary to add to change its pH; minimizing pH variability means denser scale structure on pipe's walls; high alkalinity also advantageous for reaching target CCPP at lower pH values, being supportive to disinfection processes
- pH – desalinated water has lower pH as the RO membranes partially let through CO_2; a too low value hinders corrosion protection forcing an increase to a typical range of 7.5 to 8.4 (but not too high otherwise buffering capacity and disinfection are reduced)

Beside that mineral supplementation has also to be done regarding nutrition minimum levels for human or agricultural use. Disinfection is as well a part of posttreatment using chemicals already bespoken in related pretreatment chapter. Details follow in the next two chapters.

4.4.1 Remineralization

Chemical addition – by adding calcium in form of lime or calcite, representing the typical process used in desalination plants worldwide. Sequential feed of calcium and carbon dioxide supply the necessary hardness and alkalinity.

Mixing with source water – only possible if it is of good quality and also pretreated. Due to taste and quality parameters this process is not really used in SWRO.

Dissolving minerals – by processing water through limestone or dolomite contactors. Former is less costly and needs less carbon dioxide than in lime-based remineralization described before but availability is not given everywhere, therefore no frequent use worldwide. Latter makes it furthermore difficult to predict water quality as the dolomite stone is nonhomogenous and interbedded with limestone; in addition dolomite is more expensive, less available and less soluble. In SWRO not been used at all so far (Voutchkov, 2013: 453-460).

4.4.2 Disinfection

Chlorination – done with chlorine gas and sodium hypochlorite, this method represents the most common one in desalination plants. As the former is more dangerous and needs detection, containment and treatment facilities, the latter is applied more often and can be produced on-site saving storage space. Both are more effective in bacterial treatment at pH below 8.

Chloramination – a secondary disinfectant with lower biocide potency but higher stability. Due to its slower rate of decay it is used for large distribution systems with high temperatures and long retention times. Not used very often as SWRO product water due to its low organics content.

Others – like ozonisation or ultraviolet light disinfection are more used for freshwater or have disadvantages like the latter which may use no chemicals and therefore produces no DBPs but also no disinfectant residuals to control bacteria growth (Voutchkov, N. 2013, p. 480-485).

UNIHA (2016): Posttreatment needs chlorination again mainly due to buffering product water in tanks. Mineralization is done with lime or calcite for up to medium plants, larger ones use limestone.

4.5 Discharge

This is the drawback of the highly valuable coin of producing potable water, namely the waste streams originating in desalination itself (concentrate), in plant system chemical-free flushing (backwash water) and in chemical cleaning of (pre-)treatment membranes (CIP). The streams occur continuously or intermittently, quality and quantity are mainly dependent on source water quality and used technologies. There are different possibilities what to do with them depending on technological and environmental aspects.

4.5.1 Waste stream categories

a) Concentrate

As the main waste stream of desalination it contains the most dissolved solids (mainly of course minerals and salts), some pretreatment additives, microbiants and particulates. Being quantitatively the opposite of RR it has around 1.5-2 times higher salinity than its source water (65,000-80,000 mg/L) which is also its osmotic pressure limit for single-pass SWRO systems. It also holds rejected heavy metals, >95% of organics, shows higher pH due to its higher alkalinity and lower values of turbidity, TSS and BOD – especially when particulates are removed in pretreatment (Voutchkov, 2013: 493-495).

b) Flushing/Backwash water

This stream originates in the periodic filter flushing/backwashes in (pre-)treatment, namely granular media filtration or MF/UF; former using 3-6%, latter 5-10% of intake water quantity. Volume increases with turbidity and it contains removed solids and coagulants if applied. The latter may cause red colour if ferric salts are used (ferric hydroxide forms, better known as rust). Therefore it gets decoloured and anyway mixed with concentrate before discharging. Small plants can even use sanitary sewage systems if applicable (Voutchkov, 2013: 495-497).

c) Membrane cleaning stream

As flushing/backwashing is not enough to clean membranes especially regarding foulants (particulate, colloidal, organic, microbiological) precipitating on its surface, chemical cleaning processes have to be done periodically called CIP, as the modules don’t have to be removed from vessels. Cleaning is done in steps, first with low then high pH solutions, followed by water flushes to drain chemicals and residuals. The annual sum of these streams (cleaning solution and flushes) is less than 0.1% of whole discharge flow and could be treated together with the main streams having no negative impact. Nevertheless it is often handled as separate waste (Voutchkov, 2013: 497-499).

4.5.2 Waste stream treatments

Although there are different ways to handle concentrate – the main category, possibly including both other side streams due to mixing advantages – focus here lies on the most common and assumed technically applicable ones regarding the project idea. All others are only described in short manner, staying within scope boundaries of this thesis.

a) Surface water discharge

The most common used method by applying near-shore or off-shore outfalls. Literature includes here also co-disposal with wastewater and power plants cooling water but as the former is only possible for small systems and the latter an assumption not integrated in project idea, they are not bespoken in detail.

This method is used for all ranges of plant size especially for large ones. Concentrate is simply conveyed back into sea, far away enough from intake and environmentally safe for aquatic life, measured by acceptable TDS levels. To reach this, discharge needs to mix fast with ambient sea water either by natural currents or mixing capacities in the tidal zone or by using diffusers at the end of outfall. A hydrodynamic analysis shows mixing potential and salinity load transport capacity. The larger the plant the more necessary are beyond-tidal-zones applications. The ion composition is usually similar to ambient seawater and therefore not toxic (when diffused correctly); in case of low oxygen levels concentrate has to be re-aerated.

Pipeline construction follows similar rules like with intake: corrosion- and damage resistant materials (plastic as common low cost option) placed on ocean floor and secured with concrete blocks. If plants are of big size, in case of heavy ship traffic or if environment or underwater current make it necessary, then sub-ocean-bottom concrete tunnels are preferred, increasing the costs manifold. They are designed for velocities to prevent scaling (at least 1m/s) and in best case for maximum intake volume for commissioning and shut-downs otherwise the saving of volume costs may limit flexibility.

The outfall’s end can be simple open, perforated or capped with diffusers – former two options are used by small and old plants, latter one if necessary regarding concentrate quality or hydrodynamic conditions to enlarge the ZID (Voutchkov, 2013: 499-507)

UNIHA (2016): Discharge of concentrate and cleaning chemicals into open sea is common; rarely there is a waste water connection for chemicals, especially in developing countries. In some areas salt concentration increases (e.g. Persian Gulf) so this practice may get in environmental focus in future. Chemicals are a small portion and maybe not dangerous so far except when fungicides have to be used.

b) Evaporation Ponds

The conventional and most intuitive ponds use solar irradiation to evaporate concentrate collected in large basins – salt crystals form during this process and are harvested periodically and landfill-disposed or further treated. Evaporation can be enhanced with spraying the concentrate (but thereby demanding more energy) or aeration of concentrate where bubbles increase contact surface of water and air. Important aspects have to be considered:

- Basically a region with warm and dry weather, low precipitation and humidity, flat terrain and low land costs is obligatory; wind increases evaporation but transports solids.
- To avoid environmental damage to groundwater aquifers, ponds need safe layers of liners and leak-detection systems combined with groundwater monitoring.
- Shallow ponds with large areas evaporate better but cost more – therefore deeper ones are often built. Volume should incorporate maximum concentrate flow and bad case storm events to prevent flooding. Several smaller ponds bring more flexibility than two large ones (Voutchkov, 2013: 560-567).

A special method is represented by solar ponds which follow a different intention: instead of maximizing heat convection and evaporation, they are built deep to retain heat and produce steam to run a turbine for electricity. In such a pond three layers of different salinity form in which the lowest heats up (hot brine) and delivers thermal energy via conduction to an ORC system (Voutchkov, 2013: 564-565).

c) Others

Deep well injection uses natural underground aquifers or former oil/gas fields to dispose concentrate. A method rather use for BWRO. Beach well disposal takes advantage of shallow costal aquifers which finally conveys concentrate through bottom sediments into the ocean. Used for small and medium SWRO if applicable.

An option called land application works with spray-irrigation of concentrate on salt-tolerant plants or rapid infiltration of permeable soil bottoms. More of use for BWRO in small size.

Technically more sophisticated are Zero Liquid Discharge systems in which disposal gets thermal evaporated into water and solid dry residuals, latter for landfill disposal or further treatment. High energy costs and complexity makes it feasible only for specific purposes (Voutchkov, 2013: 535, 543-546, 573-578).

5 Complementary components

5.1 Photovoltaics

The PV technology aims to transform solar irradiation (where photons act as energy carrier) into electricity. The spectrum ranges from ultraviolet (0.25-0.38 µm) over visible (0.38-0.78 µm) to infrared (0.78-2.5 µm) wavelengths, whereas the shorter ones contain the higher energy portions (www.PVEducation.org).

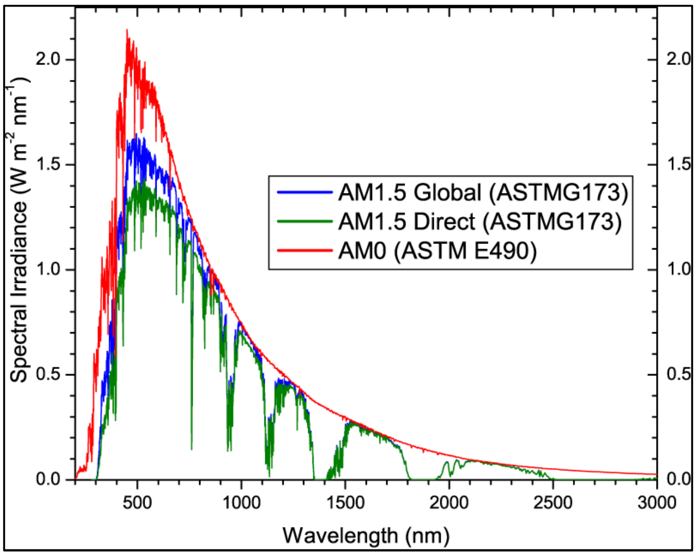


Figure 5-1: Standard solar spectra, Source: www.pveducation.org (2016)

This leads to the solar constant – the extraterrestrial irradiation outside the earth's atmosphere – of around 1,367 W/m^2. When passing the atmosphere, molecules of dust, H^2O or CO^2 diffuse/reflect/absorb the irradiation and reduce it to around 1,000 W/m^2 (clear skies).

Further reductions depend on the inclination angle of the sun: depending on location the waves have a longer way through atmosphere. The standard test models for PV cells define this as air mass (AM) with a factor of 1.5. On the other side, not only direct radiation reaches objects on earth but also diffuse radiation (scattering) from the atmosphere. Locations at the equator get more direct, latitudes like Germany or Austria regain through diffusions (Mertens, 2014: 25).

The sum of the two build the value "Global Radiation" and detailed maps show data for Europe, averaged and scaled for the whole year in kWh/m^2:

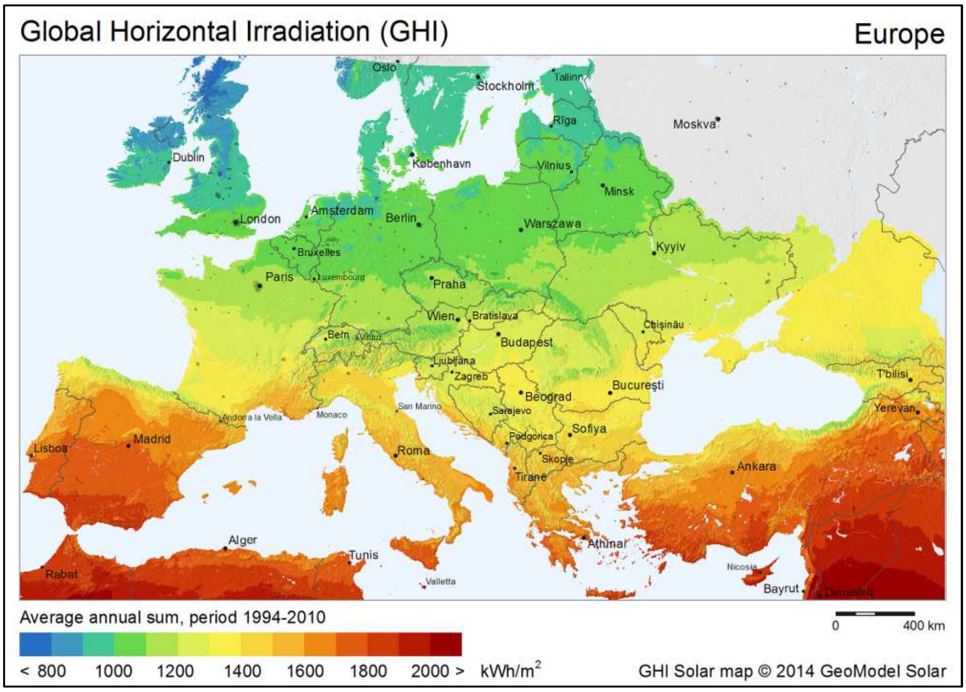


Figure 5-2: GHI Europe, Source: www.solargis.com (2015)

To gain the most (direct) irradiation two specific angles depending on the users location have to be defined (northern hemisphere):

- Azimuth = orientation towards south = 0°degree
- Tilt = the optimal (beneficial) angle toward sun's declination = 30°degree (thumb rule)

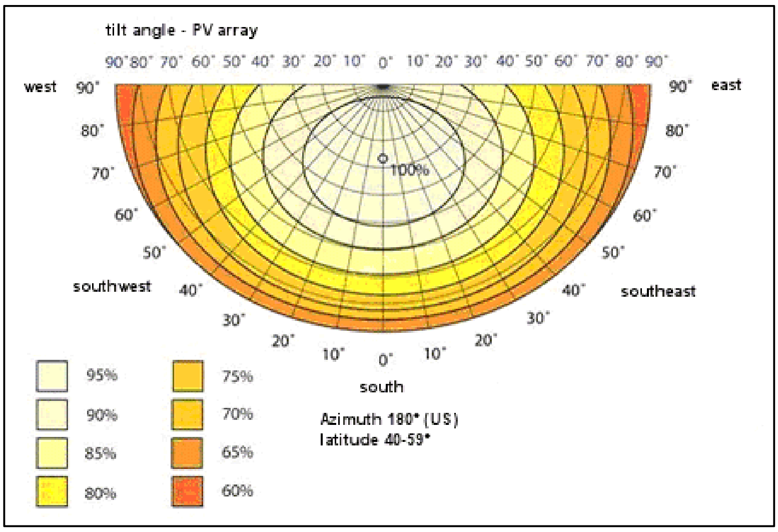


Figure 5-3: Energy yield dependency on orientation & tilt, Source: www.renewable-energy-concepts.com (2016)

a) Photovoltaic principle and cell technology

By using the photovoltaic effect free electrons/atom holes and electric fields are generated in a solar cell when photons (light) fall on it.
Main component of common solar cells is silicon, a semi-conductor. Two layers in the cell are doped with foreign atoms like boron and phosphorus to create different electrical attributes – a positive base (p) and a negative emitter (n) layer. In between a p-n-junction separates electrons and holes and voltage occurs.
Back and front contacts transport the current to a connected load followed by recombination: the electrons go back to the base (holes) and the process continues (Zahoransky, 2004: 343).

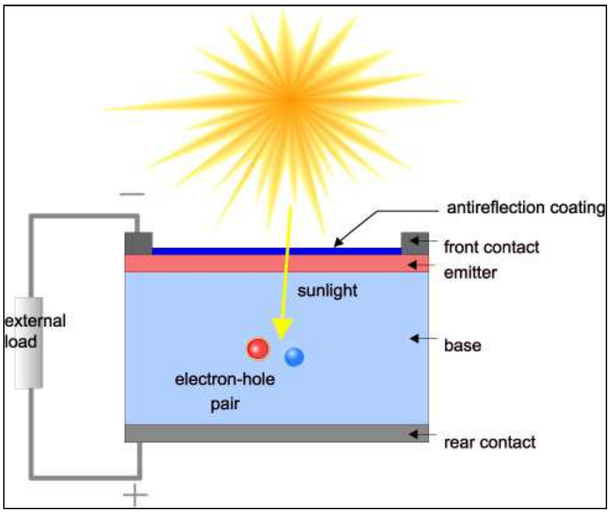


Figure 5-4: Solar cell operation scheme, Source: www.pveducation.org (2016)

There exist different technologies how to prepare the material (silicon), main differentiation is between (mono- and poly-) crystalline and amorphous forms. The former are the common known and seen in modules around the world, the latter are thin film products with lower efficiencies and different usages. Additional organic cells are in progress in research programs.

A typical crystalline cell of 10x10 cm under STC (25 °C temperature, 1000 W/m² radiation, AM 1.5) generates 1-1.5 W. Several cells are connected sequential (where voltage adds up) and/or parallel (where current adds up) to produce a solar module – depending on the usage and needs these modules are then combined.

As PV generates direct current an inverter (and voltage control) is necessary to use or feed-in the produced energy. All these components together build the PV system and are the base for the calculations in the next chapters.

b) Efficiencies of modules and system

Again two efficiency criteria have to be considered – the proportion of solar energy turned into electrical energy by the cell/modules and the then lost quantity by the peripheral PV-system (cabling, inverters, transformers etc.) before final feed-in into grid.

Table 5-1: Comparison of PV module efficiencies, Source energypedia.info (2016)

Cell material	Module efficiency	Surface area needed for 1 kW_p	Advantages	Disadvantages
Monocrystalline silicon	15-18 %	7-9 m²	- most efficient PV modules - easily available on the market - highly standardised	- most expensive - waste of silicon in the production process
Polycrystalline silicon	13-16 %	8-9 m²	- less energy and time needed for production than for monocrystalline cells (= lower costs) - easily available on the market - highly standardised	- slightly less efficient than monocrystalline silicon modules
Micromorph tandem (aμ-Si)	6-9 %	9-12 m²		- more space for the same output needed
Thin film: Copper indium diselenide (CIS)	10-12 %	9-11 m²	- higher temperatures and shading have lower impact on performance - lower production costs	- more space for the same output needed
Thin film: Cadmium telluride (CdTe)	9-11 %	11-13 m²	- higher temperatures and shading have lower impact on performance - highest cost-cutting potential	- more space for the same output needed
Thin film: Amorphus silicon (a-Si)	6-8 %	13-20 m²	- higher temperatures and shading have lower impact on performance - less silicon needed for production	- more space for the same output needed

The main technologies (mono- and polycrystalline silicon) reach from 13/16% to 15/18% module efficiency.

Regarding the whole system to the point of feed-in hence the electricity used or sold all production-related and peripheral losses need to be taken in to account with their estimated efficiency reduction:

- Temperature degradation: the power of a Si solar cell depreciates 0.4-0.5% per Kelvin increase, due to expansions in the cell structure (Mertens, 2014: 82)
- Peripherals like cables/wiring, the inverters, the transformer etc. altogether can reach losses of 14%

c) System costs

Literature gives a wide range of turn-key cost per MW installed capacity. According to IFC (2015: 174) they range from USD 1.5M to 2.2M depending on country, applied technology, taxes etc. Munsell (2015) lists quite similar results for utility-scale plants. A breakdown of cost compartments depictures like this:

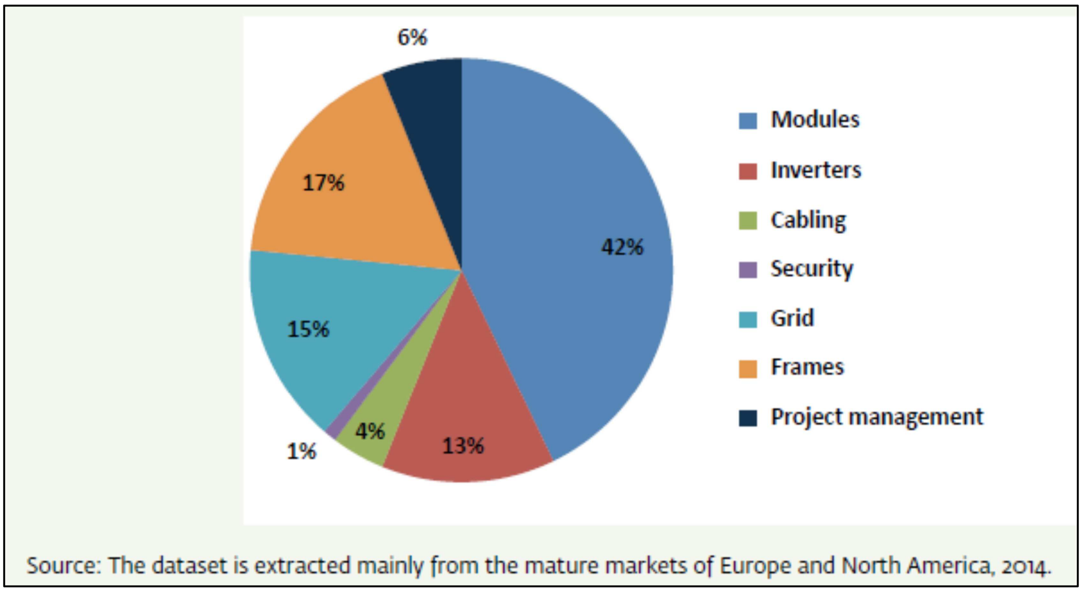


Figure 5-5: Avg. breakdown costs for a ground-mounted solar PV project, Source: IFC (2015)

d) Fixed vs. tracking PV systems

Orientation and tilt define how much of irradiation can be used by PV cells. If the modules are of fixed type the installation is done based on angles most suitable for systems purpose, mainly oriented to maximum yield in summer. So called trackers move on one or both axes to follow the suns movement based. This brings incremental yield of 20-40% (of which the first axis following horizontal movement brings the majority) depending on tracker type and location – the further away from equator, the higher the marginal surplus. Table 5-2 gives an overview of this effect.

Table 5-2: Tracker effect comparison, Source: greentechmedia.com (2012)

	1 AXIS	2 AXIS	AZIMUTH
Axis of rotation relative to ground	Horizontal plane	Horizontal and vertical planes	Horizontal but fixed in vertical plane
Land efficiency	Most efficient	Least efficient	Moderately efficient
Typical GCR	0.33 - 0.50	0.2	0.25
Region	US/Asia	EU	EU
Production increase over fixed array*	20%	35%	30%
*estimated for 30-degree latitude			

The additional harvest has a price (summarized in table 5-3):

- the system is more complex and has moving parts which increases O&M (monitoring, service, motor repair or replacement) costs
- it may require a larger footprint as the modules have to be places farther away from each other to avoid shadowing (1 MW fixed needs 4-5,000 m² whereas a tracker requires 4-7,000 m²)

Table 5-3: Tracker effect comparison 2: Source: greentechmedia.com (2012)

TYPE	ENERGY YIELD OF FIXED TILT	LAND USE (ACRES/MW)	O&M COST ($/KW/YEAR)
Fixed Tilt	100%	4.0 - 6.0	$8.00 - $15.00
1-Axis Tracking	120%-135%	4.5 - 7.5	$12.00 - $30.00

Hence the yield expressed in financial units (FiT or grid electricity savings) needs to be higher compared to all kind of costs. On the other side, lesser modules with tracking systems are necessary for the same output (Greentechmedia 1a, 2012).

5.2 Energy storage systems

Beside renewable energy as electricity source, the ability to store planned and random excess energy is a key complementary part. The related SBC factbook depicts the following groups of storage technologies:

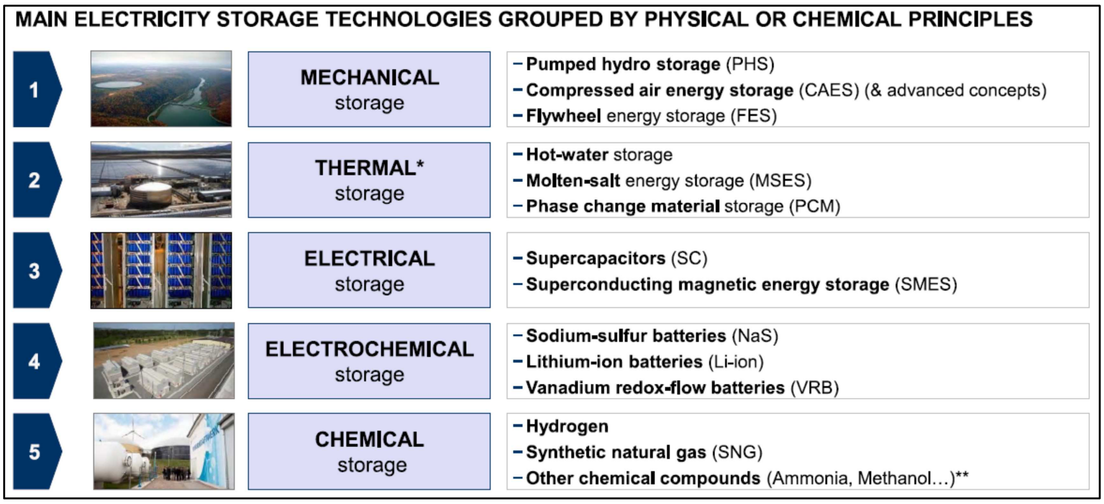


Figure 5-6: Electricity storage technologies, Source: Debarre & Decourt (2013)

To choose the suitable storage system(s) a few factors have to be taken into account:

- Rated power, energy content and discharge time as structural parameters (Fig. 5-7)
- Power-to-energy ratio, cycling, efficiency etc. as performance parameters
- The technological maturity and marketability (Fig. 5-8)
- Capital and operating costs (Fig. 5-9)

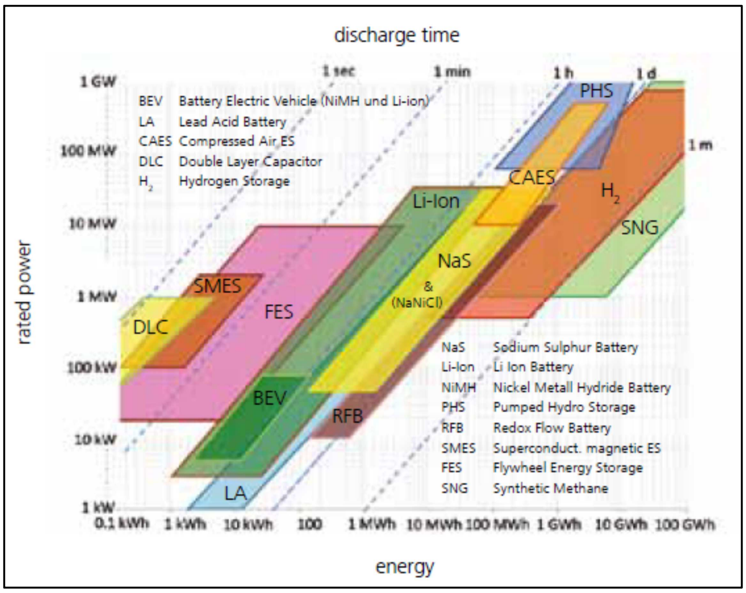


Figure 5-7: Structural features, Source Fraunhofer ISE (2012)

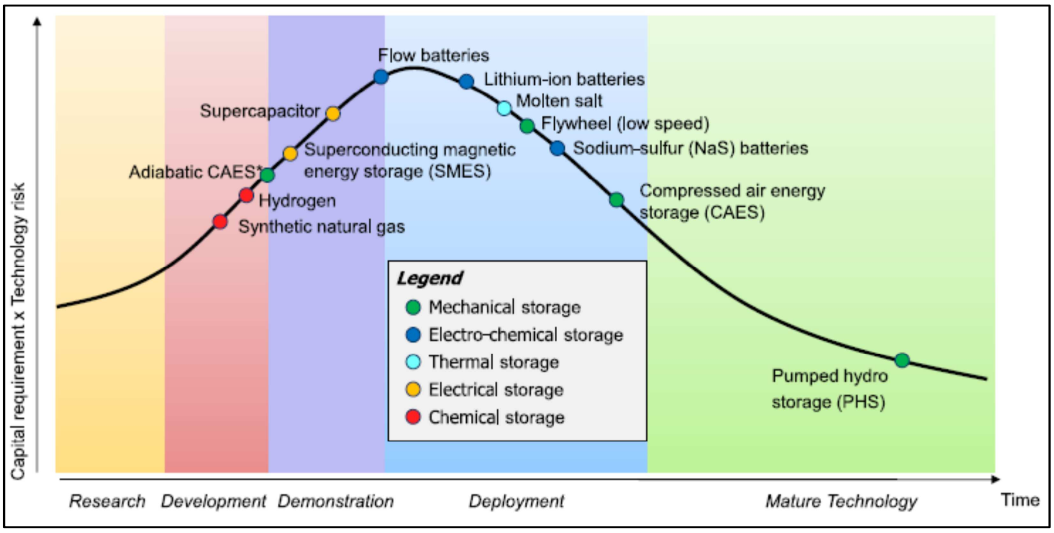


Figure 5-8: Technological maturity, Source: Debarre & Decourt (2013)

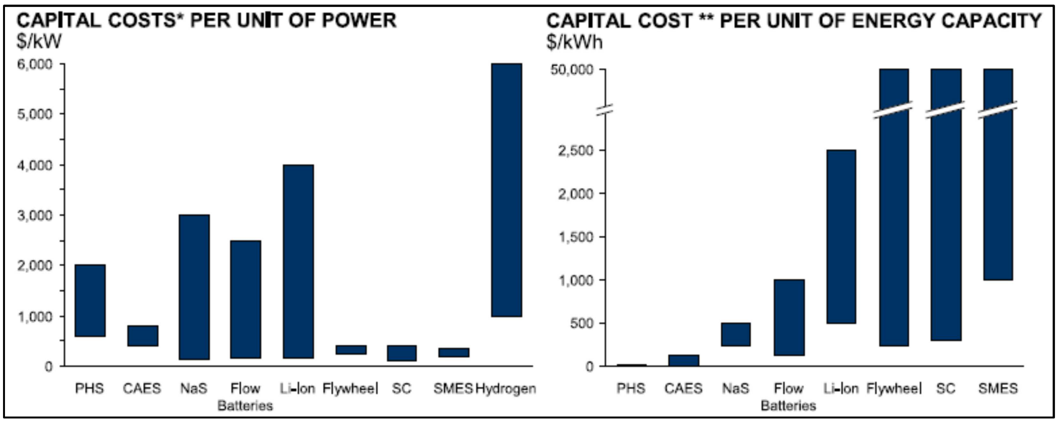


Figure 5-9: Power and energy costs, Source: Debarre & Decourt (2013)

Xing, L. et al (2014) give a comprehensive overview of technical and economical characteristics of energy storage systems which can be found in combined and commentated form in appendix 1. Taking into account the so far elaborated plant design and the factors of desalination and PV, the following alternatives reduction can be done:

- **Mechanical storages** like the mature PHS are an infrastructure category of its own, depending on topography and long term holistic energy plans. Alternatives like seawater-PHS like Yanbaru in Okinawa (DOE, 2014) using the ocean as lower reservoir, exist and may play a role in future but would enlarge the scope and financials of proposed project of this thesis hence not included. CAES need also specific underground structures and use additional fossil fuels to run turbines for producing electricity. Such structures are not assumed here (therefore no deep-well aquifers as feed water source and discharge option) and burning fossil fuels as main energy source is no option for this project. Flywheels are suitable only for specific purposes and in early stage of commercialization.
- **Direct electrical storage** using (super-)capacitors or SMES in electrostatic or magnetic fields is also suitable only for specific purposes not in the range of this project.
- **Chemical storage** like in hydrogen or synthetic natural gas using solar energy in a broad sense is as well not in arm's length for the projects purpose. For thermal storage it's the same as RO does not need heat for desalination.

As a result, **electrochemical options (batteries)** seem to fit as complimentary technology to collect produced overcapacity from PV and reuse it in desalination process. The core barriers like low cycle times and partly toxic materials are still a concern but also core of research and development. Next core parameters for this technology will be listed with battery properties in parentheses (Xing, 2014: 524-527)

- Power rating in MW: rated capacity (moderate)
- Energy rating in MW/h: rated energy (moderate)
- Power density in W/L: capacity per amount of energy (moderate to high)
- Energy density in Wh/L: volume per amount of energy (moderate to high)
- Specific power in W/kg: capacity per amount of energy (moderate to high)

- Specific energy in Wh/kg: volume per amount of energy (moderate to high)
- Nominal discharge time in h: discharge duration at rated power (up to 10 h)
- Cycle or round-trip efficiency in %: electricity input to output (medium to high, >60%)
- Discharge efficiency in %: part of cycle efficiency (mainly high, >80%)
- Self-discharge in %/day: electrochemical loss (very small, 0.1-5%)
- Depth-of-discharge in %: completeness of discharge (not possible during cycle) and influence on lifetime (negative)
- Lifetime in years: moderate (5-20 years)
- Cycle times in cycles: number of round-trips (low to moderate, 500-10,000)
- Storage duration: (short, minutes-days)
- Discharge duration: (short, minutes-hours)
- Power capital costs in USD/kW: (low to moderate, 300-4000)
- Energy capital costs in USD/kWh: (moderate to high, 200-2,500)
- O/M costs in USD/kW/year: (high, 20-80)

Basically a rechargeable battery consists of electrochemical cells producing electricity from an electrochemical reaction. A cell contains two electrodes (anode and cathode) and an electrolyte (solid, liquid or viscous) reacting bi-directionally, depending on direction of applied external voltage. In common types the components are statically assembled in the battery system (Fig. 5-10).

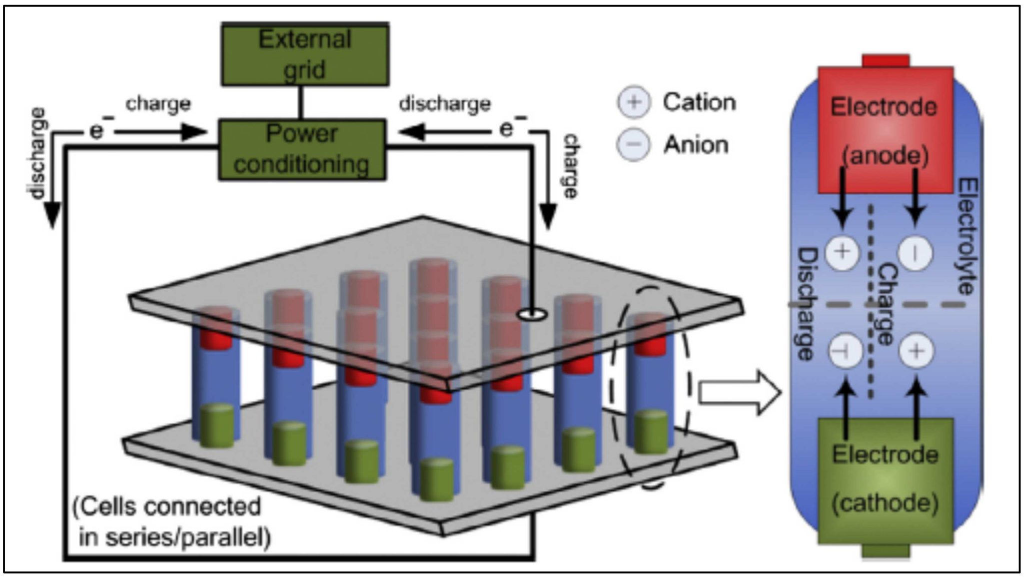


Figure 5-10: Schematic diagram of a static battery system, Source: Xing (2014)

In so called flow batteries the electrolyte is soluble, stored in external tanks and pumped through cell stacks with compartments separated by ion selective membranes as electrodes (Fig. 5-11). The main advantage here is the separation of power from storage capacity – former depends on size and number of electrodes/cells, latter on concentration and quantity of electrolyte.

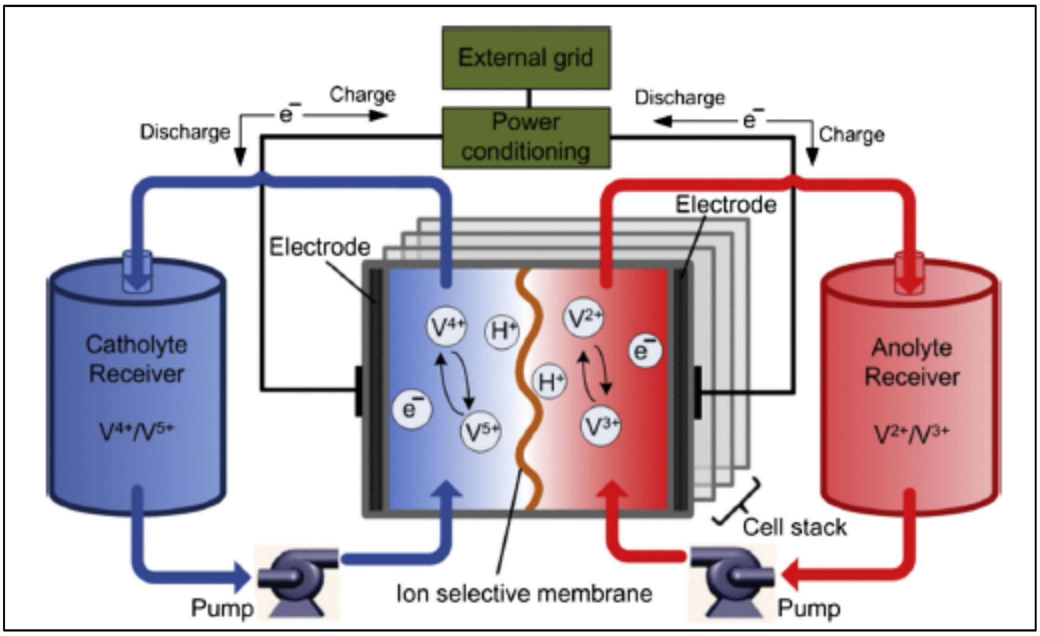


Figure 5-11: Schematic diagram of a flow battery system, Source: Xing (2014)

In table 5-4 the characteristics of different battery technologies are listed, which have to be considered beside economical aspects.

Table 5-4: Comparison of battery type characteristics, Source: Xing (2014)

Battery type	Advantages	Disadvantages
Lead-acid	+Fast response time +Small self-discharge +High cycle efficiency +Low capital costs	-Low cycling times -Low energy density -Low specific energy -Poor performance at low temperatures
Lithium-ion (Li-ion)	+Fast response time +Small in dimension and weight +High cycle efficiencies	-DoD affects lifetime -On-board computer necessary to manage operations
Sodium-sulfur (NaS)	+High reactivity +Zero self-discharge +High energy density +High rated capacity +High pulse power capacity +Low cost materials +Non-toxic materials = high recycability	Electrodes are molten, therefore: -Extra system to operate required temperatures (574-624 K) -High O/M costs
Nickel-cadmium (NiCd)	+Robust and reliable +Low maintenance +Low temperatures possible	-Uses toxic heavy metals -Suffers memory effect = reducing capacity -Only few installations and commercial successes
Nickel-metal Hydride (NiMH)	+Specific energy +Energy density +Environmental friendly +Longer life than Li-ion	-High self-discharge within short time -High DoD sensitivity
Sodium-nickel-chloride (ZEBRA)	+Pulse power +Maintenance free +Low self-discharge +Long life	-Working on high temperatures (523-623 K) needing hours ofheat-up time -Few installations
Vanadium Redox FLOW	+Quick response +Many cycles +High efficiency +Continuous power possible (>24h)	-Technically challenging -Low electrolyte stability and solubility -Low energy density -High O/M costs
Zinc Bromine FLOW	+High energy density +High voltage +Deep DoD +Long lifetime	-Corrosion -Dendrite formation -Low cycle efficiency -Narrow temperature range -Early stage of developement
Polysulfide Bromine FLOW	+High soluble +Cost-effective +Fast response	-Environmental issues -Technical difficulties

Lead-acid batteries are right now mainly used. Commercially acceptable conditions seem a preference reasonable, but the asymptotic distribution of the core factors ‘life cycles’ and ‘DoD’ show that it may be cheaper to set-up the necessary capacity but replace investments occur more often negating the alleged cheapness.

Lithium-ion is more expensive and partly in demonstration status for large capacities nevertheless promising. Its high energy density helps in cases of usable area limits (e.g. on islands).

Sodium-sulfur represents also a commercialized option with a number of advantages – the higher O/M costs may be acceptable in exchange for lower CAPEX.

Nickel-cadmium is somewhere in the same range but due to toxic materials applied not free of restrictions especially in case of sustainability concerns. **Flow batteries** are at the beginning of commercialization and bring technical difficulties into a project.

6 The project

This chapter describes planning considerations regarding desalination as the core technology and the risk matrix for the whole project.

6.1 Planning considerations

a) Service area, capacity and site

Service area is mainly bound to existing demand and infrastructure conditions of the location especially proximity to distribution system. The larger it is the larger the plant can be, profiting from economies of scale – for the price of additional conveyance and storage facilities increasing the price of water for the end customer would be the consequence.

To define plant's capacity one needs to know what kind of demand has to be served: part of status quo to reduce endangered sources like ground aquifers or rivers; enhance support for projected increased demand in future or additional support in drought-prone areas etc. Depending on intention, capacity and flexibility are set to deliver a stable part of infrastructure justifying product price increases.

Regarding the site where the plant is build the natural boundary of land availability and proximity to product users is crucial. The factor footprint comes into play. First several alternatives are compared based on: availability, accessibility, proximities (seawater and distribution system), zoning requirements, contamination, vegetation, surface, environmental sensitivities and of course costs/m². After choosing some main options, engineering and environmental analysis have to be done in fields like: geology, traffic, biology, archaeology, marine resources, bathymetry and hydrology, beach erosion and meteorology, source water examination etc. For all options schedules of design, review, permission and implementation are developed (Voutchkov, 2013: 82-85).

b) Intake type and location

This aspect has already been narrowed to open offshore intakes to count for capacity and availability of aquifers, risks for open onshore options like beach erosion and costs of deep-wells etc. The technology and advantages are described in chapter 4.1.3 and the location is directly connected to aspects of plants location itself, mainly the seawater bottom conditions and distances.

c) Source and product water quality

The former is the driver for the core technology – the RO system. Content and concentration of ions (TDS) followed by temperature and pH define what kind of RO setup is requested. For open seawater additional contents like algae, oil, grease, hydrocarbons, suspended solids and nutrients influence RO operations and before that, require specific pretreatment. Product water then is the result of all treatments and may serve distinct purposes: drinking water, agricultural irrigation or industrial use (high purity water). Regulators define the quality standards for the first one and single-pass RO is usually capable to deliver, driven by posttreatments like mineralization and disinfection. The second application may need second-pass or dilution as some plants are salinity-sensitive. The third purpose may need multi-pass and is not in the scope of this thesis (Voutchkov, 2013: 94-96).

d) Plant discharge

Concentrate, pretreatment filter backwash and membrane cleaning residuals (chemical and flush) water represent the main streams, disposed commonly by surface water discharge through a separate outfall pipeline – probably except the cleaning chemicals processed by special treatment or discharged to sewage systems if quantity is not too large. Alternatives like evaporation ponds, ZLD or beneficial use are available but limited and costly. A combination may be chosen depending on site specific conditions. Concentrate is the largest part and causes no harm if diffused accordingly at outfall point. Backwash is blended with concentrate and reflects the effect of pretreatment (high turbidity, TSS, organic content …), but as it is only a fraction of concentrate it may too not cause intoxication. MF/UF produces more backwash water but contain fewer coagulants compared to granular filters (Voutchkov, 2013: 103-106).

e) Plant design

After elaboration of key input criteria mentioned above a main and some alternative plant designs evolve, taking all physical, operational and environmental constraints into account (Voutchkov, 2013: 106-116).

- Treatment Processes – regarding pretreatment, RO and posttreatment
- Equipment Selection – based on treatments, energy needed, costs, O/M requirements, track record, supplier
- Pilot testing – recommended for medium and large plants for optimization and risk reduction; alternative setups may also be tested
- Configuration and layout – maximizing flexibility and minimizing cost drivers
- Energy source and use – as RO is quite energy-demanding in comparison to alternatives like reclamation or conventional treatments, this factor is quite important for all designs and calculations
- Chemical use – depends on source water quality and treatment facilities

f) Project schedule and phasing

Parallel to plant design(s) a phasing and construction schedule has to be developed. Start dates and duration of whole project and parts like site preparation, construction, RO installation and other facilities, commissioning and testing. For a medium plant with production capacity of 40,000 m^3/day, design takes 3-6 months, construction 14-16 months and commissioning 2-3 months – in sum therefore up to two years. All kind of complications may cause postponements and additional costs, ranging from adverse weather conditions to regulatory restrictions (Voutchkov, 2013: 116-118)

g) Establishment and operation

There are several legal positions involved in such project: authorities, water owner, water user, water supplier and plant owner/water producer, whereas one subject may hold more than one position. Depending on the specific positioning, different contractual layouts exist. The most common is **BOOT** – Build-Own-Operate-Transfer: all capital and O&M costs are in responsibility of constructors and operators, the initializing authority only pays for the water produced based on negotiated contracts for time spans of 20-30 years. After that period the plant is transferred to the authority for a low amount representing residual value (Barak in Lior, 2013: 277-280).

The majority of project sponsors set up so called SPVs as separate legal entity with limited liability as the investments are quite high and the initiators want to separate obligations from their parent company. This entity builds the heart of the whole structure: it connects all contractors, investors, customers and authorities, acting as counterparty with specific several contracts. SPVs can have different corporation forms and ownership or management designs. On the other side the complex nature makes detailed analysis necessary to understand and control all kind of flows and accounts (Investopedia.com, 2016)

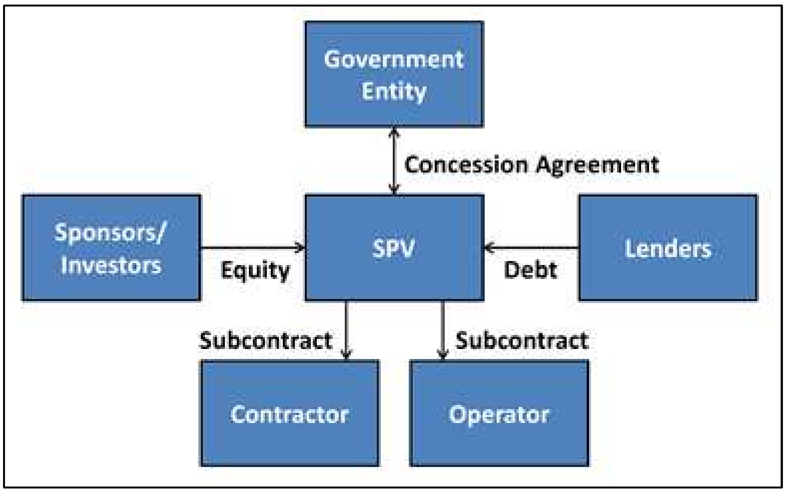


Figure 6-1: Simple illustration of SPV structure, Source: Nixonpeabody (2013)

6.2 Risk assessment

This is one of most important tasks in project management – to collect all possible and alleged impossible factors which can influence a project at any phase for any kind of reason ending in a negative effect or result. Positive effects are welcome but concentration lies on the damaging ones.

Appendix 2 gives an idea of a risk matrix. There for all project parts factors, effect and solutions are depicted, not exhaustive but to give an imagination how to set it up. Here is an example:

Factor/Risk	Category	Effect/Impact	Solution/Countermeasure
Algal bloom	Desalination	Overall deterioration of source quality Damaging whole treatment process	Accurate pre-phase water analysis Pretreatment with DAF

Algal bloom is a risk falling into desalination category. The matrix may be expanded with threat levels (low, high, etc.) of respective factors; algal would get medium level as they can damage the whole plant core processes. The solution is primarily to analyse the source water to know kind, frequency and concentration and secondarily to use the right pretreatment technology, in this case and according to practical advice like from UNIHA (2016): dissolved air flotation.

One missing part in this matrix but a typical one in project management is occurrence probability of respective risk, the damage in case of occurrence and the multiplied result of these two: risk weighted value.

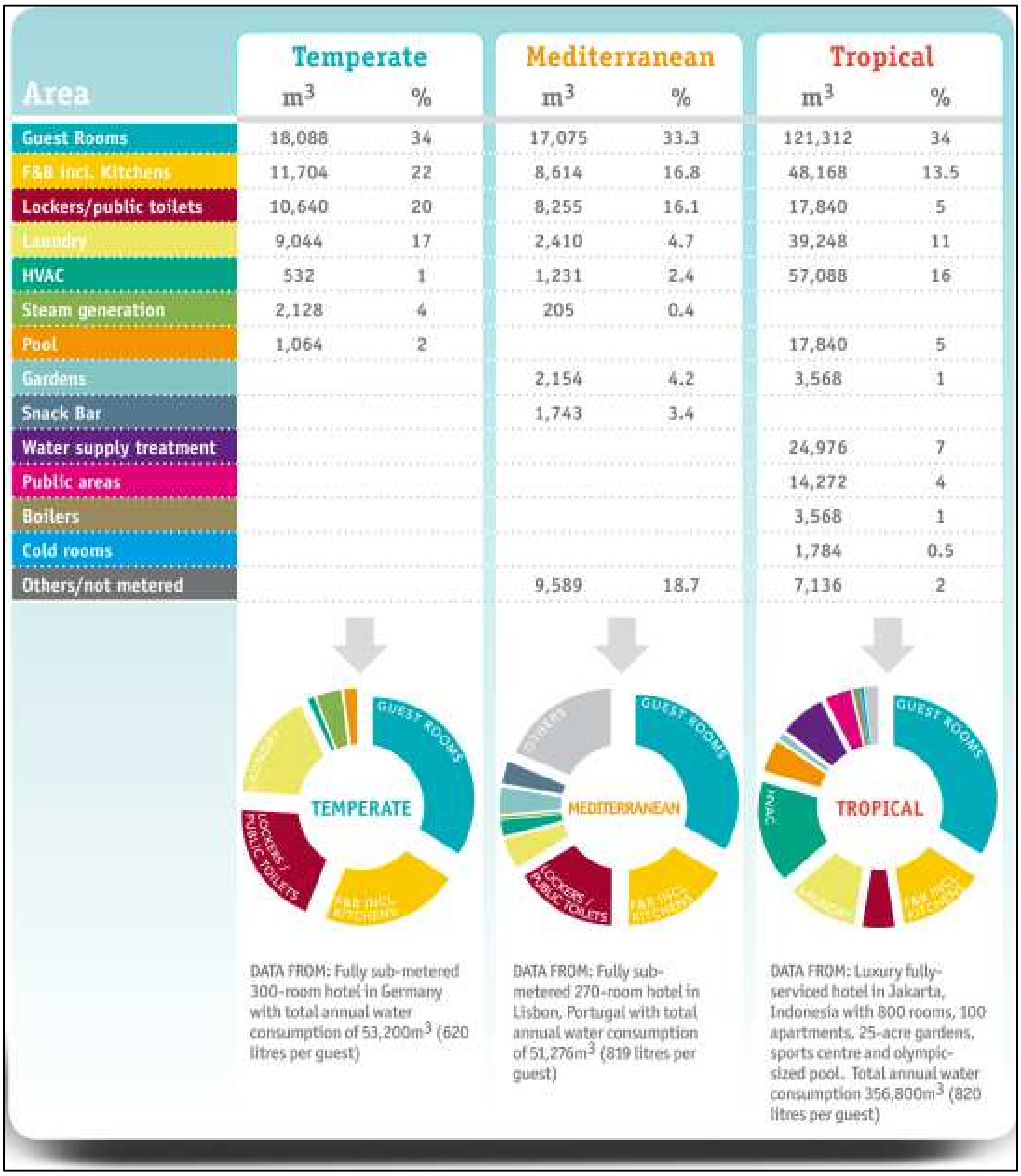
Besides exceeding scope and room of this thesis if connected to all scenarios calculated down below, such calculation may make sense in some cases, but bears the risk of understating threats. Human nature tends to set risk lower than in reality and also tends to ignore low probabilities. If therefore risk weighted values are set too low and no or insufficient reserves are incorporated in financial planning, projects are endangered to fail although such outcome was not inevitable. A qualitative and conservative approach is more important than crunching numbers into unconscious falsities or even project outcome ‘fitting’.

6.3 Searching for an island

Concentrating on Mediterranean area, searching for issues and observations mentioned in chapter 2 brings many results showing the threat of droughts, overstressing of natural water sources (groundwater) as well as plans for and installations of desalination plants.

Majorca for example suffers the worst drought in ten years at a time of record tourist visits with water reserves at 44% of normal levels. The municipalities spend already millions of Euros in desalination especially at the islands biggest plant in Palma (MajorcaDailyBulletin, 2016). Beside that the Balearic government introduces an action plan for water rationing and properly irrigation in agriculture. Lack of rain and supply problems with ground aquifers reduced the water reserves significantly, already before the tourist season 2016 started (Euroweeklynews, 2016).

In case of islands with high tourism portion the common per-capital water demand statistics do not fit as the recreation industry needs huge amount of water for pools, gardens, golf courses, kitchens, laundries etc. Standard statistics show per-capita consumption of 145 litres per day for Spain (Castillo, 2013), indicating the thumb rule of a person’s need of 1m³ (1,000 litres) water per week. For 2013 the Spanish statistical department confirms this amount for Balearic households (141 litres/capita/day) but shows much higher values for total water supplied (269 litres/capita/day), which may not only due to commercial and industrial use but for tourism as well (INE, 2015). Literature gives a wide range of values, up to 2,000 litres/tourist/day or +3,400 litres/bedroom/day; a five star hotel with golf course may use up to 1 million m³ a year (Gössling, 2013). Figure 6.2 shows data for more standard hotels in different areas:



Area	Temperate m³	Temperate %	Mediterranean m³	Mediterranean %	Tropical m³	Tropical %
Guest Rooms	18,088	34	17,075	33.3	121,312	34
F&B incl. Kitchens	11,704	22	8,614	16.8	48,168	13.5
Lockers/public toilets	10,640	20	8,255	16.1	17,840	5
Laundry	9,044	17	2,410	4.7	39,248	11
HVAC	532	1	1,231	2.4	57,088	16
Steam generation	2,128	4	205	0.4		
Pool	1,064	2			17,840	5
Gardens			2,154	4.2	3,568	1
Snack Bar			1,743	3.4		
Water supply treatment					24,976	7
Public areas					14,272	4
Boilers					3,568	1
Cold rooms					1,784	0.5
Others/not metered			9,589	18.7	7,136	2

Figure 6-2: Regional examples of hotel water consumption, Source: Truppen (2013)

The phenomena of water scarcity and rising demand from several sectors and especially from tourism on holiday destinations led to installations of desalination plants on nearly every main island in the Mediterranean including the Canaries. The latter are not only early adopters of desalination but also thinking forward in making their islands self-sufficient regarding energy. El Hierro with its 10,000 inhabitants is a good example: a wind farm with 11.5 MWel does not only deliver household electricity, but also feeds their desalination plant and a PHS pumping water in a volcano reservoir, released during low-wind phases to drive turbines; additionally they plan to have only E-cars on the island working together with a carmaker (Daly, 2014). There are many other examples also using PV and battery systems, some of them in test phase under the umbrella of the ITC (Instituto Tecnologico de Canarias).

Back to the Baleares an alleged troublesome example of planning and integrating desalination into an islands system seems to be Ciutadella on Menorca. One article from 2010 informs that the plant is built but on hold due to some controversies (Menorca, 2010):

- A lower than expected subsidy from EU left the Balearic government with EUR 45 Million left to pay within 15 years.
- The sale price to Ciutadella council has not been negotiated so far
- The municipality only wants desalinated water in case of droughts; the government wants them to use it as main source and let the groundwater wells regenerate and avoid expensive standstills of the plant
- Delivery to distant city Mao to ease their water problems is on table but brings further expenditures for pipelines

Another article (Roqueta, 2016) tells about EUR 19.1 million outstanding debt of the still not in use plant and remaining EUR 11 million extra costs in dispute. The main contractor and supplier under a BOOT contract, Acciona Agua lists the plant as a 10,000 m³ project from 2006 (Acciona Agua, 2016).

The amounts in these articles seem quite high for such a relative small plant. Of course the price levels 2006-2010 have been higher and some factors like location, technical difficulties and other input criteria. It also unknown if land is part of the capital costs which may have pushed the prices. According to UNIHA (2016) it is common practice at describing BOOT projects to include the sum of O&M costs during project lifetime; than the numbers may be quite indicative.

Anyway it seems interesting to calculate this plant based on knowledge gathered during elaboration of this thesis, not only the desalination but also for scenarios including PV as part supplier of energy and battery storage as energy shift support. The next chapter goes into details of these tasks and its results.

7 Business case and investment structure

In this chapter, the whole business case with all assumptions and scenarios will be presented.

7.1 Data overview

a) Location

Menorca is one of the Balearic Islands, Mao its capital city. Ciutadella in the west is the largest community. Menorca has around 100,000 inhabitants, the city Ciutadella around 30,000 (laenderdaten.info, 2016).

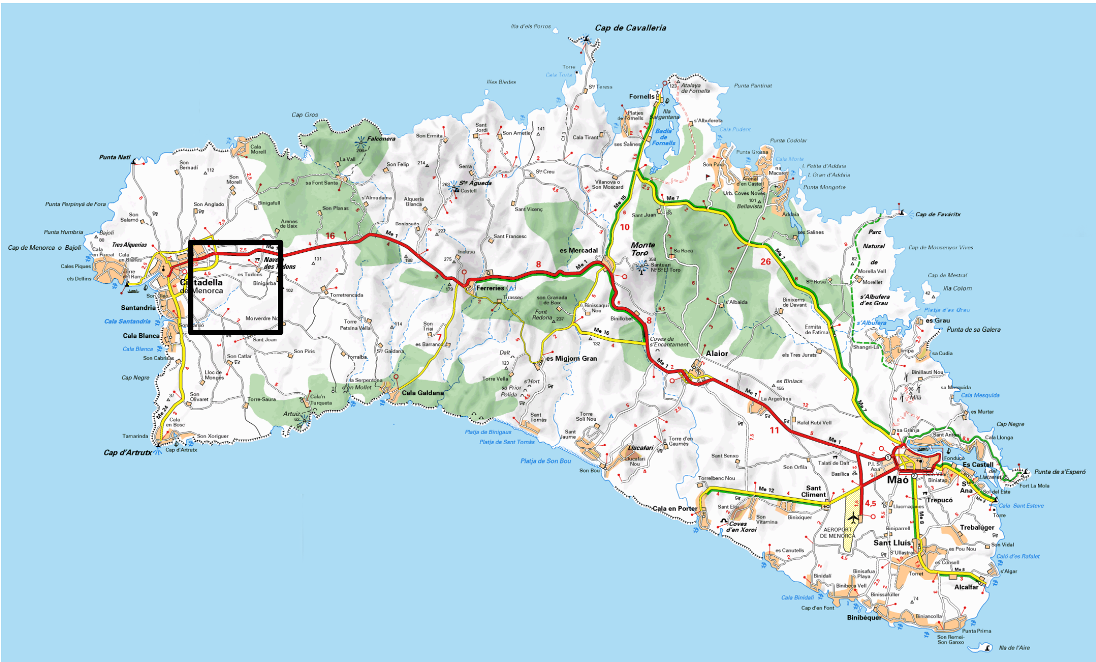


Figure 7-1: Map of Menorca, Source: mapsof.net (2016)

b) Water

The INE water statistics show data only for the Balears as a whole but that is acceptable for the medium level of calculations done for this thesis. Important here is the difference of 2013 water supply costs of EUR 1.11/m³ and total unit water costs of EUR 2.21/m³ which is EUR 1.10/m³ - in the project calculation this value is inflation-adjusted and taken as sale price.

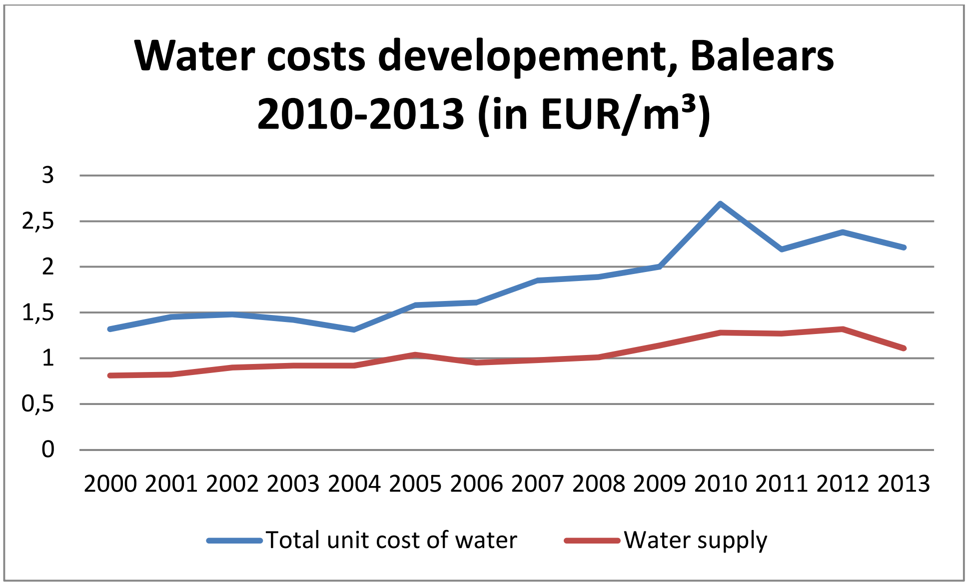


Figure 7-2: Water costs Balears, own graph, Source: INE (2015)

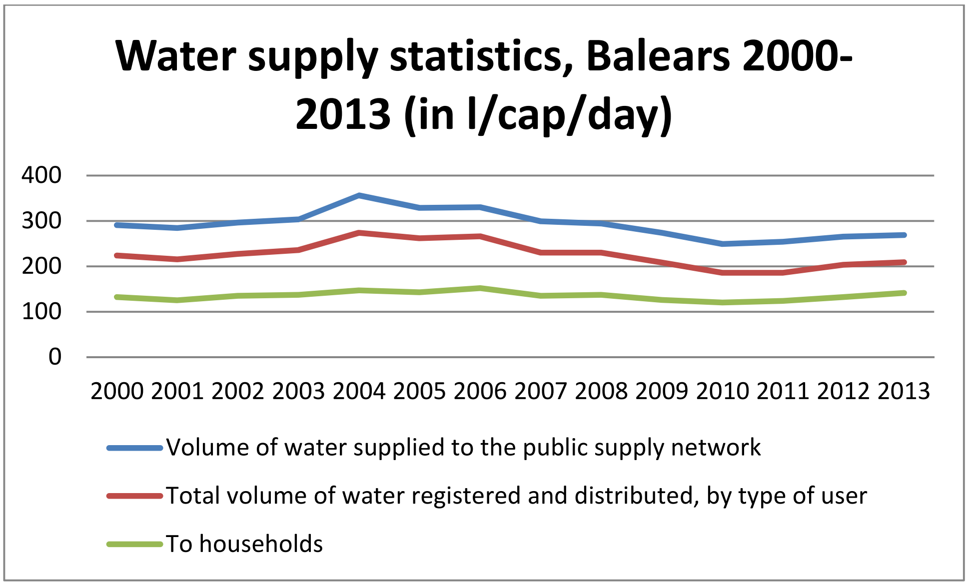


Figure 7-3: Water supply Balears, own graph, Source: INE (2015)

c) Electricity

According to Eurostat the industrial prices for electricity in Spain reached EUR 0.113/kWh after a slide decrease from EUR 0.12/kWh in 2012. The prices tend to fall further but on the other side the specific one on Menorca may be higher. It is assumed these influences equalize each other and EUR 0.11/kWh is set as grid-electricity price for calculation.

d) Solar irradiation

PV has been chosen as REN form to bring sustainable energy into this project. The GHI map of Spain shows for Menorca, especially for the west coast of Ciutadella, values of >1,650 kWh/m².

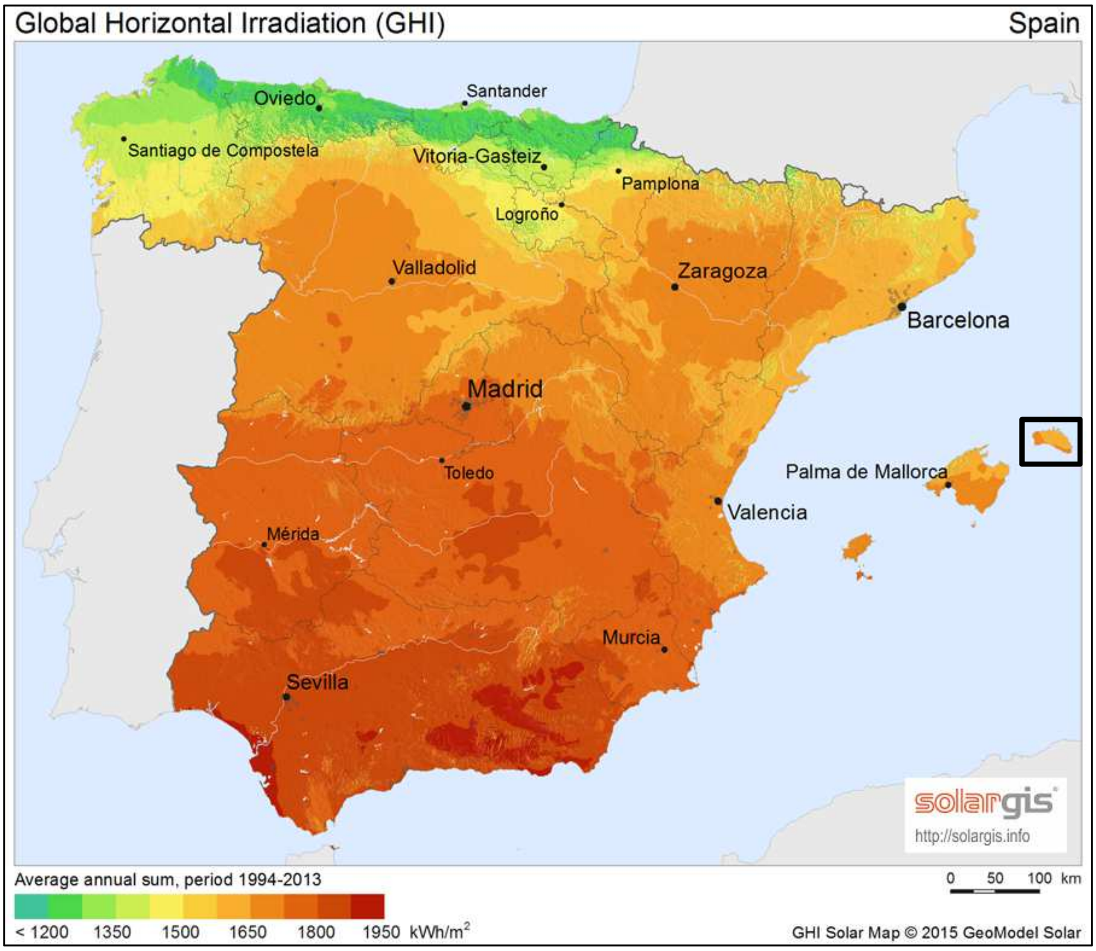


Figure 7-4: GHI map of Spain, Source: solargis.com (2016)

7.2 Base case and Project Ciutadella

As the information about the original plant on Menorca is sparse and the range of possible components and set-ups for a desalination plant is wide, a base case as anchor is helpful at which assumptions, adaptions and risk-matrix outcomes can be applied to achieve desired thesis project calculations. Literature delivers some examples, one have been chosen (Voutchkov, 2013) and adjusted as necessary. Appendix 3-6 gives details about this base and the adjustments; the next overview summarizes the core points:

Table 7-1: Key assumptions and adaptions for Project Ciutadella

Key criteria	Comments and adjustments
Conservative approach	Main research point is to find out, if the plant can finance itself (also for scenarios including PV and EES). No production subsidies (FiTs etc.) are included; sale of potable water is the only regular income. Corporate tax is at standard level for Spain, no tax subsidies or deferrals are included-
Technology	The same as in base case are assumed, which are according to literature mature and reliable set-ups. As there a reserve RO track is used but not obligatory in our small example, the load factor may be lower.
Production range	The average flow of 10,000 m³/day is used for calculation, although a range of +/- 20% is possible – especially useful for summer times with higher demand, equalized by lower demand in winter.
Water quality	Average of main ion composition represents typical saltwater, also accepting a wider range.
Energy demand	Due to progress in technology and ERD a lower quantity compared to base (3.5 instead of 3.85 kWh/m³) has been chosen. This value was also confirmed as average by UNIHA (2016) On the other side 0.06 USD/kWh for base seems low so the European statistical average of 0.11 EUR/kWh has been used, which might be too high but supports conservative approach. Therefore and due to the tendency of falling energy prices, no increase by inflation is assumed.
Cost items	Except for the higher power costs, all items have been linearly reduced to target production flow. Of course economies of scale exist but for the chosen production ranges they do not preponderate. Main replacement criteria (membranes, filters) are included in variable O&M, no CAPEX for technology changes are assumed.
Financial data	- Equity 20% (at 8% expected dividend) - Debt 80% (at 4% interest rate, standard repayment) - Repayments and dividends start at year two - Debt contingency and reserves hold in cash (implied backflow over project length) - Corporate tax Spain: 25% (tax reductions and deferrals are possible, but not taken into account due to conservative approach) - Inflation rate: 1% (due to actual deflationary situation in Europe)
Meta data	- Pre-phase 24 months (for simplification costs accumulated at end of year zero) and a shorter building

	phase of 12 months, accumulated and activated at end of year one. - Start date operations (first revenue) in year two. - Project length 20 years, in year 21 sale to municipality at book value and cash.

7.3 Calculations and scenario results

The following chapters show the results for the plant with stepwise incorporation of complementary technologies. In additional scenarios the conservative approach is abandoned and non-recourse investment subsidies are included (from institutions like EIB for infrastructure or REN projects). To avoid exceeding of scope, only financial reports (investment calculation, P&L, balance sheets) of main scenarios are shown in related appendices. Additional scenarios are presented only with result snapshot and comments.

To ease comparison a table of information and comments is used, which shows (average) values **pre-tax**:

Table 7-2: Results analysis description (own listing)

Parameter	Explanation	Comment
Project NPV	Present value of all project flows including investment costs, discounted by WACC.	A questionable criterion as it tries to evaluate a complex and dynamic situation based on many assumptions with a single non-existing amount.
Project IRR	Discount rate at which NPV gets zero, calculated by iteration.	
Equity NPV	As above, but only taking equity flows into account.	
Equity IRR	As above, but only taking equity flows into account.	
DSCR (avg.)	Relation of net operating income to total debt service, averaged over payback period of 20 years.	Values above 1 show that cash flows are more than able to pay back debt and interest
Total water costs (avg.)	Costs of product water	Shown per m^3

	including project, financing and equity flows, averaged over sale period of 20 years.	
Start of income tax obligation	Shows the year in which EBT is positive, leading to corporate tax payments	Depending on operating results and accounting rules like depreciation etc.
Start of dividend payment	Shows the year in which P&L is positive post-tax so that expected dividends can be paid out.	Only possible if results post-tax are positive, so the earlier the better. Lower than expected amounts may start earlier.
Cash flow development	Indicates the liquidity of business; includes here for simplification also the contingencies and reserves.	As 'life blood' of business it is of crucial concern. Negative values can be bridged with overdraft facilities, but in the long run it should evolve positive.

7.3.1 Only desalination

Here the adapted Ciutadella plant has been calculated, in appendices 7-8 the related excel sheet snapshots can be found.

Table 7-3: Results for desalination (own calculation)

Parameter	Result	Comment
Project NPV	EUR 9.1 Mln	Positive/OK
Project IRR	9.16%	OK
Equity NPV	EUR 1 Mln	Positive/OK
Equity IRR	9.86%	OK
DSCR (avg.)	1.79	OK
Total water costs (avg.)	1.05	OK
Start of income tax obligation	First year of operations	Due to simplifications very early, in practice and under tax deferral regimes a later year is more realistic.
Start of expected dividend payment	Second year of operations	Same as with income tax.
Cash flow development	Positive from first year of operations on, even	OK

	excluding contingencies and reserves.
Comment	The plant's financial data show enough strength and positive business results so that there is some room for input data changes with negative influence like higher costs of all kind or lower income – even without any subsidies.

7.3.2 Desalination with PV

This adaption includes PV as energy supplier for one third of the plants daily demand. As the daily product water quantity is the anchor its daily energy demand builds the base and one third represents simplified the hours where the sun can be utilized. Here already some options occur:

- Should fixed or tracking systems be applied hence weighing advantages of production versus costs and complexity? As absolute footprint is crucial for islands and with falling prices along PV technology, **2-axis-tracking has been chosen**, assuming that higher performance with lesser modules outweigh relative higher footprint requirements.
- Is the PV capacity oriented on winter or summer production hence shall PV deliver the demand only in summer or already in winter (forcing higher capacity and more modules)? **The 'full third' option has been chosen, orienting on winter production.** Figure 7.5 depicts the production surpluses which occur then:

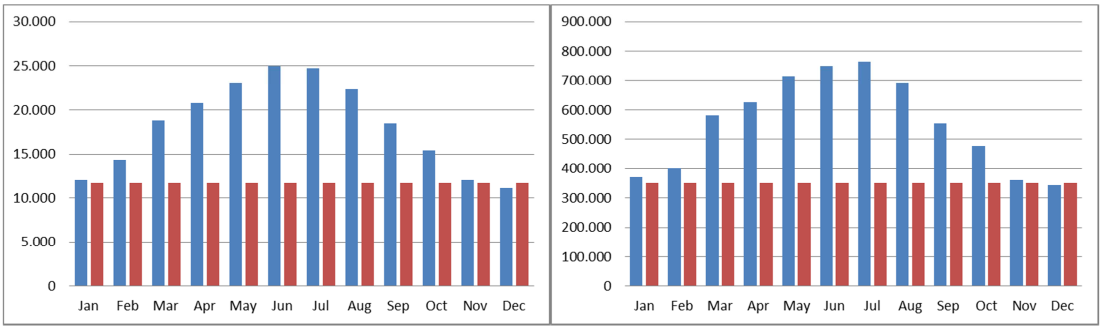


Figure 7-5: Model PV – Average daily and monthly production surplus (in blue) compared to respective desalination demand (in red) measured in kWh, Source: own graph based on PVGis data (2016)

In sum, 2.4 GWh of electricity surplus is 'unused'. Even if the desalination production reserve of 20% is applied for the warmer six months of the year only around 10% more energy is necessary, leaving 2 GWh left. Profiting from FiTs is one solution although their levels are falling or threatened to be cancelled. To stay within a conservative approach at best the prices of electricity on EEX (ranging in September 2016 between spot EUR 30 and futures EUR 38 per MWh) reduced by a margin can be achieved. If we take e.g. EUR 25/MWh we could sell the yearly surplus of 2 GWh for EUR 50,000 – an additional but no reliable revenue thus not included in business plan.

Table 7-4: Key assumptions PV for option 'one third' (own listing)

Key criteria	Units	Data and information
Location		Ciutadella, 39°59'56" North, 3°50'20" East
Technology		Crystalline silicon
Energy demand daily	kWh	11,667
System loss	%	10%
Combined loss	%	21,60%
Tracking		2-axis
Investment horizon	Years	20
Capacity	MW	3
System costs (turn-key)	EUR/MW	1.900.000
Investment costs	EUR	5.700.000
O/M costs	% of IC	1,00%
O/M costs per year	EUR	57.000
O/M costs inflation	EUR	1,00%
Replacements (inverters etc.)	% of IC	5,00%
Repl. Costs (year 10 & 20)	EUR	285.000 & 142.500 (simply booked as costs which decrease with 50 % for year 20; no activation)
PV degradation per year	%	0,40% (incorporated through respective energy cost increase of desalination plant)

For simplification the equity amount stays the same thus only debt has been increased – the relation therefore changes to 15/85. Also the contingencies and reserves stay the same in absolute amounts. Calculation snapshots to be seen in appendices 9-10.

Table 7-5: Results for desalination with PV (own calculation)

Parameter	Result	Comment
Project NPV	EUR 8.1 Mln	Positive/OK
Project IRR	7.79%	OK
Equity NPV	EUR 0.6 Mln	Positive/OK
Equity IRR	9.17%	OK
DSCR	1.58	OK
Total water costs	1.07	OK, within range
Start of income tax obligation	First year of operations	Due to simplifications very early, in practice and under tax deferral regimes a later year is more realistic.
Start of expected dividend payment	Fourth year of operations	Same as with income tax.
Cash flow development	Positive from first year of operations on, even excluding contingencies and reserves.	OK
Comment	Including PV marginally reduces the business results. Main criteria here are investment costs per installed MW. Literature gives a wide range of them so it is highly possible that they are higher in reality. Up to a point the project can handle higher CAPEX here, otherwise cheaper fixed arrays may be installed depending on available footprint.	

7.3.3 Desalination with PV and EES

Here the project is further adapted by inclusion of batteries for electricity storage. To feed the batteries based on winter demand model the capacity of PV has to be more than doubled – caused by the main EES criteria DoD and cycle efficiency, beside other details described in table 7-5.

As well we have the phenomenon of PV overcapacity in summer months. Taking the data from above we have around 4,000 GWh which can be sold for e.g. EUR

25/MWh, then the plant may earn EUR 100,000 a year – once again not reliable therefore not included in business plan.

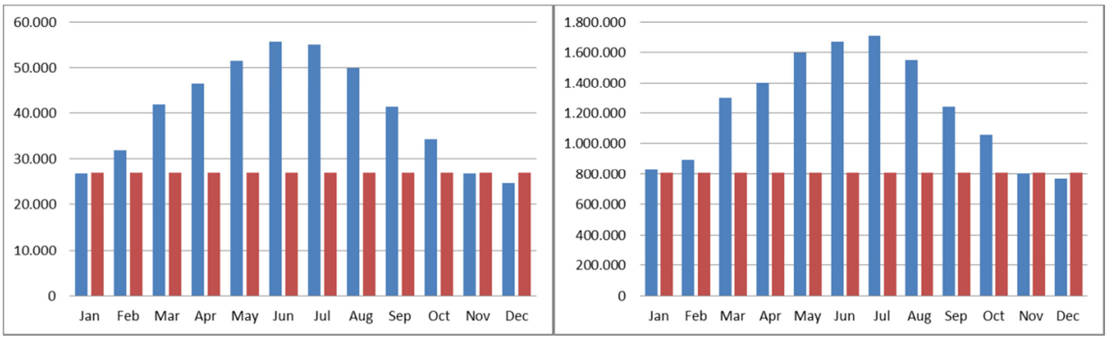


Figure 7-6: Model PV & EES – Average daily and monthly production surplus (in blue) compared to respective desalination demand (in red) measured in kWh (Source: own graph based on PVGis data, 2016)

Table 7-6: Key assumptions for EES (own listing)

Key criteria	Units	Data and information
Technology		Lithium-ion
DoD	%	85%
Cycle efficiency	%	90%
Cycles		4,000 (10 years)
Costs/kWh	EUR	1,000
Gross energy capacity (to meet net daily demand)	kWh	15,251
Investments costs	EUR	15,250,545
Depreciation (10y)	EUR	1,525,054
Repl. costs declining factor	%	50 %
Replacement costs (after 10y)	EUR	7,625,272 (financed by new debt and activated)
Depreciation (10y)	EUR	762,527
O&M costs (of IC)	%	0.5%
O&M costs per year	EUR	76,253
O&M costs inflation	%	1
Adaptions for PV		
Capacity	MW	6,7
System costs (turn-key)	EUR/MW	1.800.000
Investment costs	EUR	12.060.000
O/M costs	% of IC	1,00%
O/M costs per year	EUR	120.600
O/M costs inflation	EUR	1,00%

Replacements (inverters etc.)	% of IC	5,00%
Repl. Costs (year 10 & 20)	EUR	603,000 & 301,500 (simply booked as costs which decrease with 50 % for year 20; no activation)
PV degradation per year	%	0,40% (incorporated through respective energy cost increase of desalination plant)

The widespread technologies and performance data in literature and from producers makes is very difficult to choose correct input criteria, especially costs and efficiencies. Furthermore PV and EES are financed by debt (equity amount stays the same) so the relation changes to 8/92 – a bit below minimum relation used commonly in literature of 10/90. Contingencies and reserves stay like above with fixed amounts. Whole results see appendices 11-12.

Table 7-7: Results for desalination with PV and EES (own calculation)

Parameter	**Result**	**Comment**
Project NPV	EUR -16.9 Mln	Negative
Project IRR	-0,52%	Negative
Equity NPV	EUR -6,4 Mln	Negative
Equity IRR	N/A	not calculable in iteration
DSCR	0.67	<1
Total water costs	1.45	Too high
Start of income tax obligation	Year 15 of operations	Due to simplifications very early, in practice and under tax deferral regimes a later year is more realistic.
Start of expected **dividend payment**	Year 18 of operations	Same as with income tax.
Cash flow development	Negative	Negative
Comment	The negative picture is massive. The investment costs of additional PV and especially EES are not recoverable through business – particularly not if the project wants to get sustainable energy for two thirds of desalination demand based on winter supply model. Here in year 20 the new necessary replacement costs for EES **have not even been considered** (new debt, new activation).	

One possibility to reduce the highest cost block EES would be switching to 50% cheaper lead-acid batteries but this comes with a price: even the advanced versions have lower DoD, lower cycling efficiencies and most important lesser cycles (1,000 – 1,500). At best the system has to be replaced after five years. Assuming declining prices of 25% of investment costs at start we have one base investment and three replacements in year 5, 10 and 15 (like above, no considerations for year 20) leading to total costs of around EUR 19M – compared to around EUR 23M for Li-ion option. Not to forget that higher capacities on PV level are necessary to achieve the same obligatory battery output. The business still has difficulties to repay that investment.

7.3.4 Alternative scenarios

What has not been taken into account so far are investment subsidies in non-recourse form; whereas the desalination (including PV) may cover itself and these subsidies would further improve their results, a support for the option including EES is most important as it may enable the project at all. The articles for Ciutadella mentioned support from EU of 15-20% of total costs although not defining if only capital costs are meant or if lifetime O&M are included.

For the alternative calculation investment subsidies of different level for the three technologies are assumed which sum together to 20% of total investment costs to stay within a conservative approach. These costs consist of desalination construction, PV and EES which sum up to around EUR 41.6M – giving a subsidy of EUR 8.3M. For simplification this amount is linked to desalination level therefore reducing the related debt, repayments and depreciation[1]. Li-ion and respective PV capacity stay the same, like all other factors mentioned above.

[1] In practice and depending on local accounting rules this would be treated differently: the CAPEX would be activated and depreciated fully and the subsidy not deducted at once but reduced in parallel and timely manner by a neutralizing reserve position.

Table 7-8: Results for desalination with PV and EES with subsidies (own calculation)

Parameter	Result	Comment
Project NPV	EUR -8.9 Mln	Negative
Project IRR	1.34%	Positive but lower than WACC
Equity NPV	EUR -4.0 Mln	Negative
Equity IRR	N/A	not calculable in iteration
DSCR	0.84	<1
Total water costs	1.27	Too high
Start of income tax obligation	Year 11 of operations	Due to simplifications very early, in practice and under tax deferral regimes a later year is more realistic.
Start of expected **dividend payment**	Year 14 of operations	Same as with income tax.
Cash flow development	Negative	Negative
Comment	The picture lightened up but is still negative. Of course the simplifications distort the picture – if the subsidies are split to all levels the influence on P&L is different, especially as EES has shorter lifetime and therefore higher repayments and depreciations. Nevertheless further project support is necessary: higher water sale prices or more investments support from local government. If the investment costs itself would be lower, especially for EES then the results would further improve.	

Hence we go one step further and calculate what happens if the Li-ion EES price is downward negotiable to EUR 700/kWh energy capacity, together with 20% investment subsidy after that reduction. EES would then cost EUR 10.6M and the subsidy eligible total project costs would decrease to EUR 37M, leading to a support of EUR 7.4M.

Table 7-9: Results for desalination with PV and EES with subsidies and lower EES costs (own calculation)

Parameter	Result	Comment
Project NPV	EUR -3.4 Mln	Negative
Project IRR	3.15%	Positive but lower than WACC
Equity NPV	EUR -2.5 Mln	Negative
Equity IRR	1.36%	Quite low

DSCR	1.01	Enough to repay debts
Total water costs	1.16	A bit too high
Start of income tax obligation	Year 11 of operations	Due to simplifications very early, in practice and under tax deferral regimes a later year is more realistic.
Start of expected **dividend payment**	Year 11 of operations	Same as with income tax.
Cash flow development	Reserves have to be used but improve from year 11 on.	Reserves help to overcome first debt-laden years.
Comment	We can see that some criteria improve and may cause discussions and further negotiations. Debt can be repaid, only equity payers do not get their expected return. Some triggers and additional support can be activated to increase feasibility and stability in this alternative set-up.	

8 Conclusion

Main reason number one for choosing this thesis topic was the obvious growing scarcity of drinking water. A chance and an obligation to dive into desalination technologies occurred. Number two was the insight into REN technologies, their development and recognition of economic and political changes in the world regarding treatment and support of green energy. The concentration on electricity-driven forms of desalination and here reverse osmosis as proven and commercially used technology followed as step one. Next PV has been chosen out of the key REN producer as the simpler, flexible, and suitable technology for water scarcity-prone areas with high irradiation. The clear disadvantage: the sun doesn't shine 24 hours so either only a part of product water comes sustainably or another cornerstone will be integrated: EES. Of course storage can also be fulfilled by using water tanks but beside the complications along this option (footprint, costs etc.) the intention of this thesis was to utilize the high exergy of electricity. Stored in electrochemical form by batteries and ready to use flexibly, it has a higher value embedded.

Putting the pieces together, the core intention of this thesis was to find out if a combination of RO, PV and suitable EES is a profitable business and investment. To anchor a project to real a situation, Mediterranean islands and their desalination status-quo have been screened with the result that many of them use already different forms and combinations. One plant on Menorca attracted attention as some organizational and political things went wrong. The existing information was taken and adapted to research results. Then PV data was introduced. Next EES findings and data has been incorporated. The way to the calculations and the result examination can be summarized as follows:

- The sheer amount of influence factors on all three technologies made core and satellite assumptions and limitations necessary otherwise to many scenarios would show up.
- Main influence factors regarding desalination have been confirmed from practical side so that it can be expected that not too many deviation come from this side.
- To cope with wide ranges of costs and prices for technologies and products, a conservative approach was mainly deployed.

- No subsidies of any kind are included as long as possible along the scenarios to see if the business can run on its own. Only if the negative results are overwhelming, non-recourse capital support has been introduced. Never any kind of FiT is part of revenues – the product water should be the only source of income.

The calculations have been done stepwise, based on the adapted Menorca plant. First only desalination fed by grid, then with one third electricity from PV, next a further third produced by PV and stored in EES. As expected the last option accumulated to high investment costs so here subsidy alternatives have been introduced. The results shortly explained:

- The RO alone delivers a positive result measured by different criteria, leaving room if some negative influences occur. Should that be the case, the conservative investment cost buffer may help, not to speak of investment subsidies available from different sources.
- RO combined with PV delivering one third of energy demand has slightly lower but still positive results – although the PV costs may be higher than assumed. Nevertheless the conservative buffer and capital subsidies wait on the side-line to support this option.
- If EES is introduced to supply a further third of energy demand, fed by a more-than-double so high capacity of PV, all financial results get red. The investment costs of PV and especially EES explode. More expensive but longer lasting Li-ion batteries have been used. Cheaper lead-acid batteries need more frequent replacement which mainly negates the alleged advantage. At this point two sub-scenarios have been played:
    - What if the project gets 20% of total construction costs as investment subsidy? This helps but is still not enough to bring up an acceptable financial situation.
    - What if EES is 30% cheaper and of the then total construction costs the project gets 20% investment subsidy? In this case the project reaches a kind of ‘orange’ status in which costs can be earned, reserves have to be touched to keep CF alive, debt service is fulfilled – only equity owners are paid far below expectations. Some additional triggers have to be activated to turn this project into complete positive territory.

The triggers mentioned in the last sentence have been listed in chapter before. However in reality and according to projects who tried to use EES, the capacities are much lower and designed for only a few hours and not for the ‘second shift’ of desalination production. Anyway these technologies are on their way to improve regarding efficiencies and costs and are for sure part in future projects of all kind, not only desalination. Maybe for small plants with production of less than 1,000 m^3 on small remote islands EES is more suitable at this time of development.

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Discussions, meetings with experts

UNIHA Wasser Technologie, 2016: In September 2016 a meeting with the technical expert for RO was held to gather practical insight into state-of-the-art RO design and implementation.

List of Abbreviations

(pg-)ATP	(picograms of) Adenosine triphosphate
BFR	Biofilm formation rate
BOD	Biochemical oxygen demand
BOOT	Build-Own-Operate-Transfer
BS	Balance sheet
CAES	Compressed air energy storage
CAPEX	Capital expenditures
CCPP	Calcium Carbonate Precipitation Potential
CF	Cash flow
CIP	Clean-in-place
DAF	Dissolved air flotation
DBP	Disinfection by-products
DER	Electrodialysis (reversal)
DoD	Depth-of-discharge
DOM	Dissolved organic matter
DSCR	Debt service coverage ratio
EBT	Earnings before taxes
EC	Electrical conductivity
EES	Electrical energy storage
EEX	European Energy Exchange
EIB	European Investment Bank
ERD	Energy recovery device
GHI	Global horizontal irradiation
GOR	Gained output ratio
HDPP	High-density polytethylene pipe
IDA	International Desalination Association
IRR	Internal rate of return
LR	Larson Ratio
LSI	Langelier saturation index
mg/L	Milligrams per liter
meq/L	Milliequivalents per liter
MF	Microfiltration
NOM	Natural organic matter
NPV	Net present value
NTU	Nephelometric turbidity units
O/M	Operations/Maintenance
OP	Osmotic pressure
ORC	Organic rankine cycle
P&L	Profit and Loss
pH	potentia Hydrogenii or pondus Hydrogenii

PHS	Pumped hydroelectric storage
ppm	Parts per million
ppt	parts per thousands
(BW/SW)RO	(Brackish water/Seawater) Reverse osmosis
RR	Recovery Rate
SAR	Sodium adsorption ratio
SDI	Silt density index
SDSI	Stiff-Davis saturation index
SMES	Superconduction magnetic energy storage
SPV	Special purpose vehicle
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
UF	Ultrafiltration
US EPA	United States Environmental Protection Agency
VFD	Variable frequency drive
WACC	Weighted average cost of capital
WHO	World Health Organization
ZID	Zone of initial dilution

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Appendix 1: Overview of energy storage technologies and characteristics

Technology	Energy density (W h/L)	Power density (W/L)	Specific energy (W h/kg)	Specific power (W/kg)	Power rating (MW)	Rated energy capacity (MW h)	Daily self-discharge (%)	Lifetime (years)	Cycling times (cycles)	Discharge efficiency (%)	Cycle efficiency (%)	Response time	Suitable storage duration	Discharge time at power rating	Power capital cost ($/kW)	Energy capital cost ($/kW h)	Operating and maintenance cost	Matu
PHS	0.5–1.5 [4], 1–2 [26]	0.5–1.5 [4], ~1 [26],	0.5–1.5 [4]	–	100–5000 [4], 30 [34], < 4000 [114]	500–8000 [4], 180 Okinawa PHS[34] and [77]	Very small [4] and [192]	40–60 [4], 40+[69], 30+[175]	10,000–30,000 [14]	~87 [114]	70–85 [4], 70–80 [175] 87 [33], 75–85 [203]	Minutes [114], not rapid discharge [203]	Hours–months [4], long-term [27]	1–24 h+[4], 6–10 h [73] 10 h [175]	2500–4300 [73], 2000–4000 [175]	5–100 [4], 10–12 [114]	0.004 $/kW h [70], ~3 $/kW/year [72]	Mature
Large-scale CAES	3–6 [4], 2–6 [26]	0.5–2 [4], ~1 [26]	30–60 [4]	–	Up to 300 [4], 110 & 290 [39], 1000 [70]	~ < 1000[10], 580 & 2860 [38] and [42]	Small [4], Almost zero [192]	20–40 [4], 30 [70], 20+[69] and [203]	8000–12,000 [14]	~70–79 [114]	42,54 [4] and [42] AA-CAES 70 [43] and [203]	Minutes [114]	Hours–months [4], long-term [27]	1–24 h+ [4], 8–20 h [73]	400–800 [4], 800–1000 [175]	2–50 [4], 2–120 [8], 2 [70]	0.003 $/kW h [70], 19–25 $/kW/year [72]	CAES commercialized, AA-CAES developing
Overground small CAES	Higher than large-scale CAES	Higher than large-scale CAES	140 at 300 bar [174]	–	0.003–3 [51] Potential ~10 [175]	~0.01[10], ~0.002–0.0083 [51]	Very small [51]	23+[51]	Test 30,000stop/starts [51]	~75–90 [51]	–	Seconds–minutes [114]	Hours–months, long-term [27]	30 s–40 min [51], 3 h [216]	517 [114], 1300–1550 [216]	1MVA from £296 k [51], 200–250 [216]	Very low [51]	Early commercialized
Flywheel	20–80 [4], [26] and [123]	1000–2000 [4], ~5000 [26]	10–30 [4], 5–100 [57], 5–80 [176]	400–1500 [4]	<0.25 [4], 3.6 [60], 0.1–20 [13] and [177]	0.0052 [60], 0.75 [70], up to 5 [177]	100 [4], ⩾20% per hour [57]	~15 [4], 15+[69], 20 [114]	20,000+ [4], 21,000+[69]	90–93 [114]	~90–95 [4], 90 & 95 [70]	<1 cycle [114], seconds [203]	Seconds–minutes [4] short-term(<1 h)[27]	Up to 8 s [4], 15 s–15 min [175]	250–350 [4]	1000–5000 [4], 1000–14,000 [8]	~0.004 $/kW h[70], ~20 $/kW/year [72]	Early commercialized
Lead–acid	50–80 [4], 50–90 [70]	10–400 [4]	30–50 [4], 25–50[178]	75–300 [4], 250 [70], 180 [57]	0–20 [4], 0–40 [14], 0.05–10 [179]	0.001–40 [179] More than 0.0005[180]	0.1–0.3 [4], <0.1 [57], 0.2 [69]	5–15 [4] and [57], 13 [69]	500–1000 [4], 200–1800 [13]	85 [114]	70–80[4], 63–90 [14], 75–80 [204]	<1/4 cycle [114] milliseconds	Minutes–days [4], short-to-med. term	Seconds–hours [4], up to 10 h [14]	300–600 [4], 200–300 [114], 400 [206]	200–400 [4], 50–100 [57], 330 [206]	~50 $/kW/year [72]	Mature
Li-ion	200–500 [4], 200–400 [26], 150 [70]	1500–10,000 [26]	75–200 [4], 90 [70], 120–200 [181]	150–315 [4], 300 [70], 500–2000 [57]	0–0.1 [4], 1–100 [73], 0.005–50 [182]	0.024 [79], ~0.004–10 [182]	0.1–0.3 [4], 1 & 5 [13]	5– 15 [4], 14–16 [205]	1000–10,000 [4], up to 20,000 [9]	85 [114]	~90–97 [4], 75–90 [73]	Milliseconds, <1/4 cycle [14]	Minutes–days [4], short-to-med. term	Minutes–hours [4], ~1–8 h [209]	1200–4000[4], 900–1300[57], 1590[73]	600–2500 [4], 2770–3800 [73]	–	Demonstration
NaS	150–250 [4], 150–300 [26]	~140–180 [26]	150–240 [4], 100 [183], 174 [184]	150–230 [4], 90–230 [9], 115 [13],	<8 [4], <34 [14]	0.4–244.8 [81], 0.4 [185]	Almost zero [13] and [185]	10–15 [4], 15 [69], 12–20 [192]	2500 [4], 3000[206] 2500–4500 [14]	85 [114]	~75–90 [4], 75 [206], 75–85 [204]	–	Long term[82]	Seconds–hours [4], ~1 h [209]	1000–3000 [4], 350–3000 [8]	300–500 [4], 350 [206], 450 [217]	~80 $/kW/year [72]	Commercialized
NiCd	60–150 [4], 15–80 [26], 80 [70]	80–600 [26]	50–75 [4], 50 [70], 45–80 [71]	150–300 [4], 160 [13], 150 [70],	0–40 [4], 27 [88], 40 [186]	6.75 [57] and [88]	0.2–0.6 [4],0.3 [57], 0.03–0.6 [14]	10–20 [4], 3–20 [13], 15–20 [57]	2000–2500 [4], 3500 [179]	85 [114]	~60–70 [4], 60–83 [14]	Milliseconds, <1/4 cycle [14]	Minutes–days [4], Short and long term	Seconds–hours [4], ~1–8 h [209]	500–1500 [4]	800–1500 [4], 400–2400 [57]	~20 $/kW/year [72]	Commercialized
VRB	16–33 [4], 25–35 [19]	~ < 2 [26]	10–30 [4]	166 [187]	~0.03–3 [4], 2 [188] possible 50 [5]	<60 [13], 2 [88], 3.6 [189]	Small [4], very low [13]	5–10 [4], 20 [193]	12,000+ [4], 13,342 [69]	~75–82 [207]	75–85 [4] and [62], 65–75 [73]	<1/4 cycle [14]	Hours–months [4], Long term [27]	Seconds–24 h+ [4], 2–12 h [106]	600–1500 [4]	150–1000 [4], 600 [217]	~70 $/kW/year [72]	Demo/early commercialized
ZnBr	30–60 [4], ~55–65 [26]	~ < 25 [26]	30–50 [4], 80 [190], 75 [191]	100 [190], 45 [191]	0.05–2 [4], 1–10 [73]	0.1–3 [13], 4 [14], 0.05 & 0.5 [192]	Small [4] and [100]	5–10 [4], 10 [69], 8–10 [205]	2000+ [4], 1500 [69]	~60–70 [208]	~65–75 [4], 66–80 [14], 66 [114]	<1/4cycle [114]	Hours–months [4] long term [27]	Seconds–10 h+ [4], ~10 h [209]	700–2500 [4], 400 [87], 200 [114]	150–1000 [4], 500 [71]	–	Demonstration
PSB	~20–30 [123]	~ < 2 [26]	~15–30 [123]	–	1–15 [4], 1 [193], 0.004 [194]	Potential up to 120 [193], 0.06 [194]	Small [4] Almost zero [193]	10–15 [4], 15 [209]	–	–	~60–75 [4], 60–75 [209]	20 ms [116]	Hours–months [4] long term [27]	Seconds–10 h+ [4], ~10 h [209]	700–2500 [4]	150–1000 [4], 450 [217]	–	Developing
Capacitor	2–10 [4], ~0.05 [124]	100,000+ [4],	0.05–5 [4], <~0.05 [121] and [124]	~100,000 [4], >~3000–10^7[124]	0–0.05 [4]	–	40 [4], ~50 in about 15 minutes [122]	~5 [4], ~1–10 [122]	50,000+ [4], 5000 (100% DoD) [210]	~75–90 [127]	~60–70 [4], 70+[210]	Milliseconds, <1/4 cycle [14]	Seconds–hours [4], ~5 h [210]	Milliseconds–1 h [4]	200–400 [4],	500–1000 [4],	13 $/kW/year [72], <0.05 $/kW h [210]	Commercialized
Super-capacitor	10–30 [4], ~10–30 [123]	100,000+ [4],	2.5–15 [4], ~0.05–15 [124]	500–5000 [4], ~10,000 [124]	0–0.3 [4], ~0.3+[26] ~0.001–0.1 [70]	0.0005 [70]	20–40 [4], 5 [10], 10–20 [211]	10–30 [4], 10–12 [66]	100,000+ [4], 50,000+[69]	95 [114] Up to ~98 [127]	~90–97 [4], 84–95 [66]	Milliseconds, ¼ cycle [114]	Seconds–hours [4] short-term(<1 h)[27]	Milliseconds–1 h [4], 1 min[209], 10 s[216]	100–300 [4], 250–450 [216]	300–2000 [4]	0.005 $/kW h [70], ~6 $/kW-year [114]	Developing/demo.
SMES	0.2–2.5 [4], ~6 [26]	1000–4000 [4], ~2500 [26]	0.5–5 [4], 10–75 [195]	500–2000 [4]	0.1–10 [4] and [14], ~1–10 [70]	0.0008 [70], 0.015 [138], 0.001 [196]	10–15 [4]	20+[4], 30 [114]	100,000+4], 20,000+ [14]	95 [114]	~95–97 [4], 95–98 [66], 95 [70]	Milliseconds, <1/4 cycle [114]	Minutes–hours [4] short-term (<1 h)[27]	Milliseconds–8 s [4], up to 30 min [209]	200–300 [4], 300 [114], 380–489[216]	1000–10,000 [4], 500–72,000 [114]	0.001 $/kW h [70], 18.5 $/kW/year [72]	Demo/early commercialized
Solar fuel	500–10,000 [4]	–	800–100,000 [4]	–	0–10 [4], 6 and developing 20 [197]	–	Almost zero [4]	–	–	–	~20–30 [4], planned eff.>54 [197]	–	Hours–months [4]	1–24 h+ [4]	–	–	–	Developing
Hydrogen Fuel cell	500–3000 [4]	500+ [4]	800–10,000 [4], ~150–1500 [124]	500+ [4], ~5–800 [124]	<50 [4], <10 [26], 58.8 [199]	0.312 [198], developing 39 [200]	Almost zero [4] and [192]	5–15 [4], 20 [119] 20+[212]	1000+ [4], 20,000+[212]	59 [114]	~20–50 [4], 32 [106], 45–66 [213]	Seconds, <1/4 cycle [114]	Hours–months [4]	Seconds–24 h+ [4]	500 [114], 1500–3000 [154]	15 [114], 2–15€/kW h [204]	0.0019–0.0153 $/kW [154]	Developing/demo.
TES	80–120, 120–200, 200–500 [4]	–	80–120, 80–200 [4], 150–250 [4]	10–30 [4]	0.1–300 [4], 15 [165], 10 [201]	–	0.05–1 [4]	10–20 [4], 5–15[4], 30 [203]	–	–	~30–60 [4]	Not for rapid response [203]	Minutes–days [4], minutes–months [4]	1–8 h [4], 1–24 h+ [4], 4–13 h [203]	200–300[4], 250 [203], 100–400[203]	20–50 [4], 30–60 [4], 3–30 [4]	–	Demo/early commercialized
Liquid air Storage	4–6 times than CAES at 200 bar [202]	–	214 [174]	–	10–200 [8], 0.3 [168]	2.5 [168]	Small [169] and [214]	25+[214]	–	–	55–80+[214]	Minutes [215]	Long-term [214]	Several hours [168] and [214]	900–1900 [214]	260–530 [214]	–	Developing/demo.

PHS Pumped Hydroelectric Storage
CAES Compressed Air Energy Storage
Li-ion Lithium-ion (batteries
NaS Sodium-sulfur (batteries)
NiCd Nickel-cadmium (batteries)
VRB Vanadium Redox Flow Battery
ZnBr Zinc Bromine Flow Battery
PSB Polysulfide Bromium Flow Battery
SMES Superconducting Magnetic Energy Storage
TES Thermal Energy Storage

Source: Xing, L. et al (2014): Overview of current development in electrical energy storage technologies and the application potential in power system operation. In: Applied Energy, Elsevier Ltd., pp. 511-536

Appendix 2: Risk matrix example for thesis project

Factor/Risk	Category	Effect/Impact	Solution/Countermeasure
Algal bloom	Desalination	Overall deterioration of source quality Damaging whole treatment process	Accurate pre-phase water analysis Pretreatment with DAF
Microbial content	Desalination	Bacteria, viruses contaminate product water	Rejectable, improved by pretreatment and disinfection
Permissions and necessary studies	Desalination	Costs, delays, derails parts or whole project	Longer and more intensive pre-phase to gather input security BOOT (transfer risk/costs to contractor) during construction and operations
Entitlements	Desalination	Especially existing infrastructure	Contracts to secure availability
Power Supply	Desalination	Availability and cost changes	Long-term contracts Match with water tariff In-house production (favouring REN)
Construction	Desalination	Cost overruns, delays, errors, lower performance	Experienced specialists, selected after accurate due diligence Turnkey prices and schedules Performance/Payment bonds 10-30%
Source water	Desalination	Basic impact and changes over time Higher scaling/fouling potential = more pretreatment = higher costs	Long term analysis during pre-phase Out of vicinity of other discharges, industry, ports, ship channels
Technology	Desalination	Wrong set-up of pretreatment or RO caused by low-level analysis	Project delay until acceptable analysis results Enhancing process range and capacity of plant
Regulation	Desalination	During construction and operation	Accurate pre-phase negotiations with authorities Flexible set-up in design
Operations	Desalination	Steady revenue interruption due to deadlocks for different reasons	Higher O&M densities in first years of operations Guarantees from contractors for technical insufficiencies Insurances Reserves in financial planning
Product water sale	Desalination	Lesser sale of product quantity than expected	Negotiations and contracting in pre-phase Take-or-pay in BOOT
Product water demand	Desalination	Expected droughts do not evolve Aquifers level improve Affordability decreases	Take-or-pay in BOOT Subsidies for product water

Appendix 2: Risk matrix example for thesis project (cont'd)

Factor/Risk	Category	Effect/Impact	Solution/Countermeasure
Weather condition/irradiation	PV	Lower production as expected Higher PV production costs Additional grid supply costs	Installation of overcapacity Partly equalization with selling overcapacity to utility
System costs	PV	Higher than expected due to different reasons (transport, lower scaling effect, …)	Reduction of capacity to stabilize costs Adaption of technology to stabilize capacity Planning with CAPEX reserve to prepare a buffer
Operations	PV	Lower production or deadlocks due to different reasons (inverters, tracking motors, hot spots …)	Higher O&M densities in first years of operations Guarantees from contractors for technical insufficiencies Insurances Reserves in financial planning
System costs	EES	Higher than expected due to different reasons (transport, lower scaling effect, …)	Reduction of capacity to stabilize costs Adaption of technology to stabilize capacity Planning with CAPEX reserve to prepare a buffer
Battery operations, especially efficiency and DoD	EES	Lower than expected Additonal grid supply necessary PV capacities not used as expected	Building energy-equivalent reserves in calculations Partly equalization with selling overcapacity to utility Guarantees from contractors for technical insufficiencies Insurances Reserves in financial planning
Replacement	EES	Sooner necessary than expected	Producer guarantees for performance or lower replacement costs in case of breach
Interest rates	Financial/Economic	Rates for debt rise and increase repayments	Fixed interest rates Interest rate hedges (forwards, swaps)
Inflation	Financial/Economic	Input prices rise	Inflation adjustment constituents in sale contracts
Currencies	Financial/Economic	Input/CAPEX prices rise relatively to home currency	Contractual binding in home currency Foreign currency hedges (forwards, swaps)
Operations	Financial/Economic	If any of above technical operational problems cause income shortfalls	See relevant block above
Reserves	Financial/Economic	In case of any negative income or CAPEX developement	Building reserves and contingencies from the project beginning on Slow withdrawing/neutralization of reserves Keeping a base reserve all the time, accepting payout reductions
Power costs	Financial/Economic	Rising electricity prices from utilities	Long term contracts Better conditions for industry Direct hedging (e.g. futures on EEX if available) Proxy hedging (e.g. futures, options on oil)

Appendix 3: Plant design and technologies taken from base case

Components	Details
RO set-up	Single pass
pH treatment	pH adjustment using sodium hydroxide
Disinfection	by chlorination
Intake & pipeline	HDPP
Intake filters	Bar racks and screens
Intake pump	Vertical turbines
Pretreatment technology	Dual media gravity filters
Pretreatment chemicals	Coagulation and flocculation
RO trains	4+1 trains each 8000 m^3/day
RO train	with transfer pump, cartridge filter, HP pump, Pelton ERD
RO rack	with piping and equipment
Posttreatment	Limestone filters
Treatment support	Chemical feed/storage system
Posttreatment	Solids handling/landfill & cleaning chemicals to sanitary sewage
Buildings	RO, Administration, electrical substation, auxiliary facilities

Appendix 4: Plant details and adaptions for Ciutadella

Plant details	Units	Base	Ciutadella
Production	m^3/day	40,000	10,000
Max Production	m^3/day	48,000	12,000
Min Production	m^3/day	32,000	8,000
RR	factor	0.5	0.5
Load factor (LF)	factor	1.00	0.95
	days	365	347
Plant foodprint	avg. m^2 per m^3	0.53	0.53
	m^2	21,250	5,300
Distance to shore	m	800	800
Intake	m	200	200
Outfall (last 50 with diffusers)	m	150	150
Elevation	m	10	10
Avg. Water quality			
Intake flow	m^3/day	84,000	21,000
TDS	mg/L	33,500	33,500
Chloride	mg/L	18,000	18,000
Bromide	mg/L	73.0	73.0
Boron	mg/L	4.5	4.5
Temperature	°C	18.0	18.0
Turbidity	NTU	2.0	2.0
TSS	mg/L	4.0	4.0
pH		7.8	7.8

Appendix 5: Capital cost adaption for Ciutadella

Cost Item	Base plant		Ciutadella (new)	
	USD	% of Total	USD	% of Total
Site preparation, roads, and parking	730.000	1,0%	182.500	1,0%
Intake	3.480.000	4,7%	870.000	4,7%
Pretreatment	5.850.000	7,9%	1.462.500	7,9%
RO system equipment	25.600.000	34,6%	6.400.000	34,6%
Post-treatment	1.460.000	2,0%	365.000	2,0%
Concentrate disposal	1.830.000	2,5%	457.500	2,5%
Waste and solids handling	1.100.000	1,5%	275.000	1,5%
Electrical and instrumentation systems	1.650.000	2,2%	412.500	2,2%
Auxiliary equipment & utilities	1.560.000	2,1%	390.000	2,1%
Buildings	3.240.000	4,4%	810.000	4,4%
Start-up, commissionings, and acceptance testing	1.460.000	2,0%	365.000	2,0%
Subtotal direct (construction) costs (% of total capital costs)	**47.960.000**	**64,8%**	**11.990.000**	**64,8%**
Project engineering services				
Preliminary engineering	780.000	1,1%	195.000	1,1%
Pilot testing	720.000	1,0%	180.000	1,0%
Detailed design	3.650.000	4,9%	912.500	4,9%
Construction management and oversight	2.200.000	3,0%	550.000	3,0%
Subtotal engineering services	**7.350.000**	**9,9%**	**1.837.500**	**9,9%**
Project development				
Administration, contracting, and management	1.500.000	2,0%	375.000	2,0%
Environmental permitting (licensing)	2.100.000	2,8%	525.000	2,8%
Legal services	490.000	0,7%	122.500	0,7%
Subtotal project development	**4.090.000**	**5,5%**	**1.022.500**	**5,5%**
Project financing costs				
Interest during construction	2.200.000	3,0%	550.000	3,0%
Debt service reserve	3.900.000	5,3%	975.000	5,3%
Other financial costs	1.100.000	1,5%	275.000	1,5%
Subtotal project financing	**7.200.000**	**9,7%**	**1.800.000**	**9,7%**
Contingency	7.400.000	10,0%	1.850.000	10,0%
Subtotal indirect capital costs (% of total capital costs	**26.040.000**	**35,2%**	**6.510.000**	**35,2%**
Total capital costs	**74.000.000**	**100,0%**	**18.500.000**	**100,0%**

Appendix 6: O&M cost adaption for Ciutadella

Cost Item	Annual O&M Costs Base			Ciutadella new		
	USD/year	USD/m³	% of Total	USD/year	USD/m³	% of Total
Variable O&M Costs						
Power	3.370.000	0,231	49,13%	1.334.988	0,385	61,69%
Chemicals	440.000	0,030	6,41%	104.500	0,030	4,83%
Replacement of membranes and cartridge filtrs	780.000	0,053	11,37%	185.250	0,053	8,56%
Waste stream disposal	330.000	0,023	4,81%	78.375	0,023	3,62%
Subtotal, variable O&M costs	4.920.000	0,337	71,72%	1.703.113	0,491	78,71%
Fixes O&M costs						
Labor	420.000	0,029	6,12%	99.750	0,029	4,61%
Maintenance	700.000	0,048	10,20%	166.250	0,048	7,68%
Environmental monitoring	120.000	0,008	1,75%	28.500	0,008	1,32%
Indirect O&M costs	700.000	0,048	10,20%	166.250	0,048	7,68%
Subtotal, fixed O/M costs	1.940.000	0,133	28,28%	460.750	0,133	21,29%
Total O/M costs	6.860.000	0,470	100,00%	2.163.863	0,62	100,00%

Appendix 7: Project flows desalination

Periode	0	1	2	3	4	5	6	7	8	9	10
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Assumptions											
1. Revenue											
Product water sold	0,00	0,00	3.814.250,00	3.852.392,50	3.890.916,43	3.929.825,59	3.969.123,85	4.008.815,08	4.048.903,23	4.089.392,27	4.130.286,19
Sum Revenue	**0**	**0**	**3.814.250**	**3.852.393**	**3.890.916**	**3.929.826**	**3.969.124**	**4.008.815**	**4.048.903**	**4.089.392**	**4.130.286**
2. Desalination											
Planning and pre-construction costs	511.250	0	0	0	0	0	0	0	0	0	0
Construction costs	0	14.338.750	0	0	0	0	0	0	0	0	0
Financial costs		825.000									
Contingency & Reserves	0	2.825.000	0	0	0	0	0	0	0	0	0
O/M costs variable (ex-energy)	0	0	368.125	371.806	375.524	379.280	383.072	386.903	390.772	394.680	398.627
O/M costs variable (energy)	0	0	889.992	891.772	893.555	895.342	897.133	898.927	900.725	902.527	904.332
O/M costs fixed	0		460.750	465.358	470.011	474.711	479.458	484.253	489.095	493.986	498.926
Sum Desal Project Costs	**-511.250**	**-17.988.750**	**-1.718.867**	**-1.728.935**	**-1.739.091**	**-1.749.333**	**-1.759.664**	**-1.770.083**	**-1.780.593**	**-1.791.193**	**-1.801.884**
3. PV											
Construction & replacement costs		5.700.000									
O/M costs			57.000	57.570	58.146	58.727	59.314	59.908	60.507	61.112	61.723
Sum PV Project Costs	**0**	**-5.700.000**	**-57.000**	**-57.570**	**-58.146**	**-58.727**	**-59.314**	**-59.908**	**-60.507**	**-61.112**	**-61.723**
5. Financials (from P/L)											
Income tax			-60.186	-73.947	-88.055	-102.522	-117.361	-132.584	-148.205	-164.236	-180.693
Dividend			-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Sum Financials	**0**	**0**	**-240.746**	**-295.787**	**-352.218**	**-398.522**	**-413.361**	**-428.584**	**-444.205**	**-460.236**	**-476.693**
6. Sale at project end											
Result	**-511.250**	**-23.688.750**	**2.038.383**	**2.065.887**	**2.093.680**	**2.121.765**	**2.150.146**	**2.178.824**	**2.207.804**	**2.237.088**	**2.266.679**
Product costs/m³ (pre-tax)	**1,07**		1,00	1,01	1,03	1,04	1,04	1,05	1,05	1,05	1,06
Project PV	-511.250	-22.644.484	1.862.629	1.804.544	1.748.201	1.693.553	1.640.550	1.589.147	1.539.298	1.490.958	1.444.085
Project NPV	**8.106.297**										
Project IRR (pre-tax)	**7,79%**										
Equity flows	-3.700.000	0	180.559	221.840	264.164	296.000	296.000	296.000	296.000	296.000	296.000
Equity PV	-3.700.000	0	154.801	176.104	194.168	201.453	186.530	172.713	159.920	148.074	137.105
Equity NPV	**605.394,24**										
Equity IRR	**9,17%**										
DSCR (average)	**1,58**		1,39	1,41	1,43	1,45	1,46	1,48	1,50	1,52	1,54

Periode	11	12	13	14	15	16	17	18	19	20	21
Year	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Assumptions											
1. Revenue											
Product water sold	4.171.589,05	4.213.304,94	4.255.437,99	4.297.992,37	4.340.972,29	4.384.382,02	4.428.225,84	4.472.508,10	4.517.233,18	4.562.405,51	4.608.029,56
Sum Revenue	**4.171.589**	**4.213.305**	**4.255.438**	**4.297.992**	**4.340.972**	**4.384.382**	**4.428.226**	**4.472.508**	**4.517.233**	**4.562.406**	**4.608.030**
2. Desalination											
Planning and pre-construction costs	0	0	0	0	0	0	0	0	0	0	0
Construction costs	0	0	0	0	0	0	0	0	0	0	0
Financial costs											
Contingency & Reserves	0	0	0	0	0	0	0	0	0	0	0
O/M costs variable (ex-energy)	402.613	406.639	410.705	414.812	418.961	423.150	427.382	431.656	435.972	440.332	444.735
O/M costs variable (energy)	906.140	907.953	909.768	911.588	913.411	915.238	917.068	918.903	920.740	922.582	924.427
O/M costs fixed	503.915	508.955	514.044	519.185	524.376	529.620	534.916	540.266	545.668	551.125	556.636
Sum Desal Project Costs	**-1.812.669**	**-1.823.546**	**-1.834.518**	**-1.845.585**	**-1.856.748**	**-1.868.008**	**-1.879.367**	**-1.890.824**	**-1.902.381**	**-1.914.039**	**-1.925.798**
3. PV											
Construction & replacement costs	285.000										142.500
O/M costs	62.340	62.963	63.593	64.229	64.871	65.520	66.175	66.837	67.505	68.180	68.862
Sum PV Project Costs	**-347.340**	**-62.963**	**-63.593**	**-64.229**	**-64.871**	**-65.520**	**-66.175**	**-66.837**	**-67.505**	**-68.180**	**-211.362**
5. Financials (from P/L)											
Income tax	-126.340	-214.943	-232.766	-251.077	-269.892	-289.230	-309.109	-329.548	-350.567	-372.187	-358.804
Dividend	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Sum Financials	**-422.340**	**-510.943**	**-528.766**	**-547.077**	**-565.892**	**-585.230**	**-605.109**	**-625.548**	**-646.567**	**-668.187**	**-654.804**
6. Sale at project end											**9.039.444**
Result	**2.011.580**	**2.326.795**	**2.357.327**	**2.388.178**	**2.419.353**	**2.450.854**	**2.482.684**	**2.514.847**	**2.547.347**	**2.580.186**	**11.510.313**
Product costs/m³ (pre-tax)	1,14	1,06	1,07	1,07	1,07	1,08	1,08	1,08	1,09	1,09	1,14
Project PV	1.225.069	1.354.570	1.311.848	1.270.430	1.230.278	1.191.357	1.153.629	1.117.060	1.081.617	1.047.265	4.465.941
Project NPV											
Project IRR (pre-tax)											
Equity flows	296.000	296.000	296.000	296.000	296.000	296.000	296.000	296.000	296.000	296.000	9.335.444
Equity PV	126.949	117.546	108.839	100.776	93.312	86.400	80.000	74.074	68.587	63.506	1.854.540
Equity NPV											
Equity IRR											
DSCR (average)	1,56	1,58	1,60	1,63	1,65	1,67	1,69	1,71	1,73	1,76	1,78

Appendix 8: BS, P&L and CF desalination

Balance Sheet																						
Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
ASSETS																						
Desal assets 50y		810.000	793.800	777.600	761.400	745.200	729.000	712.800	696.600	680.400	664.200	648.000	631.800	615.600	599.400	583.200	567.000	550.800	534.600	518.400	502.200	486.000
Desal assets 20y		13.528.750	12.852.313	12.175.875	11.499.438	10.823.000	10.146.563	9.470.125	8.793.688	8.117.250	7.440.813	6.764.375	6.087.938	5.411.500	4.735.063	4.058.625	3.382.188	2.705.750	2.029.313	1.352.875	676.438	0
PV 20y		5.700.000	5.415.000	5.130.000	4.845.000	4.560.000	4.275.000	3.990.000	3.705.000	3.420.000	3.135.000	2.850.000	2.565.000	2.280.000	1.995.000	1.710.000	1.425.000	1.140.000	855.000	570.000	285.000	0
Cash	3.188.750	2.825.000	3.114.212	3.375.886	3.608.922	3.823.740	4.052.099	4.293.913	4.549.087	4.817.512	5.099.072	5.179.886	5.487.312	5.807.448	6.140.123	6.485.158	6.842.355	7.211.504	7.592.377	7.984.731	8.388.305	8.553.444
Total assets	**3.188.750**	**22.863.750**	**22.175.324**	**21.459.361**	**20.714.760**	**19.951.940**	**19.202.661**	**18.466.838**	**17.744.374**	**17.035.162**	**16.339.084**	**15.442.261**	**14.772.050**	**14.114.548**	**13.469.586**	**12.836.983**	**12.216.543**	**11.608.054**	**11.011.290**	**10.426.006**	**9.851.943**	**9.039.444**
LIABILITIES																						
Registered capital	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000
Debt desal		14.800.000	14.302.990	13.786.100	13.248.534	12.689.465	12.108.034	11.503.345	10.874.469	10.220.438	9.540.246	8.832.846	8.097.150	7.332.026	6.536.297	5.708.739	4.848.079	3.952.992	3.022.102	2.053.976	1.047.125	0
Debt PV	0	5.700.000	5.508.584	5.309.511	5.102.476	4.887.159	4.663.229	4.430.343	4.188.140	3.936.250	3.674.284	3.401.839	3.118.497	2.823.821	2.517.358	2.198.636	1.867.165	1.522.436	1.163.918	791.058	403.285	0
Profit/Loss pre-period		-511.250	-1.336.250	-1.336.250	-1.336.250	-1.336.250	-1.324.684	-1.268.602	-1.166.850	-1.018.235	-821.526	-575.446	-492.424	-143.597	258.701	715.931	1.229.608	1.801.299	2.432.626	3.125.271	3.880.972	4.701.533
Profit/loss	-511.250	-825.000	180.559	221.840	264.164	307.566	352.082	397.752	444.614	492.709	542.080	379.021	644.828	698.298	753.230	809.677	867.691	927.328	988.645	1.051.702	1.116.561	1.076.411
Dividend	0	0	-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Profit/loss after dividend	-511.250	-1.336.250	-1.336.250	-1.336.250	-1.336.250	-1.324.684	-1.268.602	-1.166.850	-1.018.235	-821.526	-575.446	-492.424	-143.597	258.701	715.931	1.229.608	1.801.299	2.432.626	3.125.271	3.880.972	4.701.533	5.481.944
Total liabilities	**3.188.750**	**22.863.750**	**22.175.324**	**21.459.361**	**20.714.760**	**19.951.940**	**19.202.661**	**18.466.838**	**17.744.374**	**17.035.162**	**16.339.084**	**15.442.261**	**14.772.050**	**14.114.548**	**13.469.586**	**12.836.983**	**12.216.543**	**11.608.054**	**11.011.290**	**10.426.006**	**9.851.943**	**9.181.944**

P&L ACCOUNT																						
Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	20
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Revenues	0	0	3.814.250	3.852.393	3.890.916	3.929.826	3.969.124	4.008.815	4.048.903	4.089.392	4.130.286	4.171.589	4.213.305	4.255.438	4.297.992	4.340.972	4.384.382	4.428.226	4.472.508	4.517.233	4.562.406	4.608.030
Costs	-511.250	-825.000	-1.775.867	-1.786.505	-1.797.236	-1.808.060	-1.818.978	-1.829.991	-1.841.099	-1.852.304	-1.863.607	-2.160.009	-1.886.510	-1.898.111	-1.909.814	-1.921.620	-1.933.528	-1.945.542	-1.957.661	-1.969.886	-1.982.219	-2.137.161
Operating cash result	**-511.250**	**-825.000**	**2.038.383**	**2.065.887**	**2.093.680**	**2.121.765**	**2.150.146**	**2.178.824**	**2.207.804**	**2.237.088**	**2.266.679**	**2.011.580**	**2.326.795**	**2.357.327**	**2.388.178**	**2.419.353**	**2.450.854**	**2.482.684**	**2.514.847**	**2.547.347**	**2.580.186**	**2.470.869**
Depreciation desal assets 50y	0		-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200
Depreciation desal assets 20y	0		-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438
Depreciation PV assets 20y			-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000
Operating result	**-511.250**	**-825.000**	**1.060.746**	**1.088.250**	**1.116.043**	**1.144.128**	**1.172.508**	**1.201.187**	**1.230.166**	**1.259.450**	**1.289.041**	**1.033.943**	**1.349.158**	**1.379.689**	**1.410.541**	**1.441.715**	**1.473.216**	**1.505.046**	**1.537.210**	**1.569.710**	**1.602.549**	**1.493.231**
Interest debt desal	0	0	-592.000	-572.120	-551.444	-529.941	-507.579	-484.321	-460.134	-434.979	-408.818	-381.610	-353.314	-323.886	-293.281	-261.452	-228.350	-193.923	-158.120	-120.884	-82.159	-41.885
Interest debt PV	0	0	-228.000	-220.343	-212.380	-204.099	-195.486	-186.529	-177.214	-167.526	-157.450	-146.971	-136.074	-124.740	-112.953	-100.694	-87.945	-74.687	-60.897	-46.557	-31.642	-16.131
Financial result	**-511.250**	**-825.000**	**240.746**	**295.787**	**352.218**	**410.087**	**469.443**	**530.336**	**592.819**	**656.946**	**722.774**	**505.362**	**859.770**	**931.063**	**1.004.307**	**1.079.569**	**1.156.921**	**1.236.437**	**1.318.193**	**1.402.269**	**1.488.748**	**1.435.215**
EBT	**-511.250**	**-825.000**	**240.746**	**295.787**	**352.218**	**410.087**	**469.443**	**530.336**	**592.819**	**656.946**	**722.774**	**505.362**	**859.770**	**931.063**	**1.004.307**	**1.079.569**	**1.156.921**	**1.236.437**	**1.318.193**	**1.402.269**	**1.488.748**	**1.435.215**
Income tax	0	0	-60.186	-73.947	-88.055	-102.522	-117.361	-132.584	-148.205	-164.236	-180.693	-126.340	-214.943	-232.766	-251.077	-269.892	-289.230	-309.109	-329.548	-350.567	-372.187	-358.804
Profit/loss	-511.250	-825.000	180.559	221.840	264.164	307.566	352.082	397.752	444.614	492.709	542.080	379.021	644.828	698.298	753.230	809.677	867.691	927.328	988.645	1.051.702	1.116.561	1.076.411
Dividend on equity	0	0	-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Profit/loss for reporting periode after dividend	**-511.250**	**-825.000**	**0**	**0**	**0**	**11.566**	**56.082**	**101.752**	**148.614**	**196.709**	**246.080**	**83.021**	**348.828**	**402.298**	**457.230**	**513.677**	**571.691**	**631.328**	**692.645**	**755.702**	**820.561**	**780.411**

LIQUIDITY																						
Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Cash 1.1.		3.188.750	2.825.000	3.020.628	3.211.988	3.420.794	3.647.064	3.890.812	4.152.046	4.430.765	4.726.963	5.040.626	5.371.733	5.720.254	6.086.150	6.469.376	6.869.874	7.287.579	7.722.415	8.174.294	8.643.118	9.128.778
Operating cash result	-511.250	-15.163.750	1.650.388	1.680.241	1.710.394	1.740.847	1.771.606	1.802.672	1.834.048	1.865.739	1.897.746	1.930.073	1.962.724	1.995.701	2.029.008	2.062.648	2.096.624	2.130.940	2.165.599	2.200.605	2.235.961	2.271.671
Cash from equity	3.700.000																					
Cash from financing activity		14.800.000																				
Income tax	0	0	-91.438	-103.871	-116.578	-129.567	-142.847	-156.428	-170.319	-184.531	-199.073	-213.956	-229.193	-244.794	-260.772	-277.140	-293.909	-311.095	-328.711	-346.771	-365.291	-384.287
Cash flow I	**3.188.750**	**2.825.000**	**4.383.950**	**4.596.998**	**4.805.803**	**5.032.074**	**5.275.822**	**5.537.056**	**5.815.775**	**6.111.973**	**6.425.636**	**6.756.743**	**7.105.264**	**7.471.160**	**7.854.386**	**8.254.884**	**8.672.589**	**9.107.424**	**9.559.303**	**10.028.128**	**10.513.788**	**11.016.162**
Cash Flow II	**3.188.750**	**2.825.000**	**4.383.950**	**4.596.998**	**4.805.803**	**5.032.074**	**5.275.822**	**5.537.056**	**5.815.775**	**6.111.973**	**6.425.636**	**6.756.743**	**7.105.264**	**7.471.160**	**7.854.386**	**8.254.884**	**8.672.589**	**9.107.424**	**9.559.303**	**10.028.128**	**10.513.788**	**11.016.162**
Repayment bank debt (capital & interest)	0	0	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010
Cash Flow III	**3.188.750**	**2.825.000**	**3.294.940**	**3.507.988**	**3.716.794**	**3.943.064**	**4.186.812**	**4.448.046**	**4.726.765**	**5.022.963**	**5.336.626**	**5.667.733**	**6.016.254**	**6.382.150**	**6.765.376**	**7.165.874**	**7.583.579**	**8.018.415**	**8.470.294**	**8.939.118**	**9.424.778**	**9.927.152**
Cash Flow IV	**3.188.750**	**2.825.000**	**3.294.940**	**3.507.988**	**3.716.794**	**3.943.064**	**4.186.812**	**4.448.046**	**4.726.765**	**5.022.963**	**5.336.626**	**5.667.733**	**6.016.254**	**6.382.150**	**6.765.376**	**7.165.874**	**7.583.579**	**8.018.415**	**8.470.294**	**8.939.118**	**9.424.778**	**9.927.152**
Cash Flow V	**3.188.750**	**2.825.000**	**3.294.940**	**3.507.988**	**3.716.794**	**3.943.064**	**4.186.812**	**4.448.046**	**4.726.765**	**5.022.963**	**5.336.626**	**5.667.733**	**6.016.254**	**6.382.150**	**6.765.376**	**7.165.874**	**7.583.579**	**8.018.415**	**8.470.294**	**8.939.118**	**9.424.778**	**9.927.152**
Dividend	0	0	-274.313	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Cash Floiw VI	**3.188.750**	**2.825.000**	**3.020.628**	**3.211.988**	**3.420.794**	**3.647.064**	**3.890.812**	**4.152.046**	**4.430.765**	**4.726.963**	**5.040.626**	**5.371.733**	**5.720.254**	**6.086.150**	**6.469.376**	**6.869.874**	**7.287.579**	**7.722.415**	**8.174.294**	**8.643.118**	**9.128.778**	**9.631.152**

Appendix 9: Project flows desalination with PV

Periode	0	1	2	3	4	5	6	7	8	9	10
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Assumptions											
1. Revenue											
Product water sold	0,00	0,00	3.814.250,00	3.852.392,50	3.890.916,43	3.929.825,59	3.969.123,85	4.008.815,08	4.048.903,23	4.089.392,27	4.130.286,19
Sum Revenue	**0**	**0**	**3.814.250**	**3.852.393**	**3.890.916**	**3.929.826**	**3.969.124**	**4.008.815**	**4.048.903**	**4.089.392**	**4.130.286**
2. Desalination											
Planning and pre-construction costs	511.250	0	0	0	0	0	0	0	0	0	0
Construction costs	0	14.338.750	0	0	0	0	0	0	0	0	0
Financial costs		825.000									
Contingency & Reserves	0	2.825.000	0	0	0	0	0	0	0	0	0
O/M costs variable (ex-energy)	0	0	368.125	371.806	375.524	379.280	383.072	386.903	390.772	394.680	398.627
O/M costs variable (energy)	0	0	889.992	891.772	893.555	895.342	897.133	898.927	900.725	902.527	904.332
O/M costs fixed	0		460.750	465.358	470.011	474.711	479.458	484.253	489.095	493.986	498.926
Sum Desal Project Costs	**-511.250**	**-17.988.750**	**-1.718.867**	**-1.728.935**	**-1.739.091**	**-1.749.333**	**-1.759.664**	**-1.770.083**	**-1.780.593**	**-1.791.193**	**-1.801.884**
3. PV											
Construction & replacement costs		5.700.000									
O/M costs			57.000	57.570	58.146	58.727	59.314	59.908	60.507	61.112	61.723
Sum PV Project Costs	**0**	**-5.700.000**	**-57.000**	**-57.570**	**-58.146**	**-58.727**	**-59.314**	**-59.908**	**-60.507**	**-61.112**	**-61.723**
5. Financials (from P/L)											
Income tax			-60.186	-73.947	-88.055	-102.522	-117.361	-132.584	-148.205	-164.236	-180.693
Dividend			-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Sum Financials	**0**	**0**	**-240.746**	**-295.787**	**-352.218**	**-398.522**	**-413.361**	**-428.584**	**-444.205**	**-460.236**	**-476.693**
6. Sale at project end											
Result	**-511.250**	**-23.688.750**	**2.038.383**	**2.065.887**	**2.093.680**	**2.121.765**	**2.150.146**	**2.178.824**	**2.207.804**	**2.237.088**	**2.266.679**
Product costs/m³ (pre-tax)	**1,07**		1,00	1,01	1,03	1,04	1,04	1,05	1,05	1,05	1,06
Project PV	-511.250	-22.644.484	1.862.629	1.804.544	1.748.201	1.693.553	1.640.550	1.589.147	1.539.298	1.490.958	1.444.085
Project NPV	**8.106.297**										
Project IRR (pre-tax)	**7,79%**										
Equity flows	-3.700.000	0	180.559	221.840	264.164	296.000	296.000	296.000	296.000	296.000	296.000
Equity PV	-3.700.000	0	154.801	176.104	194.168	201.453	186.530	172.713	159.920	148.074	137.105
Equity NPV	**605.394,24**										
Equity IRR	**9,17%**										
DSCR (average)	**1,58**		1,39	1,41	1,43	1,45	1,46	1,48	1,50	1,52	1,54

Periode	11	12	13	14	15	16	17	18	19	20	21
Year	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Assumptions											
1. Revenue											
Product water sold	4.171.589,05	4.213.304,94	4.255.437,99	4.297.992,37	4.340.972,29	4.384.382,02	4.428.225,84	4.472.508,10	4.517.233,18	4.562.405,51	4.608.029,56
Sum Revenue	**4.171.589**	**4.213.305**	**4.255.438**	**4.297.992**	**4.340.972**	**4.384.382**	**4.428.226**	**4.472.508**	**4.517.233**	**4.562.406**	**4.608.030**
2. Desalination											
Planning and pre-construction costs	0	0	0	0	0	0	0	0	0	0	0
Construction costs	0	0	0	0	0	0	0	0	0	0	0
Financial costs											
Contingency & Reserves	0	0	0	0	0	0	0	0	0	0	0
O/M costs variable (ex-energy)	402.613	406.639	410.705	414.812	418.961	423.150	427.382	431.656	435.972	440.332	444.735
O/M costs variable (energy)	906.140	907.953	909.768	911.588	913.411	915.238	917.068	918.903	920.740	922.582	924.427
O/M costs fixed	503.915	508.955	514.044	519.185	524.376	529.620	534.916	540.266	545.668	551.125	556.636
Sum Desal Project Costs	**-1.812.669**	**-1.823.546**	**-1.834.518**	**-1.845.585**	**-1.856.748**	**-1.868.008**	**-1.879.367**	**-1.890.824**	**-1.902.381**	**-1.914.039**	**-1.925.798**
3. PV											
Construction & replacement costs	285.000										142.500
O/M costs	62.340	62.963	63.593	64.229	64.871	65.520	66.175	66.837	67.505	68.180	68.862
Sum PV Project Costs	**-347.340**	**-62.963**	**-63.593**	**-64.229**	**-64.871**	**-65.520**	**-66.175**	**-66.837**	**-67.505**	**-68.180**	**-211.362**
5. Financials (from P/L)											
Income tax	-126.340	-214.943	-232.766	-251.077	-269.892	-289.230	-309.109	-329.548	-350.567	-372.187	-358.804
Dividend	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Sum Financials	**-422.340**	**-510.943**	**-528.766**	**-547.077**	**-565.892**	**-585.230**	**-605.109**	**-625.548**	**-646.567**	**-668.187**	**-654.804**
6. Sale at project end											**9.039.444**
Result	**2.011.580**	**2.326.795**	**2.357.327**	**2.388.178**	**2.419.353**	**2.450.854**	**2.482.684**	**2.514.847**	**2.547.347**	**2.580.186**	**11.510.313**
Product costs/m³ (pre-tax)	1,14	1,06	1,07	1,07	1,07	1,08	1,08	1,08	1,09	1,09	1,14
Project PV	1.225.069	1.354.570	1.311.848	1.270.430	1.230.278	1.191.357	1.153.629	1.117.060	1.081.617	1.047.265	4.465.941
Project NPV											
Project IRR (pre-tax)											
Equity flows	296.000	296.000	296.000	296.000	296.000	296.000	296.000	296.000	296.000	296.000	9.335.444
Equity PV	126.949	117.546	108.839	100.776	93.312	86.400	80.000	74.074	68.587	63.506	1.854.540
Equity NPV											
Equity IRR											
DSCR (average)	1,56	1,58	1,60	1,63	1,65	1,67	1,69	1,71	1,73	1,76	1,78

Appendix 10: BS, P&L and CF desalination plant with PV

Balance Sheet

Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
ASSETS																						
Desal assets 50y		810.000	793.800	777.600	761.400	745.200	729.000	712.800	696.600	680.400	664.200	648.000	631.800	615.600	599.400	583.200	567.000	550.800	534.600	518.400	502.200	486.000
Desal assets 20y		13.528.750	12.852.313	12.175.875	11.499.438	10.823.000	10.146.563	9.470.125	8.793.688	8.117.250	7.440.813	6.764.375	6.087.938	5.411.500	4.735.063	4.058.625	3.382.188	2.705.750	2.029.313	1.352.875	676.438	0
PV 20y		5.700.000	5.415.000	5.130.000	4.845.000	4.560.000	4.275.000	3.990.000	3.705.000	3.420.000	3.135.000	2.850.000	2.565.000	2.280.000	1.995.000	1.710.000	1.425.000	1.140.000	855.000	570.000	285.000	0
Cash	3.188.750	2.825.000	3.114.212	3.375.886	3.608.922	3.823.740	4.052.099	4.293.913	4.549.087	4.817.512	5.099.072	5.179.886	5.487.312	5.807.448	6.140.123	6.485.158	6.842.355	7.211.504	7.592.377	7.984.731	8.388.305	8.553.444
Total assets	**3.188.750**	**22.863.750**	**22.175.324**	**21.459.361**	**20.714.760**	**19.951.940**	**19.202.661**	**18.466.838**	**17.744.374**	**17.035.162**	**16.339.084**	**15.442.261**	**14.772.050**	**14.114.548**	**13.469.586**	**12.836.983**	**12.216.543**	**11.608.054**	**11.011.290**	**10.426.006**	**9.851.943**	**9.039.444**
LIABILITIES																						
Registered capital	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000
Debt desal		14.800.000	14.302.990	13.786.100	13.248.534	12.689.465	12.108.034	11.503.345	10.874.469	10.220.438	9.540.246	8.832.846	8.097.150	7.332.026	6.536.297	5.708.739	4.848.079	3.952.992	3.022.102	2.053.976	1.047.125	0
Debt PV	0	5.700.000	5.508.584	5.309.511	5.102.476	4.887.159	4.663.229	4.430.343	4.188.140	3.936.250	3.674.284	3.401.839	3.118.497	2.823.821	2.517.358	2.198.636	1.867.165	1.522.436	1.163.918	791.058	403.285	0
Profit/Loss pre-period		-511.250	-1.336.250	-1.336.250	-1.336.250	-1.336.250	-1.324.684	-1.268.602	-1.166.850	-1.018.235	-821.526	-575.446	-492.424	-143.597	258.701	715.931	1.229.608	1.801.299	2.432.626	3.125.271	3.880.972	4.701.533
Profit/loss	-511.250	-825.000	180.559	221.840	264.164	307.566	352.082	397.752	444.614	492.709	542.080	379.021	644.828	698.298	753.230	809.677	867.691	927.328	988.645	1.051.702	1.116.561	1.076.411
Dividend	0	0	-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Profit/loss after dividend	-511.250	-1.336.250	-1.336.250	-1.336.250	-1.336.250	-1.324.684	-1.268.602	-1.166.850	-1.018.235	-821.526	-575.446	-492.424	-143.597	258.701	715.931	1.229.608	1.801.299	2.432.626	3.125.271	3.880.972	4.701.533	5.481.944
Total liabilities	**3.188.750**	**22.863.750**	**22.175.324**	**21.459.361**	**20.714.760**	**19.951.940**	**19.202.661**	**18.466.838**	**17.744.374**	**17.035.162**	**16.339.084**	**15.442.261**	**14.772.050**	**14.114.548**	**13.469.586**	**12.836.983**	**12.216.543**	**11.608.054**	**11.011.290**	**10.426.006**	**9.851.943**	**9.181.944**

P&L ACCOUNT

Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	20
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Revenues	0	0	3.814.250	3.852.393	3.890.916	3.929.826	3.969.124	4.008.815	4.048.903	4.089.392	4.130.286	4.171.589	4.213.305	4.255.438	4.297.992	4.340.972	4.384.382	4.428.226	4.472.508	4.517.233	4.562.406	4.608.030
Costs	-511.250	-825.000	-1.775.867	-1.786.505	-1.797.236	-1.808.060	-1.818.978	-1.829.991	-1.841.099	-1.852.304	-1.863.607	-2.160.009	-1.886.510	-1.898.111	-1.909.814	-1.921.620	-1.933.528	-1.945.542	-1.957.661	-1.969.886	-1.982.219	-2.137.161
Operating cash result	**-511.250**	**-825.000**	**2.038.383**	**2.065.887**	**2.093.680**	**2.121.765**	**2.150.146**	**2.178.824**	**2.207.804**	**2.237.088**	**2.266.679**	**2.011.580**	**2.326.795**	**2.357.327**	**2.388.178**	**2.419.353**	**2.450.854**	**2.482.684**	**2.514.847**	**2.547.347**	**2.580.186**	**2.470.869**
Depreciation desal assets 50y	0		-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200
Depreciation desal assets 20y	0		-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438
Depreciation PV assets 20y			-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000	-285.000
Operating result	**-511.250**	**-825.000**	**1.060.746**	**1.088.250**	**1.116.043**	**1.144.128**	**1.172.508**	**1.201.187**	**1.230.166**	**1.259.450**	**1.289.041**	**1.033.943**	**1.349.158**	**1.379.689**	**1.410.541**	**1.441.715**	**1.473.216**	**1.505.046**	**1.537.210**	**1.569.710**	**1.602.549**	**1.493.231**
Interest debt desal	0	0	-592.000	-572.120	-551.444	-529.941	-507.579	-484.321	-460.134	-434.979	-408.818	-381.610	-353.314	-323.886	-293.281	-261.452	-228.350	-193.923	-158.120	-120.884	-82.159	-41.885
Interest debt PV	0	0	-228.000	-220.343	-212.380	-204.099	-195.486	-186.529	-177.214	-167.526	-157.450	-146.971	-136.074	-124.740	-112.953	-100.694	-87.945	-74.687	-60.897	-46.557	-31.642	-16.131
Financial result	**-511.250**	**-825.000**	**240.746**	**295.787**	**352.218**	**410.087**	**469.443**	**530.336**	**592.819**	**656.946**	**722.774**	**505.362**	**859.770**	**931.063**	**1.004.307**	**1.079.569**	**1.156.921**	**1.236.437**	**1.318.193**	**1.402.269**	**1.488.748**	**1.435.215**
EBT	**-511.250**	**-825.000**	**240.746**	**295.787**	**352.218**	**410.087**	**469.443**	**530.336**	**592.819**	**656.946**	**722.774**	**505.362**	**859.770**	**931.063**	**1.004.307**	**1.079.569**	**1.156.921**	**1.236.437**	**1.318.193**	**1.402.269**	**1.488.748**	**1.435.215**
Income tax	0	0	-60.186	-73.947	-88.055	-102.522	-117.361	-132.584	-148.205	-164.236	-180.693	-126.340	-214.943	-232.766	-251.077	-269.892	-289.230	-309.109	-329.548	-350.567	-372.187	-358.804
Profit/loss	-511.250	-825.000	180.559	221.840	264.164	307.566	352.082	397.752	444.614	492.709	542.080	379.021	644.828	698.298	753.230	809.677	867.691	927.328	988.645	1.051.702	1.116.561	1.076.411
Dividend on equity	0	0	-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Profit/loss for reporting periode after dividend	**-511.250**	**-825.000**	**0**	**0**	**0**	**11.566**	**56.082**	**101.752**	**148.614**	**196.709**	**246.080**	**83.021**	**348.828**	**402.298**	**457.230**	**513.677**	**571.691**	**631.328**	**692.645**	**755.702**	**820.561**	**780.411**

LIQUIDITY

Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Cash 1.1.		3.188.750	2.825.000	3.114.212	3.375.886	3.608.922	3.823.740	4.052.099	4.293.913	4.549.087	4.817.512	5.099.072	5.179.886	5.487.312	5.807.448	6.140.123	6.485.158	6.842.355	7.211.504	7.592.377	7.984.731	8.388.305
Operating cash result	-511.250	-20.863.750	2.038.383	2.065.887	2.093.680	2.121.765	2.150.146	2.178.824	2.207.804	2.237.088	2.266.679	2.011.580	2.326.795	2.357.327	2.388.178	2.419.353	2.450.854	2.482.684	2.514.847	2.547.347	2.580.186	2.328.369
Cash from equity	3.700.000																					
Cash from desal financing		14.800.000																				
Cash from PV financing		5.700.000																				
Income tax	0	0	-60.186	-73.947	-88.055	-102.522	-117.361	-132.584	-148.205	-164.236	-180.693	-126.340	-214.943	-232.766	-251.077	-269.892	-289.230	-309.109	-329.548	-350.567	-372.187	-358.804
Cash flow I	**3.188.750**	**2.825.000**	**4.803.197**	**5.106.152**	**5.381.512**	**5.628.166**	**5.856.525**	**6.098.339**	**6.353.513**	**6.621.938**	**6.903.498**	**6.984.312**	**7.291.738**	**7.611.873**	**7.944.549**	**8.289.584**	**8.646.781**	**9.015.930**	**9.396.803**	**9.789.157**	**10.192.731**	**10.357.870**
Cash Flow II	**3.188.750**	**2.825.000**	**4.803.197**	**5.106.152**	**5.381.512**	**5.628.166**	**5.856.525**	**6.098.339**	**6.353.513**	**6.621.938**	**6.903.498**	**6.984.312**	**7.291.738**	**7.611.873**	**7.944.549**	**8.289.584**	**8.646.781**	**9.015.930**	**9.396.803**	**9.789.157**	**10.192.731**	**10.357.870**
Repayment desal debt (capital & interest)	0	0	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010
Repayment PV debt (capital & interest)	0	0	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416	-419.416
Cash Flow III	**3.188.750**	**2.825.000**	**3.294.771**	**3.597.726**	**3.873.086**	**4.119.740**	**4.348.099**	**4.589.913**	**4.845.087**	**5.113.512**	**5.395.072**	**5.475.886**	**5.783.312**	**6.103.448**	**6.436.123**	**6.781.158**	**7.138.355**	**7.507.504**	**7.888.377**	**8.280.731**	**8.684.305**	**8.849.444**
Cash Flow IV	**3.188.750**	**2.825.000**	**3.294.771**	**3.597.726**	**3.873.086**	**4.119.740**	**4.348.099**	**4.589.913**	**4.845.087**	**5.113.512**	**5.395.072**	**5.475.886**	**5.783.312**	**6.103.448**	**6.436.123**	**6.781.158**	**7.138.355**	**7.507.504**	**7.888.377**	**8.280.731**	**8.684.305**	**8.849.444**
Cash Flow V	**3.188.750**	**2.825.000**	**3.294.771**	**3.597.726**	**3.873.086**	**4.119.740**	**4.348.099**	**4.589.913**	**4.845.087**	**5.113.512**	**5.395.072**	**5.475.886**	**5.783.312**	**6.103.448**	**6.436.123**	**6.781.158**	**7.138.355**	**7.507.504**	**7.888.377**	**8.280.731**	**8.684.305**	**8.849.444**
Dividend	0	0	-180.559	-221.840	-264.164	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000	-296.000
Cash Floiw VI	**3.188.750**	**2.825.000**	**3.114.212**	**3.375.886**	**3.608.922**	**3.823.740**	**4.052.099**	**4.293.913**	**4.549.087**	**4.817.512**	**5.099.072**	**5.179.886**	**5.487.312**	**5.807.448**	**6.140.123**	**6.485.158**	**6.842.355**	**7.211.504**	**7.592.377**	**7.984.731**	**8.388.305**	**8.553.444**

Appendix 11: Project flows desalination with PV and EES

Periode	0	1	2	3	4	5	6	7	8	9	10
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Assumptions											
1. Revenue											
Product water sold	0,00	0,00	3.814.250,00	3.852.392,50	3.890.916,43	3.929.825,59	3.969.123,85	4.008.815,08	4.048.903,23	4.089.392,27	4.130.286,19
Sum Revenue	**0**	**0**	**3.814.250**	**3.852.393**	**3.890.916**	**3.929.826**	**3.969.124**	**4.008.815**	**4.048.903**	**4.089.392**	**4.130.286**
2. Desalination											
Planning and pre-construction costs	511.250	0	0	0	0	0	0	0	0	0	0
Construction costs	0	14.338.750	0	0	0	0	0	0	0	0	0
Financial costs		825.000									
Contingency & Reserves	0	2.825.000	0	0	0	0	0	0	0	0	0
O/M costs variable (ex-energy)	0	0	368.125	371.806	375.524	379.280	383.072	386.903	390.772	394.680	398.627
O/M costs variable (energy)	0	0	444.996	448.556	452.144	455.761	459.407	463.083	466.787	470.522	474.286
O/M costs fixed	0		460.750	465.358	470.011	474.711	479.458	484.253	489.095	493.986	498.926
Sum Desal Project Costs	**-511.250**	**-17.988.750**	**-1.273.871**	**-1.285.720**	**-1.297.680**	**-1.309.752**	**-1.321.938**	**-1.334.239**	**-1.346.655**	**-1.359.188**	**-1.371.839**
3. PV											
Construction & replacement costs		12.060.000									
O/M costs			120.600	121.806	123.024	124.254	125.497	126.752	128.019	129.300	130.593
Sum PV Project Costs		**-12.060.000**	**-120.600**	**-121.806**	**-123.024**	**-124.254**	**-125.497**	**-126.752**	**-128.019**	**-129.300**	**-130.593**
4. EES											
Construction & replacement costs		15.250.545									
Repayment (C+I, 20y)			1.880.254	1.880.254	1.880.254	1.880.254	1.880.254	1.880.254	1.880.254	1.880.254	1.880.254
O/M costs			76.253	77.015	77.785	78.563	79.349	80.142	80.944	81.753	82.571
Sum		**-15.250.545**	**-76.253**	**-77.015**	**-77.785**	**-78.563**	**-79.349**	**-80.142**	**-80.944**	**-81.753**	**-82.571**
5. Financials (from P/L)											
Income tax			0	0	0	0	0	0	0	0	0
Dividend			0	0	0	0	0	0	0	0	0
Sum Financials		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6. Sale at project end											
Result	**-511.250**	**-45.299.295**	**2.343.526**	**2.367.852**	**2.392.427**	**2.417.256**	**2.442.340**	**2.467.682**	**2.493.285**	**2.519.152**	**2.545.284**
Product costs/m³ (pre-tax)	**1,44**		1,54	1,54	1,54	1,55	1,55	1,56	1,56	1,57	1,57
Project PV	-511.250	-43.422.126	2.153.323	2.085.516	2.019.842	1.956.234	1.894.628	1.834.961	1.777.170	1.721.199	1.666.989
Project NPV	**-16.637.468**										
Project IRR (pre-tax)	**-0,42%**										
Equity flows	-3.700.000	0	0	0	0	0	0	0	0	0	0
Equity PV	-3.700.000	0	0	0	0	0	0	0	0	0	0
Equity NPV	**-7.906.395**										
Equity IRR	#ZAHL!										
DSCR (average)	**0,68**		0,61	0,61	0,62	0,63	0,63	0,64	0,65	0,65	0,66

Periode	11	12	13	14	15	16	17	18	19	20	21
Year	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Assumptions											
1. Revenue											
Product water sold	4.171.589,05	4.213.304,94	4.255.437,99	4.297.992,37	4.340.972,29	4.384.382,02	4.428.225,84	4.472.508,10	4.517.233,18	4.562.405,51	4.608.029,56
Sum Revenue	**4.171.589**	**4.213.305**	**4.255.438**	**4.297.992**	**4.340.972**	**4.384.382**	**4.428.226**	**4.472.508**	**4.517.233**	**4.562.406**	**4.608.030**
2. Desalination											
Planning and pre-construction costs	0	0	0	0	0	0	0	0	0	0	0
Construction costs	0	0	0	0	0	0	0	0	0	0	0
Financial costs											
Contingency & Reserves	0	0	0	0	0	0	0	0	0	0	0
O/M costs variable (ex-energy)	402.613	406.639	410.705	414.812	418.961	423.150	427.382	431.656	435.972	440.332	444.735
O/M costs variable (energy)	478.080	481.905	485.760	489.646	493.563	497.512	501.492	505.504	509.548	513.624	517.733
O/M costs fixed	503.915	508.955	514.044	519.185	524.376	529.620	534.916	540.266	545.668	551.125	556.636
Sum Desal Project Costs	**-1.384.609**	**-1.397.498**	**-1.410.510**	**-1.423.643**	**-1.436.900**	**-1.450.282**	**-1.463.790**	**-1.477.425**	**-1.491.188**	**-1.505.081**	**-1.519.105**
3. PV											
Construction & replacement costs	285.000										142.500
O/M costs	131.898	133.217	134.550	135.895	137.254	138.627	140.013	141.413	142.827	144.255	145.698
Sum PV Project Costs	**-416.898**	**-133.217**	**-134.550**	**-135.895**	**-137.254**	**-138.627**	**-140.013**	**-141.413**	**-142.827**	**-144.255**	**-288.198**
4. EES											
Construction & replacement costs	7.625.272										
Repayment (C+I, 20y)	1.880.254	940.127	940.127	940.127	940.127	940.127	940.127	940.127	940.127	940.127	940.127
O/M costs	83.396	84.230	85.073	85.923	86.783	87.651	88.527	89.412	90.306	91.210	92.122
Sum	**-7.708.669**	**-84.230**	**-85.073**	**-85.923**	**-86.783**	**-87.651**	**-88.527**	**-89.412**	**-90.306**	**-91.210**	**-92.122**
5. Financials (from P/L)											
Income tax	0	0	0	0	0	-9.526	-39.594	-70.656	-102.750	-135.915	-134.567
Dividend	0	0	0	191.085	78.337	-28.578	-118.782	-211.969	-296.000	-296.000	-296.000
Sum Financials	**0**	**0**	**0**	**191.085**	**78.337**	**-38.103**	**-158.376**	**-282.625**	**-398.750**	**-431.915**	**-430.567**
6. Sale at project end											**-22.154.040**
Result	**-5.338.587**	**2.598.359**	**2.625.306**	**2.652.531**	**2.680.035**	**2.707.823**	**2.735.896**	**2.764.258**	**2.792.911**	**2.821.860**	**2.708.605**
Product costs/m³ (pre-tax)	1,61	1,31	1,31	1,32	1,32	1,32	1,33	1,33	1,34	1,34	1,34
Project PV	-3.351.524	1.563.633	1.514.381	1.466.680	1.420.480	1.375.734	1.332.397	1.290.423	1.249.771	1.210.398	1.113.674
Equity flows	0	0	0	-191.085	-78.337	28.578	118.782	211.969	296.000	296.000	-21.858.040
Equity PV	0	0	0	-65.057	-24.695	8.342	32.103	53.045	68.587	63.506	-4.342.225
DSCR (average)	-1,38	0,89	0,90	0,91	0,92	0,93	0,94	0,95	0,96	0,97	0,93

Appendix 12: BS, P&L and CF desalination plant with PV and EES

Balance Sheet																						
Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
ASSETS																						
Desal assets 50y		810.000	793.800	777.600	761.400	745.200	729.000	712.800	696.600	680.400	664.200	648.000	631.800	615.600	599.400	583.200	567.000	550.800	534.600	518.400	502.200	486.000
Desal assets 20y		13.528.750	12.852.313	12.175.875	11.499.438	10.823.000	10.146.563	9.470.125	8.793.688	8.117.250	7.440.813	6.764.375	6.087.938	5.411.500	4.735.063	4.058.625	3.382.188	2.705.750	2.029.313	1.352.875	676.438	0
PV 20y		12.060.000	11.457.000	10.854.000	10.251.000	9.648.000	9.045.000	8.442.000	7.839.000	7.236.000	6.633.000	6.030.000	5.427.000	4.824.000	4.221.000	3.618.000	3.015.000	2.412.000	1.809.000	1.206.000	603.000	0
EES 10y (start and replacement)		15.250.545	13.725.490	12.200.436	10.675.381	9.150.327	7.625.272	6.100.218	4.575.163	3.050.109	1.525.054	7.625.272	6.862.745	6.100.218	5.337.691	4.575.163	3.812.636	3.050.109	2.287.582	1.525.054	762.527	0
Cash	3.188.750	2.825.000	1.311.867	-176.942	-1.641.174	-3.080.578	-4.494.898	-5.883.876	-7.247.250	-8.584.759	-9.896.134	-11.466.109	-11.784.283	-12.075.510	-12.148.427	-12.306.588	-12.553.401	-12.892.414	-13.327.313	-13.849.685	-14.376.274	-15.014.767
Total assets	**3.188.750**	**44.474.295**	**40.140.469**	**35.830.969**	**31.546.045**	**27.285.949**	**23.050.937**	**18.841.267**	**14.657.201**	**10.499.000**	**6.366.933**	**9.601.539**	**7.225.200**	**4.875.808**	**2.744.726**	**528.401**	**-1.776.577**	**-4.173.755**	**-6.666.819**	**-9.247.356**	**-11.832.109**	**-14.528.767**
LIABILITIES																						
Registered capital	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000	3.700.000
Debt desal		14.800.000	14.302.990	13.786.100	13.248.534	12.689.465	12.108.034	11.503.345	10.874.469	10.220.438	9.540.246	8.832.846	8.097.150	7.332.026	6.536.297	5.708.739	4.848.079	3.952.992	3.022.102	2.053.976	1.047.125	0
Debt PV	0	12.060.000	11.655.004	11.233.808	10.795.765	10.340.199	9.866.412	9.373.672	8.861.223	8.328.276	7.774.011	7.197.576	6.598.083	5.974.610	5.326.199	4.651.851	3.950.529	3.221.154	2.462.604	1.673.713	853.265	0
Debt EES (start and replacement)	0	15.250.545	13.980.312	12.659.271	11.285.388	9.856.549	8.370.557	6.825.125	5.217.876	3.546.337	1.807.937	7.625.272	6.990.156	6.329.635	5.642.694	4.928.275	4.185.278	3.412.563	2.608.938	1.773.169	903.968	0
Profit/Loss pre-period		-511.250	-1.336.250	-3.497.837	-5.548.210	-7.483.642	-9.300.265	-10.994.066	-12.560.876	-13.996.368	-15.296.051	-16.455.261	-17.754.155	-18.160.189	-18.460.463	-18.460.463	-18.460.463	-18.460.463	-18.460.463	-18.460.463	-18.448.213	-18.336.467
Profit/loss	-511.250	-825.000	-2.161.587	-2.050.373	-1.935.432	-1.816.624	-1.693.801	-1.566.810	-1.435.493	-1.299.683	-1.159.210	-1.298.894	-406.034	-300.274	-191.085	-78.337	28.578	118.782	211.969	308.251	407.745	403.700
Dividend	0	0	0	0	0	0	0	0	0	0	0	0	0	0	191.085	78.337	-28.578	-118.782	-211.969	-296.000	-296.000	-296.000
Profit/loss after dividend	-511.250	-1.336.250	-3.497.837	-5.548.210	-7.483.642	-9.300.265	-10.994.066	-12.560.876	-13.996.368	-15.296.051	-16.455.261	-17.754.155	-18.160.189	-18.460.463	-18.460.463	-18.460.463	-18.460.463	-18.460.463	-18.460.463	-18.448.213	-18.336.467	-18.228.767
Total liabilities	**3.188.750**	**44.474.295**	**40.140.469**	**35.830.969**	**31.546.045**	**27.285.949**	**23.050.937**	**18.841.267**	**14.657.201**	**10.499.000**	**6.366.933**	**9.601.539**	**7.225.200**	**4.875.808**	**2.744.726**	**528.401**	**-1.776.577**	**-4.173.755**	**-6.666.819**	**-9.247.356**	**-11.832.109**	**-14.528.767**

P&L ACCOUNT																						
Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	20
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Revenues	0	0	3.814.250	3.852.393	3.890.916	3.929.826	3.969.124	4.008.815	4.048.903	4.089.392	4.130.286	4.171.589	4.213.305	4.255.438	4.297.992	4.340.972	4.384.382	4.428.226	4.472.508	4.517.233	4.562.406	4.608.030
Costs	-511.250	-825.000	-1.470.724	-1.484.541	-1.498.489	-1.512.570	-1.526.784	-1.541.133	-1.555.618	-1.570.241	-1.585.002	-1.884.903	-1.614.946	-1.630.132	-1.645.462	-1.660.937	-1.676.559	-1.692.330	-1.708.250	-1.724.322	-1.740.546	-1.899.424
Operating cash result	**-511.250**	**-825.000**	**2.343.526**	**2.367.852**	**2.392.427**	**2.417.256**	**2.442.340**	**2.467.682**	**2.493.285**	**2.519.152**	**2.545.284**	**2.286.686**	**2.598.359**	**2.625.306**	**2.652.531**	**2.680.035**	**2.707.823**	**2.735.896**	**2.764.258**	**2.792.911**	**2.821.860**	**2.708.605**
Depreciation desal assets 50y	0		-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200	-16.200
Depreciation desal assets 20y	0		-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438	-676.438
Depreciation PV assets 20y			-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000	-603.000
Depreciation EES 10y (start and replacement)	0	0	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-1.525.054	-762.527	-762.527	-762.527	-762.527	-762.527	-762.527	-762.527	-762.527	-762.527	-762.527
Operating result	**-511.250**	**-825.000**	**-477.166**	**-452.840**	**-428.265**	**-403.436**	**-378.352**	**-353.010**	**-327.407**	**-301.540**	**-275.408**	**-534.006**	**540.194**	**567.141**	**594.366**	**621.870**	**649.658**	**677.731**	**706.093**	**734.747**	**763.695**	**650.441**
Interest debt desal	0	0	-592.000	-572.120	-551.444	-529.941	-507.579	-484.321	-460.134	-434.979	-408.818	-381.610	-353.314	-323.886	-293.281	-261.452	-228.350	-193.923	-158.120	-120.884	-82.159	-41.885
Interest debt PV	0	0	-482.400	-466.200	-449.352	-431.831	-413.608	-394.656	-374.947	-354.449	-333.131	-310.960	-287.903	-263.923	-238.984	-213.048	-186.074	-158.021	-128.846	-98.504	-66.949	-34.131
Interest debt EES			-610.022	-559.212	-506.371	-451.416	-394.262	-334.822	-273.005	-208.715	-141.853	-72.317	-305.011	-279.606	-253.185	-225.708	-197.131	-167.411	-136.503	-104.358	-70.927	-36.159
Financial result	**-511.250**	**-825.000**	**-2.161.587**	**-2.050.373**	**-1.935.432**	**-1.816.624**	**-1.693.801**	**-1.566.810**	**-1.435.493**	**-1.299.683**	**-1.159.210**	**-1.298.894**	**-406.034**	**-300.274**	**-191.085**	**-78.337**	**38.103**	**158.376**	**282.625**	**411.001**	**543.661**	**538.266**
EBT	**-511.250**	**-825.000**	**-2.161.587**	**-2.050.373**	**-1.935.432**	**-1.816.624**	**-1.693.801**	**-1.566.810**	**-1.435.493**	**-1.299.683**	**-1.159.210**	**-1.298.894**	**-406.034**	**-300.274**	**-191.085**	**-78.337**	**38.103**	**158.376**	**282.625**	**411.001**	**543.661**	**538.266**
Income tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-9.526	-39.594	-70.656	-102.750	-135.915	-134.567
Profit/loss	-511.250	-825.000	-2.161.587	-2.050.373	-1.935.432	-1.816.624	-1.693.801	-1.566.810	-1.435.493	-1.299.683	-1.159.210	-1.298.894	-406.034	-300.274	-191.085	-78.337	28.578	118.782	211.969	308.251	407.745	403.700
Dividend on equity	0	0													191.085	78.337	-28.578	-118.782	-211.969	-296.000	-296.000	-296.000
Profit/loss for reporting periode after dividend	**-511.250**	**-825.000**	**-2.161.587**	**-2.050.373**	**-1.935.432**	**-1.816.624**	**-1.693.801**	**-1.566.810**	**-1.435.493**	**-1.299.683**	**-1.159.210**	**-1.298.894**	**-406.034**	**-300.274**	**0**	**0**	**0**	**0**	**0**	**12.251**	**111.745**	**107.700**

LIQUIDITY																						
Periode	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Cash 1.1.		3.188.750	2.825.000	1.311.867	-176.942	-1.641.174	-3.080.578	-4.494.898	-5.883.876	-7.247.250	-8.584.759	-9.896.134	-19.091.381	-19.409.555	-19.700.782	-19.773.699	-19.931.860	-20.178.673	-20.517.686	-20.952.586	-21.474.957	-22.001.546
Operating cash result	-511.250	-42.474.295	2.343.526	2.367.852	2.392.427	2.417.256	2.442.340	2.467.682	2.493.285	2.519.152	2.545.284	-12.963.859	2.598.359	2.625.306	2.652.531	2.680.035	2.707.823	2.735.896	2.764.258	2.792.911	2.821.860	2.708.605
Cash from equity	3.700.000																					
Cash from desal financing		14.800.000																				
Cash from PV financing		12.060.000																				
Cash from EES financing		15.250.545										7.625.272										
Income tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-9.526	-39.594	-70.656	-102.750	-135.915	-134.567
Cash flow I	**3.188.750**	**2.825.000**	**5.168.526**	**3.679.718**	**2.215.486**	**776.082**	**-638.238**	**-2.027.216**	**-3.390.591**	**-4.728.099**	**-6.039.474**	**-15.234.721**	**-16.493.022**	**-16.784.249**	**-17.048.252**	**-17.093.664**	**-17.233.563**	**-17.482.371**	**-17.824.084**	**-18.262.425**	**-18.789.013**	**-19.427.507**
Cash Flow II	**3.188.750**	**2.825.000**	**5.168.526**	**3.679.718**	**2.215.486**	**776.082**	**-638.238**	**-2.027.216**	**-3.390.591**	**-4.728.099**	**-6.039.474**	**-15.234.721**	**-16.493.022**	**-16.784.249**	**-17.048.252**	**-17.093.664**	**-17.233.563**	**-17.482.371**	**-17.824.084**	**-18.262.425**	**-18.789.013**	**-19.427.507**
Repayment desal debt (capital & interest)	0	0	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010	-1.089.010
Repayment PV debt (capital & interest)	0	0	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396	-887.396
Repayment EES debt (capital & interest)	0	0	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-1.880.254	-940.127	-940.127	-940.127	-940.127	-940.127	-940.127	-940.127	-940.127	-940.127	-940.127
Cash Flow III	**3.188.750**	**2.825.000**	**1.311.867**	**-176.942**	**-1.641.174**	**-3.080.578**	**-4.494.898**	**-5.883.876**	**-7.247.250**	**-8.584.759**	**-9.896.134**	**-19.091.381**	**-19.409.555**	**-19.700.782**	**-19.964.784**	**-20.010.197**	**-20.150.096**	**-20.398.904**	**-20.740.617**	**-21.178.957**	**-21.705.546**	**-22.344.040**
Cash Flow IV	**3.188.750**	**2.825.000**	**1.311.867**	**-176.942**	**-1.641.174**	**-3.080.578**	**-4.494.898**	**-5.883.876**	**-7.247.250**	**-8.584.759**	**-9.896.134**	**-19.091.381**	**-19.409.555**	**-19.700.782**	**-19.964.784**	**-20.010.197**	**-20.150.096**	**-20.398.904**	**-20.740.617**	**-21.178.957**	**-21.705.546**	**-22.344.040**
Cash Flow V	**3.188.750**	**2.825.000**	**1.311.867**	**-176.942**	**-1.641.174**	**-3.080.578**	**-4.494.898**	**-5.883.876**	**-7.247.250**	**-8.584.759**	**-9.896.134**	**-19.091.381**	**-19.409.555**	**-19.700.782**	**-19.964.784**	**-20.010.197**	**-20.150.096**	**-20.398.904**	**-20.740.617**	**-21.178.957**	**-21.705.546**	**-22.344.040**
Dividend	0	0	0	0	0	0	0	0	0	0	0	0	0	0	191.085	78.337	-28.578	-118.782	-211.969	-296.000	-296.000	-296.000
Cash Floiw VI	**3.188.750**	**2.825.000**	**1.311.867**	**-176.942**	**-1.641.174**	**-3.080.578**	**-4.494.898**	**-5.883.876**	**-7.247.250**	**-8.584.759**	**-9.896.134**	**-19.091.381**	**-19.409.555**	**-19.700.782**	**-19.773.699**	**-19.931.860**	**-20.178.673**	**-20.517.686**	**-20.952.586**	**-21.474.957**	**-22.001.546**	**-22.640.040**