MSc Program
Renewable Energy in Central and Eastern Europe

Technical and economic analysis of combining RES with Desalination technologies in Mediterranean countries.

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supervised by
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Roland Szalai
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Affidavit

I, **Roland Szalai**, hereby declare

1. that I am the sole author of the present Master Thesis, Technical and economic analysis of combining RES with Desalination technologies in Mediterranean countries.",
   128 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.

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Abstract

Water is a strategic resource. 71 % of the planet is covered by water. From this tremendous volume drinking water is just 2.5%. According to UNESCO more than 1 billion people on the earth suffer from water scarcity. The more rapid the number of people increases, the more rapid the demand for water utilization expands. Different interests bring face to face with each other like: industry, agriculture and households.

Therefore the aim of the master thesis is to analyze the opportunities of water production from sea water for drinking water or industrial water purposes. The costs of electricity during the water production provide 54% of the O&M costs. Therefore, the core idea to reduce the water production costs is combining the existing renewable energy source like photovoltaic or wind with desalination technology like reverse osmosis. The thesis will provide a general technical overview, the combining option of technology for a selected location in Mediterranean countries and an analysis from the economic point of view.

The core questions to be answered are:

Which renewable energy source would be suitable for sea water desalination?

Would the implementation of desalination technology be feasible for the chosen Mediterranean country?

What would a competitive water production cost €/m^3 be?

To answer this question, first of all, the country needs to be analyzed from the demand side, political willingness to be interested creating a pleasurable regulation frame conditions. Geographical and water data are necessary for choosing the location. After all, the technical and

financial requirement will provide a result, that helps the decision maker to see the investment opportunity. The potential investor can use the master thesis as an entire business plan.

The pre-selected frames for the master thesis:

The analyzed countries are Algeria, Tunisia and Morocco

The considered renewable technologies are photovoltaic and wind energy

The thesis focus on reverse osmosis desalination technology

After determining the frame parameters of the master thesis, the main countries need to be investigated to present basic background information about the possible choice of area for the project. The examination is followed by the determination of area, the required water quality. To hold the focus on economic feasibility, the demand analysis was carefully realized.

The technical description of the possible desalination technologies gave an informational overview followed by the detail characterization of a seawater desalination plant. In the economic part of the master thesis, the capital cost, operation and maintenance and water production cost are discussed.

In the end the three different possible scenarios for water production will be calculated and discussed in details to answer the core questions of the master thesis.

Executive Summary

Our world is constantly changing on every level of our life. The effect of global warming can be measured today. The temperature is rising, the number of drought is increasing and evermore the area faces physical water scarcity. The potable water is the source of our life. In my point of view, everyone has a right to have enough water for drinking and hygienic purposes.

Therefore it is essential to look for ways, how to ensure the supply for the growing water demand of industries and people. In the coastal region seawater desalination can be a solution. The aim of this master thesis was to investigate the option of applying the RO membrane desalination in the Mediterranean countries. As in the point of an investor, not just the economic calculation, but the political, military and geographical risks need to be analyzed. Therefore, among the preselected countries, Morocco seemed to be the best choice for the project.

The results of the demand analyses show a tremendous potential for creating business in the water supply sector. Among the three sectors, the drinking water seems to have the most predictable demand in term of volume and time. In this master thesis the core aim was to examine a situation with 100% capacity, production 24h a day in 360 days of the year. The remaining 5 days are reserved for maintenance and cleaning purposes, therefore during this time is no production available. The master thesis is analyzing a plant of large scale. The capacity of the plant is selected for 100,000 m^3/day, because at this scale the 100% of the production can be assumed by the water distributor.

For the drinking water production three different scenarios were calculated. The basic idea of the business consists of a built-own-operate-transfer (BOOT) contract. The investor build and operate the desalination plant. The lifetime of a membrane desalination plant like this exceeds 50 years. However, the investment horizon is 30 years in the calculation of considering different scenarios.

The converted water tariff is 0.74 US$/m^3 in Morocco. (Moroccan Investment Development Agency)

Since the 54% of the O&M cost is electricity, it is important to search for a reduction solution in the term of the energy price, to be competitive against other technologies on the water market like Multistage Flash-, Multiple-Effect Distillation or Vapor compression. Three scenarios were compared with each other:

Energy supply from the conventional electricity entity

Production of the electricity itself with photovoltaic

Energy supply with Wind Park

The following table summarizes the key parameters of the scenarios:

Table 1 The key parameters of the scenarios (Own calculation)

Source of electricity	Conventional	PV	Wind
Investment horizon (yr)	30yr	30yr	30yr
Investment cost (US$)	166.172.942.	242.636.942	236.732.942
O&M (US$/m3)	0,4396	0,2001	0,2001
NPV (US$)	-18.449.325	9.552.111	3.113.782
Annuity (US$)	-941.270	487.341	15.862
Water production price (US$/m3)	0,98	0,55	0,53

In the core objectives the following questions were mentioned:

A,) Which renewable energy source would be suitable for sea water desalination?

In the chosen region, the electricity generation with wind power seems to be the best choice for combining the renewable energy with the seawater desalination in the economic point of view, because it has the lowest water production cost.

B,) Would the implementation of desalination technology be feasible for the chosen Mediterranean country?

As the summary table shows, the actual water tariff is not sufficient for the water production from the conventional energy sources. On the other hand, if the electricity is generated by the renewable energies, the desalination is economically feasible.

C,) What would a competitive water production cost US$/$m^3$ be?

In the given area, a water production cost under 55US$cent/$m^3$ would be realistic in the economic point of view.

The importance to supply the increasing demand of industry and people therefore, the humanity should look for new solutions. For the coastal region of the world, RO membrane desalination is proved to be an as economic feasible way to produce drinking water. The point of my view, I believe that this technology can solve the water scarcity in the near future.

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Abbreviations

Alternating current	AC
Algérienne des Eaux	AdE
Buil-Operate-Transfer	BOT
Build-own-operate-transfer	BOOT
Balance-of-system components	BOS
Cellulose Acetate	CA
Calcium carbonate precipitation potential	CCPP
Chemically enhanced backwash	CEB
Clean-in place	CIP
Cimentos de L'Atlas	CIMAT
Dissolved air flotation	DAF
Design-bid-build	DBB
Direction Générale du Genie Rurale	DGGR
Design-build-operate	DBO
Direct current	DC
European Union's European Neighborhood Policy	ENP
Fluorosilicic acid	FSA
Gained output ratio	GOR
Langelier saturation index	LSI
Multistage Flash Distillation	MSF
Multiple Effect Distillation	MED
Natural organic matter	NOM
Nephelometric turbidity units	NTU
Organisation of Islamic Cooperation	OIC
Office National d'Assainissement	ONAS
Aromatic polyamide	PA
polyethersulfone	PES
polyvinylidene diflouride	PVDF
Reverse osmosis	RO
Silt density index	SDI
Sociéte Nationale d'Exploitation et de Distribution des Eaux	SONEDE
Specific UV absorbance	SUVA
Total dissolved solids	TDS
Total organic carbon	TOC
Total suspended solids	TSS
Arab Maghred Union	UMA
Ultraviolet	UV
Vapor compression	VC

1 Introduction

Water is a basic and essential element. This is the source of life. It surrounds us and also located in our body. For the perfect function of the body, we need high quality and clean water. Our growing society consumes more and more water for different purposes. Almost every industrial and agricultural process needs water. Just to get an imagination, the table below shows some collected datas of water usage.

Table 2 Water demand for the production (Source :HHU, Wikipedia)

Product	Water demand for the production
1 kg of beef	20,000 l
1 kg of butter	5-10 l
1 t of paper	400,000 l
1 t of steel	200,000 l
1 kg of plastic	500 l
1 l of milk	5 l
1 kg of sugar	120l
1 kg of leather	16,600 l
1 pair of jeans	10,855 l

Our natural water wells cannot keep in step with the expanding demand. As we know 2/3 of the earth’s surface is covered with water. From this large volume only 2.5% is useful as drinking water. According to the United Nations more than 1 billion people do not have access to clean water. The access to clean water is a fundamental right for all people, that’s why the water scarcity is a really important issue. (UNDESA Human right to water and sanitation, 2010)

There are two type of water scarcity:

- Physical water scarcity
- Economical water scarcity

Water stress is typically measured by comparing the amount of water used to that which is readily available. The figure below tells us how the water stress changed through the years with a prognosis for the year 2025.

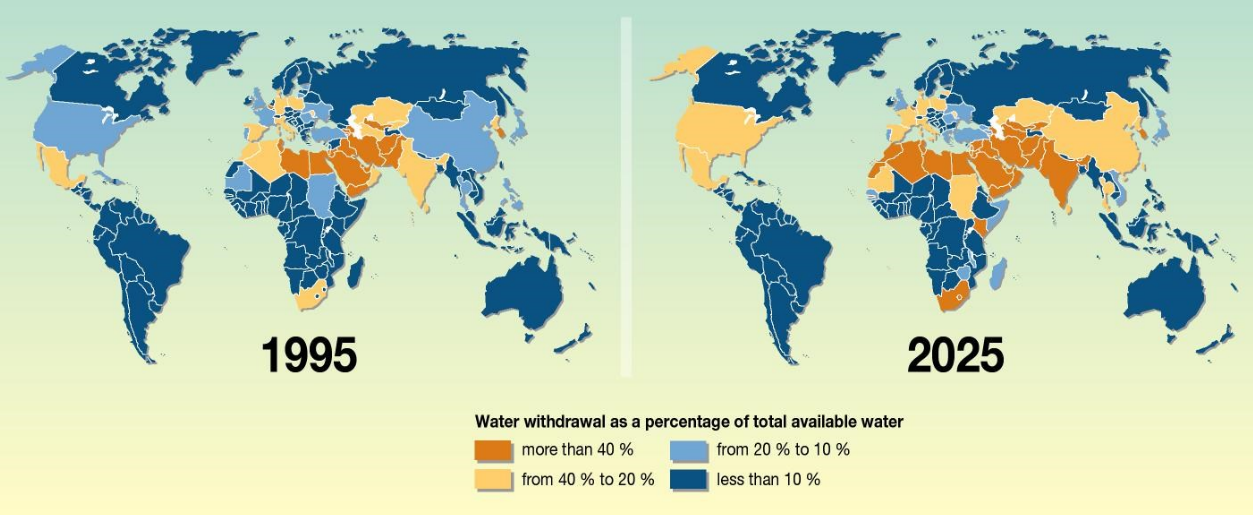

Figure 1 Global water stress Source: Jane Kucera, Desalination water from water, 2006.

For the measuring the water scarcity, the water stress index can also be used. This is the ratio of total water use to renewable water supply such as river, streams or shallow groundwater, which is the available local runoff. (Invented by Maplecroft) The number of countries facing water stress could rise from 48 to 54 by 2050. To solve this problem, we need to find new ways for the water supply. In many urbanized and coastal region the low-cost surface/groundwater sources disappeared. Therefore, the sea water desalination is an alternative for municipal water supply. Sir Richard Hawkins wrote about how his crew produced drinking water from the sea water with the help of distillation. The desalination in bigger scales appeared in the early twentieth century on the Island of Curacao. From the middle of the twentieth century an exponential increase started in the number of desalination facilities.

Over the last five decades the research and development in this sector had a significant impact on the learning curve, causing competitive efficient and cost-effective water production. The desalination will be the future for solving the water scarcity.

1.1 Motivation

The three essential elements for every human being are: air, food, water. Water is a must. Because of this, and the fact, that scarcity expands, a really important economic market will be created in the future. On the figure 1 it can be remarked, that by 2025 the Mediterranean countries will face a massive water supply problem. A lot of agricultural products are transported from the North African countries to Europe. This trading economy can be influenced negatively by the water scarcity in the future. The country leaders and organizations already realized the difficulty. For that reason the Dialogue 5+5 was created. The Dialogue 5+5 consists of 10 members[1]:

5 countries from the north side: Portugal, Spain, France, Italy, Malta

5 countries from the south side: Morocco, Algeria, Tunisia, Libya, Mauritania

The meeting was called alive for a cooperation amongst member countries to tackle issues as security and stability, economic integration and regional migration.

The last meeting was hold in Madrid 10th September 2015. At the end of the meeting the members agreed on the WS4 (Action Plan) [2].

The main point of the agreement:

- Actions oriented to enhance water governance at the national and regional level, including capacity building programs and training actions.
- Identification of replicable and cross-country defined national best practices and solutions.
- Development on national data water systems.

- Identification of projects aimed at addressing the following issues:
    - From the demand side, water efficiency and waste water reuse projects, including a proposal to optimize existing water provision systems with a focus on modernization of irrigation systems.
    - From the offer side, development of non-conventional resources, including desalination.
    - From environmental perspectives, projects oriented to preserve and restore water ecosystems, to develop wastewater treatment at the urban and rural level and to implement ground water monitoring and management systems

(Source:WS4 Action Plan, 2015)

Other organizations like UFM, UMA and MENBO help as well to form expedient political and financial conditions for the water management development in the region. Development programs like 2030 Global Sustainable Development Agenda or H2020 foster for project realizations with 4 billion €. (Union for Mediterranean: Water & Environment)[3]

1.2 What is the core objective/ the core question?

As discussed in the previous chapter the importance of this topic is unquestionable. From my perspective I believe that the water becomes the most valuable substance in the future. Knowing this fact, the master thesis provides me an opportunity to gain experience and deep knowledge in this topic. Seeing this potential, this master thesis will offer a solution for the water scarcity and give an overview for investors for this subject.

Therefore the aim of the master thesis is to analyze the opportunities of water production from sea water for drinking water or industrial water purposes. The core idea is to combine existing renewable energy source like photovoltaic or wind with desalination technology like reverse osmosis. The thesis will provide a general technical overview, the combining option of technology for a selected location in Mediterranean countries and an analysis from the economic point of view.

The core questions to be answered are:

> Which renewable energy source would be suitable for sea water desalination?
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> Would the implementation of desalination technology be feasible for the chosen Mediterranean country?
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> What would a competitive water production cost US$/m^3 be?

To answer this question, first of all, the country needs to be analyzed from the demand side, political willingness to be interested creating a pleasurable regulation frame conditions. Geographical and water data are necessary for choosing the location. After all the technical and financial requirement will provide a result, that helps the decision maker to see the investment opportunity. The potential investor can use the master thesis as an entire business plan.

The pre-selected frames for the master thesis:

The analyzed countries are Algeria, Tunisia, Morocco, because these countries seem to be politically stable today.

The considered renewable technologies are photovoltaic and wind energy, because those technologies seem to have the most potential in the area.

The thesis focus on reverse osmosis desalination technology, because this is the most common used and the most experienced technology.

1.3 Structure of work

First of all, some background information will be provided about the conditions of the pre-defined Mediterranean countries. After analyzing the collected data, in the project description will be the demand and the location determined. It is followed by the source water examination and the description of frame parameters. For the technical investigation the chapter 3.2 gives an overview about the different desalination technologies. After an explication of the desalination facility components is given the focus shifts to the possible water production using renewable energies. Since the electricity demand contributes 54% of the O&M cost of water production, therefore, reducing the cost of energy is essential. Electricity generation with renewable energies can provide a sufficient solution. Under consideration of different scenarios the result will be evaluated. The thesis's interest is directed towards investment alternative. After the technical evaluation, the economic calculation with NPV presents a business plan for the potential decision makers.

2 Background Information

2.1 Primary information about the Mediterranean Countries

This chapter provides the necessary information about the chosen countries. A short history about the country serves as an introduction, followed by a geographical description. To make a decision for the project, dates about the agricultural and industrial potential, as well as political and natural risk need to be investigated. The information was collected from several sources like internet, reports, books etc.

2.1.1 Algeria

Figure 2 Country map Algeria (Source: Google Map)

Algeria is located in North Africa, surrounded with Morocco, Mauritania, Mali, Niger, Libya, Tunisia and the Mediterranean Sea. On the area of 2,381,741 square kilometers about 40 million people live.[7]

With the capital city Algiers, Algeria is the biggest country of the continent. 80 % of the population is located in the north of the country, 80 % of the country is desert. The south part of the country is already in the Sahara. The daily temperature difference between day and night is enormous. The temperature range can be from –10° to 34° C. [4]

The land was inhabited with the Berbers in the ancient time.[5] In 1830 the French empire arrived and conquered Algeria. The occupation of the country took time and between 1830 and 1872 one third of the population died. The nation became independent in 1962 with the first president called Ahmed Ben Bella, leader of the Front de Libération Nationale. He began an impressive industrialization, starting with the nationalization of the Oil extraction. The country has a big power due to the tremendous energy reserves. Algeria controls the 17th largest oil, and the 9th largest natural gas reserves of the world. The main leading force of the economy is the energy export to Europe. Because of the controlled power and the large defense military trade with Russia, Algeria has a political support of Russia. Beside membership of the African Union, the Arab League, OPEC, the United Nations and the Maghreb Union, the state is also a part of the European Union's European Neighborhood Policy (ENP), which tries to maintain a good relationship with the neighbouring countries inclusive some subsidies.[8] The Democracy Index categorized Algeria as an authoritarian regime with not existing media and press freedom.[6] The politicians have a little influence over the country. The real power and control is held by the military and a group of civilian, on the top with the head of military intelligence, Mohamed Mediéne.[9]

The GDP of Algeria is divided in 31% services, 61% industry and 8% agriculture. Since 1969 it is the state member of OPEC and has a daily crude oil production of 1.1 million barrels. To reduce the dependence of the oil price, the state tries to develop other industry sectors, but the bureaucracy matters big barriers. The privatization progress of state-owned industries interrupted and limited the participation of foreign investors in the economy and set a constraint for the import.[8]

The smallest part of the GDP is the agricultural sector. 14 percent of the workforce is in the agricultural sector, but on the limited arable territory (3% of the land) enough food cannot be produced to fulfill the population’s needs. As a result, 75% of food need to be imported. The main agricultural products are: citrus fruit, vegetables, and grapes, dates, fish, wheat, barley, oats, wine grapes, olives, tobacco, potatoes.[9]

In Algeria a boosting fishing industry exist, with small family-owned businesses. The whole production reached 142,000 tons per year. 54% are sardines, the rest are bonito, mackerel smelt and sprats. The fish will be transported mainly to France, Spain and Italy. The state will reinforce the industry with subsidizing, giving permits for foreigners and modernizing fish ports.

Algeria has abundant mineral resources like iron, lead, zinc, copper, calamine, antimony and mercury. Yearly 2,000,000 tons of steel will be produced, which has a tremendous water demand. It needs 277500 l of water to produce 1 ton of steel.[9]

Due to the profitable exports the country improved the drinking water supply, built long-distance water pipelines and desalination plants, to be able to provide water to the customers at a low price. Since 2000 the policy maker and the water manager is the ministry of water resources for drinking water supply and sanitation. A year after, two state-owned companies were created. Algérienne des Eaux (AdE) is responsible for 80% of the water distribution system. The second company, Office National d'Assainissement (ONA) operates the sewer system in the country.[10]

In the four largest cities of Algeria the operation of the water system was privatized with management contracts. The private company's partner is the local utility and the contracts are valid for a defined period. The water tariffs are allocated for five tariff zones, with a fixed fee and a performance based variable fee. There are also three different categories of the users: residential; administration and services; as well as industrial and touristic. In the residential category the consumption is divided into 4 blocks. The fee difference exceeds 6.5 times of the lowest price. 74% of the population has access to drinking water, 84% to an improved water source and 95% to improved sanitation. The water supply is not permanent. Just 22% of urban residents gets water 24 hours per day, 34% receives water only once per day, 24% every second day and 14% only every third day. The situation is explained by the poor execution and lack of completion of work. From both conventional and non-conventional resources the country gains drinking water. Over the years the pollution of water resources reached an unacceptable level. For example the groundwater near the capital is polluted with nitrates and the salinity of groundwater near the coastal regions increased.[11]

Also Algeria wants to increase the water production. There are 15 operating sea water desalination plants in the land, and other 43 are under construction. The world largest desalination plant is planned to build in Mactaa, Algeria with a capacity of 500,000 m^3/day.[13]

The government reports an average water production of 170l per capita per day. It is highly varied from regions from 220l to 65l. Under consideration of physical and administrative losses, the estimated non-revenue water was 40% in 2004. Parts of the investments in the development of water infrastructure were carried out by the Algerian state covered with the exports revenues. But mainly the desalination plants are realized with Buil-Operate-Transfer (BOT) contracts.[12]

For the efficient operation of the water system, the constantly improving wastewater treatment is essential. Through public-private partnerships with French companies, the number of wastewater treatment facilities reached 113 in 2011.[10]

30 % of the GDP depends on the oil and gas prices. The falling oil prices reduced the revenues in the previous years. Therefore a lot of infrastructure projects will be postponed. The subsidies for food remain in place, because of the high dependence of import. This fact could be also the leading contributor to the inflation, which accelerated very fast in the year 2015. The Algerian dinar fell in value 20% against USD from the beginning of 2015. It is an expected reduce of subsidies and increases indirect taxes in the future. According to coface risk assessment, the country shows signs of a developing economic crisis and it is ranked as a country with high risk.[19]

Table 3 Country related water information[16,17,18]

Algeria			
Water Source	Surface water: 4.8km^3	Groundwater: 3km^3	Desalination: 0.615 km^3
Water withdrawal	8.425 km^3/year	2012	
Connection rate	84% of the population	2015	

2.1.2 Tunisia

Figure 3 Country map Tunisia (Source: Google Map)

Tunisia is located in the north of the African continent. In the country 11 million people live on 165,000 square kilometers. Tunisia is bordered by Algeria, Lybia and the Mediterranean Sea. The capital city is called Tunis and the official regulations form is Republic. In the history, first the berbers lived in this area and they were followed by the Phoenician in the 12th century BC. This tribe built the most important trading city at this time, Carthage. The city was destroyed by the roman republic, who occupied the country for eight hundred years. After that the Islam took over the area for the next three hundred years. From 1881 till 1957 the French conquered the country. In the year 1957 Tunisia gained the independence and became the Tunisian Republic.[20]

The north side of the state is situated in a mountainous region of the Atlas Mountains. It has a Mediterranean climate, characterized by hot, dry summers and mild rainy winters. Tunisia has the second nearest points to Europe after Gibraltar on the African continent. On the way to the south the climate changes to semiarid and it is followed by the Sahara. The south part of the country is desert. [21]

The economy of Tunisia is in process of liberalizing and privatizing. It is mainly export oriented. The country signed an association agreement with the European Union and it is a member of diverse trading Unions. The main trading partners are France and Italy. The country's GDP is divided into 11.6% for the agricultural sector, 25.6% for the industry and 62.8% for services. The main export products are textile and leather, this sector has 40 % share of industry. The rest is manufacture for car components; chemical industry – phosphate manure; mineral industry – iron, steel, lead, cement. 2.3 million metric tons of cement (Mt/yr) per year are produced in Tunisia. This is interesting in the point of our view, because 1 m^3 of cement needs 160 l clean salt-free water. Today in the agricultural sector there are 345,000 hectare available for food production. The main products are: wheat, barley, citrus fruits, dates, vegetables, beef, olives, viniculture, and fish. 18 % of workforce are employed in this sector and 80 % of the freshwater is used for agricultural purposes. It is caused by the desertification every year 20,000 hectare get lost. In the services the tourism is considerable. The most attractive places are Tunis and the ruin of Carthage.[22,23]

Among the Middle East and North African countries, Tunisia accomplished the highest access rates to water supply. 96% of the population has access to drinking quality water. Under the regulation of Ministry of Agriculture the Sociéte Nationale d'Exploitation et de Distribution des Eaux (SONEDE), the national water supply authority operates.[25]

The freshwater supply is divided into surface water 57% and groundwater 43%. The renewable water availability (486 m^3/ capita) is below the average (1200 m^3/capita) for the Middle East. Therefore Tunisia is a physical water stressed country. With eighteen existing dams and groundwater extractions in the coastal region the authority tries to improve the available water supply but the rapid sedimentation of reservoirs and the high salinity levels of water (more than 1500 mg/l) represent some obstacles.[24]

Since the country has a physical water stress, the government created the Plans Directeurs des Eaux (the first Water Master Plan) in the 1980s. The main characteristic policies of the plan:

-Control the exploitation of groundwater and protect the resources against pollution

-Enhancement in the control of water demand in all sectors.

-The aim is to obtain a mobilization rate of 95% of available water resources.

-Increasing the use of treated wastewater in agriculture sector and building desalination plants

-Improving the water storages for saving water from the rainy periods

In Tunisia the water supply has 3 big players. The planning and investment in drinking water distribution happens through the Direction Générale du Genie Rurale (DGGR). As mentioned above the responsible entity for water supply service is the SONEDE. It is mainly owned by the government. In the water sector the private participation is very low. In the field security and cleaning are some private contracts. The utility constantly monitors the quality of the drinking water from the production to the distribution to ensure high quality water throughout the year. For example in the capital city, the entity is able to supply permanent 110 liters per capita per day. In 2007 the utility reached a sewerage network connection in the urban areas up to 81.6%.[21]

The third part of the supply takes care about the sanitation of the distribution. This is the Office National de l'Assainissement (ONAS) and responsible for cities, industrial and tourist zones. The ONAS arranges to protect the water environment, planning and implementing wastewater treatment and sale of sub-products such as treated wastewater and sludge.

The reuse of waste water plays an important role to improve the effectiveness of water supply. The number of plants increases continuously, where orchards or livestock feed implanted. Today the biggest wastewater treatment plant of the country is located in Choutrana with a capacity of 120,000 ^{3} per day. [26]

To be able to provide permanent drinking water for the growing demand and cover the peak demand during the summer season, the government aimed to build four seawater desalination plants in Djerba, Kerkennah, Zaarat and Sfax within a total installed capacity of 381,000 cubic meter/day. The project is mainly financed by external partners like The French Development Agency AFD, the African Development Bank, the European Investment Bank, the German development bank KfW and the World Bank or by the private sector through Build-operate-Transfer (BOT).[27]

Tunisia has the lowest rate of non-revenue water supply in the region at 21 % in 2012. The tariffs for drinking water are given by the ministry and they are the same in the country. It includes a fixed part and a variable part that depends on the consumption of water. With the revenues the SONEDE covers the operation and maintenance costs. Under the regulation of the Ministry of Agriculture the distributor makes a remarkable annual deficit of TND82 million ($50 million). The dependence of the utility on subsidies shows, that the average cost of a cubic metric is TND0.716 ($0.44) and it is sold at TND0.570 ($0.35).[28]

Tunisia is a republic with a president. Still from the independence of the country there are several forms of corruption aware, including active and passive bribery, abuse of office, extortion and conflicts of interest. It boosted during the Arab Spring, the Tunisian Revolution in 2011, which was the consequence of high unemployment, lack of political- and media freedom. In 2015 the terrorist attacks also shacked the economy, affected household and business confidence. As a result the country faced an increasing number of industrial strikes, leading to breakdowns in production. The coface risk assessment associates Tunisia with a significant risk. [29]

Table 4 Country related water information[30]

Tunisia			
Water Source	Surface water: 1.15km^3	Groundwater: 2.06km^3	Desalination: 0.01 km^3
Water withdrawal	3.21 km^3/year	2012	
Connection rate	98% of the population	2015	

2.1.3 Morocco

Figure 4 Country map Morocco (Source: Google Map)

The country is officially called as the Kingdom of Morocco and located in North Africa as a part of the Maghreb zone. The land has connection with the Atlantic Ocean and the Mediterranean sea. The country counts 33.8 million people living on a field of 446,550 km2. The five biggest cities are:[31]

Casablanca (3,359,818); Fez (1,112,072); Tangier (947,952); Marrakech (928,850); Salé (890,403). The capital city is Rabat.[31]

In the ancient time the landscape was more fertile than today and it has been populated with Aterians and then Berbers. In the industrialization time of Europe, for the European Powers some of the North African countries seemed to be interesting for colonization. Because of the important strategic location of Morocco France started to colonize the country in 1830. In 1860 Spain declared war against the country and won. Spain occupied Ceuta and created a protectorate there. In the year 1956 the French and Spanish protectorate ended but Spain kept his Ceuta and Melilla. Morocco gained independence as the Kingdom of Morocco with the Sultan Mohammed.[33]

Geographically the country is bordered by the Atlantic Ocean and the Mediterranean Sea. It has mountainous and desert areas too. 18% of the land is arable and 12% is forested but today just 5% of the arable land is used for agricultural purposes. Morocco has a diversity of climate beginning from the Mediterranean through the Sub-Mediterranean; Continental; Alpine and Semi-arid. The country has a neighbour like Algeria and Mauritania. There are still some Spanish-controlled enclaves areas: Ceuta, Melilla, and Peñón de Vélez de la Gomera. The Canary Islands are ruled by Spain and Madeira belongs to Portuguese.[32]

Morocco is an authoritarian regime with not existing press freedom. The most power is over the military, religious affairs and foreign policy controlled by the King of Morocco. The legislative and executive power is executed by the government, however the king can dissolve the parliament. In 2011 there was a constitutional reform, which reduced the executive power of the king. The country is part of several organizations like the United Nations, Arab League, Arab Maghred Union (UMA), Organisation of Islamic Cooperation (OIC), the Non-Aligned Movement and the Community of Sahel-Saharan States (CEN_SAD). It also maintains a good relationship with the Western states. Primary trading partners are France and Spain and also the most important foreign investors. 73.5% of the foreign investment come from the European Union. The official languages are Arabic and Berber, but most of the population speaks French. The main religion is Islam.[32,35]

The Moroccan economy seems to be liberal. In 1993 the process of privatization of government owned assets began. According to the world economic forum, Morocco is the most competitive economy among the North African countries in 2015. About 85,000 km2 is available for food production. The climate is mainly Mediterranean and the country has the potential to reach the production to fully supply the food demand of the population. Now in a good year it can supply two thirds of the consumption. There are a lot of agriculture products like: rice, legumes, orange, almonds, apricots, strawberries, asparagus, potato, wheat, barley, and corn. For the export : olives, citrus fruits, and wine grapes, cotton, sugarcane, sugar beets, and sunflowers, tea, tobacco, and soybeans. 40% of the workforce is employed in this sector and the country tries to expand the arable land with irrigation. [37,32,34]

Next to the agricultural sector, Morocco is the world's largest producer and exporter of cannabis. The estimated area for the production is located in the north, and comprises 1340 km2. The main product is hashish and has an economic value of 0.57% of Morocco's GDP.[37]

Morocco has the largest fish market in Africa with an annual production of 1,084,638 MT. This sector was an economic pillar for the Kingdom. The fish industry produce 3% of the GDP and gives 400,000 people a direct and indirect a job. The coastal region are rich in sardines, bonito and tuna, but the fishermen cannot fully benefit from the resources because of the missing facilities and ports, and the unmodern fleet. Therefore the EU pays for the fishing rights since 1996 and mainly Spanish fleets fish in the area.[41,40]

The other important part of the economy is the manufacturing sector. It is designed mainly for the local consumption, but some goods are exchanged with the EU. Main products are: foodstuffs, beverages, textiles, matches, and metal and leather. The heavy industry covers the petroleum refining, automobile and tractor assembly, asphalt and cement industry. The mining industry plays also a major role. Morocco has 75% of the world's phosphate reserves. Next to the phosphate the silver and lead mining is common too. Nearly 39,000 people are involved in this sector. The phosphate fertilizer industry and sugar-milling capacity is owned by the country. But the manufacturing sector is mainly divided by private owners. Since 2006 July the country has opened itself for the offshoring sector, attracted a lot of French speaking multinational companies. In 2007 were 18,000 people are employed for 200 call centers.[42]

From the geographical point of view, the country has a good solar irradiation and Morocco also ensures a development plan for the renewable energies. There are some bigger projects like 200 – 220-MW thermo-solar and 30 MW photovoltaic facility in d'Ain Beni Mathar. In the wind energy sector a 60 MW park in Essaouira and 140 MW in Tangiers. In 2009 a solar energy project worth 9 billion USD was signed by the Moroccan king, which needs to be installed by 2020. The project is founded by private and state capital with an electricity capacity of 2,000 MW. Some German companies have already showed interest for participating in the project and also in development of water desalination plants.[38]

In Morocco there is a wide range of utilities providing water and sanitation. In 13 cities there are public municipal utility entities, a national electricity and water company (ONEE) that was created in 2011 merging the ONEP (water supply utility) and ONE (national electric utility). From the 90s a privatization of the water management began in 4 major cities. Of course the private operators are interested in contracts, which are economic feasible. The duration of those contracts exceeds 25 years. The table below summarizes the contracts:[43,44,45]

Table 5 List of cities and delegated contracts to private companies Morocco (Source: Water Resources and Freshwater Ecosystems: Morocco, 2009)

City	**Private leaders**	**Year of delegation**
Casablanca	Lydec –SUEZ Group	1997
Rabat-Salé	Redal- VEAOLIA Group	1999
Tanger	Amendis Tanger- VEOLIA Group	2002
Tétouan	Amendis Tétouan- VEOLIA Group	2004

The water management system still has some challenges, in the urban region the household of the poorest district do not have enough access to water, the wastewater treatment is very low, and there is no stable and enough capacity to serve the rural regions uniformly. The aim by 2020 is to increase to 60 % of collected wastewater and connect at least 80% of households to sewers.

In 1990 the estimated renewable water source was about 29 billion cubic meter. However, the economical and technically feasible capacity is just 20 billion cubic meter that is divided into 16 billion m^3 of surface water and 4 billion m^3 of groundwater. With 100 existing dams the country has a storage capacity of 15 billion m^3. In 2008 the access to drinking water in the urban region achieved 93% of the population. The remaining 7% partly supplies itself with stand pipes. This looks different in the rural areas: 86% of households are connected. 33% with individual meters and 67% of them with stand pipes. It causes a tremendous minus in the budget balance since the utility collects fees. In Morocco the main consumption belongs to the agriculture sector, followed by the municipal needs and industry. The table below shows the consumption per sector in 2010.[44]

Table 6 The consumption per sector in 2010, Morocco (Source: AQUASTAT Morocco)

WATER WITHDRAWAL	Year	Value	Unit
Agricultural	2010	9.156	Km^3
Municipal	2010	1.063	Km^3
Industrial	2010	0.212	Km^3
Total	2010	10.43	Km^3
Total water withdrawal per capita	2010	316.2	m^3

According to the UN statistics, the water demand of the country will increase with 25% by 2020. For covering the growing needs Morocco is highly interested in seawater desalination. Some studies were already completed by the order of the Environmental Ministry, which suspects building a new large desalination plant in the region Casablanca. Also in 2014 the national utility made a contract with a Spanish firm (Abengoa Water). The contract is a Build-Operate-Transfer for a plant capacity of 100,000 m^3/day.

The tariff system in Morocco is very complicated. It has different stages for the user, also varies between the demand and the location. The tariffs are higher than the ones in other countries in the Middle East and North Africa. It is a reason for the lack of connection in the poor urban districts. The fees in Morocco:

-In 1995 the Water Law was presented, that charges for the water abstraction and wastewater discharge. It is very low and was not increased since the appearance of the fee.

-The bulk water tariffs vary in every cities because of the production costs. They are set by the government

-The structure of the retail tariff is the same for the whole country. It is increased by the blocks depending on the consumption. It varies between 6 m^3 and 40 m^3 per month. In the poorest region the water supply happens through standpipes. This services are free, the bills are paid by the government. In 2006 was the biggest tariff increase with 11%, increasing the fixed portion of the tariff.

-The connection fees are collected just once from the service provider. It depends on the length of the water and sewer network. To rise the number of the connections, the fee can be paid monthly with the water bill under a duration of 7 years. The average connection fee for water was 500 USD and 1650 USD for sewerage in 2004. The cost covered primarily tariff revenues, connection fees and subsidies. [49]

The Moroccan economy had a growth rate of 4.5% in 2015, caused by the increase rate of 13% in the agriculture sector. Due to the favorable oil prices the country deficit was reduced in 2015. From this saving the new social housing program benefited. According to the coface country risk assessment Morocco was listed with acceptable risk. [47,48,50,51,52]

Table 7 Country related water information Morocco [47]

Morocco			
Water Source	Surface water: 8.25 km^3	Groundwater: 2.32 km^3	Desalination: 0.007 km^3
Water withdrawal	10.43 km^3/year	2012	
Connection rate	85% of the population	2015	

Table 8 Consideration of the chosen countries

Consideration of the chosen countries			
Parameters	Algeria	Tunisia	Morocco
Surface water (km^3)	4.8	1.15	8.25
Groundwater (km^3)	3	2.06	2.32
Desalination (km^3)	0.615	0.01	0.007
Water withdrawal (2012)	8.425	3.21	10.43
Connection rate (2015)	84%	98%	85%

3 Documentation of data and data collection

3.1 Project description

After the investigation of the collected data about the Mediterranean countries, Morocco seems to be the optimal choice for the project purposes. The infrastructure for the water distribution reached 93% in the urban regions. The water management sector is already in the process of privatizing, what in the view of an investor shows, that the system is profit oriented. Considering the countries, Morocco is politically stable, and maintains a good relationship with the EU. Also the risk assessment from coface listed the state with acceptable risk. It does not depend on the oil prices. Because of the climate change and the dependence on the import of agricultural products, the country is supporting irrigation project. The land also has a good solar irradiation

and a good average wind speed. The kingdom itself invests in renewable energies, which is the sign for creating a good investment environment. To describe the project detailed, further investigation need to be done. First of all, the possible demand for drinking water needs to be calculated. Followed by a more precise illustration for the selected location in Morocco. The water

quality is different from location to another location. After examining all the criteria, the frame parameters will be presented in the section 3.1.4.

3.1.1 Description of the location

The chosen land for the plant is in Ben Slimane, Morocco. This small town pertains to Casablanca region and located between Casablanca (41.6km) and Rabat (50.2km). The water demand in the region Casablanca exceeds 164 million m^3/year. This demand increases every year, thanks for the urbanization process (300ha/year) and the climate change. 40% of the water is transferred from the north part of the region. Casablanca has developed a 420km long water distribution system. As the Figure below shows, there is a connection between Casablanca and Rabat.[53]

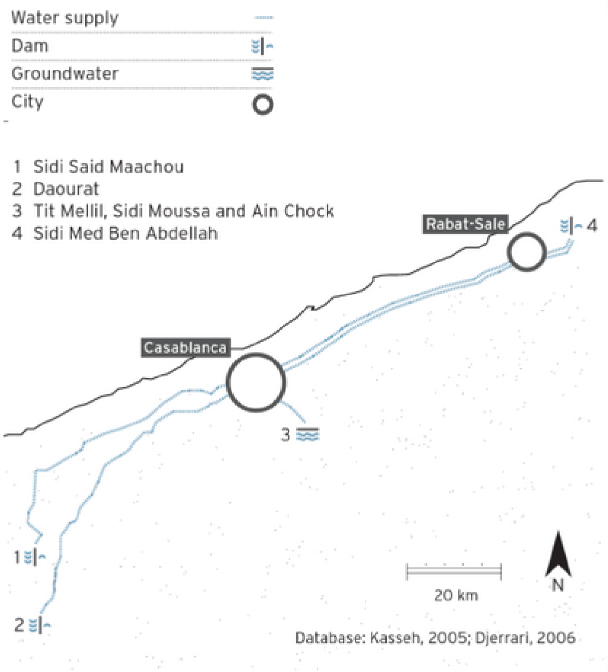

Figure 5 Drinking water supply network Casablanca-Rabat Source: The Report: Emerging Morocco 2007

The plant will have a close access to the road and the distribution system and is located 29 m above the sea level. The area of the plant is approx. 3.4 ha. By choosing the location it is important, that in a radius from 10km there is no or low ship traffic, which could have an impact on the water quality. This area is also between two big cities, which allows an easy water distribution for both municipality.

Figure 6 Location of Ben Slimane, project location (source : Google)

3.1.2 Finding demand for Industry and Drinking water

The first step of the analysis is searching for sectors with water demand. The table 3 shows the water withdrawal by sectors in the country in year 2010. As the table presents, the agriculture has the most demand in the country. 22% of the country area is arable (9,895,000 ha). More than 2000 companies operates in the food industry, the most are owned by the ONA group and some multinational companies like Coca cola, Unilever and Nestle. The government plans to create 6 agro polis (Meknes, Berkane, Souss, Gharb, Tadla and Haouz).[55]

To determine the potential, the agricultural products need to be investigated individually first in general view, than calculated for the general location. The percentual distribution of the agricultural products in the total arable land is as follows:

- 43% for cereals
- 7% for corps (olives, almonds, citrus, grapes, dates)
- 3% for pulses
- 2% for forage
- 2% for vegetables
- 2% for industrial crops (sugar beets, sugar cane, cotton) and oilseeds,
- 42% is fallow

The method of estimation contains information about the agriculture products like:

- The production capacity in tons per year
- The water demand per ton
- The production capacity in tons per year for the selected area

Wheat

The current wheat production of the country is 6,017,821t /year. The government calculates for 2017 with 7.5 million tons.

Production in the selected location: 324,240t/yr

Plant water demand: 208m^3/t

Carrots

The current production of the country: 3,208,000t/year

Production in the selected location: 93,800t/year

Plant water demand: 61 m^3/t

Orange

On an average, one orange (150 gram) has a water footprint of 80 litres of water.

The current production of the country: 850,000t/yr

Production in the selected location: 45,300t/yr

Plant water demand: 49m^3/t

Banana

The current production of the country: 240,000t/yr

Production in the selected location: 23,700t/yr

Plant water demand: 33m^3/t

Strawberries

The current production of the country: 74,000 t/yr

Production in the selected location: 0t

Plant water demand: 37m^3/t

Potato

The global average water footprint of potato is 290 litre/kg.

The current production of the country: 1,721,402t/yr

Production in the selected location: 75,240t/yr

Plant water demand: 63m^3/t

Barley

The current production of the country: 2,317,611t/yr

Production in the selected location: 0t

Plant water demand: 1292 m^3/t

Tomato

On an average, one tomato (250 gram) costs 50 litres of water.33% of the tomato production will be exported. The rest is sold on the interior market for fresh consumption and transformation. In 5 regions of the country the tomato will be produced: Souss-Massa-Drâa Doukkala-Abda, Oued-Eddahab-Lagouira, Greater Casablanca and Rabat-Zemmour-Zaer.

The current production of the country: 1,217,905t/yr

Production in the selected location: 115,600t/yr

Plant water demand: 43m^3/t

Olives

The olives trees grow mostly on the fallow lands and 65% of the trees are olive trees. The average water footprint of the olives amounts to 3020l/kg and 14400l/kg for the olives oil.

The current production of the country: 1,415,902t/yr

Production in the selected location: 0t

Plant water demand: 45m^3/t

Citrus fruits

34% of the production will be exported. 65% of the planted area is irrigated. 13,000 citrus producers give 90,000 people a permanent job.

The current production of the country: 1,600,000t/yr

Production in the selected location: 0t

Plant water demand: 35m^3/t

Wine grapes

In the region Casablanca the annual wine production exceeds 400,000 hectoliters and one kilogram of grapes gives 0.7 litre of wine.

The current production of the country: N/A

Production in the selected location: 571,428t/yr

Plant water demand: 87m^3/t

Onion

The current production of the country: 860,913t/yr

Production in the selected location: 85,000t/yr

Plant water demand: 65m^3/t

The summarized yearly water demand in the agricultural sector exceeds 141,115,676 m^3

Therefore the daily water demand: 386,618 m^3

[54,56,57,58,59,60]

The second row represents the demand for drinking water in Morocco. The kingdom achieved a high connection rate for the drinking water. The existing water distribution system makes the investment environment more comfortable, because it makes the water supply easier and the customers can be reached more easily. According to the WHO, the optimal water use per capita per day is 50l (including the demand for preparing meals and personal hygiene). The use is divided into 3 parts: 1/3 for toilet – flushing; 1/3 for body hygiene; 1/3 for cooking and drinking, washing the dishes. In the defined area within the radius of 150 km are adjudged 3 big cities; Casablanca (3,359,818); Salé (890,403); Rabat (620.996). The targeted population is more than 4.8 million people. [61]

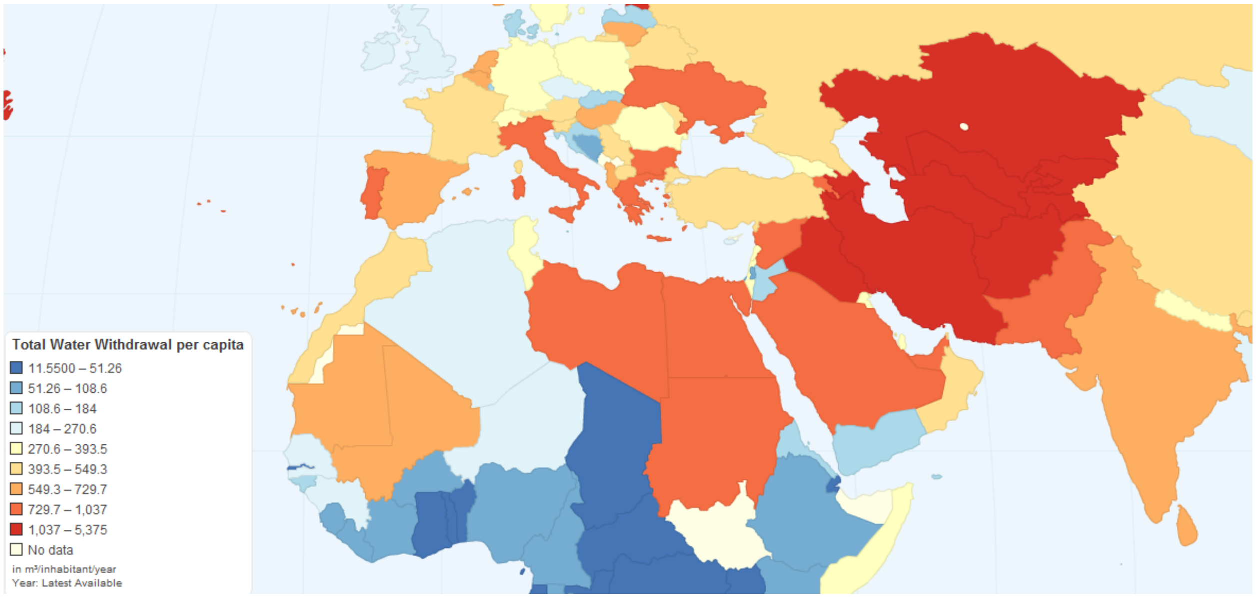

Figure 7 Total water use per capita per year by country Source: ChartsBin Total Water Use per capita by Country

The figure above shows the total water use per capita per year. For Morocco the value is 427 m^3/inhab/yr. The calculated demand for drinking water: 5,615,342 m^3/day.[62]

The industry also plays a major role in the prediction of demand. There are mainly two sectors with a lot of water demand: Steel and cement industry

First the steel sector will be analyzed.

The main application of the water in the steel industry is for cooling, but it is also used to protect equipment and to ensure a better working conditions for the labourers. Processes like the concentration of iron ore, cleaning coke-oven gases, quench coke and slag, and the decalcification of steel, for sanitary and service purposes.

According to the worldsteel member survey for an integrated plant the average water intake reached 28.6 m^3 per ton of steel in 2011. The average discharge amounts to 25.3 m^3. The electric arc furnace method consumes a little bit less water. The intake amounts to 28.1 m^3 per ton of steel and the discharge to 26.5 m^3. The overall water consumption per ton of steel production moves in the range of 1.6 m^3 to 3.3 m^3. The main reason for the water loss is the evaporation. This seems to be a small consumption per ton. However, not all water quality is sustainable to use in the steel industry. Because of the wide range of producers and used equipment there is no general standard for water quality. It varies between the technologies. If poor quality water is used, dissolved solids remain after the evaporation. If it is not controlled, it can lead to a negative impact on the steel components. The most common ramifications:

- Corrosion - reduces the life expectancy of the components
- Scale Formation – caused by calcium or magnesium, it reduces the heat transfer and system efficiency
- Biological Fouling – slime and algae appear in the system, they favor the corrosion, reducing the heat transfer and supporting the appearance of pathogens [63,64]

Therefore, the table below represents a guideline for the water characterize for galvanized steel (95°F)

Table 9 water quality for galvanized steel Source: FAULKNER B. WALLING, Water Requirements of the Iron and Steel Industry1967

pH	6.5 to 9.0
Total Suspended Solids	25 ppm
Total Dissolved Solids (TDS)	1,500 ppm
Conductivity	2,400 (microohms/cm)
Alkalinity as CaCO	500 ppm
Calcium Hardness as CaCO	50 to 600 ppm
Chlorides (CL)	250 ppm
Sulfates	250 ppm
Silica	150 ppm

The annual steel production varies in the recent years in the range from 500 to 650 thousand metric ton. In the selected region a tremendous steel production plant was built by the German company SMS Siemag. The operation started in 2012 under the ownership of Maghreb Steel employing Electric-arc furnace technology. It has an annual production capacity of 1 million ton per year. As already mentioned above, the production of 1 ton steel requires 28.6 m^3 water. It means, to cover the whole country production, the value of 500,000 metric ton is calculated, the demand represents 39,178m^3/day. [64]

The second large sector is the concrete industry

The total annual capacity amounts to 22.8 Mt/yr. The production happens with 13 operating cement plants which are mainly owned by by Lafarge, Holcim, Italcementi and Camargo Corrêa . There is just one Moroccan producer called Cimentos de L'Atlas (CIMAT).

The main player among the four plants is the Lafarge Maroc. The biggest plant is located in Bouskoura in Region Casablanca with a production of 4.5Mt/year. The other plants of the company were built in Meknès (1.2Mt/yr); Tétouan (2.5Mt/yr); Tangier (1Mt/yr).

Under the investigation it needs to be mentioned, that during a year there are two periods with minimum cement production. The first period is in February, caused by the plant shutdowns and the second one is in September. This is related to the Ramadan. The Kingdom itself consumes on an average more than 10Mt/year.[65,66]

*Table 10 Annual cement sales in the 3 regions of Morocco and Western Sahara, 2011 - 2013. (*Source***:** *L'Association Professionnelle des Cimentiers du Maroc:2014)*

Region	**Sales in 2011 (t)**	**Sales in 2012 (t)**	**Sales in 2013 (t)**
Grand Casablanca	2,458,596	2,161,001	1,968,913
Rabat-Salé-Zemmour-Zaer	1,219,948	1,237,947	1,135,229
Tanger-Tétouan	1,792,111	1,803,693	1,644,608

For the selected region the annual cement production is about 4.5Mt/year. The raw density of cement is 2500 kg/m^3 and 1 m^3 b cement production needs 160l (0.16m^3) water. It means a yearly water demand of 288,000 m3; 790 m^3/day.[66]

Summarized demand for the region Casablanca:

Agriculture: 386,618 m^3/day

Drinking water: 5,615,342 m^3/day

Industry: 40,068m^3/day

The water distribution is unequal in time and space, therefore the main target is the drinking water production, because of his predictability and continuous demand. The chosen plant capacity is 100,000m^3/day.

3.1.3 Source water quality characterization

Introduction

The quality of water determines plant the treatment system for the desalination and has an effect on the produced drinking water. Basically there are two types of collecting source water:

Subsurface intakes or coastal seawater aquifers.

This master thesis will focus on the open seawater intakes. Next to the concentration level of iron, manganese, arsenic, cyanide, ammonia, sodium bisulfite and other compounds, the side impacts of human activity for contamination need to be analyzed like ship traffic or wastewater discharges and pathogens. Because of that the water assessment is the primary information for planning and designing the projects. Some of the water characteristics are regulated by the government, but others also need to be investigated, because those parameters influence the durability and performance of the plant. This chapter will present the compounds of water; how to measure them; how they impact the elements of the plant and how the water is characteristic for the chosen region.

The state regulatory postulates a watershed sanitary survey from the owner of the plant. This survey contains the potential water contaminations within a 1.64 km radius of the plant intake. The creation of the survey is very cost effective and takes more than one year. It also needs to contain the following information:

- In terms of intake: physical elements, configuration and structure
- Details of the water treatment process
- The influence for the water distribution system - water quality after mixing the product water; requirement of the distribution system modification
- Information about the location and the construction of the product water storage, water pump and control facilities
- Summary of collected monitoring data of the water quality during one year.
- Approval from different regulatory for the water treatment plant, drinking water production and connection details for the distribution part.

Besides the watershed sanitary survey, the operator is obligated to develope a source water assessment for the pathogen content. The water needs to be analyzed for: viruses, Escherichia coli, Giardia cysts, and Cryptosporidium fecal coliform and heterotrophic plant. The eEstablished regulator for the elimination suppositions is the US Environmental Protection Agency's Surface Water Treatment Rule. The human pathogens tend to survive in freshwater than in highly saline water. However, there are no sufficient studies for the pathogens survive rates in saline water, therefore one per months the source water has to be investigated for viruses and bacteria.[67]

The involved parts of the water can have categories in four groups:

- organics
- microorganisms
- dissolved minerals and gases
- colloids and suspended solids

These elements deposit on the membrane surface or in the structures, induce a reduction of product water quantity and quality. These harmful components are also called foulants. They can be:

- Particulate foulants
- Colloidal foulants
- Mineral scaling foulants – it accrues during the salt separation from inorganic elements
- Organic foulants – organic matter
- Microbial foulants–aquatic organisms

In the source water the organic matters and microorganisms have a relatively large size and weight (500 to 3000 daltons). The membrane of the SWRO can remove the molecules over 200 Da, more than 90%. During the process, these foulants can accumulate on the membrane surface reducing his capacity. For these biofouling one of the used measurement parameters is the natural organic matter (NOM) which presents the amount of proteins, carbohydrates, oils, pigments, humic and fulvic substances (acids). The NOM of seawater is normally low (2mg/L), it multiplies under the algal-bloom. During the treatment and pumping the algae die and their cells serve as food for other organic matter creating biofouling. The high NOM can also lead to a discoloration of water.

If high number of humic acids is present in the water, the formation of chelates via metal ion can be developed, as a result a gellike layer of chelates appears on the surface and it contributes by bio fouling. This challenge can be solved by rising the pH value of water above 9, but it can affect the membrane negatively.

Another widely used measurement for organic content of water is the total organic carbon (TOC). It is easy to measure and it can easily predict the bio fouling tendency. The method is converting organic carbon to carbon dioxide in a high temperature furnace in the presence of catalyst. Typically the TOC level of seawater is lower than 0.2mg/L but under the algal bloom it can rise till 12mg/L. High TOC accelerates bio fouling and increases the operating pressure which in turn increases the energy demand of the plant and reduces the lifetime of the equipment.

Specific molecular structure of natural organic matter absorbs the UV light. Therefore, by using the method of ultraviolet (UV) absorbance at 254 nm, the water sample is filtered through a 0.45-mycrometer filter and quantify the filtrate's absorbance of UV with a spectrophotometer. Dividing this value by the concentration of dissolved organic carbon gives the specific UV absorbance (SUVA). It is an indirect indicator for algal bloom. The value between 2-4 predicts an upcoming algal bloom. [67]

Microorganisms such as fungi, algae, protozoa are less present than bacteria like Pseudomonas, Bacillus, Arthrobacter, Corynebacterium, Flavobacterium. These microroganisms form a microbal cake layer on the membrane surface. The layer reduces the membrane productivity, and to maintain a standard water production the pressure needs to be increased. The high feed pressure can damage the membrane and also brake the cells of organisms leading again to a bio fouling. Active and inactive forms of the bacteria are present in the water. The inactive bacteria are characterized by low metabolic rate, often just one cell, they are protected with a cellular cover. If the environmental conditions change, the food content and the oxygen in the water rises and the choline reduces, they will be active again and start to build up a cake layer. First of all, a primary organic film will be formed, it is followed by the process of colonizing bacteria, then a biopolymer matrix appears, the last is that a secondary biofilm accrues. The first step already covers 10 to 15% of the membrane surface. With an increasing cross-flow, the bacteria do not have the opportunity for colonizing on the surface. It can easily be done by decreasing the recovery by 50%, but it leads to 30% higher investment costs. Other alternatives like controlling TOC with chlorine need to be used with high attention, because it executes the active bacteria but these cells serve as food for other organisms. The best alternative to handle the fouling problems is using of downflow gravity granular media filtration and dissolved air flotation or chemicals like acids and polymers. [67]

Of course, the aim of the desalination is to separate the dissolved minerals and dissolved gasses in the source water. The total dissolved solids (TDS) is the widely used measurement factor to determine the water compounds. It contains information about the concentration of different elements such as: sodium, potassium, bromide, boron, calcium, magnesium, chloride, sulfate, bicarbonate, nitrate, metals and all ions.

The common dissolved gases which are sited in the seawater are: oxygen, carbon dioxide, hydrogen sulfide, and ammonia. It is important to mention, that all of these gases traverse the RO membranes. Because of that, the water needs a pretreatment for degasification. In the seawater the dissolved oxygen concentrate is intermediate 5 and 8mg/L.

The TDS is measured either in milligrams-per-liter (mg/L) which reflects the ratio of ion weight to solution volume or in milliequivalent-per-liter that shows the capacity of ions to react with one another. This parameter is the most important factor during the calculation of feed pressure which is in coherence to the energy demand of the production. The osmotic pressure increases with 0.07 bar by every 100mg/L of TDS. A seawater concentration with 35,000mg/L of TDS requires therefore 24.5 bar to overcome the osmotic pressure. The TDS values varies among the different Seas of the earth. The table below gives an overview about the TDS concentration and temperatures. The warmer the water is the lower the water viscosity is, which in turn expands the output capacity. [67]

Table 11 Seawater TDS and temperature Soruce: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Seawater Source	Typical TDS Concentration, mg/L	Temperature, çC
Pacific and Atlantic Oceans	35,000	9–26 (avg 18)
Caribbean Sea	36,000	16–35 (avg 26)
Mediterranean Sea	38,000	16–35 (avg 26)
Gulf of Oman and Indian Ocean	40,000	22–35 (avg 30)
Red Sea	41,000	24–32 (avg 28)
Persian Gulf	45,000	16–35 (avg 26)

For measuring clay, silt, suspended organic matter and aquatic life the parameter called turbidity or nephelometric turbidity units (NTU) is used. The ocean has an NTU from 0.5 to 2. The maximum feed water turbidity of RO membrane is 1 NTU. The particulate fouling potential is described by silt density index (SDI). It presents the reduction of flux for a standard filter size at a constant pressure for a given period of time. A source water with SDI under 2 has a low fouling potential and a good quality. Generally, the manufacturer stipulates SDI less than 5 to secure the warranties of their products. The total suspended solids (TSS) parameter gives the total weight of the solid residuals of the source water. The measuring process is the following: a preweighed glass-fiber filter is filled up with a volume of water, after drying the filter at 105°C, it will weighted again. The difference gives the total amount of the particulate solid. This parameter is a good indicator for storms, strong winds or algal blooms. Analyzing the water with a spectrophotometer allows to measure the chlorophyll concentration. Detecting green pigmentation indicates the high content of algae. [67]

Under the group of metal oxide and hydroxide foulants appertain iron, manganese, copper, zinc and aluminum. The attendance of chlorine catalyzes an oxidation process which damages the membrane.

The higher the salinity of the source water is, the less likely the mineral fouling will be created in the desalination system at a pH of 7.6 to 8.3. If the water pH exceeds 8.8, the calcium sulfate and magnesium hydroxide case the membrane scaling.

Source water quality in Casablanca

Table 12 Source water quality Casablanca Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Water Quality Parameter	**Atlantic Ocean Source Seawater Quality**
Temperature °C	16–30
pH	8.0
Ca^{2+}, mg/L	410
Mg^{2+}, mg/L	1302
Na^{+}, mg/L	10,506
K^{+}, mg/L	390
CO_3^{2-} mg/L	2.0
HCO_3^{-} mg/L	145
SO_4^{2-} mg/L	2720
Cl^{-}, mg/L	19,440
F^{-}, mg/L	2.5
NO_3^{-}, mg/L	0.00
B^{-}, mg/L	4.5
Br^{-}, mg/L	78
TDS, mg/L	35,000

3.1.4 Frame parameters of the project

After analyzing the location, the demand and the required water characteristics, the following frame parameters of the project will be presented in this section. During the investigation it turned out that the sector for drinking water has the most demand and it is also the most predictable. The size of the plant was designed to operate 24hours and produce predictable secure revenues. The plant capacity is 100,000m^3/day. Since the primary criterion is drinking water production, Ben Slimane as a plant location was chosen which is located between two big cities, Casablanca and Rabat. The area is optimal for the connection to the water distribution system and has an access to the road for construction purposes. The water quality standard is discussed in details in 3.1.3

3.2 Overview of desalination technologies

As already mentioned 97.5% of existing water has high salt concentration. The rest is freshwater but just 30% of that can be found in rivers, lakes and groundwater. Currently the total water production via desalination is 1.5% of the worldwide water supply. The given pressure from the constantly growing water demand, the negative impact by global warming, the decreasing costs for construction and energy trigger an expansion for desalination technologies. From the function point of view, mainly two groups of technologies are available on the market: [67]

-Thermal distillation -Reverse osmosis

In the first group the salt will sunder via evaporation from the fresh water. In RO as the name already says, the natural process osmosis will be inverted with the help of pressure, that transports the water through the semipermeable membrane and filters the salt out. The pressure needs to be higher than the natural osmotic pressure and it is proportional with the salinity. The other existing technology is the electrodialysis (ED), where the separation happens with the application of direct electric current. The ion exchange works by ion-selective resin media which adsorbs the opposite charged elements in the water. According to the WHO the optimal TDS for fresh water is under 100mg/L. The following table gives an overview of which technology is economic suitable at a given TDS of water. Todays 60% of the plants are equipped with RO membrane. [67]

Table 13 overview of economic suitable desalination technologies for a given TDS of source water Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Separation Process	Range of Source Water TDS Concentration for Cost-Effective Application, mg/L
Distillation	20,000–100,000
Reverse osmosis separation	50–46,000
Electrodialysis	200–3000
Ion exchange	1–800

The table below provides information for comparing the removal efficiency of different desalination technologies.

Table 14 Removal efficiency of different desalination technologies Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Contaminant	Distillation (%)	ED/EDR (%)	RO (%)
TDS	>99.9	50–90	90–99.5
Pesticides, Organics/VOCs	50–90	<5	5–50
Pathogens	>99	<5	>99.99
TOC	>95	<20	95–98
Radiological	>99	50–90	90–99
Nitrate	>99	60–69	90–94
Calcium	>99	45–50	95–97
Magnesium	>99	55–62	95–97
Bicarbonate	>99	45–47	95–97
Potassium	>99	55–58	90–92

The following chapters will give detailed information about the function of different technologies.[67]

3.2.1 Multistage Flash Distillation

The distillation is the key schema in all thermal desalination technologies. First the seawater will be transformed into vapor, then this damp goes under the condensation process and the low-salinity water remains. Since there is no practical correlation between the extrinsically added energy and the salinity concentration of the water, in the economic point of view this technology is the best option for drinking water production from high salinity water. On the other side, the distillation process requires a lot of steam, which is only cost effective if it is a waste steam from power generation. This is the reason, why the technology is not common in the world. There are 5 different streams during the production of drinking water in all thermal desalination process. First of all, the source water, then the one that is used for evaporation followed by the cooling water for condensation and the concentrate brine. To evaluate the performance of the different technologies, the term “gained output ratio” (GOR) needs to be explained which is influenced by

the technology, the quality of water and the specific conditions. The higher the GOR is the better the performance of the desalination is. This is the proportion of the mass of low- salinity water (distillate) produced to the mass of heating steam used to produce this water. The value is generally between 4-40; this means, using 1 kg of steam allows to produce 4-40 kg freshwater. After this general background information, the function of different technologies will be presented. 67

In the history of the thermal desalination the Multistage Flash Distillation (MSF) was the first available technology on the market for the large scale production and today it also has 80% market share in the thermal desalination. The vessels for evaporation are called flash stages, where the high salinity seawater is warmed up to a temperature of 90 to 115°C. Then the seawater enters the first flash stages, where the pressure is hold a bit lower than the saturation vapor pressure. After entering the water is rapidly transformed into steam. Every flash stage is equipped with heat exchanger tubes to convert the steam into distillate. The source water is used as condense water for the cooling purposes. In the stages the demister pads detach the high salinity mist from the low salinity rising steam. After the condensation the steam turns into water which is then transported to the product water tank. The distillate and the generated brine as well is collected at the last stage. The recycling of this concentrate has two main advantages. First, it reduces the amount of seawater which needs to be collected via the inlet. Second by the use of brine in the heat exchanger removes the latent heat of condensation. Therefore, the process needs less energy for the heating. One flash stage generates almost 1 percent of the total volume of condensation. An MSF plant has maximal 28 stages, so the recovery of the plan amounts to 29%. It is relatively low if it is compared to RO plant which has 40-45 percent. This technology achieved a GOR range of 7 to 9. The required energy for the operation is 2.0 to 3.5 kWh/m^3.The most cost effective alternative is that the stream used for heating comes as a waste heat of a power plant. [67]

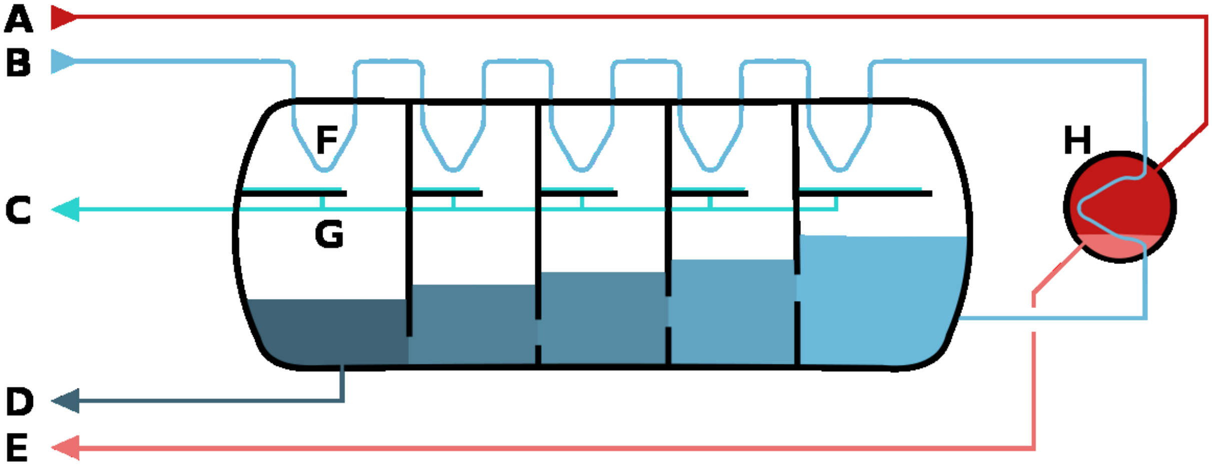

Figure 8 Multistage Flash Distillation; A - Steam in; B - Seawater in; C - Potable water out; D - Waste out; E - Steam out; F - Heat exchange; G - Condensation collection; H - Brine heate[67]r

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3.2.2 Multiple-Effect Distillation

In the MSF technology the vapor is created via flashing, in contrast of that, in the Multiple Effect Distillation (MED) the seawater is not warmed. In cold form it is spurted with perforated plates on the heat exchanger tubes. The water takes the energy of the heat and starts to boil generating the vapor. In the first stage heating vapor is introduced which is supplied from an outside steam ejector. As in the MSF technology, every stage is equipped with a mist separator. The ambient pressure is lower in every upcoming stage, so the seawater boils consecutive in the stages without utilization of the new heat. The condensed steam is collected in every stage. This technology has also a brine recovery system. The MED system operation is at a temperature of 62 to 75°C. It also represent an advantage for this technology that the energy demand for the operation is lower than MSF plants. It is identical to 0.8 to 1.4 kWh/m^3. With MED technology 24 kg of freshwater can be produced from 1kg of steam. (GOR 24)

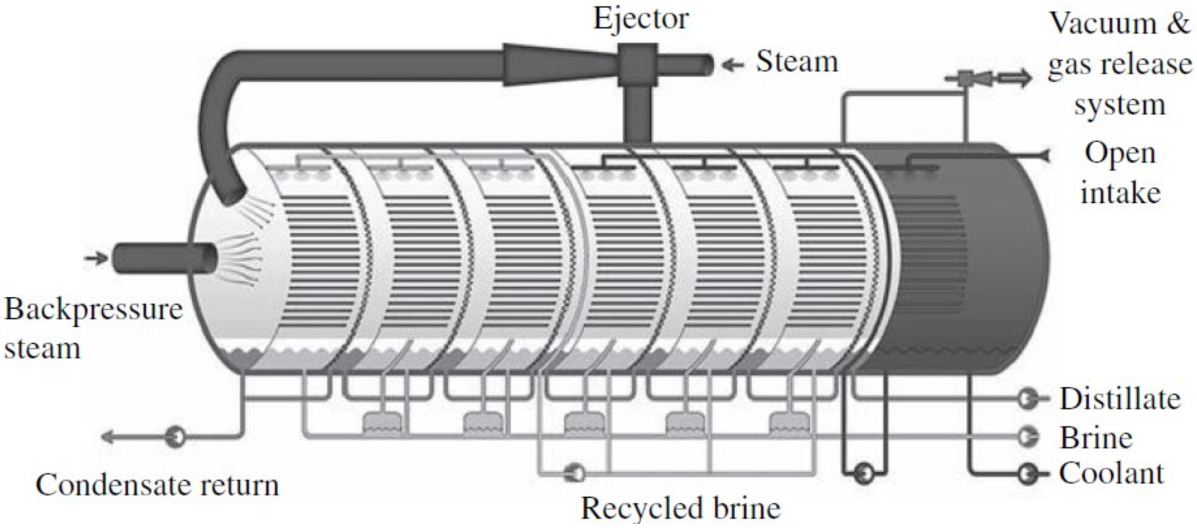


Figure 9 Multiple Effect Distillation Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

3.2.3 Vapor Compression

A mechanical compressor produces the required heat for the vapor compression (VC) system. First, the seawater becomes vaporized then it is sent to the compressor. The steam jet ejector compresses the vapor to elevate the temperature. Afterwards, the compressed vapor will be mixed with the source water which is spurted on the evaporation tubes and the fresh water remains. At the beginning of the process a source water preheater is used to reach the evaporation temperature. As opposed to MED, the developed steam from source water is conveyed to the outside surface of the heat exchanger, with the help of the vapor compressor it will be recycled and entered in the inner side of the same heat exchanger, where it will be condensed to distillate. Among all the thermal desalination technologies, the VC system consumes the most power for the production. The range is 8 to 12 kWh/m^3. [67]

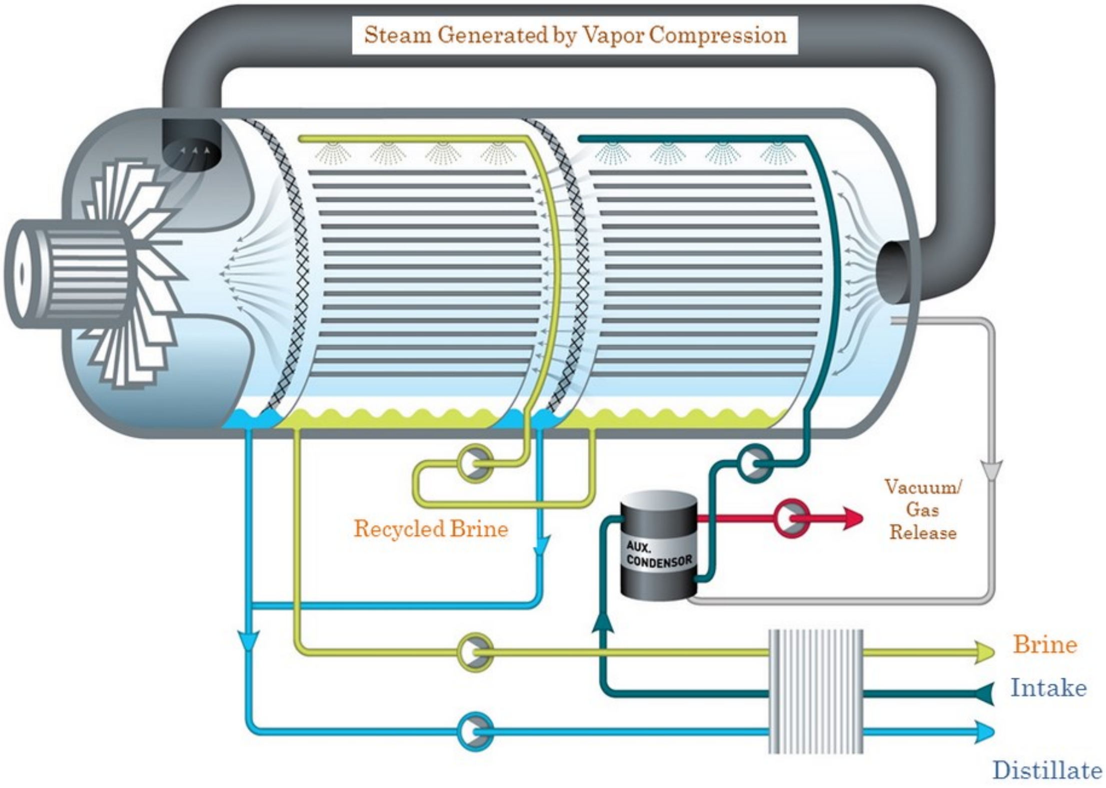


Figure 10 Vapor Compression System Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

3.2.4 Membrane Desalination

A semipermeable membrane has a major role in the desalination technology, which separates the minerals from the seawater. It exists in two main types: Electrodialysis and Reverse Osmosis.

3.2.4.1 Electro dialysis

In the electrodialysis (ED) technology the main driving force for the detachment of the water elements is the direct electric current. This electric charge drifts the mineral ions through the ion-selective membranes for pairing with the electrodes of the opposite charges. After a while the operation ions are collected on the surface of the electrodes and they are fouling the equipment. Therefor a constantly cleaning is required. Changing the polarity of the charged electrodes frequently (two to four times per hour) can solve this problem. The desalination system is made up of more than 300 pairs of cation and anion exchange membranes. Between the membranes concentrate spacers are located which do not just separate the membranes from each other, it also removes the remained salt. There are some differences between the ED and RO desalination membrane. The ED membrane has a porous structure like microfiltration membranes and they are more resistant to chlorine and fouling. An ED membrane unit separates just half of salts, therefore more membranes are linked to each other to achieve the aimed TDS concentration of the water. The higher the salinity of the water is the more energy is needed for the operation. The ED systems are more cost effective with a TDS level under 3000mg/L. The non-ionized particles do not have an effect to the removal efficiency. Hence it can operate with higher turbidity and it is more resistant against biofouling and scaling. Salt ions, silica, nitrates and radium, these elements have a strong electric charge, therefore with the direct current they can be easily separated from the source water. On the other side, the organics, pathogens and low charged minerals are just partially removed from the seawater. It is also true for nutrients. In the case if the produced water will be used for irrigation of agricultural crops, the ED system is more attractive against other desalination technologies. But after the investigation of demand, the decision is made for producing drinking water. The TDS concentration of the water is also too high for a cost attractive application of ED membranes. [67]

3.2.4.2 Reverse Osmosis

Since the main focus of the investigation lies on the use of RO membrane technology, it will be described in details. How it works; how the structure looks like, which parameters are the most important for the membrane and what are the influenced factors for the performance.

In every living cell a natural process of water transport exists, which is the equalization of the difference of the water salinity concentration between the two sides of the membrane. It is known as osmosis. The pressure that drives the water from the low-salinity side to the high-salinity is called osmotic pressure. This parameter is proportional to the TDS concentration, to the source water temperature and the different ion types of the TDS. To turn this process back, a higher pressure for the process is needed than a natural osmotic pressure in the opposite direction. It is called reverse osmosis (RO). In this process the semipermeable membrane particularly lets the water through, which is more time higher rate than other contaminants like minerals, suspended solids, organics and aquatic microorganisms. The membrane rejects almost all constituents, except the dissolved gases, because of their small molecular size. Therefore, pretreatment for the dissolved gases is needed. The next figure presents the rejected contaminants by their size. [67]

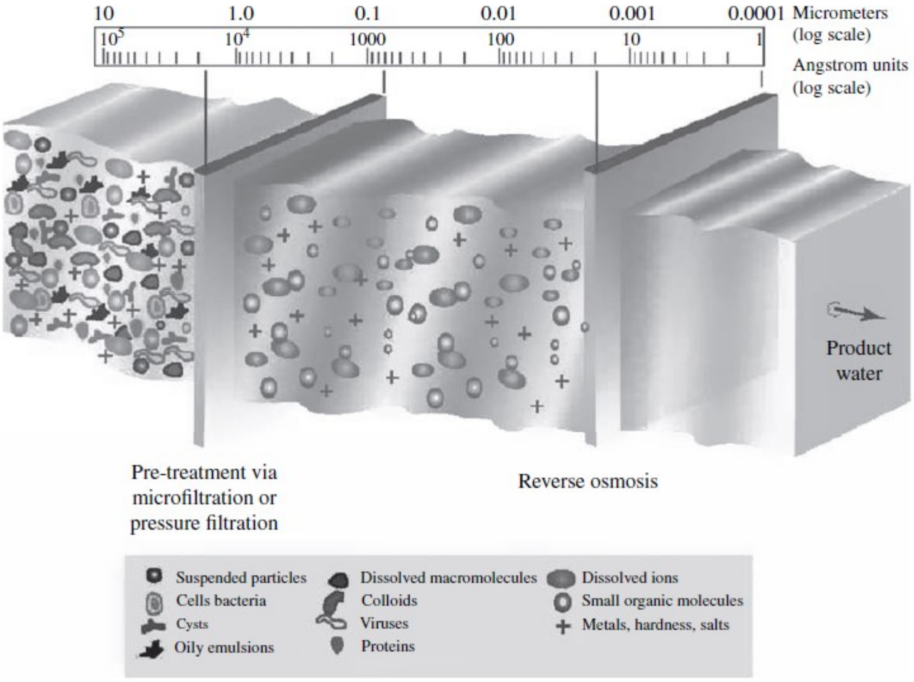


Figure 11 Rejected contaminants by their size Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

The membrane structure generally can be divided in two groups: conventional thin-film composite and thin-film nanocomposite. The structure of the membrane consists of three levels. On the top the semipermeable ultrathin film (0.2 µm) is, in the middle the micro porous layer (40µm) is located followed by the reinforcing fabric (120µm). The salt rejection competence is related to the ultrathin film. The other two layers are responsible for the reinforcement of the structure. The membrane has a random molecular matrix based structure. The main difference between the conventional and nanocomposite thin-film membrane is first of all the structure. The nanocomposite has uniformed carbon nanotubes on the surface, a higher specific permeability, a better removal of specific ions and lower fouling rates. [67]

Based on the material the membrane can differentiate in aromatic polyamide (PA) or cellulose acetate (CA). The aromatic polyamide membrane is the most common used material today in the industrial and drinking water production. The PA has a higher productivity than CA. Also, the operation pressure is lower, that effects the energy use. The PA rejects more salt, causing the negative charge of the membrane if the pH value is more than 5. In another case, if the pH is lower than 4, the salt passage is increasing enormous. The cleaning and maintenance of PA is significantly easier than CA, hence it operates a widely range of pH value (2-12). In comparison of the lifetime the PA also has a much higher value, which has an effect on the economic sustainability of the plant. As a disadvantage of the membrane it can be mentioned, that it is sensitive for the strong oxidants and high concentration of chloride which is causing the degradation and reducing the performance of the membrane. Since for the biofouling control the oxidants are used, the feed water needs to be dechlorinated. The following table shows the important parameters for the membrane comparison.

Table 15 Comparison of PA and CA membrane parameters Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Parameter	Polyamide Membranes	Cellulose Acetate Membranes
Salt rejection	High (> 99.5%)	Lower (up to 95%)
Feed pressure	Lower (by 30 to 50%)	High
Surface charge	Negative	Neutral
Chlorine tolerance	Poor (up to 1000 mg/L-hours); dechlorination needed	Good; continuous feed of 1 to 2 g/L of chlorine is acceptable
Maximum temperature of source water	High (40 to 45°C)	Relatively low (30 to 35°C)
Cleaning frequency	High (weeks to months)	Lower (months to years)
Pretreatment requirements	High (SDI < 4)	Lower (SDI < 5)
Salt, silica, and organics removal	High	Relatively low
Biogrowth on membrane surface	May cause performance problems	Limited; not a cause of performance problems
pH tolerance	High (2 to 12)	Limited (4 to 6)

The viscosity of the saline water is reducing with rising temperature that leads to an increase of the membrane permeability. As a rule of thumb with every 1°C of temperature increase, the permeate flux is rising by 3%. On the other hand, it also carries some negative impacts with the temperature. The warmer the source water is, the higher the osmotic pressure is. Up to 30°C the use of warm water is overall beneficial because of the positive impact on permeate flux, reducing the feed pressure and the energy demand of the desalination plant. Above this temperature the biofouling is accelerated, the membrane structure is damaged and with increasing salt passage the product water quality is decreasing. [67]

There are three different types on the market for the membrane element configuration: Spiral-wound, Hollow-fiber and Flat-sheet. In our point of view just the Spiral-wound element membrane will be described in this chapter.

The Spiral-wound membrane consists of three layers structured individual flat membrane sheets. These membranes are with the standard diameter size from 2.5-in. through 6-in. and 8-in. till 19-in. available on the market. A typical 8-in. element has 40 flat sheets. There are about 20 leafs on one flat sheet. Between the sheets there is a thin plastic net, which structures a channel for the separated permeate. Two membranes are cohered together, where one of the four sides is open. A 0.7mm wide feed spacer divides the leafs from each other, which is also responsible for mixing and transporting the water through the membrane elements. The feed water is introduced on the outside surface of the leaf and the desalinated water is cumulated on the inside of the sheets and transported on the open side to the central permeate collector tube. Around this collector tube the sheets are in a spiral form and wrapped with a fiberglass envelope. The end of the membrane is built from seal carriers and end caps, which has a lot of holes for saline water distribution for the next element. The seal prohibits the water from bypassing the RO element. The water flow is straight from the beginning of the membrane till the end. The removed salt on the feed side of the membrane is mixed again with the feed water creating brine. There are more membranes connected to each other with the help of integrated O-rings in the vessel. [67]

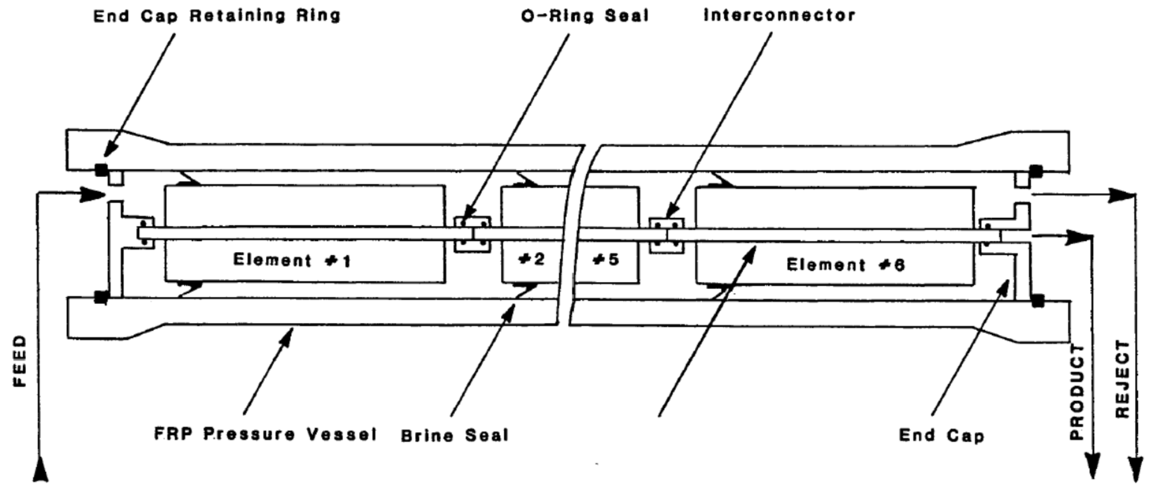


Figure 12 Structure of a RO membrane module Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Typically in a vessel there are 8 membrane elements assembled, which can produce 13-25m^3/day of drinking water. As the figure shows, the saline source water is entering in the front and the permeate and the brine is collected at the end. It means that the first membrane module is suspended to the entire vessel feed flow and has the highest permeate flux of all modules. The flow distribution in a vessel is uneven, as a rule of thumb the first membrane produces about 25% and the last about 6 to 8%. The fall in the production can be explained by the salinity increase in the feed water during the vessel. On the other hand, the first membrane has the highest biofouling potential. The feed water, which was not driven through the membrane, at the end of the module it will be mixed with the concentrate. The feed pressure is reducing with every membrane module, decreasing the permeate flow. Usually the first two modules have a high biofouling and the last two have a high mineral scale formation possibility. The following figure presents the decrease of permeate production in percentage. [67]

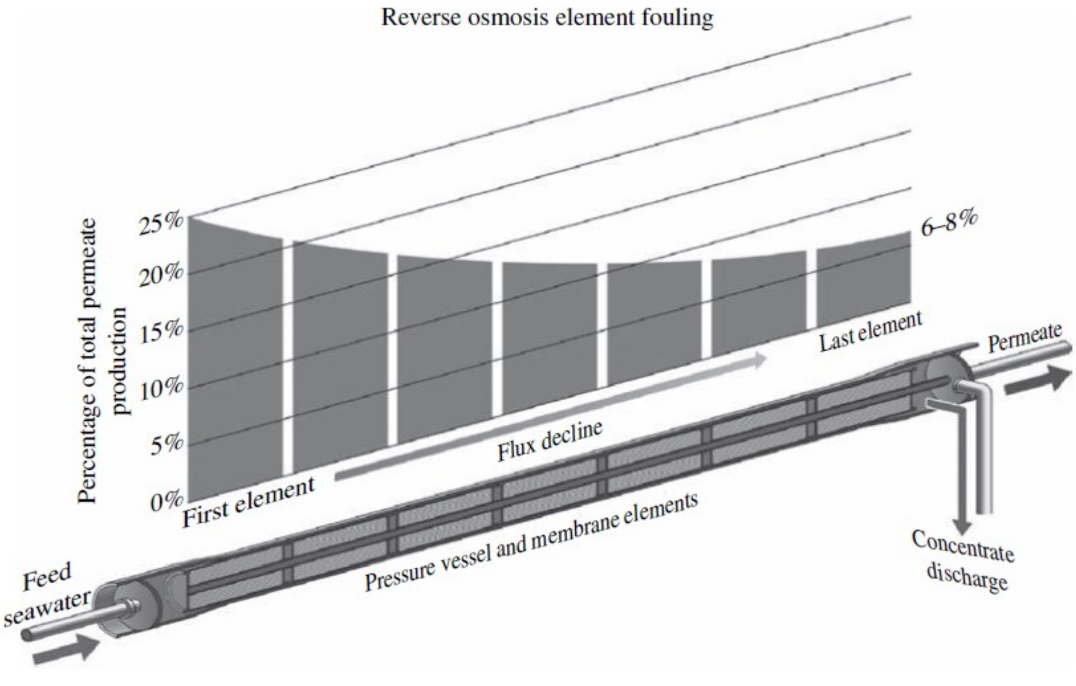


Figure 13 Decrease of permeate production in percentage[67]

For the design of the desalination system, the general parameters for configuration need to be understood.

The osmotic pressure:

P_o is related to the water salinity and calculated form the molar concentrations of the dissolved salts. The formula:

$$Op = R * (T + 273) * \sum mi$$

where O_p = the osmotic pressure of the saline water (in bars−1 bar = 14.5 lb/in^2)

R = the universal gas constant [0.082 (L· atm)/(mol· K) = 0.0809 (L· bar)/(mol· K)]

T = the water temperature in degrees Celsius

$\sum m_i$ is the sum of the molar concentrations of all constituents in the saline water.

The osmotic pressure is calculated at 25°C

P_o =26.8bar

The relative osmotic pressure per 1000 mg/L of TDS of the Atlantic Ocean is 26.8/(35,000/1000)=0.77 bar. It varies from temperature and water quality.[67]

Permeate Recovery

There are several reasons, why just a portion of seawater can be transformed into drinking water. The permeate rate gives the percentage of the feed water flow ($Q_{p)}$, which is converted into freshwater (Q_f). The percentage for seawater varies between 40 to 65%.

$$\mathrm{Pr} = (\mathrm{Qp}/\mathrm{Qf}) * 100\%$$

With increasing recovery factor, the permeate flux is decreasing till the point, where the net driven pressure(it will be described detailed later) is insufficient to transport water through the membrane. So the freshwater production in stopped.

With help of the permeate recovery factor, the TDS of the concentrate can be deduced:

$$TDSc = \frac{TDSf - TDSp\frac{Pr}{100}}{1 - \frac{Pr}{100}}$$

Where TDS_f is the feed water concentration

TDS_p is the permeate concentration

TDS_c is the TDS of the brine

P_r is the permeate recovery factor

According to the WHO drinking water guide, the freshwater salt concentrations need to be under 100mg/L. Therefore in the calculation this value is used:

$$TDSc = \frac{35{,}000 - 100\frac{50\%}{100}}{1 - \frac{50\%}{100}} = 69{,}900mg/L$$

The drinking water production is proportional with the permeate recovery rate and also with the rate that is related to the TDS of the brine. The higher the mineral concentration in the brine is, the higher the possibility to form scales is. Therefore, it is important for the brine management. [67]

Membrane Salt Rejection

It presents in percentage, how much of the TDS of feed water was rejected by the membrane.

$$Sr = \left[1 - \left(\frac{TDSp}{TDSf}\right)\right] * 100\%$$

In our case, 99.71% of the salt is rejected. This formula can also be used for the ion rejection. The higher the electric charge of the ion is the better it will be rejected. It needs to be mentioned that the membrane does not remove gasses like chlorine gas, carbon dioxide or oxygen just if they are transformed into ammonium ion or bicarbonate ion. [67]

Net Driving Pressure (NDP)

This is the pressure that drives the feed water through the membrane. It is calculated as a difference from the feed pressure and the counter forces like average osmotic pressure O_p, the permeate pressure P_p and the pressure drop P_d across the feed/concentrate side.

$$NDP = Fp - (Op + Pp + 0.5Pd)$$

Two factors can be controlled by the operator of the plant. The feed pressure with the feed pumps and the permeate pressure that is also set up by the operator. The pressure drop can be influenced by the fouling grade. It is usually between 1 to 3.5 bar.

Membrane Permeate Flux

Membrane permeate flux (J) is a ratio between the permeate flow (Q_p) of the membrane and the unit membrane area (S). The unit is defined in L/m2h.

$$J = Qp/S$$

There is a proportional correlation between the source water quality and the membrane flux. If the SDI is below 3, the high flux can be applied, but if it is more than 4, the high flux would accelerate the biofouling. Consequence would be a more frequent cleaning demand. [67]

After explanation of basic terms about the reverse osmosis membrane, the next chapter will present all of the components of a desalination plant.

3.3 Components of RO seawater desalination plant

3.3.1 Technical overview of RO desalinations plant

The size of the plant, the source water quality, the membrane for the desalination and the location for the service area are defined. The next step begins with the planning and configuring the intake of the plant to achieve the target water volume including the intake conduits, pump station and screening of the source water. To minimize the membrane fouling potential, the seawater needs to undertake a pretreatment, which eliminates the organic and inorganic particles from the water and also filtering dissolved gases. The process includes chemical conditioning and water filtering systems. They are followed by the reverse osmosis separation system. The permeate water needs to have a post-treatment to correspond for the drinking water guideline. At the last, the accrued brine need to be discharged into the ocean. Figure below shows a general schematic of a seawater desalination plant.

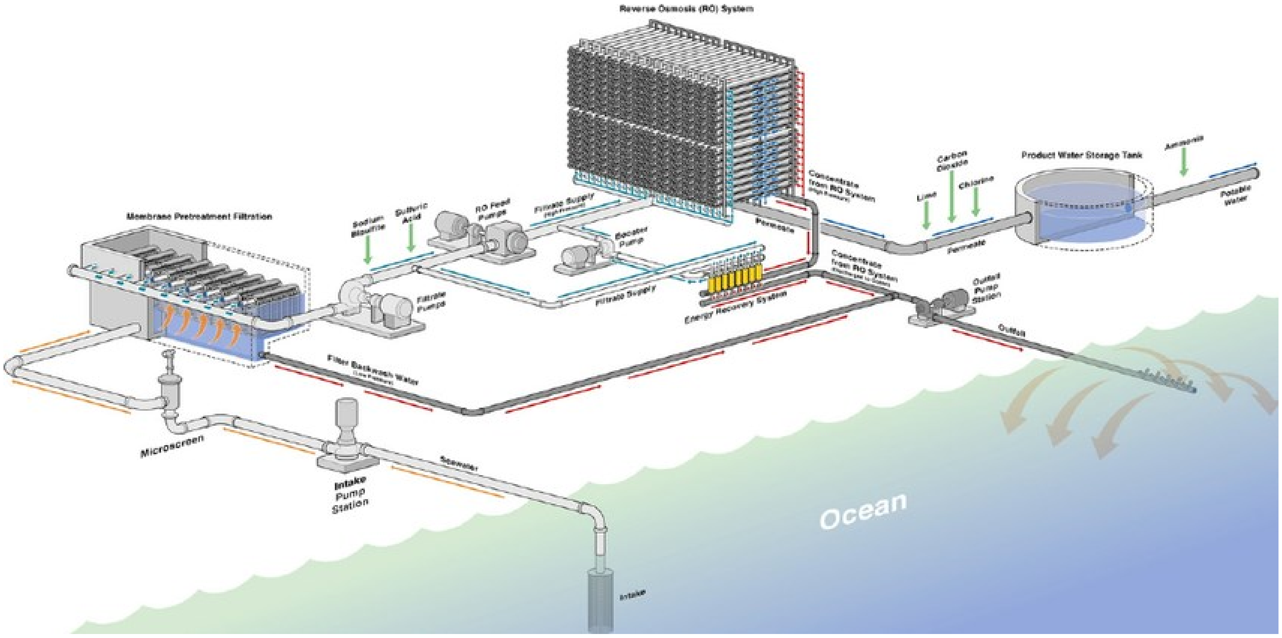


Figure 14 Schematic of a seawater desalination plant Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

3.3.1.1 Plant intake

There are mainly two intake systems used for collecting water: surface or subsurface intakes. For the seawater desalination the open intakes is the common one. First of all, the location, depth and the configuration are the main parameters, which need to be determined. For the decision the floor of the water body needs to be scanned. The route for the intake conduit needs to be analyzed in the geotechnical point of view. If the bottom does not have any seismic fault, the conduit can be directly installed on it, reducing the influence of the wave on the pipeline. Depending on the plant size, the offshore intake system has a velocity-cap-type inlet structure with different numbers of water conduits, which transfer the water to the onshore intake chamber, through the pump station into the fine screens. The intakes well has usually a vertical position and it is made from steel or copper-nickel. The well is located at least 300m (max 2000m) from the coast. It is recommended not to design the intake too deep in the ocean, because the use of cold water increases the energy demand of the production exponentially. The entrance of the well also called wedgewire screen is installed about 4m from the floor of the water body and 4 to 20m from the water surface. The distance allows the well to collect water outside of the surfzone, where the algae and the organic concentration is higher. Wedgewire screens can be used up to an intake capacity of 20,000 m^3/h. The requirements for the application: the sweeping velocity needs to exceed 0.3m/s and the distance from the bottom of the water to the surface is at least 1m. The application is beneficial, because the construction costs, the maintenance are lower than the conventional intake, the installation is faster and less aquatic creature pass into the water conduit. For the intake structure configuration the plant intake flow needs to be calculated: [67]

$$Qin = \left(Qmax * \frac{100}{R}\right) * (1 + \frac{BW + OW}{100})$$

Where Qmax is the maximal daily production flow, for the desalination plant with capacity 100,000m^3/day is 105,000m^3/day

R is the recovery percent of the permeate 50%

BW is backwash water use, assumed 5 percent

OW is other water use, assumed 1 percent

The intake pump stations ensure a constant seawater supply for the desalination plant. Most pumps are suitable up to 90m depth. The common used pump station is the wet well station, whose pumps are equipped with vertical turbines. One of the key disadvantages is the potential of the corrosion, therefore a ventilation for the pump is needed. The pump motor in the station needs to be installed above the 100-year flood level and the ground floor of the station needs also to be constructed at least 0.6m higher than the adjacent ground. Depending on the intake well depth, the maximum velocity is 1.5m/s. The pump station is equipped with a sonic level sensor, a wet-well level indicator, a pump controller, flow meter and a flow recorder, control valves, temperature sensors and indicators, and oil and grease sensors. For an entire cleaning of the pipeline, the desalination plant is shut down once in every 12 month for 1 day. Therefore, the source water is already treated with chemicals in the pimping station, because the growth of biofouling expands the head loss of the pipeline and decreases the intake capacity. The biofilm on the wall is formed by the plankton bonds, which accelerates the biofouling. The problem can be treated with reducing the pH of the water till the value of 4. The added sodium and sulfuric acid is consumed till the pretreatment section. The following table presents the use of chemicals in the pump station. [67]

Table 16 Chemical use by the pumping station Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

	Sodium hypochlorite	Sulfuric acid
Dosage (summer, winter)	6 mg/L, 4 mg/L	100 mg/L, 140 mg/L
Frequency (summer, winter)	every 48 h, weekly	weekly, biweekly
Dosage (average, maximum)	6 h, 4 h	6 h, 4 h

The main purpose of the screening is to protect the pretreatment and the RO membrane from the physical damage. The most of the organic life is removed from the source water with the coarse bar screen, where the bar racks are 50 mm from each other. The bars need to be cleaned every year manually to ensure the intake capacity. For the fine screening there are more options for the desalination plant owner. It can be screened by the self-cleaning rotating screen, which has an opening of 3mm and it is installed in vertical position in the water intake channel. To remove the debris, a water-spraying nozzle is implemented, which has a flow about 68m^3/h and a pressure of 7 bar. It has two groups: band and drum screen. For the larger desalination plant the application of drum screen is common, therefore the band screen will be not described in details.

The key component of the drum screen is a wire-mesh cylindrical frame, which is driven by a horizontal center shaft. The source water is introduced in the inner side of the cylinder and it has a radially motion out of the screen. The pattern refers to in-to-out screening. The debris is collected in a water trough within the cylindrical frame and transported with sprayed water from the top. On the market the single and double- entry is available and the maximal screening capacity is 3,000,000m^3/day. The main advantages against the band screening are, that it has lower maintenance costs and it can handle the jellyfish outbreaks. [67]

The second option for screening, is the application of wedgewire screen, where the main difference is that it does not have any mechanical moving parts and it is installed directly before the intake pump station. Therefore there is no need for coarse and fine screening. The offshore wedgewire screen is built 3m above the bottom and has a 3mm cylindrical metal screen. The slots have a trapezoid shape. At the screen a high velocity flow dominate, therefore, the organisms are carried away with the flow. An airburst back-flush system secures the cleaning of the screens. The water then flows into the microscreen system. A disk filter or chamber filter can be used as a microscreens filter. The openings are 80µm wide. The solids accumulate in the inner surface of the filter, which increase the differential pressure. If this pressure overcomes a given value, the backwash water will transfer the deposited solid. The process takes 30s. Both sides of the filter are armed with Polypropylene disks. These disks are lying upon another. The groove on the top of a disk runs opposite to the groove below, creating a filtration element with a series of valleys and traps for the source water debris. The disk filter has high efficiency and often combined with fine screens. The accumulated aquatic organisms between the disk filter and the shell of the filter are cleaned with the backwash, if the head loss is more than 0.35 bar. The low operation pressure and the organism return pipe limit the biofouling. The opening size needs to be smaller than 120µm, because the size of the embryonic barnacles is 130 to 150µm. [67]

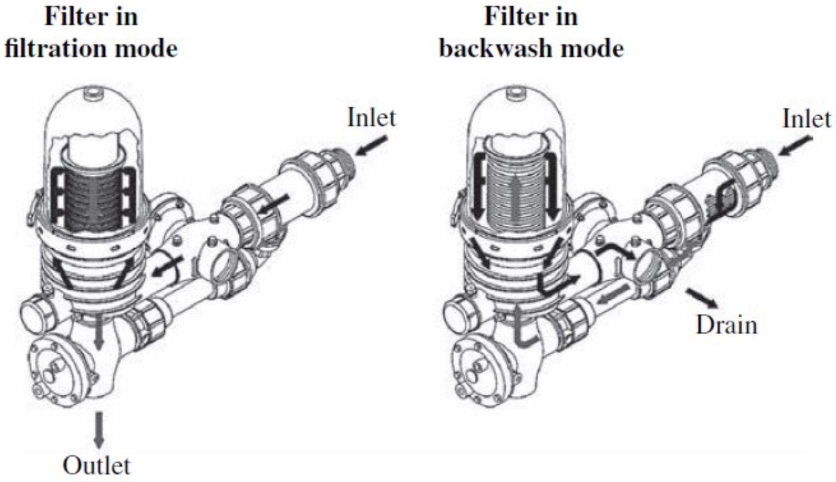


Figure 15 Operation of disk filter Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

The finest filter system is the cartridge filter. The central tube consists of small thin plastic fibers. It is also common to use the cartridge filter alone for the screening with a filter range of 1 to 5μm.

The algal cells, oil, grease or solid, which pass through the microscreening will be eliminated from the water by the dissolved air flotation (DAF) technology. The technology based on the application of small air bubbles removes the solids from the water collected on the top of the tank. The technology is mostly equipped with the granular media filter together.

To control the biofouling in the desalination system, the source water needs to be treated with chemicals. The most common used chemicals are: coagulants, flocculants, scale inhibitors, oxidants. Ferric sulfate or ferric chloride are used as coagulant for the source water, which is added during the filtration process. The dosage depends on the pH value of the water, which change with the temperature. The correlation between the temperature and pH value for coagulant is disproportional. With increasing temperature, the optimum pH is decreasing. At the use of membrane pretreatment, the coagulant is added just by algal bloom, when the particles have a high negative charge. The feed system has three components. In the coagulant tank the chemicals will be mixed with the source water and therefore the electric charge will be neutralized. The subsequent agglomeration of the coagulated particles into larger, easy-to-remove flocculants is completed in flocculation tanks. The last is the feed system itself, which ensures an equal mixing of coagulant, because the reaction time of the coagulation and flocculation is different. It can be accomplished by in-line static or a mechanical mixer in the coagulation tank. The in-line static mixer function is at the velocity range of 0.3 to 2.4 m/s. The velocity gradient contact time for such mixers can be determined by the formula: [67]

$$G * T = (1212 * d) * (Dp * \frac{L}{Q})^{0.5}$$

Where G = velocity gradient, sec$_{-1}$

T = time, sec

d = diameter of static mixer, in.

D_p = differential pressure through mixer, lb/in$_2$

L = length of static mixer, in.

Q = flow, gpm

The advantages are the low energy consumption and the low maintenance. The disadvantages: the flow turbulence provides the mixing energy and the equipment is special by designed for the project, so the operator has limited options for the repair in the case of damage. In this sector there is a highly risk depending on one manufacturer. The physical head loss of 1m is also associated with the mixer and the additional length of the pipeline (at least 20 times the pipe diameter).

The mechanical flash mixer is used when there is an enormous difference between the minimum and maximum plant production. The energy demand is about 1.64kWh per 10,000m^3/day and the velocity gradient multiplied by time is between 4,000 and 6,000.

For the flocculation (polymers) dosage, some pilot tests are needed, because the slightly over dosage can negatively impact the fouling. [67]

A weaker oxidant is used at a low pH level for the remove of microorganisms. This is the chlorine dioxide, which has a short life time. Therefore, it needs to be created in the desalination plant area. Some site product lice chlorites can be generated. The level of chlorite is necessary for monitoring, if it exposes, the RO membrane can be damaged. If the level is 1mg/L, the

degradation begins after 200h. In the water retained chlorine is handled with sodium metabisulfite ($Na_2S_2O_5$). Three times higher oxidant scavenger is needed for the removal of the free chlorine.

The preparation tanks and storages are located in the building to protect them from the environment. They are usually designed for 30 days. The next table summarizes the characteristics of the chemicals.

Table 17 Characteristic of the chemicals Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Chemical	Typical Application	Typical Product Concentration, %	Bulk Density, kg/L	Application Concentration, %
Liquid ferric chloride	Coagulation	40	1.42	5
Liquid ferric sulfate	Coagulation	40	1.55	5
Sulfuric acid	pH adjustment	98	1.83	20
Sodium hypochlorite	Biogrowth control	13	1.23	5
Sodium bisulfite	Dechlorination	99	1.48	20
Antiscalant	Scale control	99	1.0	20
Sodium hydroxide	pH adjustment	50	1.525	20

For the project the following calculation is needed regarding for the chemical use in the feed system, the storage capacity, water dilution flow and the chemical metering pumps.[67]

The daily amount of the needed chemicals in kg/day is calculated using:

$$Qdc = \left[Concentration\left(\frac{mg}{L}\right) * Flow\left(\frac{m3}{day}\right)\right]/1000$$

Qavg for ferric acid for example = (5%*100,000)/1000= 500 kg/day

Qmax= (30*100,000)/1000Q =3,000 kg/day

Chemical Storage Tanks

The daily max chemical use of 3,000 kg/day is at 100 percent chemical concentration. As mentioned above, the storage is designed for 30 days. The ferric chloride is supplied in liquid form and 40% of concentration.

$$Ast = \left(average\ daily \frac{amount}{Storage} concentration\right) * Storage\ time$$

= (3000/0.4) * 30= 225,000 kg of 40% liquid ferric chloride for 30 days

The density of ferric chloride acid is 1420 kg/m^3, therefore the storage needs to be designed at least 159 m^3. In the practical life, the storage capacity is designed 15 percent larger.

Water Dilution Flow

This is the needed flow for the reduction of the concentration of the chemicals to the application concentration. Given in L/h. Delivery concentration is C_d and application concentration is C_a. The formula:

$$Qdavg = Wavgdc * [\left(\frac{Cd}{Ca}\right) - \left(\frac{1}{Dd}\right)]/24$$

= 911L/h

3.3.1.2 Pretreatment

After the fine screens, the water reaches the pretreatment facilities of the desalination plant. The system can be differentiated in microfiltration (MF) or ultrafiltration (UF) or from the driving force of view as pressure or vacuum driven membrane. The membrane system shows a very good turbidity reduction till 0.1 NTU and removes pathogens till log 4.

The pretreatment system includes the MF or UL membrane, the backwash system with pumps and an air compressor, a water storage tank for the chemical cleaning and a clean-in place (CIP)system. Similar like the RO, the membrane modules are in the vessel. The same types are available on the market: spiral, turbular or hollow fiber. The membrane manufacturer constructs the membrane from hydrophilic material like polyethersulfone (PES) or polyvinylidene diflouride (PVDF). These materials get wet, which has a positive effect on the pore size and biofoul is less likely to accrues on the surface. The permeability of the PES material is higher than PVDF, on the other hand it is weaker and has a lower flexibility. Since the driven pressure from the pumps is usually about 4 bar, the material needs to have a good mechanical resistant. Therefore the PVDF variation is the most common used. [67]

The filtration procedure in all cases is the same. Beginning with the processing following by the backwash, cleaning and the last integrity testing. The filtration can be with direct of cross flow. In the cross flow just 90% of the source water goes through the membrane and 10 % will be rejected, so it will be transported to the feed pumps again. The main advantage of such an application is that the filtration can be continuous. In direct flow the membrane needs time for cleaning. Therefore the membrane flux – production volume per unit area- needs to be designed between 24 to47 gfd (gallons per day per square foot) for the optimum operation and reducing the potential for biofouling. The pressure difference between the feed pressure and filtrate pressure of the pretreatment system is the transmembrane pressure, which forces the water to drive through the membrane. Depending on the technology used, it varies from 0.2 to 2.5 bar. The backwash system cares about the frequently cleaning of the pretreatment system. It happens every 120 min and take 30s. It can also be triggered by the TMP if the value reaches a preset point. If the backwash system is combined with an air compressor, there is no need for chemical cleaning. The backwash system using chemicals is called chemically enhanced backwash (CEB). This process is repeated every month. First, low-pH water with sulfuric acid is driven through the conduits, then high-pH water with sodium hypochlorite. The chemical water stays in the system for 8h. Than it will be flushed and the operation can start again. During the offline pretreatment system, air will be conveyed into the conduit. If it loses the pressure, this is a signal for the operator that the system has a brake somewhere. These tests are made periodically during the lifetime of the desalination process. [67]

Depending on the configuration, two main systems can be installed. In the pressurized system the flow has an outside-in direction, so the water flows around the filter fibers, then the water filtered via the membrane is accumulated in the fiber lumen. The submerged system has the same flow direction, just the driving force for the water transport is the vacuum. The membrane modules are in the metal tank, which allow a fast and easy cleaning and maintenance process. The submerged membranes can handle a wider range of turbidity and have significant by higher capacity than the pressurized system. The construction cost and the energy consumption is lower by the submerged technology. The pressurized membrane are more suitable for the source water below 15°C. With decreasing temperature the viscosity of water is increasing, causing a much higher pressure demand. Therefore as a pretreatment system the submerged membrane is chosen.

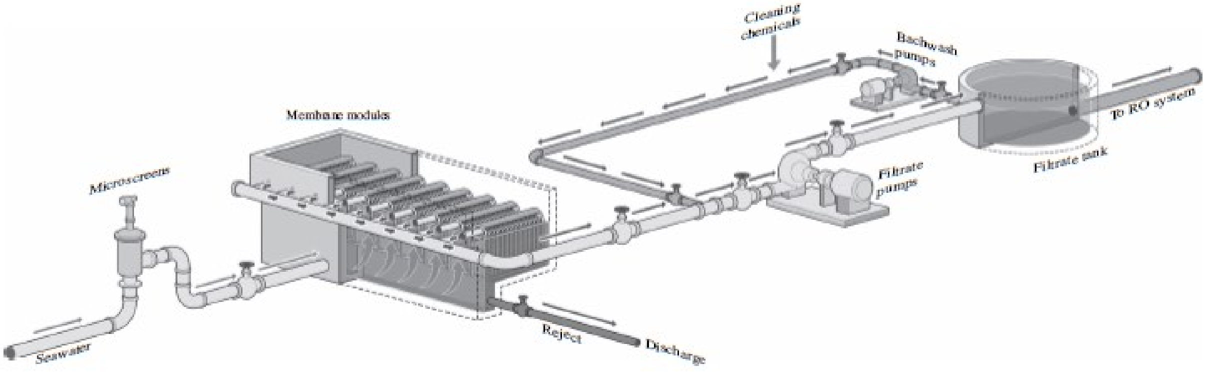


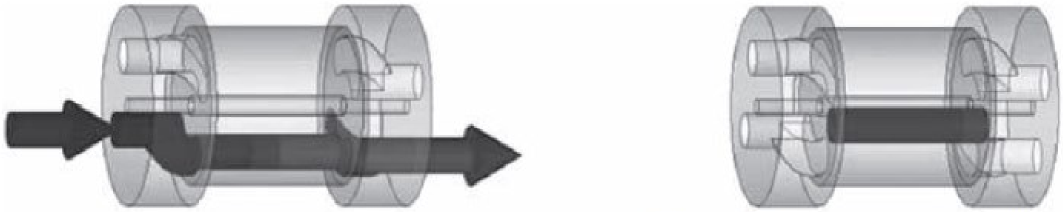
Table 18 Submerged membrane pretreatment system Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

3.3.1.3 RO separation system

The chapter 3.2.4. already provided the basic information about the membrane structure, the material, the vessel structure and the general parameters. This chapter presents information about the piping schema of the RO desalination, the energy recovery, the control system and the system configuration. For the seawater desalination, the pumps usually operate from 55 to 70 bar. It is designed with 15 percent more performance than the calculated flow and pressure to ensure the continuous production. By the start of the plant, the pressure of the pump needs to be increased consistent with maximal 0.7 bar pro second. Otherwise, the membrane leafs in the module deform and the O-rings brake. The common capacity of a pump is about 19,000m^3/day, so it can serve two vessels.

The efficiency of the pumping system can be supported with an energy recovery solutions. It can be a centrifugal system with a turbo charger or an isobaric system with a pressure exchanger. 50% of the overall energy input for the entire desalination process is consumed by the RO membrane. 50% of the O&M costs and 25 % of the water production costs also have a correlation with the energy demand. Therefore, this is an inevitable investment to be cost competitive on the market. The centrifugal system relies on a hydraulic turbocharger, which converts the pressure of the brine into rotational energy. This energy is conveyed to the feed pump, with what reducing the energy of the pump (approx. 50%).

In the isobaric system the energy of the concentrate will be reused with the pressure-exchanger. It has a high efficiency (93%) and transports almost half of the water, which was fed into the RO membrane. It means a 15 percent overall energy reduction. The pressure-exchanger is built from fiberglass vessels. These lead to a common feed. The vessels consist of the ceramic rotor with more chambers. The low pressure water flows in the chamber, than driven by the flow, it rotates itself and will be mixed with the high pressure water, which is conveyed to the feed pump.[67]



Low-pressure feed water fills rotor chamber, displacing brine

Rotor chamber seals, containing low-pressure feed water

High-pressure brine pressurizes and displaces feed water

Rotor chamber seals, containing high-pressure brine

Figure 16 Function of the pressure-exchanger for energy recovery system Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

The wide range of instruments like, magnetic flow meters, rotameters, electronic pressure transmitter, temperature and pH sensors provide reliable information to the control staff for optimal operation. The most common used information network is the SCADA system, it supports the monitoring of the pressure changes in the system, the energy consumption and gives important data for the operator.

Depending on the source water and the aimed product water quality, the configuration of RO system can be single or multi pass and single or multi stage system. If the source water quality contains high salt concentration, two pass systems are applied. With the multi pass application the product water quality improves, but the volume of the water flow of the membrane is reducing. Therefore, the investment costs are higher than the single pass system has. However, the use of the multi pass system, is reducing the feed pressure needed in the first membrane with 65%, which has a positive effect on the fouling rate, which in turn results in a low chemical demand and cleaning frequency.

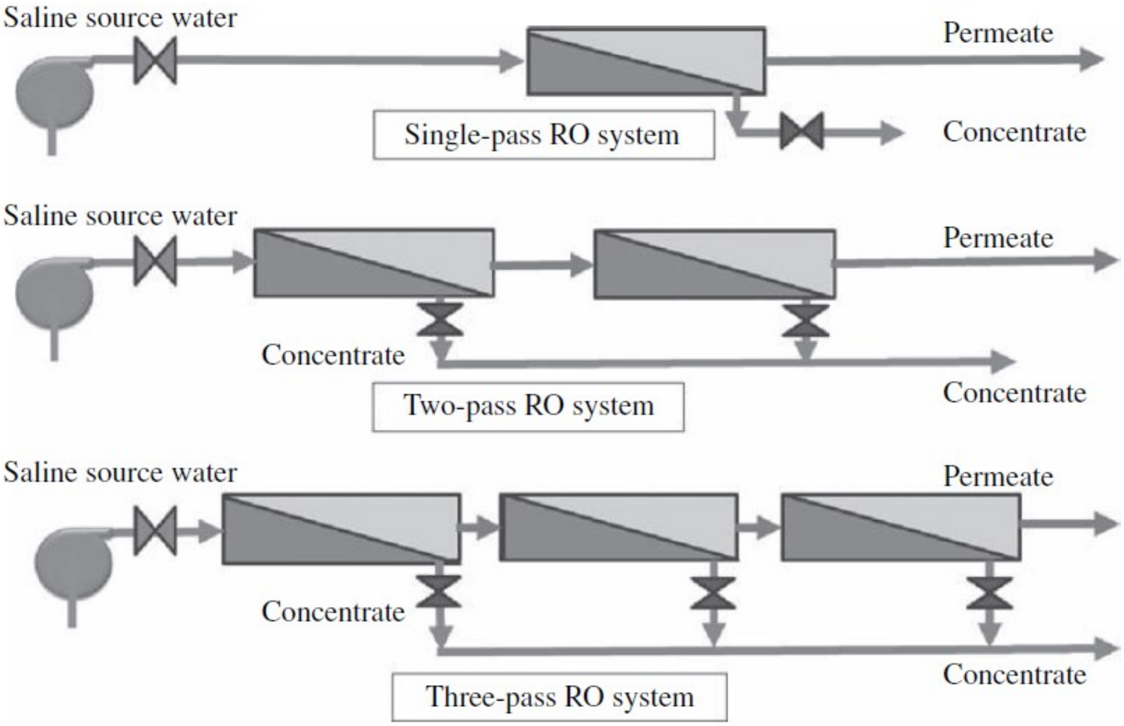


Figure 17 Pass variation for RO system Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

The system can be structured with multi stages, however, it decreases the overall energy recovery. The source water quality with 35,000 TDS requires a split partial system with two passes to achieve the target water quality. In this case, the brine produced by the second pass is conveyed to the feed water of the first pass. This brine increases the salinity of the source water, which increases the energy use, but with the use of the second pass, the energy saving is higher than using just multi pass configuration. [67]

3.3.1.4 Post treatment

The desalinated water requires some additional treatment to correspond to the targeted water quality. Therefore the remineralization is the first treatment process to protect the distribution system from the corrosion and ensure the water quality for health guideline. The low concentration of the carbonate alkalinity, calcium and magnesium is not sufficient for the creation of the calcium carbon film on the conduit walls, which would protect it from the corrosion. On the other hand, some ions and gases like chlorides, oxygen or hydrogen sulfide can passes through the membrane and they accelerate the corrosion process. There are mainly two indicator for the corrosion potential: The calcium carbonate precipitation potential (CCPP) and the langelier saturation index (LSI). If the LSI is negative, the product water is undersaturated and with the positive LSI, the water is oversaturated in terms of calcium carbonate. The CCPP indicates the volume of the calcium carbonate. The alkalinity means the proton-accepting capacity of the water. The higher the alkalinity is the more stable the pH value of the water is. Depending on the conduit material, the high alkalinity can raise the corrosion potential. The higher the calcium concentrate of the water is, the more likely a protective film will be firmed on the pipe wall. On the other hand, if the film is too big, a higher pressure is needed for the water transportation. The pH value is relatively low in the product water. The low pH value (under 7) accelerates the corrosion, therefore, it needs to be treated. The optimal value is between 7.5 and 8.4. Adding choline dioxide or chloramines ensures the disinfection and raises the pathogen inactivation efficiency of the water. Below there are some recommended values from the literature research for the economical post-treatment:

- Alkalinity $>$ 80 mg/L as $CaCO_3$
- $80 < Ca^{2+} < 120$ mg/L as $CaCO_3$
- $3 < CCPP < 10$ mg/L as CaCO3
- $7.5 < pH < 8.5$

The remineralization can be passed by the direct addition of calcium and magnesium or by mixing the product water with the source water or adding minerals, which contains dissolved calcium and magnesium. The post-treatment process starts with the addition of lime and carbon dioxide. For the fluoridation, chlorine and fluorosilicic acid (FSA) is used. The mix of these chemicals with the desalinated water reduces the pH of the water, therefore adding sulfuric acid is the last step. The figure gives an overview about the post-treatment schematic. [67]

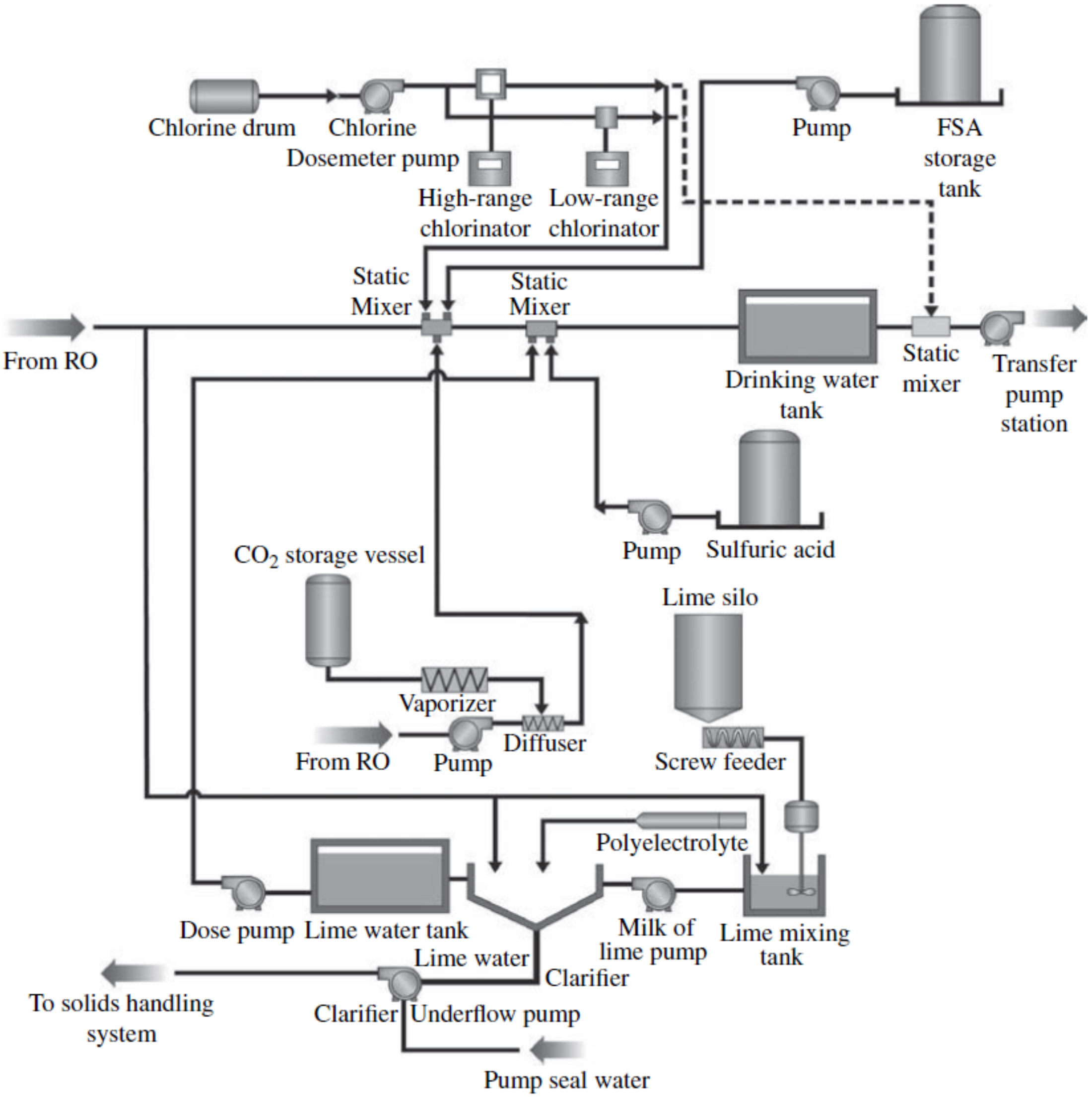


Figure 18 Post-treatment schematic for RO desalination plant Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

Calcium hydroxide in the form of lime and carbon dioxide is added to the water. The ratio is 0.74mg/L hydrated lime and 0.88mg/L carbon dioxide for elevating the alkalinity of the water by 1mg/L. The lime used for remineralization is stored in silos and the pressure storage tanks are used for carbon dioxide. Usually the pathogens are eliminated to 2 log. The post-treatment for disinfection happens either with the addition of chlorine gas or with sodium hypochlorite. Since sodium hypochlorite is easier to handle and needs a lower mixing percent, it is the common chosen option. On the other hand, this chemical loses its strength very fast, 20 percent during 10 days. Therefore a cost-lifecycle analysis gives the required information for the operator about the decision.

3.3.1.5 Desalination Plant discharge management

The discharge of a desalination process consists of the brine, the backwash water and the chemical water used for membrane cleaning. This can be treated with the deep well injection, evaporation ponds, the sewer disposal or the most common application is the surface water discharge. During the desalination process the waste streams accrues. [67]

The reverse osmosis membrane produces the brine as a by-product. This water has an elevated concentration of the source water contaminant and chemicals, which were added during the pretreatment. The brine volume depends on the plant size and the recovery system efficiency. The higher the recovery of the plant is the higher the salinity of the concentrate is. The brine production per day can be calculated with the formula:

$$Qc = Qp * \frac{1 - R}{R}$$

where Qp is the volume of fresh water production

Qc is the volume of concentrate production

R is the plant recovery in decimal.

For the 100,000m^3/day capacity desalination plant with 50% recovery, the generated concentrate has a volume of 100,000m^3

Of course, the quality of the concentrate depends on the source water quality. In case of seawater desalination it is usually 2 times higher. The membrane rejects heavy metals in the same ration then the calcium and the brine has a low turbidity .The TDS of the brine can be calculated with the following formula:

$$TDSc = TDSs * \frac{1}{1-R} - \frac{R * TDSp}{100 * (1-Y)}$$

Where the TDSc is the concentrate TDS

TDSs is the source water TDS

TDSp is the product water TDS

R is the plant recovery

The concentration factor (CF) can be calculated with the following formula.

$$CF = \frac{1-(R * SP)}{(1-R)}$$

Where SP is the salt passage through the membrane = 1-% salt rejection = permeate TDS (TDSp)/feed TDS (TDSs)= 0.003

R is the recovery percent.

CF=1.997

The membrane pretreatment system produces the backwash water approximately every hour and takes about 10 percent volume of the intake. The quantity of the backwash water can be calculated by the following formula:

$$Qbw = Qp * \frac{BW}{R}$$

Where Qbw is the daily backwash volume

Qp is the plant product water capacity

R is the recovery percentage

$$Qbw = Qp * \frac{BW}{R}$$

The backwash water contains the solids, which are removed from the source water by the pretreatment and ferric hydroxide. The total suspended solid concentration can be calculated by the following formula

$$TSSbw = \frac{(TSSs + 0.8 * DOSE_{FE}) * Qs}{Qbw}$$

Where TSSbw is the suspended solid concentration of the backwash water

TSSs is the suspended solid concentration of the source water (mg/L)

$DOSE_{FE}$ is the dose of the ferric salt

Qbw is the backwash volume m^3/day

Qs is the source water volume m^3/day

TSSbw=14.5 mg/L

For the cleaning process of the RO membrane and the pretreatment system, the membrane flush water is applied. The flush water is calculated as the total volume of the RO system:

$$V_{RO\ System} = Nt * Nvpt * Nepv * Aro * Ucl$$

where VRO system is the volume of the RO system

Nt is the number of the RO trains

Nvpt is the number of the vessels per train

Nepv is the number of the elements per vessel

Aro is the total membrane surface area of one RO element (m2)

Ucl is the unit cleaning volume (L/m2)

For the discharge, the common used surface discharge management is chosen. Near offshore tidal zone with enormous turbulent energy provides an excellent mixing zone for the concentrate. The ion concentration of the brine is similar to the ocean water, therefore, there is no need for additional treatment. However, if the brine contains the high concentration of ferric hydroxide, mixing with the source water can discolor the area. Therefore, the iron needs to be oxidized during the pretreatment. The outfall pipeline is designed to have velocity of 1 m/s and commonly built from plastic materials. [67]

3.4 Use of renewable energy technology for electricity generation

The key factor for designing a market competitive drinking water production with seawater desalination is the water production cost. Since the cost of power contributes about 20 to 35% of the overall production costs and 40 to 60% of O&M costs, the solutions of reducing the energy demand have primary importance. There are more options to decrease the electricity costs such as an application of energy recovery systems, negotiating an electricity market based on contracts with the utility or producing electricity by renewable energies.

3.4.1 Use of PV technology for electricity generation

Morocco is a country with a high solar irradiation and a lot of sunny hours. Therefore, one of the available options generating energy for seawater desalination is the application of photovoltaic. This section will provide a general overview of PV considering the function, the material, the components of the PV system, the operation and the maintenance and planning information.

3.4.1.1 Technical overview of PV

A photovoltaic system converts the solar energy into direct current electricity with solar cells. As a material for the solar cells there can be monocrystalline silicon or polycrystalline silicon. There are thin modules and concentrator cells, where the second application cannot use diffuse sunlight, therefore, it needs a complex sun tracking system. Because of the complex tracking system and the within increasing costs this type will not be further considered in the investigation. The first manufacturing process of creating solar cells is the wafer stage, where mono crystalline cells are sliced from ribbon or ingots; poly crystalline from polysilicon. The layers of the thin modules are based on low cost materials like glass, stainless steel or plastic. The thin film modules can be categorized by the efficiency. The modules made from Copper Indium Diselenide show a high efficiency up to 12% opposite to the Cadmium Telluride modules, which have a very low efficiency rate, therefore the main market for the application is the solar watches and calculators. It has a lot of advantages using the thin film technology, like the production could be automated, for the module structure less work is needed, a lot of labour and material costs are saved. [69]

Compare to the mono and poly-crystalline silicon cells it has a lower efficiency, therefore the focus lies only on the mono and poly-crystalline technologies. Among the cells, that are available on the market, the mono-crystalline has the highest efficiency with 18 % and the poly-crystalline reaches 15 %, however, the manufacturing cost is much lower. For the cells the production has two options. First, the raw material is melted, then from the melt single-crystal ingots are made or the crystalline will be cooled down and it will be sliced. The low prices of the raw material led to the PV boom, causing an increasing number of the silicon production plants, and solving the initial shortage of silicon. It is followed by the next step, the cell stage, in which a p-n junction is created and is building an electric circuit by applying metallization paste. The p-n junctions have two types of layers:

p-type: Adding atoms with one electron less creates a layer with fewer negative electrons in the valence band, pushing the overall energy level up. For instance: In Silicon, add Boron, Aluminium or Gallium.

n-type: Adding atoms with one electron more creates a layer with more electrons in the valence band, pushing the overall energy level down. In Silicon, n-type dopants are Antimony, Arsenic or Phosphorous.

(Fechner 2015) [69]

The conversion of light into an electric current is called the photo effect. The light is a stream of photons, where each photon has a certain amount of energy. Each photon is associated with just one wavelength or frequency. The higher the frequency of photons is the higher energy it has. Only a certain range of the solar spectrum can be used for crystalline silicon PV, namely wavelength of approximately 300 nm - 1200 nm. If the incoming photon has enough energy, than it can push the electron from the valence band to become a free electron in the conduction band. The minimum energy needed for the process is called the band gap. This energy varies from material to material and the temperature has also an impact on it. This is the reason why with increasing temperature the performance of the solar modules deteriorates. In the case of p-n junction, the electrons and holes diffuse to create the charge-free depletion zone. This junction creates a slope in the resulting bands. Now, if the photo effect happens, the electron subsequently "rolls down" into a lower energy band rather than instantly recombines. This is what generates the photo current. Voltage is generated when electron holes (positive) and electrons (negative) assemble at the P-N junction (positive and negative semiconductor) and electricity is generated when leading wires are connected. (Fechner 2015)[69]

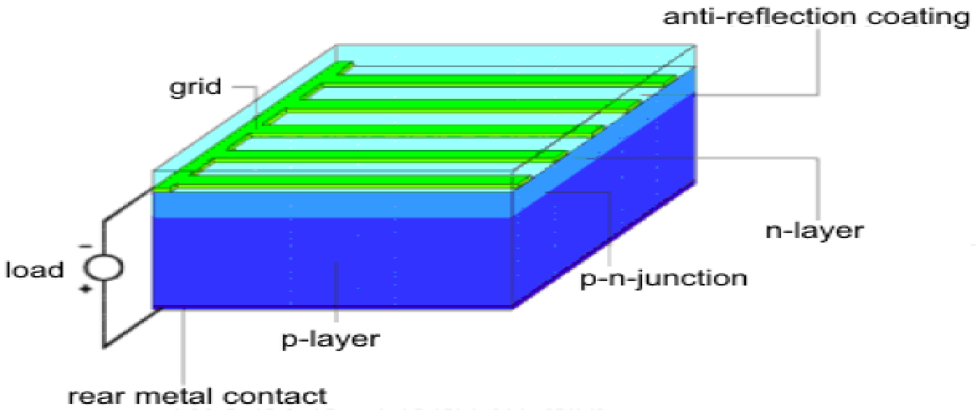


Figure 19 Solar cell Source: Fechner:2015.

The following text describes the design of PV installation:

The cells are accumulated into a unit named module. A string consists of several modules. At the mounting of strings, the modules should have the same type with the same electric values otherwise the string assimilates to the module with the lowest power.

The PV modules are under the free sky, hence they need to be designed for extreme weather conditions. Some producers with high quality products gives a guarantee for 20 years. Ditto for the related equipment, is also called balance-of-system components (BOS) like wiring, mounting structure, etc. A PV tracker is an additional option for the PV systems. With adapting the modules towards the sun, the power output can increase by 30-40%. There are two types of the tracker: the Single axis tracker is to follow daily changes and the two axis tracker is for the daily and seasonal variation. The system is most effective in locations with a high share of the direct solar radiation. Because of the higher complexity and the cost of the system it isn´t described furthermore. (Fechner 2015) [69]

The PV modules generate a direct current (DC) power, hence an inverter is required to convert the power into alternating current (AC), to be able for the grid connection. It also sets up the maximum power point for the PV module, optimizing the electricity output. There are basically two ways for installing the inverter. For the small scale the module integrated inverter is commonly used, where each module has one or a single central inverter used for the large scale plants. In this case

each PV string is connected to the central inverter. It is important to install a DC switch in order to make the service work possible. An installed monitoring system makes an overview of the electricity production and helps to detect the problem for a faster maintenance. (Fechner 2012; EPIA 2009). [69]

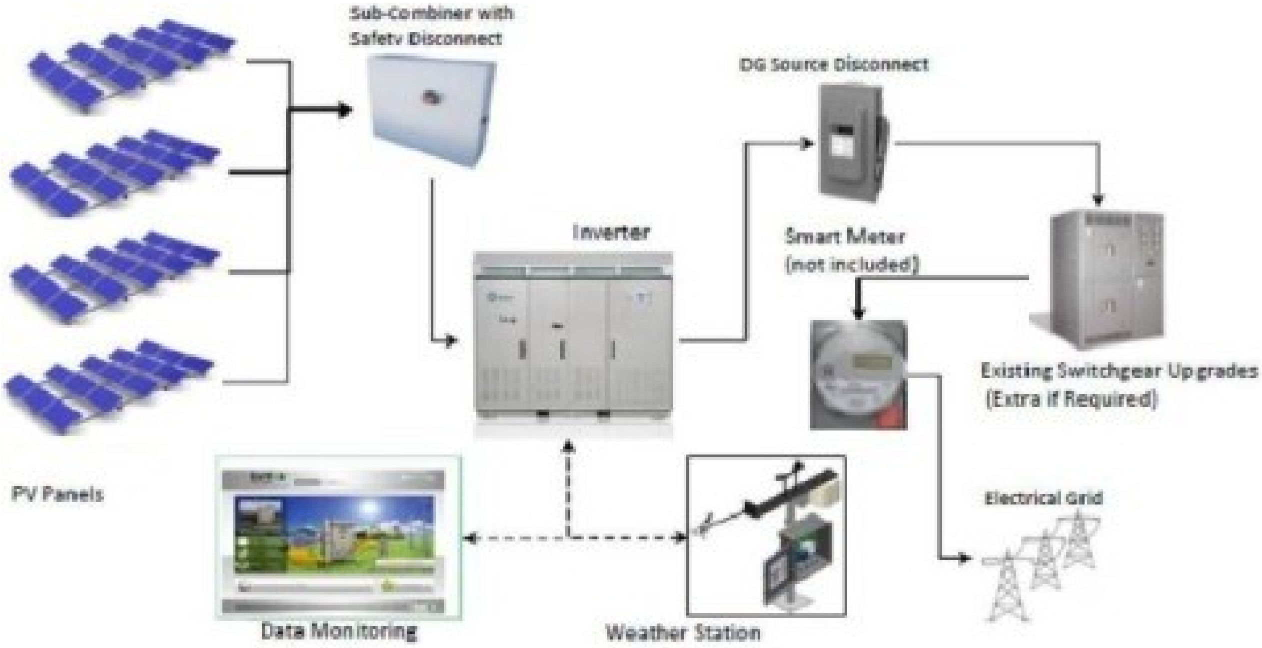


Figure 20 Overview of PV system Source: QPA Solar Inc.

3.4.2 Use of Wind technology for electricity generation

The second option of generating electricity for the desalination project is the use of wind energy. According to the Moroccan weather forecast institute, the average wind speed varies between 3 to 4 m/s at 50m height.

3.4.2.1 Technical overview of Wind energy

The wind is generated by the uneven heating of the surface of our earth by the sun. The reason for the uneven heating is due to the different surfaces of our earth (land and water). The air above the land mass heats up more rapidly during the day time, while the air above the water will heat up at a slower rate. As the air above the land rises and expands (due to heating), the cooler air above the water will rush in to fill its place. It is this process which causes the wind to blow, as the wind is the force of air rushing to fill a gap. (Clean Energy Ideas)[74]

Harvesting wind power is not exactly a new idea. The ancient civilization already used the power of wind for sailing, milling and pumping water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. The first windmill for electricity generation was built in Scotland in July 1887.(Wikipedia)

There are two options for the rotation of the turbine. It can trundle about the horizontal or the vertical axis.

Vertical-axis wind turbines characteristics:

+ the turbine does not need to be aimed into the wind to be able to use the power of wind, therefore this characteristic can be used where the wind direction is highly variable

+the generator and gearbox can be placed near the ground, hence it is easier to maintain

-the 360 degree rotation of the aerofoil and the pulsating torque cause a low power coefficient

-relatively low rotational speed and high torque

Horizontal-axis wind turbines characteristics:

The main rotor shaft and the electrical generator are located at the top of a tower. The turbines must be pointed into the wind. At very large aerodynamic torques or rotational speeds, the forces on the blades and other parts of the turbine are enormous and it will literally tear the turbine apart. Therefore the windmills are designed with a specific cut-out speed. If the wind speed is above this limit, the control system will brake the turbine. For this purpose there are two options available. (PITCH VS TALL 2013)[72]

-Stall regulation:

In stall control the electric generator is directly connected to the grid, hence an essentially speed regulation and an aerodynamic design of the rotor is necessary. As the wind speed increases and the rotor speed is held constant, flow angles over the blade sections steepen. The blades become increasingly stalled and this limits the power to acceptable levels, without any additional active control.

-Pitch regulation:

To regulate the output power the control system turns the wind turbine blades around their long axis. It requires the changes of the rotor geometry by inclination of the blades. For the optional function of the system some sensors for collecting data about the position of the blade, the output power and the wind speed need to be installed. Nowadays the pitch control systems dominates on the market.[73]

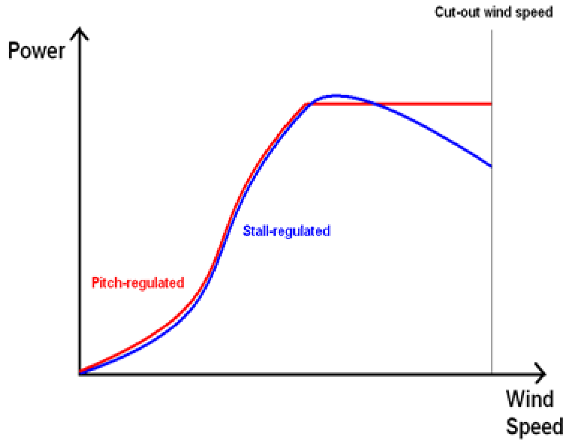


Figure 21 The power development difference between Stall- and Pitch-regulation

As the graphic shows the wind plant with the pitch regulation can operate at a higher speed than the plant with the stall regulation. The wind turbines from the company Acciona manufacturer has been chosen for our investigation. The model capacity is about 1,5 MW and called AW 1500, with an cut in speed of 3m/s.

Before designing a wind park, several data need to be collected about the wind speed, location, land rights etc. The instrument used for wind measurement is called Anemometer. For the appraisal the data need to be measured at least for 1 year. The sensor should be placed more than 2/3 of hub height (optimum would be hub height). Not every anemometer is able to measure the wind speed at the requested height. Therefore, sometimes the wind speed will be calculated with the logarithmic wind law: (Krenn 2015)[71]

$$\frac{v1}{v2} = \frac{ln(\frac{h1}{z0})}{\ln(\frac{h2}{z0})}$$

Logarithmic law

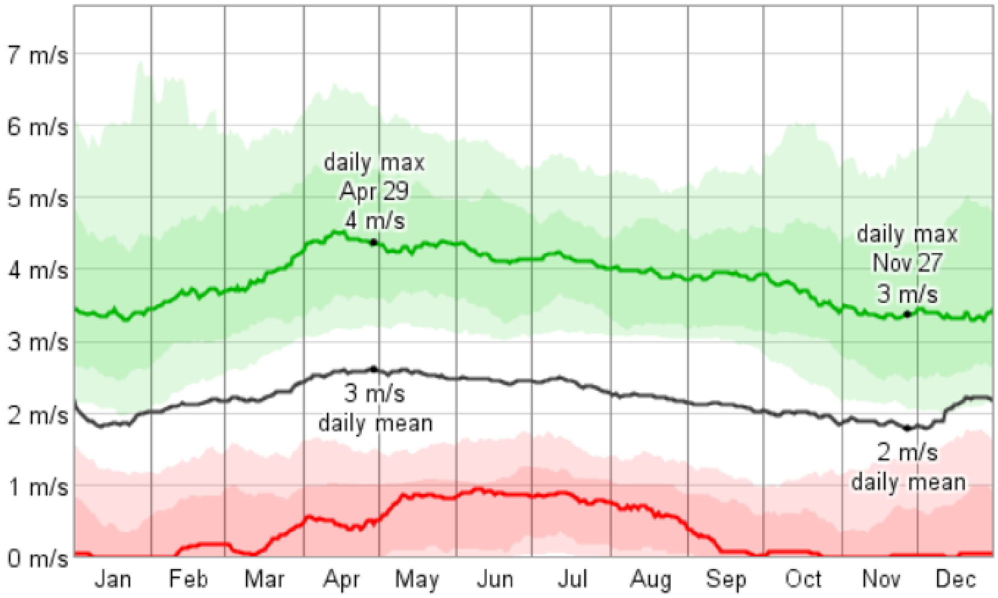
Where h1 is height 1

h2 is height 2

v1 wind speed at h1

v2 wind speed at h2

In order to evaluate the collected wind speed data, the information will be summarized in a histogram. The wind is not steady and in order to calculate the mean power delivered by a wind turbine from its power curve, it is necessary to know the probability density distribution of the wind speed. The histogram shows simply the distribution of the proportion of time spent by the wind within narrow bands of wind speed. (Weibull distribution)



The average daily minimum (red), maximum (green), and average (black) wind speed with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

Figure 22 Average wind speed Casablanca at 50 m height Source Windfinder, Weather statictic Intitute Casablanca

In the last decades the wind power industry has made an enormous development. It has reached a standard turbine capacity between 1.2 MW and 3 MW on the market. Nowadays the turbine and generator size is bigger, the hub is higher and the blades have a smaller aerodynamic drag. As known the higher the distance from the ground is the higher the wind speed is and the direction changes less frequently. (Krenn 2015)[71]

The following formula shows the calculation of the theoretical wind power:

$$pth = \frac{\rho}{2} Av3$$

Where pth theoretical power contained in the wind

P air density, which depends on air pressure and temperature

A vertical surface

V flow speed of the wind

(Krenn 2015)[71]

As the formula describes, the power of the wind depends exponentially on the wind speed. If the velocity behind the wind turbine is zero, the theoretical wind power is reached. In the reality it is impossible. According to Betz´s law, which is based on the concept of the stream tube, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind. The factor 16/27 (0.593) is known as Betz's coefficient. (Betz law , Wikipedia)[75]

3.5 Economic calculation of the concept

This chapter provides an economic overview of a desalination plant for the selected location. It describes, which technology in the individual parts of the plant is chosen and the within associated costs.

Three main ingredients are associated with a total project cost: Capital costs, O&M costs and water production costs. According to the researched literature the average water production cost by seawater desalination varies from 1.6 $ to 3$/m^3. The following figure presents in percentage, how the costs of water assemble. [67]

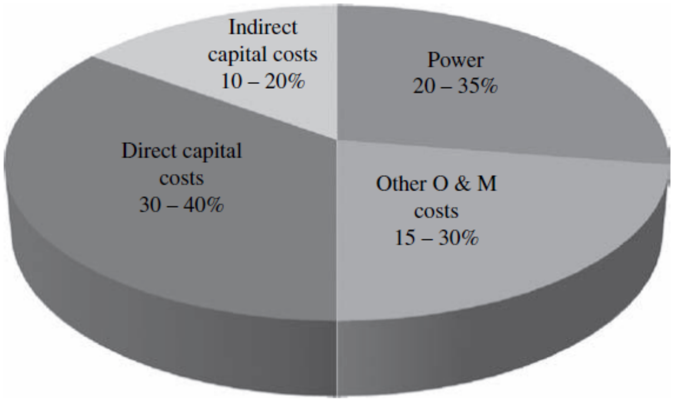


Figure 23 Cost of water in percentage Source: Nikolay Voutchkov, Desalination Engineering Planning and Design: 2013.

The capital costs

It can be divided into two groups: direct and indirect capital costs.

Direct capital costs

The direct capital costs include all of the construction expenditures. The construction costs associated with the project area are summarized as the land acquisition, the land preparation work and with the connection construction to the road. This cost is typically varies between 15$ to 200$/m^3.

This is followed by the costs of intake construction. The most cost effective variation for intake construction is to use a co-located power plant for intake and discharge. It could save 60 to 80% of the intake costs. However in our case, the open source intake construction is the best option for collecting source water. It includes the conduits, pipeline, the pump facilities and the screening facilities. The intake costs can vary between 100$ and 800$/m^3/day

To ensure the optimal operation of the membrane separation, the pretreatment technology needs to be selected carefully. The better the removal efficiency of the pretreatment is, the less likely biofouling accrues in the membrane, which in turn leads to a longer life time, better efficiency and costs saving. The costs are associated with the coarse, the fine and microscreening equipment, the membrane filtration and the chemical costs for conditioning the collected water. The average cost varies between 150$ and 450$/m^3/day. [67]

The next step in the estimation is the RO system costs, which includes the cartridge filter, the high-pressure pumps, the system for energy recovery, the RO membrane modules, the cleaning and flushing system and the feed pumps. Approximately the RO equipment costs half of the construction expenditures. The average cost varies between 450$ and 1150$/m^3/day.

The product water quality defines the post-treatment equipment costs, which consists of the chemical condition and disinfection system. The average cost varies between 80$ and 275$/m^3/day.

The cost for discharge consist of the brine management and the waste stream disposal. The average costs varies between 50$ and 750$/m^3/day. [67]

During the cleaning process and the pretreatment process, the waste and the solid accumulate, which need to be handled. These costs are divided into storage tanks and pumps for the chemical disposal and into the backwash solid handling system. It is typically in the range of 15$ to 75$.

The desalination plant also needs to connect to the electricity distributor. Therefore the electrical system costs are associated with the electrical supply system, the transformers, the electrical conduit and the emergency power generation equipment.

For the estimation of the direct capital costs, the costs for service equipment, building costs, start-up and commissioning costs also need to be investigated.

The indirect capital costs are calculated for the project engineering services like preliminary engineering, pilot testing, detailed design, project development costs, construction management, administration, contracting costs, environmental studies and fees for permitting processes. financing costs such as legal services, paying interest during the construction. [67]

Operation and Maintenance Cost

It consists of the chemical use, labor, maintenance, energy consumption, brine disposal and the replacement of the membrane and the cartridge filter.

The largest part of the O&M costs is the power use. It is defined in kWh/m^3. It varies widely from the project. Almost every large size desalination plant is equipped with the energy recovery system, which is reducing the overall energy consumption.

The labor costs mainly depend on the size of the plant and the automation grade. Usually a plant needs a plant manager, mechanics and electrical engineers, laboratory and administrative staff and a shift supervisor. At the large scale two shifts are always used every day. A desalination plant with 100,000 m^3/day requires 20-24 employees and it costs about 0.015$/m^3 to 0.04$/m^3. The fixed maintenance cost for the given equipment like piping, structure, and building is approximately 1-2 percent of their purchase cost. To maintain a constantly high efficiency the pumps and recovery system need to be refurbished every 10 years. It is typically about 0.035$ to 0.075$/m^3. [67]

In the O&M cost estimation the replacement part for RO membrane, screening and filtration need to be investigated. The lifetime of a microfiltration pretreatment membrane is 5 - 8 years. Therefore, it is calculated in the maintenance with 12 to 20% of his original purchase price for every year. For the RO membrane calculation it is the same process. One membrane element depending on the manufacturer costs about 400$ to 800$. The component, which needs to be replaced the most, is the cartridge filter. The filter costs 30$, but the replacement passes every month. The overall replacement costs are about 0.02$ to 0.07$/m$^{3.}$In the discharge process the costs of pumping need to be considered. Depending on the amount of the brine it exceeds 0.015$ - 0.035$/m^3.

At the end, the indirect O&M costs take place in the calculation. It includes the discharge quality monitoring and measurement costs, investments for the staff training, the insurance, the taxes related to the operation, the administrative and utility service costs (0.025$ to 0.075$/m^3). [67]

The water production cost is composed of fixed and variable costs. The fixed cost includes the investment cost for the plant construction, the capital cost recovery and a share of O&M like labor, maintenance, monitoring and indirect costs. The variable part consists of the power and chemical demand, the replacement frequency and the amount of discharge water.[67]

For such a large project the common used contracts can be: design-bid-build(DBB), design-build-operate(DBO) or build-own-operate-transfer (BOOT). Which contract is used, depends on the risk profile and the funding source.

The capital cost recovery presents the amortization of the capital cost. It is between 5 to 20 years, depending on the interest rate. It can be calculated by the following formula:

$$CRF = [(1+i)^{n-1}]/[i*(1+i)^n]$$

The detailed description of the capital costs and the economic calculation is attached to the master thesis. See Appendix 1

4 Description of the results

The power contributes about 20-35% of the total production cost. To be competitive with the other market player, the economic scenarios are investigated, in which the whole consumption for the desalination plant is produced by renewable energy sources. Therefore 3 scenarios are compared with each other:

-Energy supply from the conventional distributor

-Energy supply by the photovoltaic plant

-Energy supply by the wind power plant

The idea of the concept is, that the plant owner can fully supply his plant with electricity, reducing within the O&M cost. The desalination plant would be built with a BOOT contract, are built-own-operate-transfer contract. In this region, the water distribution entity sets a water tariff by 74US\$cent/m^3 for the produced water. The lifetime of such a desalination plant exceeds 50 years. For the calculation of the considered scenarios the investment horizon is selected for 30 years. After this time frame the investor can decide to operate the plant afterwards or sell it.

The detailed capital cost is described in the Attachment 1. The investment cost for a conventional desalination plant is about 166,172,943US\$. The O&M cost is total 0,4396US\$/m^3. From this value the energy cost amounts to 0.2395 US\$/m^3. In both scenarios with the renewable energy, the RE plant capacity was chosen to cover the total consumption of electricity.

4.1 RO with PV technology

Morocco is a country with a really good solar irradiation, roughly 1850 kW/m2. The given desalination plant has a production capacity about 100,000 m^3/day. To produce one cubic meter, 3kWh electricity is needed. Therefore the annual energy consumption of the plant is about 108,000 MWh. Next to the positive features of the PV technology like the easy installation and the maintenance, the efficiency of the photovoltaic module decreases approximately 0.5% per year. Therefore, to cover the power demand of the seawater desalination plant in the investment horizon of 30 years, a photovoltaic power plant with 75.857 MW capacity needs to be built.

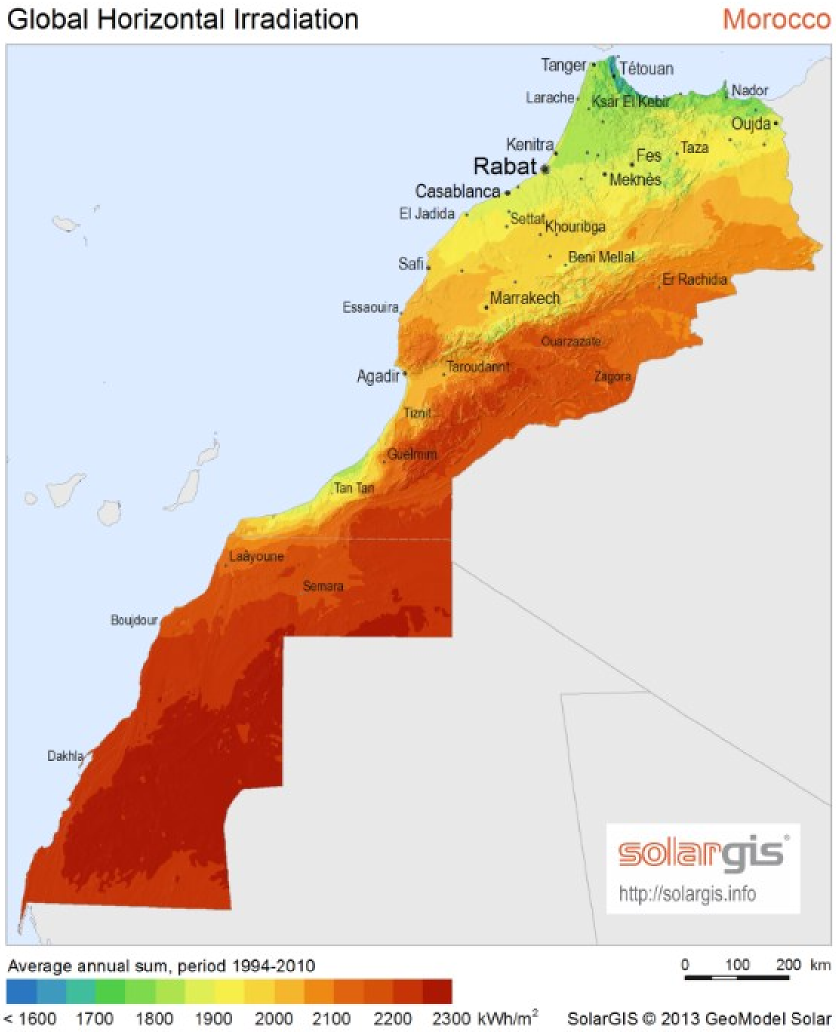


Figure 24 Global horizonal irradiation Source solargis.info

The peak capacity of the PV is about 1680kWh/kWpeak. Regarding to the efficiency decrease of PV, in the 30 years there is some surplus energy generated. To have a realistic view about the reduction of the O&M cost of water, the long run generation cost was contemplated. As an investment cost for PV, based on the prices in 2016, the system cost can be calculated with 900 €/kW.

In this scenario the surplus energy is sold to the electricity supplier. Today there is no official feed in tariff in the Kingdom of Morocco. The state shows interest in subsidizing the expansion of the renewable energy. The target is 2000MW of the solar capacity by 2020. Some bigger projects are now under construction. According to the internet data research the 3 big projects done by companies are subsidized:

Acwa Power (Saudi Arabia), Aries Ingeniería y Sistemas (Spain) and TSK Electronica y Electricidad (Spain): MAD 1.597944 (18.87 $ cents) a kWh

Enel (Italy) and ACS Servicios Comunicaciones y Energia (Spain): MAD2.057201 a kWh

Abeinsa (Spain), Abengoa Solar (Spain), Mitsui (Japan) and Abu Dhabi National Energy Company (UAE): MAD 2.057503 a kWh. [68]

Again, because of non-existent official FIT, the assumed electricity price is 10US$cent/kWh.

It is assumed that the O&M costs are 1% of the total investment for a year. In the 15th year some parts of the pv system can be damaged, which need to be changed. So for reparatory such as changing the inverter, some modules, 2% of the investment cost is calculated. The estimated investment costs are 67,967,999US$ with a long run generation cost which is about 0.53 to 0.82US$cent/kWh depending on the year of investigation.

The NPV of the project can be calculated by the following formula:

$$\text{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Where Ct is the capital in year t

r is the interest rate

C0 is the capital cost in the year 0.

The annuity of the project can be calculated with the following formula:

$$\mathbf{a} = \boldsymbol{NPV} * \frac{\boldsymbol{r}*(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{T}}}{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{T}}-\mathbf{1}}$$

Where NPV is the net present value

r is the interest rate

T is the investment horizon

The project has a NPV of 75,737,617 US$. The annuity of the project is about 3,864,077US$.If the NPV is positive, the investment seems to be a good decision. After the amortization of the capital, the investor makes a profit till the 30th years. Then he can decide either to operate the plant afterwards or sell it.

4.2 RO with Wind energy

The selected area for the desalination plant is located in a coastal region in Casablanca. The second scenario investigates the option, which is the application of the wind energy for producing enough electricity for the desalination plant. The energy yield from wind is not as exactly predictable as the energy yield from photovoltaic. For the average wind speed and for the creation of wind histogram, wind measurements for at least 2 years are needed. During the incurrence of this master thesis there were no option to do the measurements. Therefore, empiric data from the internet research are used in the calculation. The following two graphs show the empiric wind data for the region Casablanca.

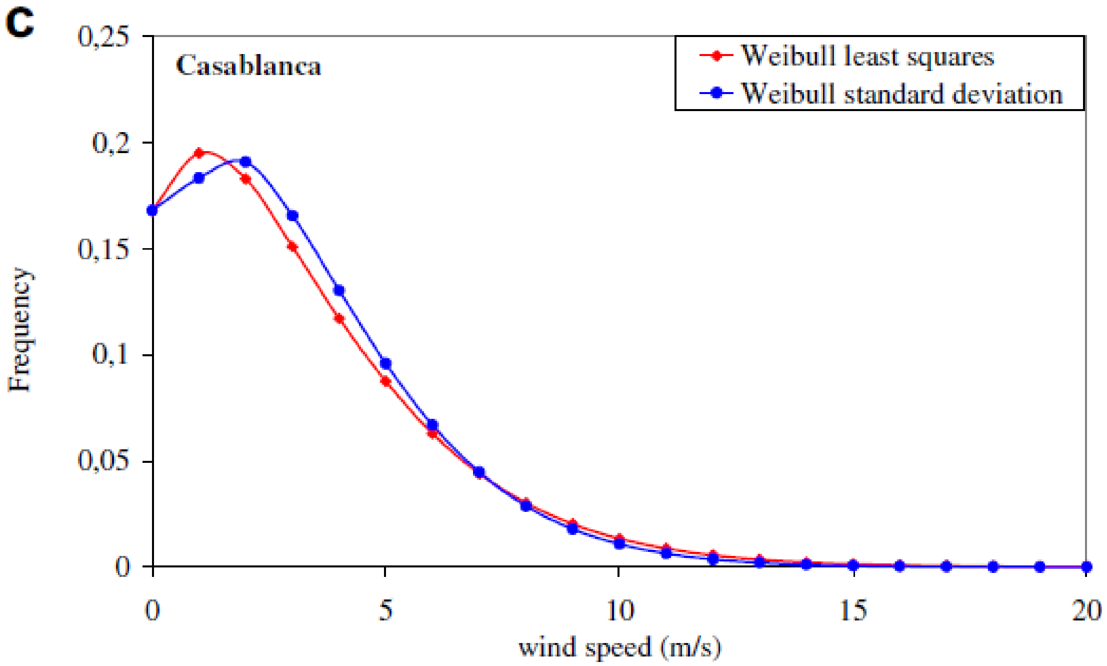


Figure 25 Wind speed histogram Casablanca Source: Roberto Sacile ,Sustainability of a wind power plant: Application to different Moroccan sites:2010

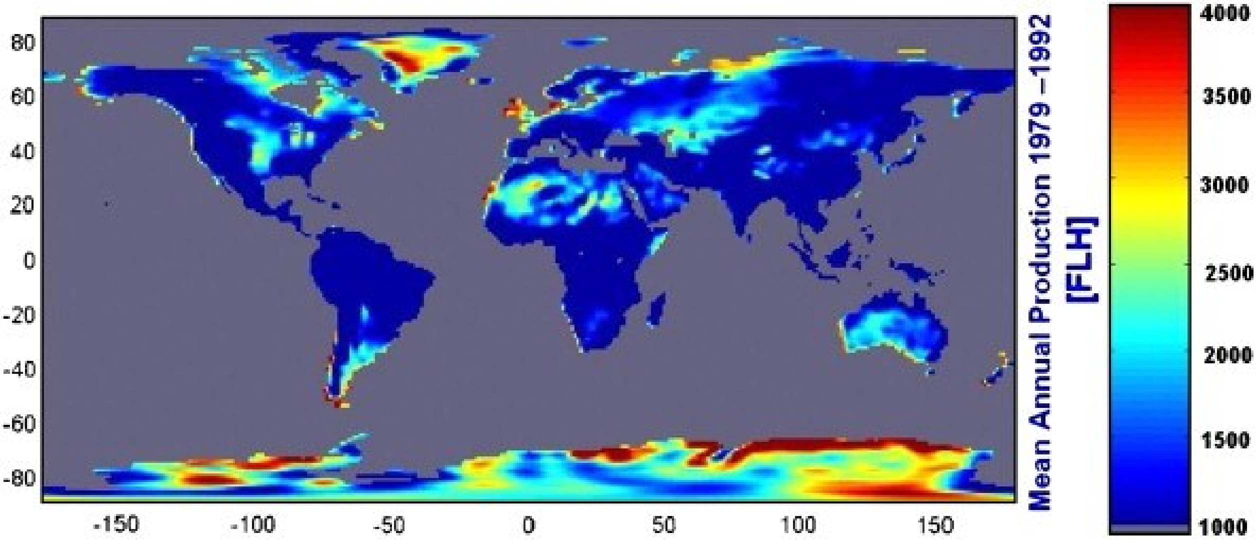


Figure 26 Full load hour map Source: Jacob A. Wisse, Wind engineering in Africa:2007.

As the graphs present, this region does not have an impressive wind speed for electricity generation. The FLH map was measured by a 1.5 MW wind mill. Therefore for the investigation the AW 1500 model from the manufacturer Acciona was chosen. It has a capacity of 1.5 MW and a cut in speed parameter of 3 m/s.

Opposite to the photovoltaic technology, the efficiency of a wind mill does not decrease by the time. Therefore there is no surplus energy to sell the energy supplier of the country. The wind park would consist of 40 installed wind mills. As in the calculation of PV, the O&M cost amounts to 1% of the total investment and in the 15th year there is a reparatory of 2% of the total investment cost.

Because of the average wind speed in the histogram, the full load hour was carefully chosen to be realistic. In the economic consideration it is 1,800h per year. The feed in tariff amounts to 0.1€cent/kW. Today exist 280MW of wind energy in the country. The same target pertains to the wind energy. The LRGC begins at 0.58 to 0.79 US$cent/kWh.

The characteristic parameter of the scenario:

Table 19 The characteristic parameter of the scenario (Own calculation)

Total Investment cost	63 mio €
Investment cost	1050 €/kW
NPV	69,299,287
Annuity	3,555,598
Total capacity	60 MW
Installed unit	40x1.5 MW

5 Conclusion

Our world is constantly changing on every level of our life. The effect of global warming can be measured today. The temperature is rising, the number of drought is increasing and evermore the area faces physical water scarcity. The potable water is the source of our life. In my point of view, everyone has a right to have enough water for drinking and hygienic purposes.

Therefore it is essential to look for ways, how to ensure the supply for the growing water demand of industries and people. In the coastal region seawater desalination can be a solution. The aim of this master thesis was to investigate the option of applying the RO membrane desalination in the Mediterranean countries. As in the point of an investor, not just the economic calculation, but the political, military and geographical risks need to be analyzed. Therefore, among the preselected countries, Morocco seemed to be the best choice for the project.

The results of the demand analyses show a tremendous potential for creating business in the water supply sector. Among the three sectors, the drinking water seems to have the most predictable demand in term of volume and time. In this master thesis the core aim was to examine a situation with 100% capacity, production 24h a day in 360 days of the year. The remaining 5 days are reserved for maintenance and cleaning purposes, therefore during this time is no production available. The master thesis is analyzing a plant of large scale. The capacity of the plant is selected for 100,000 m^3/day, because at this scale the 100% of the production can be assumed by the water distributor.

For the drinking water production three different scenarios were calculated. The basic idea of the business consists of a built-own-operate-transfer (BOOT) contract. The investor build and operate the desalination plant. The lifetime of a membrane desalination plant like this exceeds 50 years. However, the investment horizon is 30 years in the calculation of considering different scenarios. The converted water tariff is 0.74 US$/$m^3$ in Morocco. (Moroccan Investment Development Agency)

Since the 54% of the O&M cost is electricity, it is important to search for a reduction solution in the term of the energy price, to be competitive against other technologies on the water market like Multistage Flash-, Multiple-Effect Distillation or Vapor compression. Three scenarios were compared with each other:

Energy supply from the conventional electricity entity

Production of the electricity itself with photovoltaic

Energy supply with Wind Park

The following table summarizes the key parameters of the scenarios:

Table 20 Own calculation

Source of electricity	Conventional	PV	Wind
Investment horizon (yr)	30yr	30yr	30yr
Investment cost (US$)	166.172.942.	242.636.942	236.732.942
O&M (US$/m3)	0,4396	0,2001	0,2001
NPV (US$)	-18.449.325	9.552.111	3.113.782
Annuity (US$)	-941.270	487.341	15.862
Water production price (US$/m3)	0,98	0,55	0,53

As the table shows, the second scenario with the PV variant seems to be the best choice. Other positive effect using the RE for electricity generating, after 30 years the plants still owned by the investor. However the water production cost for the given time duration is higher than the other options. It can explained with the higher capital cost for PV installation, which on the other side compensate the income from the surplus energy.

In the core objectives the following question ware mentioned:

A,) Which renewable energy source would be suitable for sea water desalination?

In the chosen region, the electricity generation with photovoltaic seems to be the best choice for combining renewable energy with seawater desalination in the economic point of view.

B,) Would be the implementation of desalination technology feasible for the chosen Mediterranean country?

The documented result show, that in Morocco, the drinking water production is feasible if the electricity generation pass with renewable energies.

C,) What would be a competitive water production cost €/m^3?

In the given area, a water production cost under 88€cent/m^3 would be realistic in the economic point of view.

It is important to supply the increasing demand of industry and people therefore the humanity should look for new solutions. For the coastal region of the world, RO membrane desalination is proved to be an economic feasible way to produce drinking water. The point of my view, I believe that this technology can solve the water scarcity in the near future.

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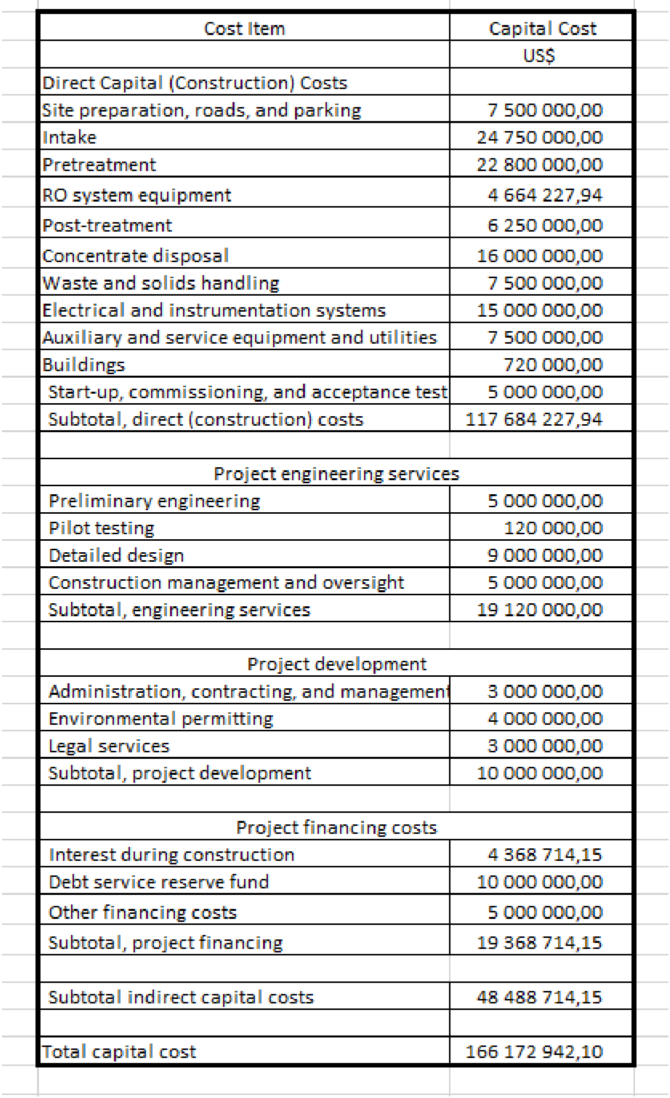
7 Appendix

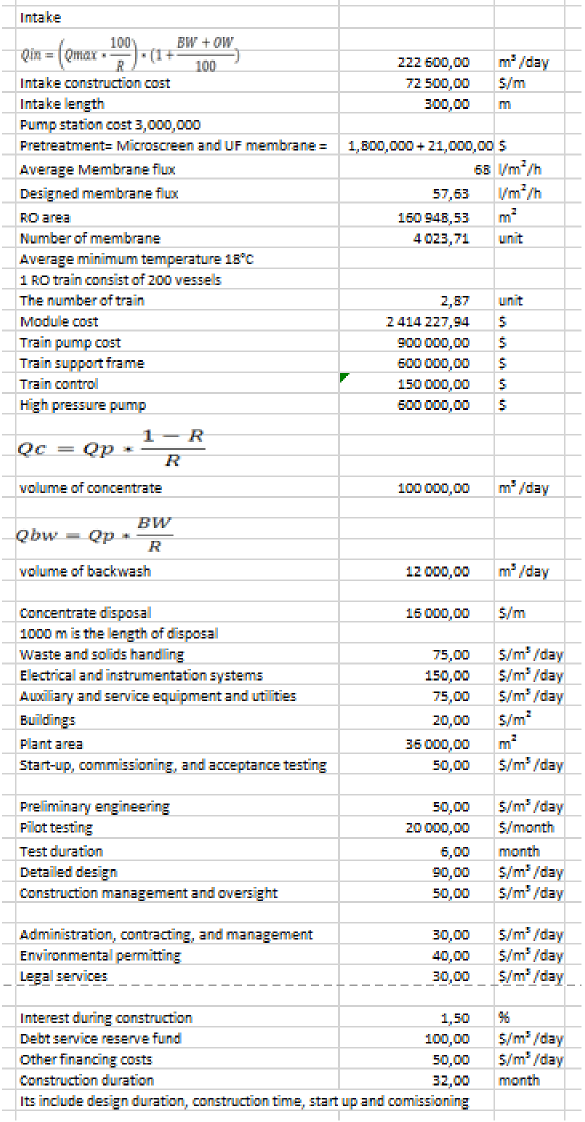
Appendix 1

Capita cost

Appendix 1 Capital cost

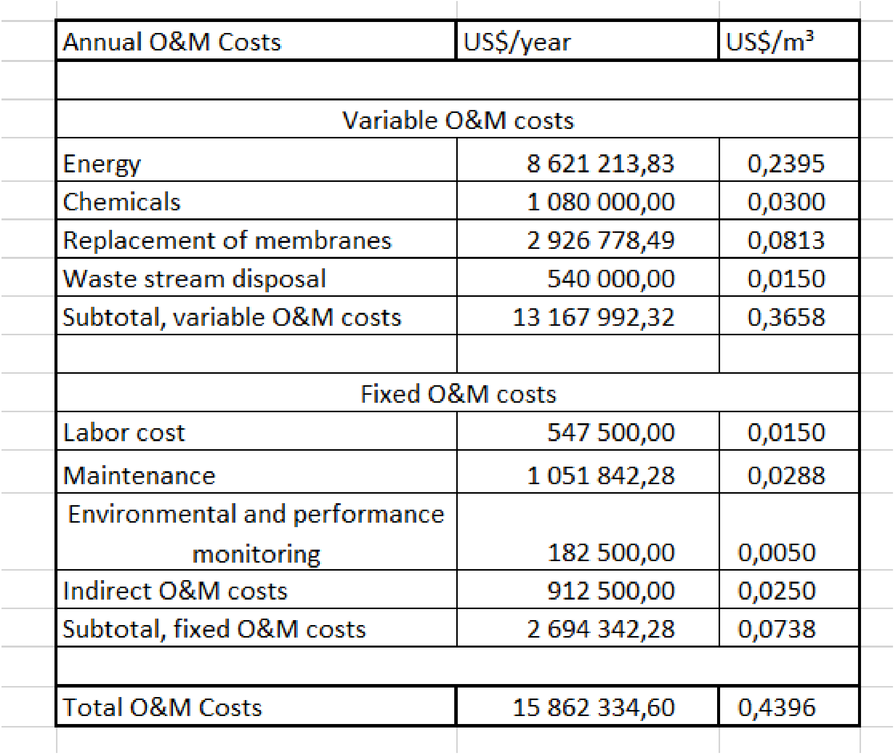


Cost Item	Capital Cost
	US$
Direct Capital (Construction) Costs	
Site preparation, roads, and parking	7 500 000,00
Intake	24 750 000,00
Pretreatment	22 800 000,00
RO system equipment	4 664 227,94
Post-treatment	6 250 000,00
Concentrate disposal	16 000 000,00
Waste and solids handling	7 500 000,00
Electrical and instrumentation systems	15 000 000,00
Auxiliary and service equipment and utilities	7 500 000,00
Buildings	720 000,00
Start-up, commissioning, and acceptance test	5 000 000,00
Subtotal, direct (construction) costs	117 684 227,94
Project engineering services	
Preliminary engineering	5 000 000,00
Pilot testing	120 000,00
Detailed design	9 000 000,00
Construction management and oversight	5 000 000,00
Subtotal, engineering services	19 120 000,00
Project development	
Administration, contracting, and managemen	3 000 000,00
Environmental permitting	4 000 000,00
Legal services	3 000 000,00
Subtotal, project development	10 000 000,00
Project financing costs	
Interest during construction	4 368 714,15
Debt service reserve fund	10 000 000,00
Other financing costs	5 000 000,00
Subtotal, project financing	19 368 714,15
Subtotal indirect capital costs	48 488 714,15
Total capital cost	166 172 942,10

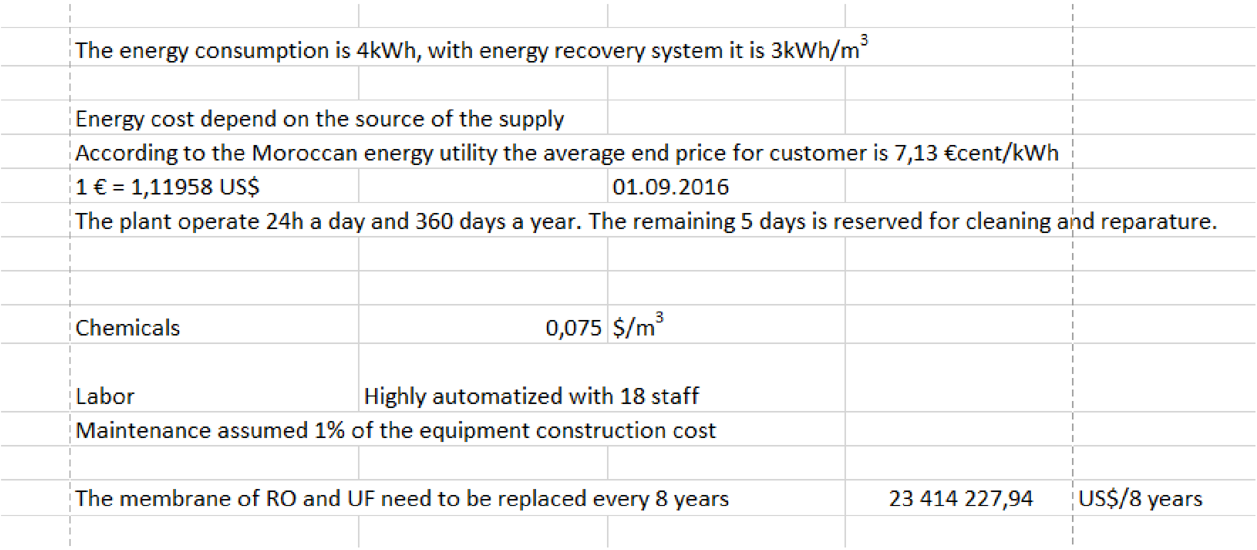


Intake		
$Qin = \left(Qmax \cdot \frac{100}{R}\right) \cdot \left(1 + \frac{BW + OW}{100}\right)$	222 600,00	m^3 /day
Intake construction cost	72 500,00	$/m
Intake length	300,00	m
Pump station cost 3,000,000		
Pretreatment= Microscreen and UF membrane =	1,800,000 + 21,000,00	$
Average Membrane flux	68	l/m^2/h
Designed membrane flux	57,63	l/m^2/h
RO area	160 948,53	m^2
Number of membrane	4 023,71	unit
Average minimum temperature 18°C		
1 RO train consist of 200 vessels		
The number of train	2,87	unit
Module cost	2 414 227,94	$
Train pump cost	900 000,00	$
Train support frame	600 000,00	$
Train control	150 000,00	$
High pressure pump	600 000,00	$
$Qc = Qp * \frac{1-R}{R}$		
volume of concentrate	100 000,00	m^3 /day
$Qbw = Qp * \frac{BW}{R}$		
volume of backwash	12 000,00	m^3 /day
Concentrate disposal	16 000,00	$/m
1000 m is the length of disposal		
Waste and solids handling	75,00	$/$m^3$ /day
Electrical and instrumentation systems	150,00	$/$m^3$ /day
Auxiliary and service equipment and utilities	75,00	$/$m^3$ /day
Buildings	20,00	$/$m^2$
Plant area	36 000,00	m^2
Start-up, commissioning, and acceptance testing	50,00	$/$m^3$ /day
Preliminary engineering	50,00	$/$m^3$ /day
Pilot testing	20 000,00	$/month
Test duration	6,00	month
Detailed design	90,00	$/$m^3$ /day
Construction management and oversight	50,00	$/$m^3$ /day
Administration, contracting, and management	30,00	$/$m^3$ /day
Environmental permitting	40,00	$/$m^3$ /day
Legal services	30,00	$/$m^3$ /day
Interest during construction	1,50	%
Debt service reserve fund	100,00	$/$m^3$ /day
Other financing costs	50,00	$/$m^3$ /day
Construction duration	32,00	month
Its include design duration, construction time, start up and comissioning		

O&M cost



Annual O&M Costs	US$/year	US$/m³
Variable O&M costs		
Energy	8 621 213,83	0,2395
Chemicals	1 080 000,00	0,0300
Replacement of membranes	2 926 778,49	0,0813
Waste stream disposal	540 000,00	0,0150
Subtotal, variable O&M costs	13 167 992,32	0,3658
Fixed O&M costs		
Labor cost	547 500,00	0,0150
Maintenance	1 051 842,28	0,0288
Environmental and performance monitoring	182 500,00	0,0050
Indirect O&M costs	912 500,00	0,0250
Subtotal, fixed O&M costs	2 694 342,28	0,0738
Total O&M Costs	15 862 334,60	0,4396



The energy consumption is 4kWh, with energy recovery system it is 3kWh/m³

Energy cost depend on the source of the supply
According to the Moroccan energy utility the average end price for customer is 7,13 €cent/kWh
1 € = 1,11958 US$ 01.09.2016
The plant operate 24h a day and 360 days a year. The remaining 5 days is reserved for cleaning and reparature.

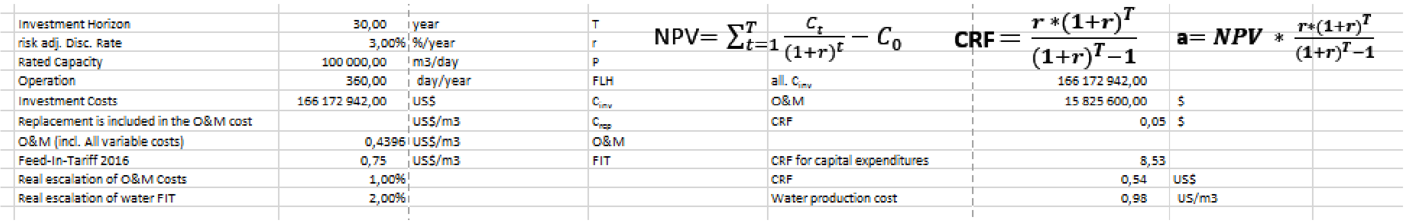
Chemicals 0,075 $/m³

Labor Highly automatized with 18 staff
Maintenance assumed 1% of the equipment construction cost

The membrane of RO and UF need to be replaced every 8 years 23 414 227,94 US$/8 years

Appendix 2

Appendix 2 Conventional solution with 75US$cent/m^3

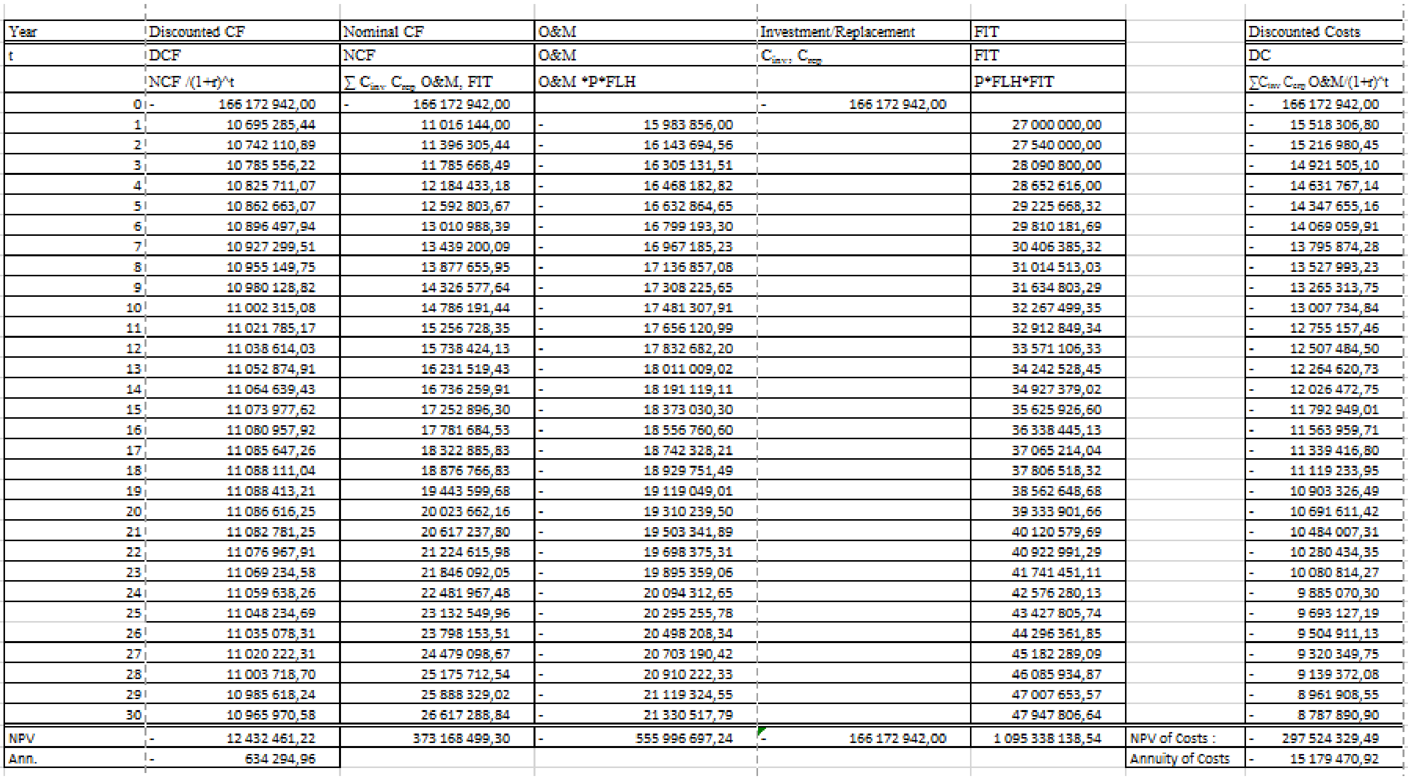


Investment Horizon	30,00	year	T			
risk adj. Disc. Rate	3,00%	%/year	r			
Rated Capacity	100 000,00	m3/day	P			
Operation	360,00	day/year	FLH	all. C_{inv}	166 172 942,00	
Investment Costs	166 172 942,00	US$	C_{inv}	O&M	15 825 600,00	$
Replacement is included in the O&M cost		US$/m3	C_{rep}	CRF	0,05	$
O&M (incl. All variable costs)	0,4396	US$/m3	O&M			
Feed-In-Tariff 2016	0,75	US$/m3	FIT	CRF for capital expenditures	8,53	
Real escalation of O&M Costs	1,00%			CRF	0,54	US$
Real escalation of water FIT	2,00%			Water production cost	0,98	US/m3

$$\text{NPV}=\sum_{t=1}^{T}\frac{C_t}{(1+r)^t}-C_0$$

$$\text{CRF}=\frac{r*(1+r)^T}{(1+r)^T-1}$$

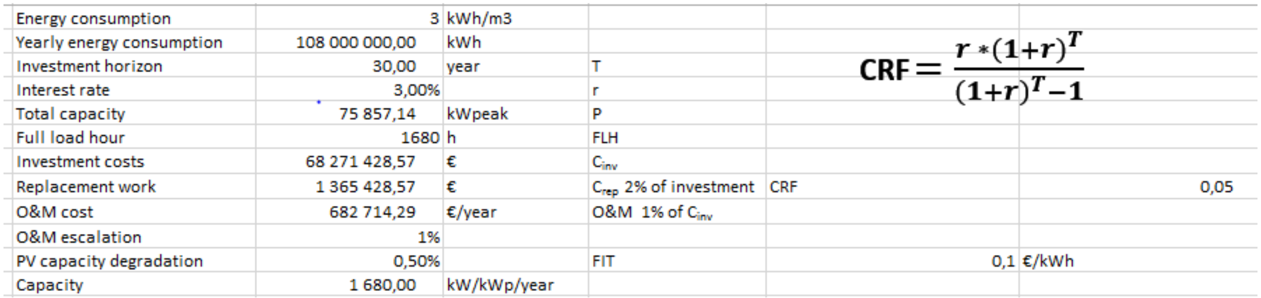
$$a=NPV*\frac{r*(1+r)^T}{(1+r)^T-1}$$



Year	Discounted CF	Nominal CF	O&M	Investment/Replacement	FIT		Discounted Costs
t	DCF	NCF	O&M	C_{inv}; C_{rep}	FIT		DC
	NCF /(1+r)^t	∑ C_{inv}, C_{rep}, O&M, FIT	O&M *P*FLH		P*FLH*FIT		∑C_{inv}, C_{rep}, O&M/(1+r)^t
0	- 166 172 942,00	- 166 172 942,00		- 166 172 942,00			- 166 172 942,00
1	10 695 285,44	11 016 144,00	- 15 983 856,00		27 000 000,00		- 15 518 306,80
2	10 742 110,89	11 396 305,44	- 16 143 694,56		27 540 000,00		- 15 216 980,45
3	10 785 556,22	11 785 668,49	- 16 305 131,51		28 090 800,00		- 14 921 505,10
4	10 825 711,07	12 184 433,18	- 16 468 182,82		28 652 616,00		- 14 631 767,14
5	10 862 663,07	12 592 803,67	- 16 632 864,65		29 225 668,32		- 14 347 655,16
6	10 896 497,94	13 010 988,39	- 16 799 193,30		29 810 181,69		- 14 069 059,91
7	10 927 299,51	13 439 200,09	- 16 967 185,23		30 406 385,32		- 13 795 874,28
8	10 955 149,75	13 877 655,95	- 17 136 857,08		31 014 513,03		- 13 527 993,23
9	10 980 128,82	14 326 577,64	- 17 308 225,65		31 634 803,29		- 13 265 313,75
10	11 002 315,08	14 786 191,44	- 17 481 307,91		32 267 499,35		- 13 007 734,84
11	11 021 785,17	15 256 728,35	- 17 656 120,99		32 912 849,34		- 12 755 157,46
12	11 038 614,03	15 738 424,13	- 17 832 682,20		33 571 106,33		- 12 507 484,50
13	11 052 874,91	16 231 519,43	- 18 011 009,02		34 242 528,45		- 12 264 620,73
14	11 064 639,43	16 736 259,91	- 18 191 119,11		34 927 379,02		- 12 026 472,75
15	11 073 977,62	17 252 896,30	- 18 373 030,30		35 625 926,60		- 11 792 949,01
16	11 080 957,92	17 781 684,53	- 18 556 760,60		36 338 445,13		- 11 563 959,71
17	11 085 647,26	18 322 885,83	- 18 742 328,21		37 065 214,04		- 11 339 416,80
18	11 088 111,04	18 876 766,83	- 18 929 751,49		37 806 518,32		- 11 119 233,95
19	11 088 413,21	19 443 599,68	- 19 119 049,01		38 562 648,68		- 10 903 326,49
20	11 086 616,25	20 023 662,16	- 19 310 239,50		39 333 901,66		- 10 691 611,42
21	11 082 781,25	20 617 237,80	- 19 503 341,89		40 120 579,69		- 10 484 007,31
22	11 076 967,91	21 224 615,98	- 19 698 375,31		40 922 991,29		- 10 280 434,35
23	11 069 234,58	21 846 092,05	- 19 895 359,06		41 741 451,11		- 10 080 814,27
24	11 059 638,26	22 481 967,48	- 20 094 312,65		42 576 280,13		- 9 885 070,30
25	11 048 234,69	23 132 549,96	- 20 295 255,78		43 427 805,74		- 9 693 127,19
26	11 035 078,31	23 798 153,51	- 20 498 208,34		44 296 361,85		- 9 504 911,13
27	11 020 222,31	24 479 098,67	- 20 703 190,42		45 182 289,09		- 9 320 349,75
28	11 003 718,70	25 175 712,54	- 20 910 222,33		46 085 934,87		- 9 139 372,08
29	10 985 618,24	25 888 329,02	- 21 119 324,55		47 007 653,57		- 8 961 908,55
30	10 965 970,58	26 617 288,84	- 21 330 517,79		47 947 806,64		- 8 787 890,90
NPV	- 12 432 461,22	373 168 499,30	- 555 996 697,24	- 166 172 942,00	1 095 338 138,54	NPV of Costs :	- 297 524 329,49
Ann.	- 634 294,96					Annuity of Costs	- 15 179 470,92

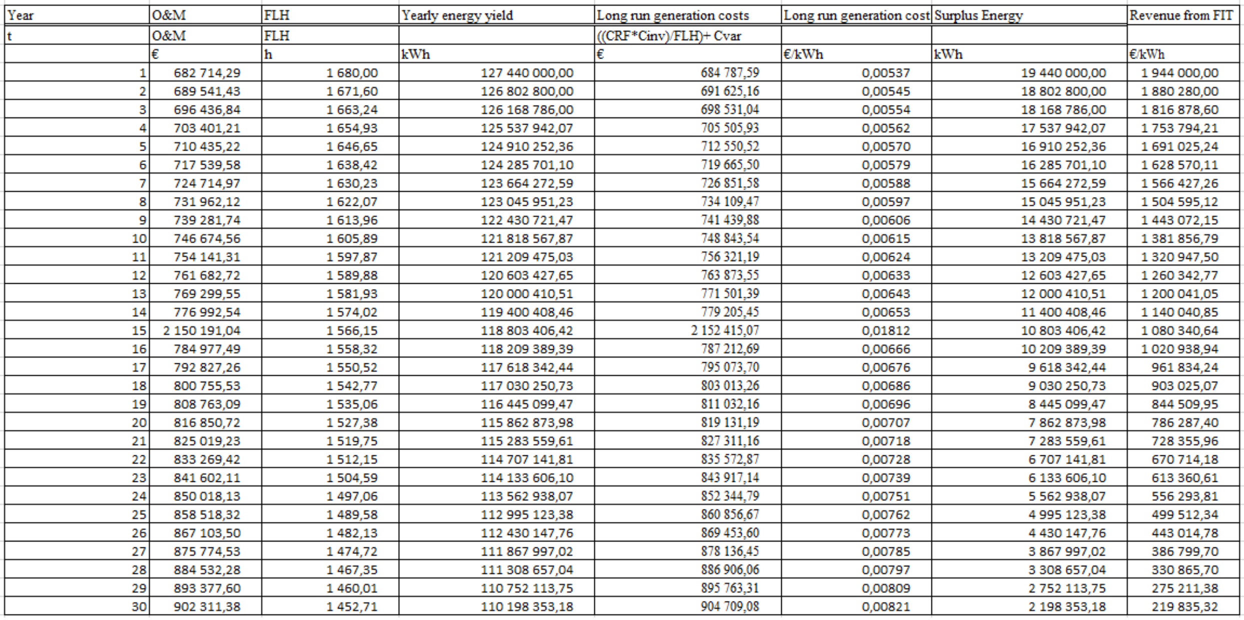
Appendix 3

Appendix 3 PV with 0.75US$cent/m³

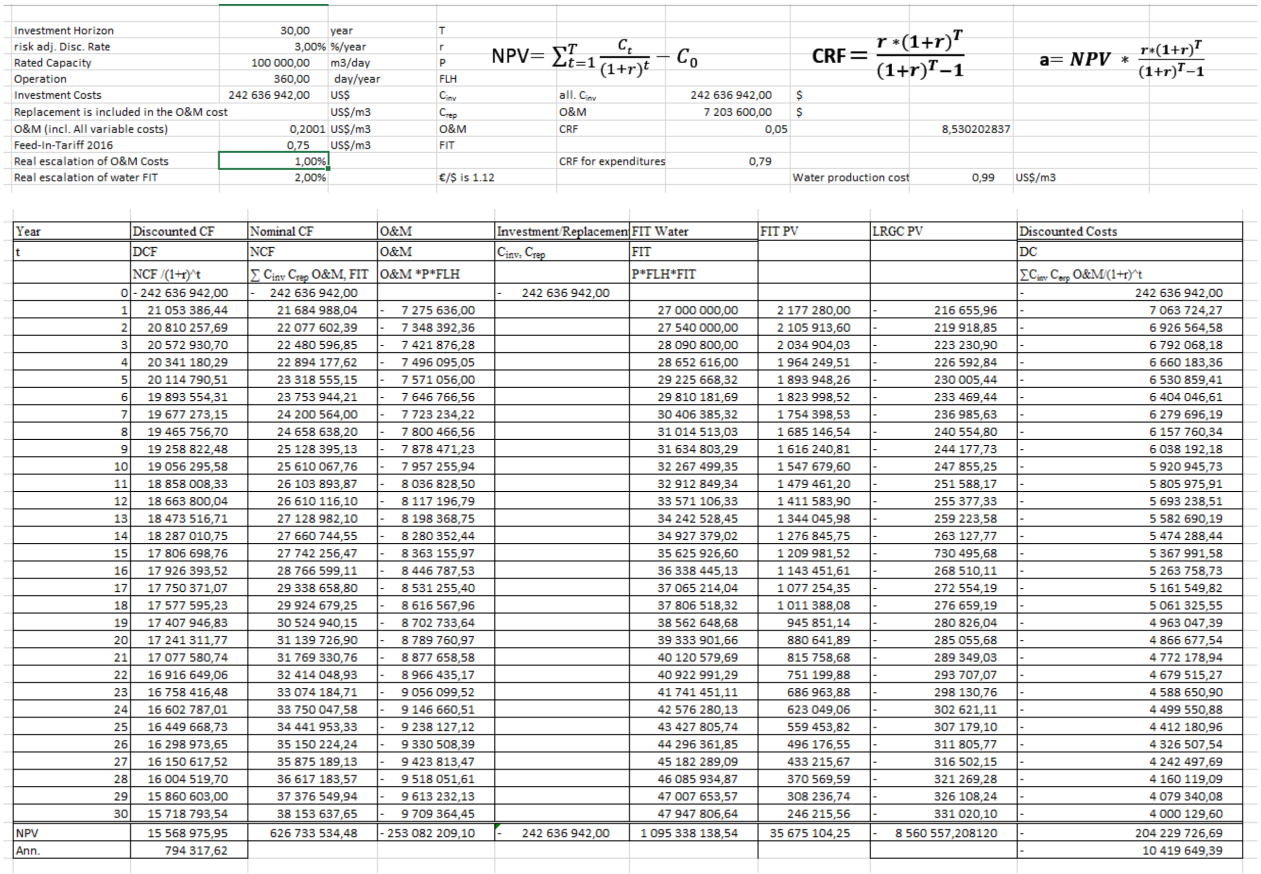


Energy consumption	3	kWh/m3			
Yearly energy consumption	108 000 000,00	kWh			
Investment horizon	30,00	year	T		
Interest rate	3,00%		r		
Total capacity	75 857,14	kWpeak	P		
Full load hour	1680	h	FLH		
Investment costs	68 271 428,57	€	C_{inv}		
Replacement work	1 365 428,57	€	C_{rep} 2% of investment	CRF	0,05
O&M cost	682 714,29	€/year	O&M 1% of C_{inv}		
O&M escalation	1%				
PV capacity degradation	0,50%		FIT	0,1	€/kWh
Capacity	1 680,00	kW/kWp/year			

$$\text{CRF} = \frac{r * (1+r)^T}{(1+r)^T - 1}$$



Year	O&M	FLH	Yearly energy yield	Long run generation costs	Long run generation cost	Surplus Energy	Revenue from FIT
t	O&M	FLH		((CRF*Cinv)/FLH)+ Cvar			
	€	h	kWh	€	€/kWh	kWh	€/kWh
1	682 714,29	1 680,00	127 440 000,00	684 787,59	0,00537	19 440 000,00	1 944 000,00
2	689 541,43	1 671,60	126 802 800,00	691 625,16	0,00545	18 802 800,00	1 880 280,00
3	696 436,84	1 663,24	126 168 786,00	698 531,04	0,00554	18 168 786,00	1 816 878,60
4	703 401,21	1 654,93	125 537 942,07	705 505,93	0,00562	17 537 942,07	1 753 794,21
5	710 435,22	1 646,65	124 910 252,36	712 550,52	0,00570	16 910 252,36	1 691 025,24
6	717 539,58	1 638,42	124 285 701,10	719 665,50	0,00579	16 285 701,10	1 628 570,11
7	724 714,97	1 630,23	123 664 272,59	726 851,58	0,00588	15 664 272,59	1 566 427,26
8	731 962,12	1 622,07	123 045 951,23	734 109,47	0,00597	15 045 951,23	1 504 595,12
9	739 281,74	1 613,96	122 430 721,47	741 439,88	0,00606	14 430 721,47	1 443 072,15
10	746 674,56	1 605,89	121 818 567,87	748 843,54	0,00615	13 818 567,87	1 381 856,79
11	754 141,31	1 597,87	121 209 475,03	756 321,19	0,00624	13 209 475,03	1 320 947,50
12	761 682,72	1 589,88	120 603 427,65	763 873,55	0,00633	12 603 427,65	1 260 342,77
13	769 299,55	1 581,93	120 000 410,51	771 501,39	0,00643	12 000 410,51	1 200 041,05
14	776 992,54	1 574,02	119 400 408,46	779 205,45	0,00653	11 400 408,46	1 140 040,85
15	2 150 191,04	1 566,15	118 803 406,42	2 152 415,07	0,01812	10 803 406,42	1 080 340,64
16	784 977,49	1 558,32	118 209 389,39	787 212,69	0,00666	10 209 389,39	1 020 938,94
17	792 827,26	1 550,52	117 618 342,44	795 073,70	0,00676	9 618 342,44	961 834,24
18	800 755,53	1 542,77	117 030 250,73	803 013,26	0,00686	9 030 250,73	903 025,07
19	808 763,09	1 535,06	116 445 099,47	811 032,16	0,00696	8 445 099,47	844 509,95
20	816 850,72	1 527,38	115 862 873,98	819 131,19	0,00707	7 862 873,98	786 287,40
21	825 019,23	1 519,75	115 283 559,61	827 311,16	0,00718	7 283 559,61	728 355,96
22	833 269,42	1 512,15	114 707 141,81	835 572,87	0,00728	6 707 141,81	670 714,18
23	841 602,11	1 504,59	114 133 606,10	843 917,14	0,00739	6 133 606,10	613 360,61
24	850 018,13	1 497,06	113 562 938,07	852 344,79	0,00751	5 562 938,07	556 293,81
25	858 518,32	1 489,58	112 995 123,38	860 856,67	0,00762	4 995 123,38	499 512,34
26	867 103,50	1 482,13	112 430 147,76	869 453,60	0,00773	4 430 147,76	443 014,78
27	875 774,53	1 474,72	111 867 997,02	878 136,45	0,00785	3 867 997,02	386 799,70
28	884 532,28	1 467,35	111 308 657,04	886 906,06	0,00797	3 308 657,04	330 865,70
29	893 377,60	1 460,01	110 752 113,75	895 763,31	0,00809	2 752 113,75	275 211,38
30	902 311,38	1 452,71	110 198 353,18	904 709,08	0,00821	2 198 353,18	219 835,32



$$\text{NPV}= \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

$$\text{CRF} = \frac{r*(1+r)^T}{(1+r)^T-1}$$

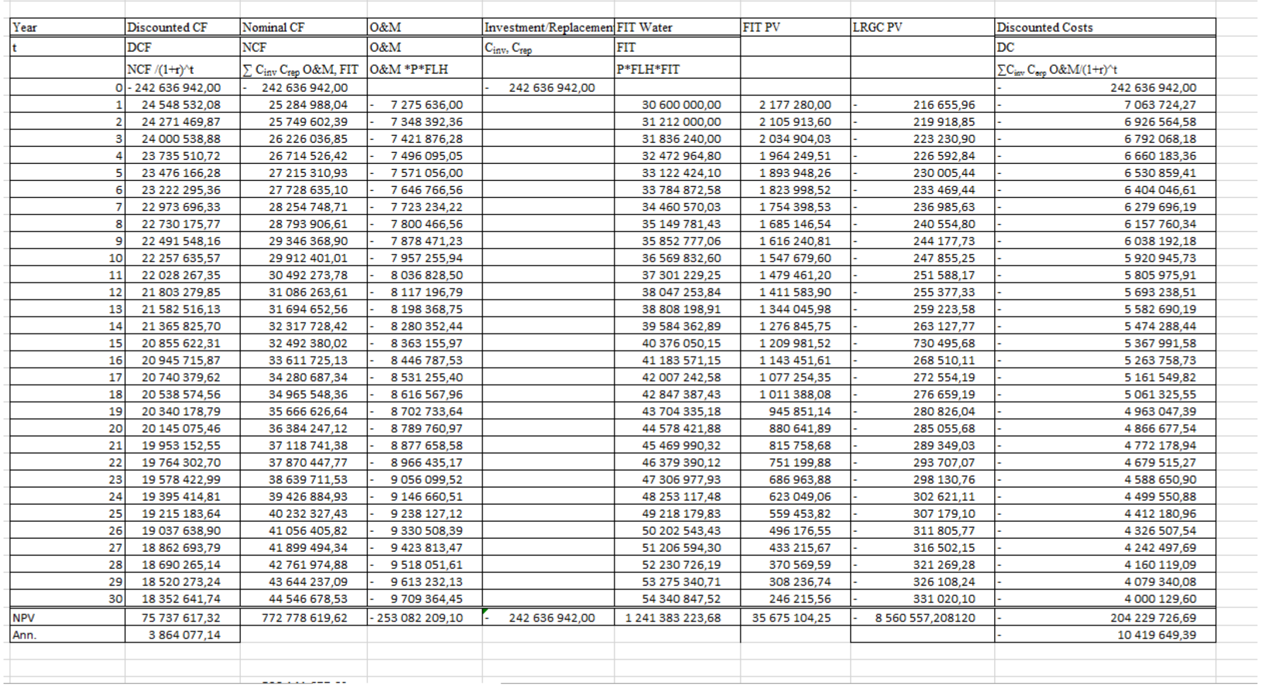
$$\text{a}= NPV * \frac{r*(1+r)^T}{(1+r)^T-1}$$

Investment Horizon	30,00	year	T					
risk adj. Disc. Rate	3,00%	%/year	r					
Rated Capacity	100 000,00	m3/day	P					
Operation	360,00	day/year	FLH					
Investment Costs	242 636 942,00	US$	C_{inv}	all. C_{inv}	242 636 942,00	$		
Replacement is included in the O&M cost		US$/m3	C_{rep}	O&M	7 203 600,00	$		
O&M (incl. All variable costs)	0,2001	US$/m3	O&M	CRF	0,05		8,530202837	
Feed-In-Tariff 2016	0,75	US$/m3	FIT					
Real escalation of O&M Costs	1,00%			CRF for expenditures	0,79			
Real escalation of water FIT	2,00%		€/$ is 1.12			Water production cost	0,99	US$/m3

Year	Discounted CF	Nominal CF	O&M	Investment/Replacemen	FIT Water	FIT PV	LRGC PV	Discounted Costs
t	DCF	NCF	O&M	C_{inv}, C_{rep}	FIT			DC
	NCF /(1+r)^t	∑ C_{inv} C_{rep} O&M, FIT	O&M *P*FLH		P*FLH*FIT			∑C_{inv} C_{erp} O&M/(1+r)^t
0	- 242 636 942,00	- 242 636 942,00		- 242 636 942,00				- 242 636 942,00
1	21 053 386,44	21 684 988,04	- 7 275 636,00		27 000 000,00	2 177 280,00	- 216 655,96	- 7 063 724,27
2	20 810 257,69	22 077 602,39	- 7 348 392,36		27 540 000,00	2 105 913,60	- 219 918,85	- 6 926 564,58
3	20 572 930,70	22 480 596,85	- 7 421 876,28		28 090 800,00	2 034 904,03	- 223 230,90	- 6 792 068,18
4	20 341 180,29	22 894 177,62	- 7 496 095,05		28 652 616,00	1 964 249,51	- 226 592,84	- 6 660 183,36
5	20 114 790,51	23 318 555,15	- 7 571 056,00		29 225 668,32	1 893 948,26	- 230 005,44	- 6 530 859,41
6	19 893 554,31	23 753 944,21	- 7 646 766,56		29 810 181,69	1 823 998,52	- 233 469,44	- 6 404 046,61
7	19 677 273,15	24 200 564,00	- 7 723 234,22		30 406 385,32	1 754 398,53	- 236 985,63	- 6 279 696,19
8	19 465 756,70	24 658 638,20	- 7 800 466,56		31 014 513,03	1 685 146,54	- 240 554,80	- 6 157 760,34
9	19 258 822,48	25 128 395,13	- 7 878 471,23		31 634 803,29	1 616 240,81	- 244 177,73	- 6 038 192,18
10	19 056 295,58	25 610 067,76	- 7 957 255,94		32 267 499,35	1 547 679,60	- 247 855,25	- 5 920 945,73
11	18 858 008,33	26 103 893,87	- 8 036 828,50		32 912 849,34	1 479 461,20	- 251 588,17	- 5 805 975,91
12	18 663 800,04	26 610 116,10	- 8 117 196,79		33 571 106,33	1 411 583,90	- 255 377,33	- 5 693 238,51
13	18 473 516,71	27 128 982,10	- 8 198 368,75		34 242 528,45	1 344 045,98	- 259 223,58	- 5 582 690,19
14	18 287 010,75	27 660 744,55	- 8 280 352,44		34 927 379,02	1 276 845,75	- 263 127,77	- 5 474 288,44
15	17 806 698,76	27 742 256,47	- 8 363 155,97		35 625 926,60	1 209 981,52	- 730 495,68	- 5 367 991,58
16	17 926 393,52	28 766 599,11	- 8 446 787,53		36 338 445,13	1 143 451,61	- 268 510,11	- 5 263 758,73
17	17 750 371,07	29 338 658,80	- 8 531 255,40		37 065 214,04	1 077 254,35	- 272 554,19	- 5 161 549,82
18	17 577 595,23	29 924 679,25	- 8 616 567,96		37 806 518,32	1 011 388,08	- 276 659,19	- 5 061 325,55
19	17 407 946,83	30 524 940,15	- 8 702 733,64		38 562 648,68	945 851,14	- 280 826,04	- 4 963 047,39
20	17 241 311,77	31 139 726,90	- 8 789 760,97		39 333 901,66	880 641,89	- 285 055,68	- 4 866 677,54
21	17 077 580,74	31 769 330,76	- 8 877 658,58		40 120 579,69	815 758,68	- 289 349,03	- 4 772 178,94
22	16 916 649,06	32 414 048,93	- 8 966 435,17		40 922 991,29	751 199,88	- 293 707,07	- 4 679 515,27
23	16 758 416,48	33 074 184,71	- 9 056 099,52		41 741 451,11	686 963,88	- 298 130,76	- 4 588 650,90
24	16 602 787,01	33 750 047,58	- 9 146 660,51		42 576 280,13	623 049,06	- 302 621,11	- 4 499 550,88
25	16 449 668,73	34 441 953,33	- 9 238 127,12		43 427 805,74	559 453,82	- 307 179,10	- 4 412 180,96
26	16 298 973,65	35 150 224,24	- 9 330 508,39		44 296 361,85	496 176,55	- 311 805,77	- 4 326 507,54
27	16 150 617,52	35 875 189,13	- 9 423 813,47		45 182 289,09	433 215,67	- 316 502,15	- 4 242 497,69
28	16 004 519,70	36 617 183,57	- 9 518 051,61		46 085 934,87	370 569,59	- 321 269,28	- 4 160 119,09
29	15 860 603,00	37 376 549,94	- 9 613 232,13		47 007 653,57	308 236,74	- 326 108,24	- 4 079 340,08
30	15 718 793,54	38 153 637,65	- 9 709 364,45		47 947 806,64	246 215,56	- 331 020,10	- 4 000 129,60
NPV	15 568 975,95	626 733 534,48	- 253 082 209,10	- 242 636 942,00	1 095 338 138,54	35 675 104,25	- 8 560 557,208120	- 204 229 726,69
Ann.	794 317,62							- 10 419 649,39

Appendix 4

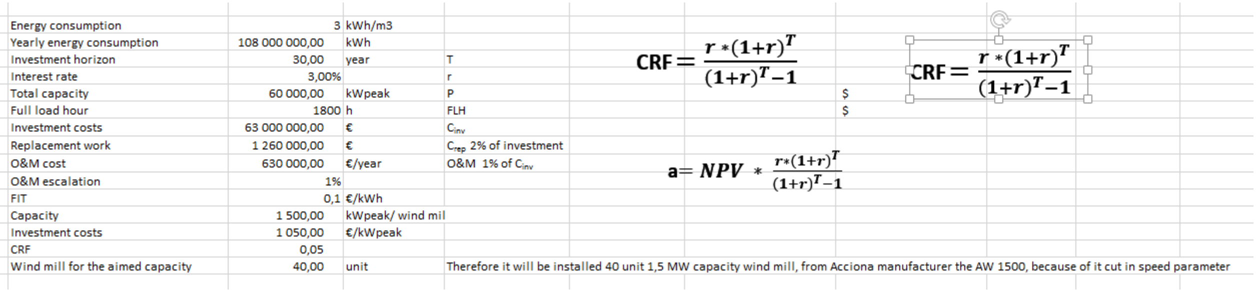
Appendix 4 PV with 0.85 US\$cent/m³



Year	Discounted CF	Nominal CF	O&M	Investment/Replacemen	FIT Water	FIT PV	LRGC PV	Discounted Costs
t	DCF	NCF	O&M	C_{inv}, C_{rep}	FIT			DC
	NCF /(1+r)^t	∑ C_{inv} C_{rep} O&M, FIT	O&M *P*FLH		P*FLH*FIT			∑C_{inv} C_{erp} O&M/(1+r)^t
0	- 242 636 942,00	- 242 636 942,00		- 242 636 942,00				- 242 636 942,00
1	24 548 532,08	25 284 988,04	- 7 275 636,00		30 600 000,00	2 177 280,00	- 216 655,96	- 7 063 724,27
2	24 271 469,87	25 749 602,39	- 7 348 392,36		31 212 000,00	2 105 913,60	- 219 918,85	- 6 926 564,58
3	24 000 538,88	26 226 036,85	- 7 421 876,28		31 836 240,00	2 034 904,03	- 223 230,90	- 6 792 068,18
4	23 735 510,72	26 714 526,42	- 7 496 095,05		32 472 964,80	1 964 249,51	- 226 592,84	- 6 660 183,36
5	23 476 166,28	27 215 310,93	- 7 571 056,00		33 122 424,10	1 893 948,26	- 230 005,44	- 6 530 859,41
6	23 222 295,36	27 728 635,10	- 7 646 766,56		33 784 872,58	1 823 998,52	- 233 469,44	- 6 404 046,61
7	22 973 696,33	28 254 748,71	- 7 723 234,22		34 460 570,03	1 754 398,53	- 236 985,63	- 6 279 696,19
8	22 730 175,77	28 793 906,61	- 7 800 466,56		35 149 781,43	1 685 146,54	- 240 554,80	- 6 157 760,34
9	22 491 548,16	29 346 368,90	- 7 878 471,23		35 852 777,06	1 616 240,81	- 244 177,73	- 6 038 192,18
10	22 257 635,57	29 912 401,01	- 7 957 255,94		36 569 832,60	1 547 679,60	- 247 855,25	- 5 920 945,73
11	22 028 267,35	30 492 273,78	- 8 036 828,50		37 301 229,25	1 479 461,20	- 251 588,17	- 5 805 975,91
12	21 803 279,85	31 086 263,61	- 8 117 196,79		38 047 253,84	1 411 583,90	- 255 377,33	- 5 693 238,51
13	21 582 516,13	31 694 652,56	- 8 198 368,75		38 808 198,91	1 344 045,98	- 259 223,58	- 5 582 690,19
14	21 365 825,70	32 317 728,42	- 8 280 352,44		39 584 362,89	1 276 845,75	- 263 127,77	- 5 474 288,44
15	20 855 622,31	32 492 380,02	- 8 363 155,97		40 376 050,15	1 209 981,52	- 730 495,68	- 5 367 991,58
16	20 945 715,87	33 611 725,13	- 8 446 787,53		41 183 571,15	1 143 451,61	- 268 510,11	- 5 263 758,73
17	20 740 379,62	34 280 687,34	- 8 531 255,40		42 007 242,58	1 077 254,35	- 272 554,19	- 5 161 549,82
18	20 538 574,56	34 965 548,36	- 8 616 567,96		42 847 387,43	1 011 388,08	- 276 659,19	- 5 061 325,55
19	20 340 178,79	35 666 626,64	- 8 702 733,64		43 704 335,18	945 851,14	- 280 826,04	- 4 963 047,39
20	20 145 075,46	36 384 247,12	- 8 789 760,97		44 578 421,88	880 641,89	- 285 055,68	- 4 866 677,54
21	19 953 152,55	37 118 741,38	- 8 877 658,58		45 469 990,32	815 758,68	- 289 349,03	- 4 772 178,94
22	19 764 302,70	37 870 447,77	- 8 966 435,17		46 379 390,12	751 199,88	- 293 707,07	- 4 679 515,27
23	19 578 422,99	38 639 711,53	- 9 056 099,52		47 306 977,93	686 963,88	- 298 130,76	- 4 588 650,90
24	19 395 414,81	39 426 884,93	- 9 146 660,51		48 253 117,48	623 049,06	- 302 621,11	- 4 499 550,88
25	19 215 183,64	40 232 327,43	- 9 238 127,12		49 218 179,83	559 453,82	- 307 179,10	- 4 412 180,96
26	19 037 638,90	41 056 405,82	- 9 330 508,39		50 202 543,43	496 176,55	- 311 805,77	- 4 326 507,54
27	18 862 693,79	41 899 494,34	- 9 423 813,47		51 206 594,30	433 215,67	- 316 502,15	- 4 242 497,69
28	18 690 265,14	42 761 974,88	- 9 518 051,61		52 230 726,19	370 569,59	- 321 269,28	- 4 160 119,09
29	18 520 273,24	43 644 237,09	- 9 613 232,13		53 275 340,71	308 236,74	- 326 108,24	- 4 079 340,08
30	18 352 641,74	44 546 678,53	- 9 709 364,45		54 340 847,52	246 215,56	- 331 020,10	- 4 000 129,60
NPV	75 737 617,32	772 778 619,62	- 253 082 209,10	- 242 636 942,00	1 241 383 223,68	35 675 104,25	- 8 560 557,208120	- 204 229 726,69
Ann.	3 864 077,14							- 10 419 649,39

Appendix 5

Appendix 5 Wind with 0.75US$cent/m3

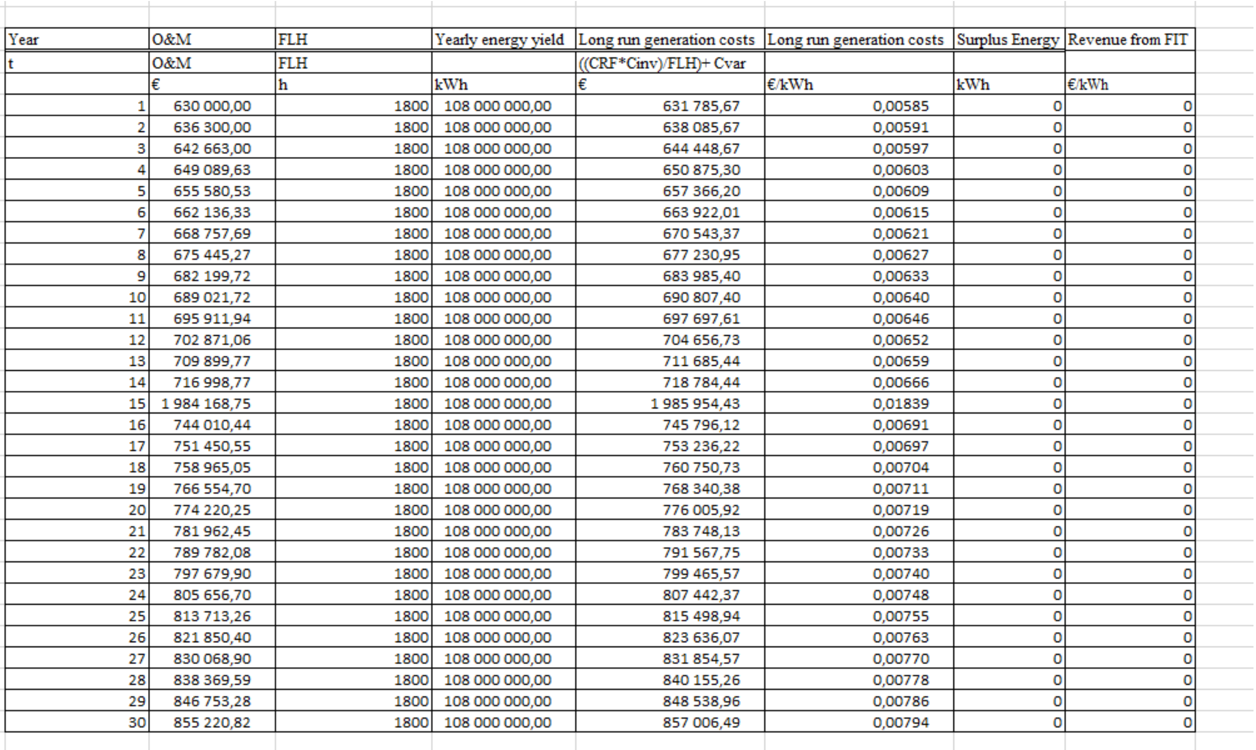


Energy consumption	3	kWh/m3		
Yearly energy consumption	108 000 000,00	kWh		
Investment horizon	30,00	year	T	
Interest rate	3,00%		r	
Total capacity	60 000,00	kWpeak	P	$
Full load hour	1800	h	FLH	$
Investment costs	63 000 000,00	€	C_{inv}	
Replacement work	1 260 000,00	€	C_{rep} 2% of investment	
O&M cost	630 000,00	€/year	O&M 1% of C_{inv}	
O&M escalation	1%			
FIT	0,1	€/kWh		
Capacity	1 500,00	kWpeak/ wind mil		
Investment costs	1 050,00	€/kWpeak		
CRF	0,05			
Wind mill for the aimed capacity	40,00	unit	Therefore it will be installed 40 unit 1,5 MW capacity wind mill, from Acciona manufacturer the AW 1500, because of it cut in speed parameter	

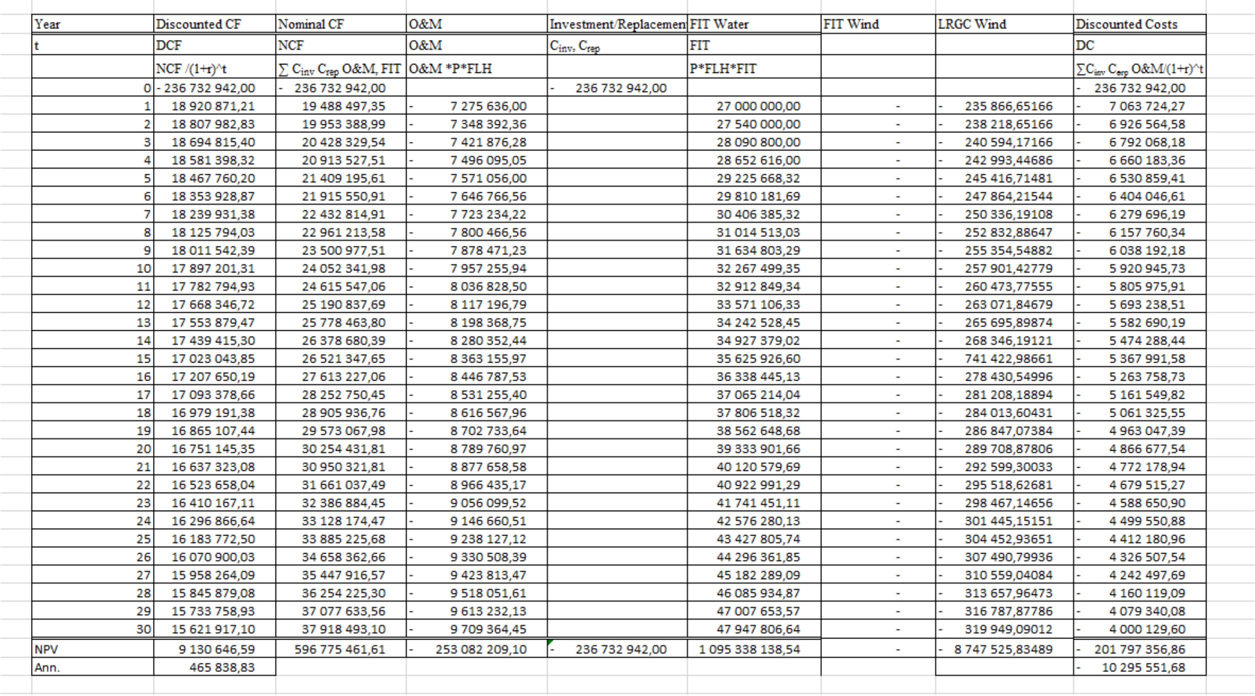
$$\mathrm{CRF} = \frac{r * (1+r)^T}{(1+r)^T - 1}$$

$$\mathrm{CRF} = \frac{r * (1+r)^T}{(1+r)^T - 1}$$

$$a = NPV * \frac{r * (1+r)^T}{(1+r)^T - 1}$$



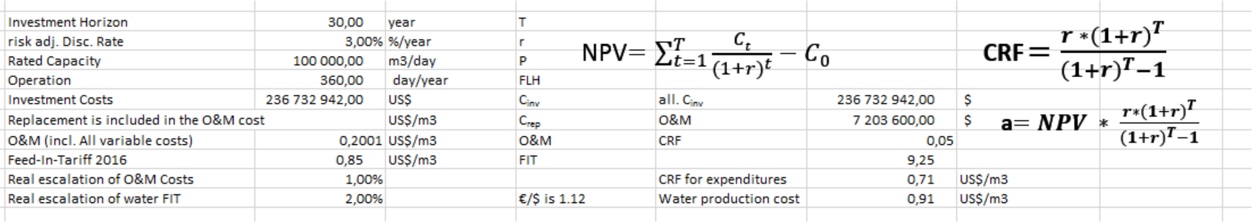
Year	O&M	FLH	Yearly energy yield	Long run generation costs	Long run generation costs	Surplus Energy	Revenue from FIT
t	O&M	FLH		((CRF*Cinv)/FLH)+ Cvar			
	€	h	kWh	€	€/kWh	kWh	€/kWh
1	630 000,00	1800	108 000 000,00	631 785,67	0,00585	0	0
2	636 300,00	1800	108 000 000,00	638 085,67	0,00591	0	0
3	642 663,00	1800	108 000 000,00	644 448,67	0,00597	0	0
4	649 089,63	1800	108 000 000,00	650 875,30	0,00603	0	0
5	655 580,53	1800	108 000 000,00	657 366,20	0,00609	0	0
6	662 136,33	1800	108 000 000,00	663 922,01	0,00615	0	0
7	668 757,69	1800	108 000 000,00	670 543,37	0,00621	0	0
8	675 445,27	1800	108 000 000,00	677 230,95	0,00627	0	0
9	682 199,72	1800	108 000 000,00	683 985,40	0,00633	0	0
10	689 021,72	1800	108 000 000,00	690 807,40	0,00640	0	0
11	695 911,94	1800	108 000 000,00	697 697,61	0,00646	0	0
12	702 871,06	1800	108 000 000,00	704 656,73	0,00652	0	0
13	709 899,77	1800	108 000 000,00	711 685,44	0,00659	0	0
14	716 998,77	1800	108 000 000,00	718 784,44	0,00666	0	0
15	1 984 168,75	1800	108 000 000,00	1 985 954,43	0,01839	0	0
16	744 010,44	1800	108 000 000,00	745 796,12	0,00691	0	0
17	751 450,55	1800	108 000 000,00	753 236,22	0,00697	0	0
18	758 965,05	1800	108 000 000,00	760 750,73	0,00704	0	0
19	766 554,70	1800	108 000 000,00	768 340,38	0,00711	0	0
20	774 220,25	1800	108 000 000,00	776 005,92	0,00719	0	0
21	781 962,45	1800	108 000 000,00	783 748,13	0,00726	0	0
22	789 782,08	1800	108 000 000,00	791 567,75	0,00733	0	0
23	797 679,90	1800	108 000 000,00	799 465,57	0,00740	0	0
24	805 656,70	1800	108 000 000,00	807 442,37	0,00748	0	0
25	813 713,26	1800	108 000 000,00	815 498,94	0,00755	0	0
26	821 850,40	1800	108 000 000,00	823 636,07	0,00763	0	0
27	830 068,90	1800	108 000 000,00	831 854,57	0,00770	0	0
28	838 369,59	1800	108 000 000,00	840 155,26	0,00778	0	0
29	846 753,28	1800	108 000 000,00	848 538,96	0,00786	0	0
30	855 220,82	1800	108 000 000,00	857 006,49	0,00794	0	0



Year	Discounted CF	Nominal CF	O&M	Investment/Replacemen	FIT Water	FIT Wind	LRGC Wind	Discounted Costs
t	DCF	NCF	O&M	C_{inv}, C_{rep}	FIT			DC
	NCF /(1+r)^t	∑ C_{inv} C_{rep} O&M, FIT	O&M *P*FLH		P*FLH*FIT			∑C_{inv} C_{erp} O&M/(1+r)^t
0	- 236 732 942,00	- 236 732 942,00		- 236 732 942,00				- 236 732 942,00
1	18 920 871,21	19 488 497,35	- 7 275 636,00		27 000 000,00	-	- 235 866,65166	- 7 063 724,27
2	18 807 982,83	19 953 388,99	- 7 348 392,36		27 540 000,00	-	- 238 218,65166	- 6 926 564,58
3	18 694 815,40	20 428 329,54	- 7 421 876,28		28 090 800,00	-	- 240 594,17166	- 6 792 068,18
4	18 581 398,32	20 913 527,51	- 7 496 095,05		28 652 616,00	-	- 242 993,44686	- 6 660 183,36
5	18 467 760,20	21 409 195,61	- 7 571 056,00		29 225 668,32	-	- 245 416,71481	- 6 530 859,41
6	18 353 928,87	21 915 550,91	- 7 646 766,56		29 810 181,69	-	- 247 864,21544	- 6 404 046,61
7	18 239 931,38	22 432 814,91	- 7 723 234,22		30 406 385,32	-	- 250 336,19108	- 6 279 696,19
8	18 125 794,03	22 961 213,58	- 7 800 466,56		31 014 513,03	-	- 252 832,88647	- 6 157 760,34
9	18 011 542,39	23 500 977,51	- 7 878 471,23		31 634 803,29	-	- 255 354,54882	- 6 038 192,18
10	17 897 201,31	24 052 341,98	- 7 957 255,94		32 267 499,35	-	- 257 901,42779	- 5 920 945,73
11	17 782 794,93	24 615 547,06	- 8 036 828,50		32 912 849,34	-	- 260 473,77555	- 5 805 975,91
12	17 668 346,72	25 190 837,69	- 8 117 196,79		33 571 106,33	-	- 263 071,84679	- 5 693 238,51
13	17 553 879,47	25 778 463,80	- 8 198 368,75		34 242 528,45	-	- 265 695,89874	- 5 582 690,19
14	17 439 415,30	26 378 680,39	- 8 280 352,44		34 927 379,02	-	- 268 346,19121	- 5 474 288,44
15	17 023 043,85	26 521 347,65	- 8 363 155,97		35 625 926,60	-	- 741 422,98661	- 5 367 991,58
16	17 207 650,19	27 613 227,06	- 8 446 787,53		36 338 445,13	-	- 278 430,54996	- 5 263 758,73
17	17 093 378,66	28 252 750,45	- 8 531 255,40		37 065 214,04	-	- 281 208,18894	- 5 161 549,82
18	16 979 191,38	28 905 936,76	- 8 616 567,96		37 806 518,32	-	- 284 013,60431	- 5 061 325,55
19	16 865 107,44	29 573 067,98	- 8 702 733,64		38 562 648,68	-	- 286 847,07384	- 4 963 047,39
20	16 751 145,35	30 254 431,81	- 8 789 760,97		39 333 901,66	-	- 289 708,87806	- 4 866 677,54
21	16 637 323,08	30 950 321,81	- 8 877 658,58		40 120 579,69	-	- 292 599,30033	- 4 772 178,94
22	16 523 658,04	31 661 037,49	- 8 966 435,17		40 922 991,29	-	- 295 518,62681	- 4 679 515,27
23	16 410 167,11	32 386 884,45	- 9 056 099,52		41 741 451,11	-	- 298 467,14656	- 4 588 650,90
24	16 296 866,64	33 128 174,47	- 9 146 660,51		42 576 280,13	-	- 301 445,15151	- 4 499 550,88
25	16 183 772,50	33 885 225,68	- 9 238 127,12		43 427 805,74	-	- 304 452,93651	- 4 412 180,96
26	16 070 900,03	34 658 362,66	- 9 330 508,39		44 296 361,85	-	- 307 490,79936	- 4 326 507,54
27	15 958 264,09	35 447 916,57	- 9 423 813,47		45 182 289,09	-	- 310 559,04084	- 4 242 497,69
28	15 845 879,08	36 254 225,30	- 9 518 051,61		46 085 934,87	-	- 313 657,96473	- 4 160 119,09
29	15 733 758,93	37 077 633,56	- 9 613 232,13		47 007 653,57	-	- 316 787,87786	- 4 079 340,08
30	15 621 917,10	37 918 493,10	- 9 709 364,45		47 947 806,64	-	- 319 949,09012	- 4 000 129,60
NPV	9 130 646,59	596 775 461,61	- 253 082 209,10	- 236 732 942,00	1 095 338 138,54	-	- 8 747 525,83489	- 201 797 356,86
Ann.	465 838,83							- 10 295 551,68

Appendix 6

Appendix 6 Wind with 0.85US$cent/m³

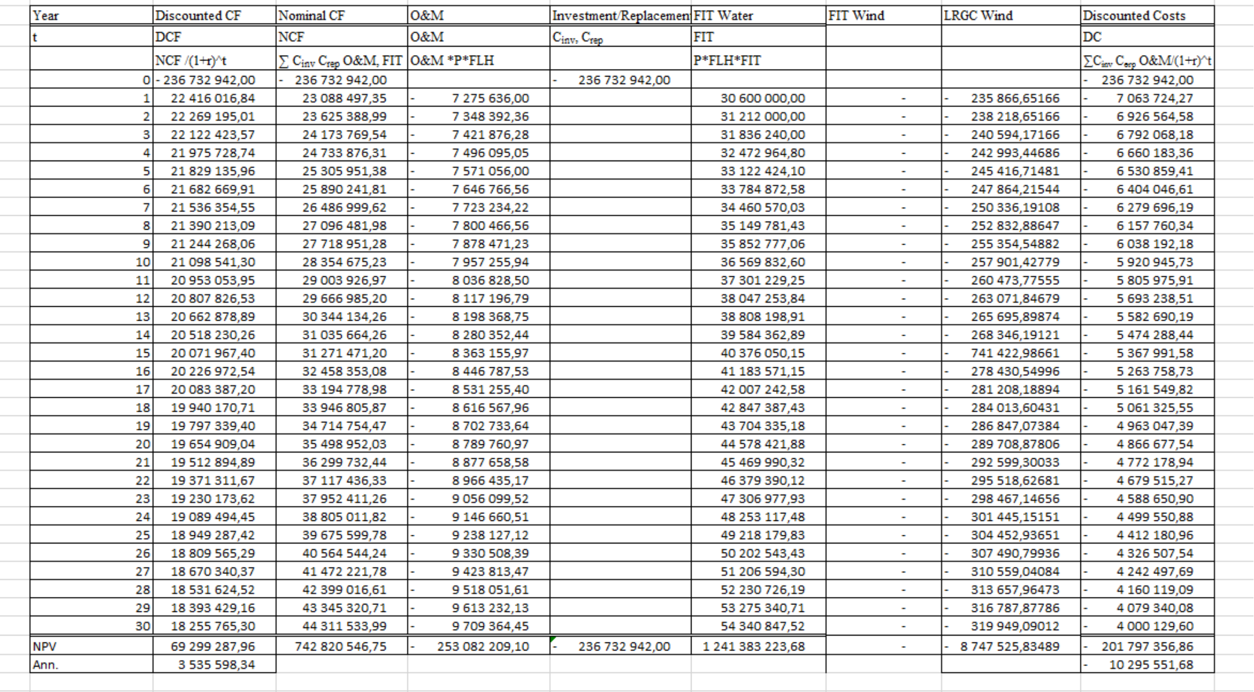


Investment Horizon	30,00	year	T			
risk adj. Disc. Rate	3,00%	%/year	r			
Rated Capacity	100 000,00	m3/day	P			
Operation	360,00	day/year	FLH			
Investment Costs	236 732 942,00	US$	C_{inv}	all. C_{inv}	236 732 942,00	$
Replacement is included in the O&M cost		US$/m3	C_{rep}	O&M	7 203 600,00	$
O&M (incl. All variable costs)	0,2001	US$/m3	O&M	CRF	0,05	
Feed-In-Tariff 2016	0,85	US$/m3	FIT		9,25	
Real escalation of O&M Costs	1,00%			CRF for expenditures	0,71	US$/m3
Real escalation of water FIT	2,00%		€/$ is 1.12	Water production cost	0,91	US$/m3

$$\mathrm{NPV}=\sum_{t=1}^{T}\frac{C_t}{(1+r)^t}-C_0$$

$$\mathbf{CRF}=\frac{r*(1+r)^T}{(1+r)^T-1}$$

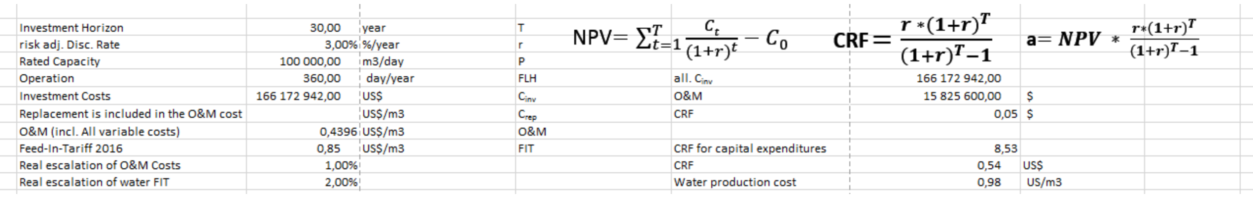
$$\mathbf{a}=NPV*\frac{r*(1+r)^T}{(1+r)^T-1}$$



Year	Discounted CF	Nominal CF	O&M	Investment/Replacemen	FIT Water	FIT Wind	LRGC Wind	Discounted Costs
t	DCF	NCF	O&M	C_{inv}, C_{rep}	FIT			DC
	NCF /(1+r)^t	∑ C_{inv} C_{rep} O&M, FIT	O&M *P*FLH		P*FLH*FIT			∑C_{inv} C_{erp} O&M/(1+r)^t
0	- 236 732 942,00	- 236 732 942,00		- 236 732 942,00				- 236 732 942,00
1	22 416 016,84	23 088 497,35	- 7 275 636,00		30 600 000,00	-	- 235 866,65166	- 7 063 724,27
2	22 269 195,01	23 625 388,99	- 7 348 392,36		31 212 000,00	-	- 238 218,65166	- 6 926 564,58
3	22 122 423,57	24 173 769,54	- 7 421 876,28		31 836 240,00	-	- 240 594,17166	- 6 792 068,18
4	21 975 728,74	24 733 876,31	- 7 496 095,05		32 472 964,80	-	- 242 993,44686	- 6 660 183,36
5	21 829 135,96	25 305 951,38	- 7 571 056,00		33 122 424,10	-	- 245 416,71481	- 6 530 859,41
6	21 682 669,91	25 890 241,81	- 7 646 766,56		33 784 872,58	-	- 247 864,21544	- 6 404 046,61
7	21 536 354,55	26 486 999,62	- 7 723 234,22		34 460 570,03	-	- 250 336,19108	- 6 279 696,19
8	21 390 213,09	27 096 481,98	- 7 800 466,56		35 149 781,43	-	- 252 832,88647	- 6 157 760,34
9	21 244 268,06	27 718 951,28	- 7 878 471,23		35 852 777,06	-	- 255 354,54882	- 6 038 192,18
10	21 098 541,30	28 354 675,23	- 7 957 255,94		36 569 832,60	-	- 257 901,42779	- 5 920 945,73
11	20 953 053,95	29 003 926,97	- 8 036 828,50		37 301 229,25	-	- 260 473,77555	- 5 805 975,91
12	20 807 826,53	29 666 985,20	- 8 117 196,79		38 047 253,84	-	- 263 071,84679	- 5 693 238,51
13	20 662 878,89	30 344 134,26	- 8 198 368,75		38 808 198,91	-	- 265 695,89874	- 5 582 690,19
14	20 518 230,26	31 035 664,26	- 8 280 352,44		39 584 362,89	-	- 268 346,19121	- 5 474 288,44
15	20 071 967,40	31 271 471,20	- 8 363 155,97		40 376 050,15	-	- 741 422,98661	- 5 367 991,58
16	20 226 972,54	32 458 353,08	- 8 446 787,53		41 183 571,15	-	- 278 430,54996	- 5 263 758,73
17	20 083 387,20	33 194 778,98	- 8 531 255,40		42 007 242,58	-	- 281 208,18894	- 5 161 549,82
18	19 940 170,71	33 946 805,87	- 8 616 567,96		42 847 387,43	-	- 284 013,60431	- 5 061 325,55
19	19 797 339,40	34 714 754,47	- 8 702 733,64		43 704 335,18	-	- 286 847,07384	- 4 963 047,39
20	19 654 909,04	35 498 952,03	- 8 789 760,97		44 578 421,88	-	- 289 708,87806	- 4 866 677,54
21	19 512 894,89	36 299 732,44	- 8 877 658,58		45 469 990,32	-	- 292 599,30033	- 4 772 178,94
22	19 371 311,67	37 117 436,33	- 8 966 435,17		46 379 390,12	-	- 295 518,62681	- 4 679 515,27
23	19 230 173,62	37 952 411,26	- 9 056 099,52		47 306 977,93	-	- 298 467,14656	- 4 588 650,90
24	19 089 494,45	38 805 011,82	- 9 146 660,51		48 253 117,48	-	- 301 445,15151	- 4 499 550,88
25	18 949 287,42	39 675 599,78	- 9 238 127,12		49 218 179,83	-	- 304 452,93651	- 4 412 180,96
26	18 809 565,29	40 564 544,24	- 9 330 508,39		50 202 543,43	-	- 307 490,79936	- 4 326 507,54
27	18 670 340,37	41 472 221,78	- 9 423 813,47		51 206 594,30	-	- 310 559,04084	- 4 242 497,69
28	18 531 624,52	42 399 016,61	- 9 518 051,61		52 230 726,19	-	- 313 657,96473	- 4 160 119,09
29	18 393 429,16	43 345 320,71	- 9 613 232,13		53 275 340,71	-	- 316 787,87786	- 4 079 340,08
30	18 255 765,30	44 311 533,99	- 9 709 364,45		54 340 847,52	-	- 319 949,09012	- 4 000 129,60
NPV	69 299 287,96	742 820 546,75	- 253 082 209,10	- 236 732 942,00	1 241 383 223,68	-	- 8 747 525,83489	- 201 797 356,86
Ann.	3 535 598,34							- 10 295 551,68

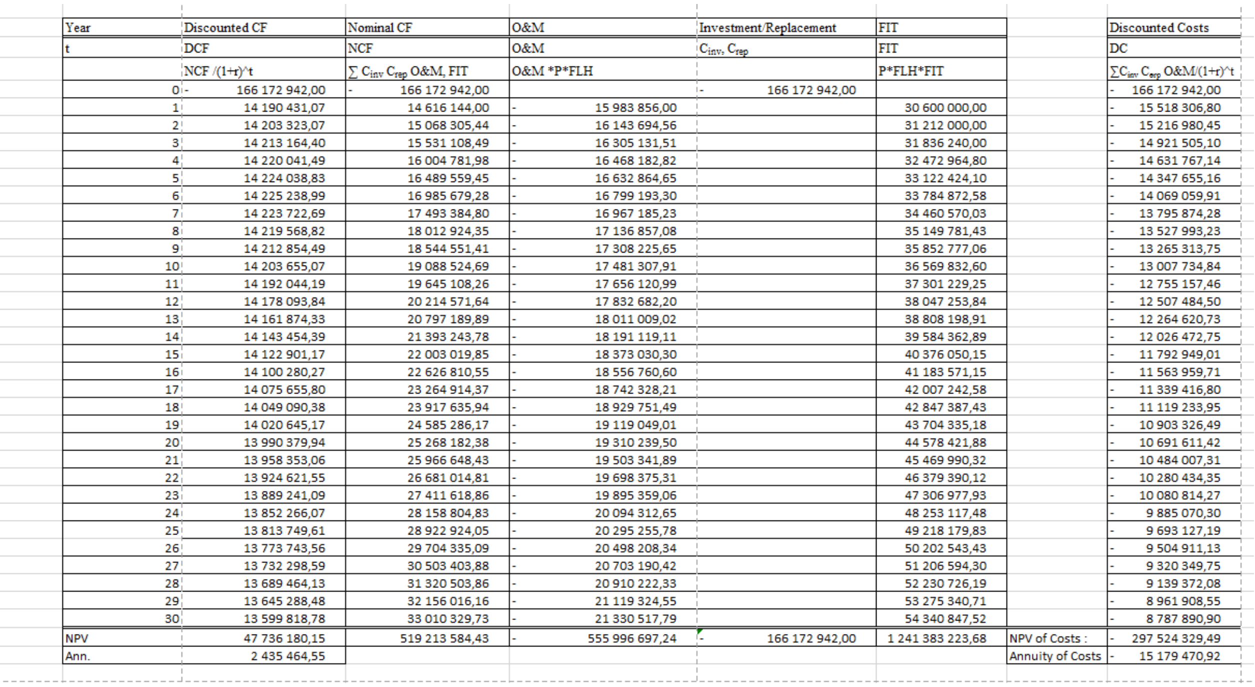
Appendix 7

Appendix 7 Conventional with 0.85US$cent/$m^3$



$$\text{NPV}=\sum_{t=1}^{T}\frac{C_t}{(1+r)^t}-C_0 \qquad \text{CRF}=\frac{r*(1+r)^T}{(1+r)^T-1} \qquad a=NPV*\frac{r*(1+r)^T}{(1+r)^T-1}$$

Investment Horizon	30,00	year	T			
risk adj. Disc. Rate	3,00%	%/year	r			
Rated Capacity	100 000,00	m3/day	P			
Operation	360,00	day/year	FLH	all. C_{inv}	166 172 942,00	
Investment Costs	166 172 942,00	US$	C_{inv}	O&M	15 825 600,00	$
Replacement is included in the O&M cost		US$/m3	C_{rep}	CRF	0,05	$
O&M (incl. All variable costs)	0,4396	US$/m3	O&M			
Feed-In-Tariff 2016	0,85	US$/m3	FIT	CRF for capital expenditures	8,53	
Real escalation of O&M Costs	1,00%			CRF	0,54	US$
Real escalation of water FIT	2,00%			Water production cost	0,98	US/m3



Year	Discounted CF	Nominal CF	O&M	Investment/Replacement	FIT		Discounted Costs
t	DCF	NCF	O&M	C_{inv}, C_{rep}	FIT		DC
	NCF /(1+r)^t	∑ C_{inv} C_{rep} O&M, FIT	O&M *P*FLH		P*FLH*FIT		∑C_{inv} C_{erp} O&M/(1+r)^t
0	- 166 172 942,00	- 166 172 942,00		- 166 172 942,00			- 166 172 942,00
1	14 190 431,07	14 616 144,00	- 15 983 856,00		30 600 000,00		- 15 518 306,80
2	14 203 323,07	15 068 305,44	- 16 143 694,56		31 212 000,00		- 15 216 980,45
3	14 213 164,40	15 531 108,49	- 16 305 131,51		31 836 240,00		- 14 921 505,10
4	14 220 041,49	16 004 781,98	- 16 468 182,82		32 472 964,80		- 14 631 767,14
5	14 224 038,83	16 489 559,45	- 16 632 864,65		33 122 424,10		- 14 347 655,16
6	14 225 238,99	16 985 679,28	- 16 799 193,30		33 784 872,58		- 14 069 059,91
7	14 223 722,69	17 493 384,80	- 16 967 185,23		34 460 570,03		- 13 795 874,28
8	14 219 568,82	18 012 924,35	- 17 136 857,08		35 149 781,43		- 13 527 993,23
9	14 212 854,49	18 544 551,41	- 17 308 225,65		35 852 777,06		- 13 265 313,75
10	14 203 655,07	19 088 524,69	- 17 481 307,91		36 569 832,60		- 13 007 734,84
11	14 192 044,19	19 645 108,26	- 17 656 120,99		37 301 229,25		- 12 755 157,46
12	14 178 093,84	20 214 571,64	- 17 832 682,20		38 047 253,84		- 12 507 484,50
13	14 161 874,33	20 797 189,89	- 18 011 009,02		38 808 198,91		- 12 264 620,73
14	14 143 454,39	21 393 243,78	- 18 191 119,11		39 584 362,89		- 12 026 472,75
15	14 122 901,17	22 003 019,85	- 18 373 030,30		40 376 050,15		- 11 792 949,01
16	14 100 280,27	22 626 810,55	- 18 556 760,60		41 183 571,15		- 11 563 959,71
17	14 075 655,80	23 264 914,37	- 18 742 328,21		42 007 242,58		- 11 339 416,80
18	14 049 090,38	23 917 635,94	- 18 929 751,49		42 847 387,43		- 11 119 233,95
19	14 020 645,17	24 585 286,17	- 19 119 049,01		43 704 335,18		- 10 903 326,49
20	13 990 379,94	25 268 182,38	- 19 310 239,50		44 578 421,88		- 10 691 611,42
21	13 958 353,06	25 966 648,43	- 19 503 341,89		45 469 990,32		- 10 484 007,31
22	13 924 621,55	26 681 014,81	- 19 698 375,31		46 379 390,12		- 10 280 434,35
23	13 889 241,09	27 411 618,86	- 19 895 359,06		47 306 977,93		- 10 080 814,27
24	13 852 266,07	28 158 804,83	- 20 094 312,65		48 253 117,48		- 9 885 070,30
25	13 813 749,61	28 922 924,05	- 20 295 255,78		49 218 179,83		- 9 693 127,19
26	13 773 743,56	29 704 335,09	- 20 498 208,34		50 202 543,43		- 9 504 911,13
27	13 732 298,59	30 503 403,88	- 20 703 190,42		51 206 594,30		- 9 320 349,75
28	13 689 464,13	31 320 503,86	- 20 910 222,33		52 230 726,19		- 9 139 372,08
29	13 645 288,48	32 156 016,16	- 21 119 324,55		53 275 340,71		- 8 961 908,55
30	13 599 818,78	33 010 329,73	- 21 330 517,79		54 340 847,52		- 8 787 890,90
NPV	47 736 180,15	519 213 584,43	- 555 996 697,24	- 166 172 942,00	1 241 383 223,68	NPV of Costs :	- 297 524 329,49
Ann.	2 435 464,55					Annuity of Costs	- 15 179 470,92