A Cost-Benefit Analysis of a Reverse Osmosis Desalination Plant with and without Advanced Energy Recovery Devices

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ABSTRACT

In recent decades seawater desalination has represented reliable and perhaps financially attractive technology to overcome water scarcity. The largest problem with this solution for solving water shortage is the cost of seawater desalination and the main portion of the total cost of desalination of water is energy consumption. One of the efficient approaches to decrease specific energy consumption is using an energy recovery device (ERDs). The total operating cost of desalination plant will considerably decrease in order to using this technology. Due to this reduction levelized cost of water (LCOW) is also decline. The aim of this study was to evaluate financially the installation of an energy recovery device on a seawater reverse osmosis desalination plant in North Cyprus. The plant is designed to have daily capacity of 66000 m3 of fresh drinking water. In this study the specific energy consumption and levelized cost of production for the base case scenario (seawater desalination plant without energy recovery device) and the incentive scenario (seawater desalination plant with energy recovery device) were conducted to illustrate the impact of an energy recovery device on seawater desalination plant. We performed a financial analysis from the owner’s point of view and the banker’s point of view to determine the feasibility and sustainability of the project under scenario II (seawater desalination plant with ERDs) to determine if it is a good way to reduce desalination cost and total and variable levelized cost of production.

Keywords: Seawater desalination, Energy recovery device, levelized cost of production, Specific energy consumption (SEC), Cost reduction, North Cyprus.

ÖZ

Son yıllarda deniz suyu arıtma yöntemi, su kıtlığını aşmak için güvenilir bir yol olup, mali açıdan da çok çekici olmaya başlamış bir teknolojidir. Su sıkıntısını çözmek için en büyük problem, deniz suyu arıtma-su arındırılması toplam maliyeti ve enerji tüketimidir. Spesifik enerji tüketimini azaltmak için etkili yaklaşımlardan biri de enerji geri kazanım cihazı kullanmaktır (ERDs). Deniz suyu arıtma tesisi toplam işletme maliyetini önemli ölçüde bu teknolojiyi kullanarak azaltacaktır. Bu azalma nedeniyle, suyun maliyetinde (LCOW) de azalma olacaktır. Bu çalışmanın amacı, Kuzey Kıbrıs'ta bir deniz suyu arıtma tesisi ve enerji geri kazanım aletini değerlendirmektir. Bu tesis, 66000 m3 içme suyu kapasitesine sahiptir. Bu çalışmanın esas senaryosu (Enerji geri kazanım cihazı olmadan deniz suyu arıtma tesisi) ve teşvik senaryosunda (Enerji geri kazanım cihazı ile deniz suyu arıtma tesisi) spesifik enerji tüketimi ve deniz suyu arıtma tesisi ile ilgili bir enerji geri kazanım aleti etkisini göstermekdir. Biz de mali analizini yaptık; değere getirilmiş maliyet azaltmak için ve iyi bir yol olup olmadığını anlamak için II. senaryo (ERDs ile deniz suyu arıtma tesisi) altında projenin fizibilite ve sürdürülebilirliğini belirlemeye çalıştık.

Anahtar Kelimeler: Deniz suyu tuzdan arındırma, enerji geri kazanım cihazı, üretim, Spesifik enerji tüketimi (SEC) Değere Getirilmiş Maliyet, Maliyet azaltma, Kuzey Kıbrıs.

I dedicated this thesis to my beloved family which I was far from them during the most stressful time of my life but only thinking about them gave me strength and calm to overcome problems, especially:

TO My wonderful father who makes him happy is the biggest motivation of my life.

TO my kind mother who always emotionally support me.

To my beloved husbands, which he is always support me in hard time and has an important role in completing my thesis, he is the best person which I known.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 Investigation Objectives

The main objective of this study is to evaluate in financial terms, the installation of an energy recovery device on a reverse osmosis (Ro) seawater desalination plant in North Cyprus. The plant is designed to have daily capacity of 66000 m^3 of fresh drinking water in order to alleviate the water scarcity that exists in that area and improve the quality of water services provided by the municipalities. After deciding what the most financially efficient technology to use is, a financial analysis is carried out on the building and operation of a reverse osmosis desalinization plant that uses this advanced technology (energy recovery device).

With the installation of ERDs in sea water reverse osmosis desalination plants, it is possible to re-use desalination processing energy by delivering this energy back to the feed. Therefore the energy consumption will be reduced. It should be mentioned that Energy consumption (electricity) is one of the main factors which effects on the levelized cost of water (LCOW) and desalination total operating cost. Consequently, when the amount of energy required for the desalination process decreases, the variable operating cost of plant as well as the levelized total cost of production, inclusive of the additional capital cost will be reduced.

Selecting the type of energy recovery device can be critical as it is based on energy cost in different region. Although the cost of installation PX is higher than others, its electrical cost for desalination plant is much lower. Therefore in countries where the cost of energy is high (usually in islands), implementing pressure exchanger for costs saving is more considerable.

In this study a financial analysis is carried out considering both the owner's and banker's perspectives and a comprehensive Net Present Value (NPV) probability distribution for both scenarios (specific energy consumption of project with energy recovery device installation and without energy recovery device) is obtained. A financial sensitivity analysis is also conducted in order to identify the critical variables with the greatest influence on the resulting financial NPV and total levelized cost of production and levelized variable cost of production.

1.2 Case of North Cyprus

North Cyprus is considered entirely as a semi-arid region as it is a small and homogeneous land in terms of climatic conditions, water resources and renewable energy potential. In the last few years climate changes, increase water demand due to population growth, recurrent draught and reduction in river flows due to decrease in annual rainfall resulted in water shortage (K.V. Reddy, 2006). Gradually over the years the average temperature of region has been rising, and the result is clear that desertification will be occurring, and this trend reversing probability is not rationally predictable. The quantity of accessible water for irrigation and domestic purposes has become inadequate Due to decrease in both annual precipitation and water flow into the dams.

Because of these problems over the years the desalination industry has been rapidly expanding and has received attention as an option to cope with this water deficit and to develop the water availability and reliability of water supply system in North Cyprus (S. Sanchez & Subiela, 2006).

Figure 1: Cyprus Map

1.3 What is Seawater Desalination?

The process of water treatment to extract salts and other impurities from seawater to produce fresh water for human consumption is called seawater desalination (Club, 2008).

1.4 How Does Desalination Work?

Two major treatment methods for desalination are the thermal desalination process and the membrane desalination process**.** In this study we use one of most effective membrane desalination processes which is the reverse osmosis technology. In the following section we will explain this method. Membrane technologies methods are divided as following:

1.4.1 Electro Dialysis (ED) and Electro Dialysis Reversal (EDR)

Electro dialysis and electro dialysis reversal are voltage-driven membrane processes in which the electric charge moves salt and other minerals through the membrane, leaving desalted water behind as fresh potable water. These two membrane technologies are mostly used for brackish water instead of seawater with high salinity.

1.4.2 Reverse Osmosis (RO)

In comparison to thermal processes**,** Reverse Osmosis (RO) is a quite new process that was initiated in early 1970s. In reverse osmosis technology, high pressure will flow feed water through a semi-permeable membrane, leaving the salts and other impurities behind and producing fresh water (Club, 2008).

Table 1: Desalination Technologies and Processes

Thermal Technology	**Membrane Technology**
Multi-stage Flash Distillation (MFS)	Electro Dialysis (ED)
Multi-Effect Distillation (MED)	Electro Dialysis Reversal (EDR)
Vapor Compression Distillation (VCD)	Reverse Osmosis

Chapter 2

REVERSE OSMOSIS TECHNOLOGY, COMPARATIVE STUDY BETWEEN RO AND OTHER TECHNOLOGY, COST EFFECTIVENESS OF UTILIZATION OF RO IN SEA WATER DESALINATION

2.1 What is Osmosis?

Osmosis is a kind of simple diffusion and is fundamentally based upon striving for equilibrium. When two fluids with different solute concentrations which are separated by a membrane come in contact with each other, the potential energy difference existing between them forces water containing a low volume of solute concentration to flow to a high solute concentration until the concentration is uniform and the flow stops (Binnie, 2002). Then you can see that water level in one side of semi-permeable membrane is higher than the other side. This height difference in the two sides of the membrane is called the osmotic pressure.

2.2 What is Reverse Osmosis Technology?

Reverse osmosis is a modern membrane-technology filtration process that generates low TDS water from seawater in the desalination process. In the Ro method, Water from a saline solution is separated from the dissolved salts by flowing through a water-permeable membrane.

For this osmotic separation we should apply pressure which is highly related to salinity of solution. It means with higher salinity of feed water, higher energy is required for this separation.

The remaining feed water which is retained behind the permeate membrane is called brine. In this separation process no heating or phase change occurs. (Kazmerski, Economic and Technical Analysis of a Reverse-Osmosis,Water Desalination Plant using DEEP-3.2 Software, 2010).

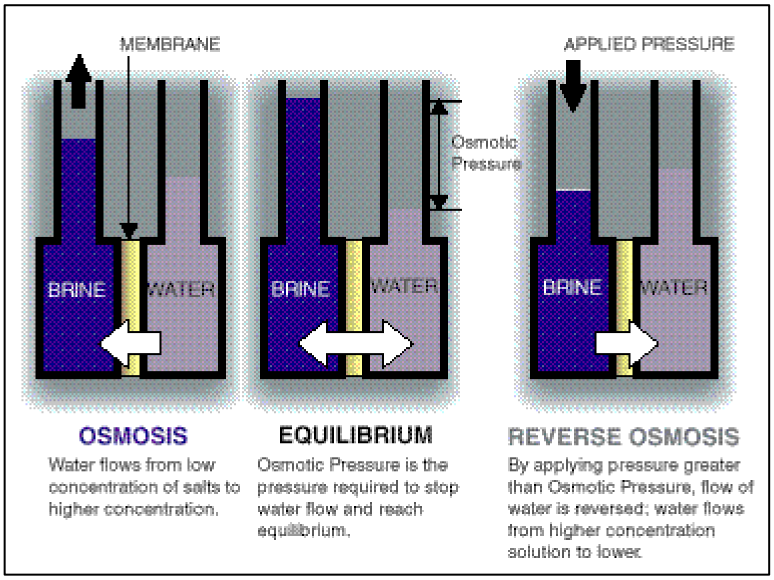


Figure 2: Reverse Osmosis Process

2.3 RO System Components

RO system essentially consists of four major processes:

Pretreatment: Pretreatment is so crucial as the membrane surface should remain clean. This process avoids fouling the membrane which is used in the system.

Therefore, all suspended solids in the feed water should be removed and other pretreatment processes like adjusting the pH and adding a threshold inhibitor to control scaling such as calcium sulfate should be applied.

Pressurization (high pressure pumps): The pumps supply the pressure which is needed to pass feed water through the membrane and cause the salt to be rejected.

Separation: The permeable membranes do not permit that dissolved salts to pass through it while the desalinated water can pass through. The seawater is pumped in a pressurized vessel and here the feed water is forced against the membrane. As a portion of the water passes through the membrane, the salt content in the remaining brine increases. At the same time, a portion of this brine is discharged without passing through the membrane.

Stabilization (post-treatment): In this part, the product water as a drinking water should be prepared for the distribution system and usually requires pH adjustment and disinfection. To reach potable water specifications the PH of water should be adjusted to between 5 and 7. And this water then stored in containers for later use. (Kazmerski, Economic and Technical Analysis of a Reverse-Osmosis,Water Desalination Plant using DEEP-3.2 Software, 2010).

2.4 Effectiveness of the RO Technology

Reverse osmosis technology is known as a most reliable, cost effective technology with a high rate of energy efficiency in producing fresh potable water in comparison to other desalination technologies.

RO is the fastest-growing desalination technology which is widely used around the world and which has the greatest number of installations (Kazmerski, 2010). The reverse osmosis (RO) method works based on the osmosis principal and uses membrane technology as a barrier to remove salts from water. Because the required energy of RO technology for operation is less than other desalination technologies, it has become more attractive than other methods and it makes desalination a much more affordable way for countries to cope with water scarcity. It should be mentioned that purified water from RO is not only used for drinking purpose.

It can also be used in industrial process applications, pharmaceuticals, chemicals, boiler feed water, medical applications and industrial and municipal wastewater recovery systems as well. Several advantages of RO membrane technique are described below (Jorg Menningmann, 2005):

- The generally specific energy requirement of RO technology is 70% less than other desalination methods.

- The water recovery ratio of reverse osmosis desalination system is relatively higher than other methods (a 45% recovery ratio means 45 m3 of purify water is produced from 100 m3 of feed water. This percentage is the ratio between feed water and permeates water).

-The installation cost of RO technology including capital cost and operating cost is much lower than other desalination techniques like multistage flash (M. F. A. Goosen2 et al, 2004).

-RO system processing is simple; the only complicating thing is to select low salinity feed water to reduce desalination cost and frequent cleaning of the membrane.

-The production capacity of reverse osmosis technology is high, normally ranging from 25,000 to 60,000 m3 per day.

- Seawater as a water source of RO technologies is unlimited and makes it different from other methods.

- The reverse osmosis desalination process is able to eliminate both organic and inorganic pollutants from seawater.

- Without considering brine disposal of the reverse osmosis method, the environmental impact of RO is negligible (John Bradshaw, 2005).

Using SWRO desalination technology has some disadvantage such as membrane fouling which is related to feed water quality. The unpredictability of seawater characteristics like the level of salinity, the PH, and the temperatures of the water can cause deterioration of the membrane’s useful life over time, so it is necessary to monitor feed water quality regularly (especially in the case of seawater).

However, over the past years the continuous development in membrane technology has decreased this disadvantageous effect. Today, the useful life of the membrane in the reverse osmosis process is estimated to be 5 years (Bellot, 2004). The other disadvantage is that high-pressure pumps pressurize the feed water to membrane for desalination process. This process need large amount of energy. When the desalination process finishes the salty water or brine should remove as a waste. This high concentrated water has high pressure, and when it back to the sea so much energy will waste. This energy should recycle with installation of the energy recovery device in this process. In following chapters; we will discuss about ERDs in seawater reverse osmosis desalination plants.

2.5 Minimizing the Cost of SWRO Desalination

In the water industry, producing fresh potable water with acceptable quality and at minimum cost is the major goal. Because of the high energy demand in seawater desalination process, this is known as an expensive affair. From the beginning of reverse osmosis technology in 1970’s, it was considered to find a way to reduce operating costs of RO technology. In recent times, due to applying energy recovery devices (ERDs) and ultra-high pressure membranes in SWRO desalination plants, the desalination cost is decreasing. In fact it should be mentioned that with installation of ERDs in sea water reverse osmosis desalination plants, the hydraulic energy in highly pressurized reject brine is no longer wasted since with the help of ERDs, it is possible to re-use this energy by delivering this energy back to the feed. Therefore the energy consumption will be reduced and total operating cost along with total unit cost of production will drop (A.M. Farooque et al, 2011).

2.6 What is Energy Recovery Device

Energy Recovery technologies are used for attaining considerable energy savings in desalination plants and generally pertains to pressure exchangers. In ERDs technology the positive displacement principal is used. As mentioned before, these devices are installed to recover the energy of rejected brine (Bellot, 2004). Energy recovery devices are categorized to centrifugal and isobaric. Centrifugal ERDs have capacity limitation and their maximum operating efficiency rate is around 82%. They are typically used for a narrow range of flow rate and pressure as well as operating conditions since the efficiency of centrifugal devices with seasonal or operational changes will decrease. Centrifugal ERDs consist of turbochargers, Pelton wheels and reverse-running pumps.

Isobaric ERDs have unlimited capacity and the rate of operating efficiency for isobaric devices is approximately 97%. They consist of piston-type work exchangers and the rotary PX Pressure Exchanger™ device. By utilizing The PX energy recovery device in the SWRO desalination process approximately 96.8% of reject brine energy will be recovered. In fact the desalination economics considerably changes due to installation of ERDs in plants. Although globally more than 98% of energy recovery devices in SWRO desalination plants are centrifugal devices, the most energy efficient energy recovery devices are pressure exchangers which work on the positive displacement principal like PX and DWEER. Due to their height efficiency rate, simplicity, quick startup of PX technology, and lack of need for maintenance, around the world more than 12,000 PX devices have been installed. Most of them have been operating more than 12 years.

Annually the PX technology is saving more than 10 billion KWh of energy; this means that annually in terms of the cost of energy in the world, almost more than 700 million dollars will be saved (ERI, 2012). For achieving higher energy recovery device capacity, utilizing multiple operating units in parallel is necessary exactly like the membranes. In addition, seawater reverse osmosis systems with centrifugal energy recovery devices need high-pressure pumps sized to manage the full membrane feed flow. In SWRO systems with isobaric ERDs, the ERD provides only the feed brine portion, therefore the high pressure pump pressurizes only the water quantity which is known as permeate (Stover, 2006).

2.7 Energy Improvement with EDRs ON SWRO Desalination Plants

Since the 1980s, different energy recovery devices have been developed for the desalination process in order to save energy consumption and reduce desalination cost. Turbine-based, centrifugal ERDs like the Pelton Wheel or Francis turbine are still used in many older desalination plants. However they are less efficient than isobaric devices.

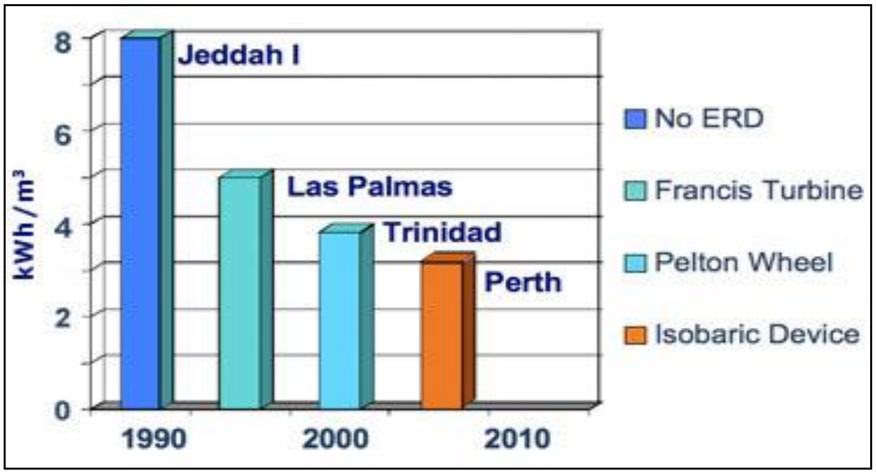


Figure 3: Impact of Energy Recovery Devices on SWRO Energy Consumption
Source: Energy Recovery Inc. (www.energy-recovery.com)

The effect of energy recovery devices technology on energy consumption which is required for producing desalinated fresh water in seawater reverse osmosis plants is shown above. You can see that in 1990 the Jeddah 1 plant in Saudi Arabia was not equipped with an energy recovery system and its energy consumption was more than 8 KWh per m3. In 1995, The Las Palmas desalination plant in the Canary Islands desalination plant utilized Francis turbines for saving energy so its energy consumption decreased to 5 KWh per m3. In 2000, in the Trinidad water desalination plant Pelton turbines were used and the energy consumption dropped below 4 KWh per m3. It should be mentioned that the Trinidad plant Pelton turbines are to be state-of-the-art due to their large size. You can see that in 2010, in the Perth desalination plant how much ERI's PX technology reduced energy consumption for producing fresh water, approximately reduced 16% (3.8 KWh/m3 to 3.2 KWh/m3) (Nir Becker et al, 2010).

It should be noted that, for desalination of 1 m3 of seawater with reverse osmosis technology approximately 3.7 to 4.5 KWh/m3 of energy is required. This amount of electricity consumption can be decreased by 30% by applying an energy recovery device in the desalination process (Poullikkas, 2000).

Selecting the type of energy recovery device can be critical as it is based on energy costs in different regions. Although the cost of installing PX is higher than other technologies, but its electrical cost for desalination plant is much lower. Therefore in countries where the costs of energy are high (usually in islands), implementing pressure exchangers for cost saving may be good consideration.

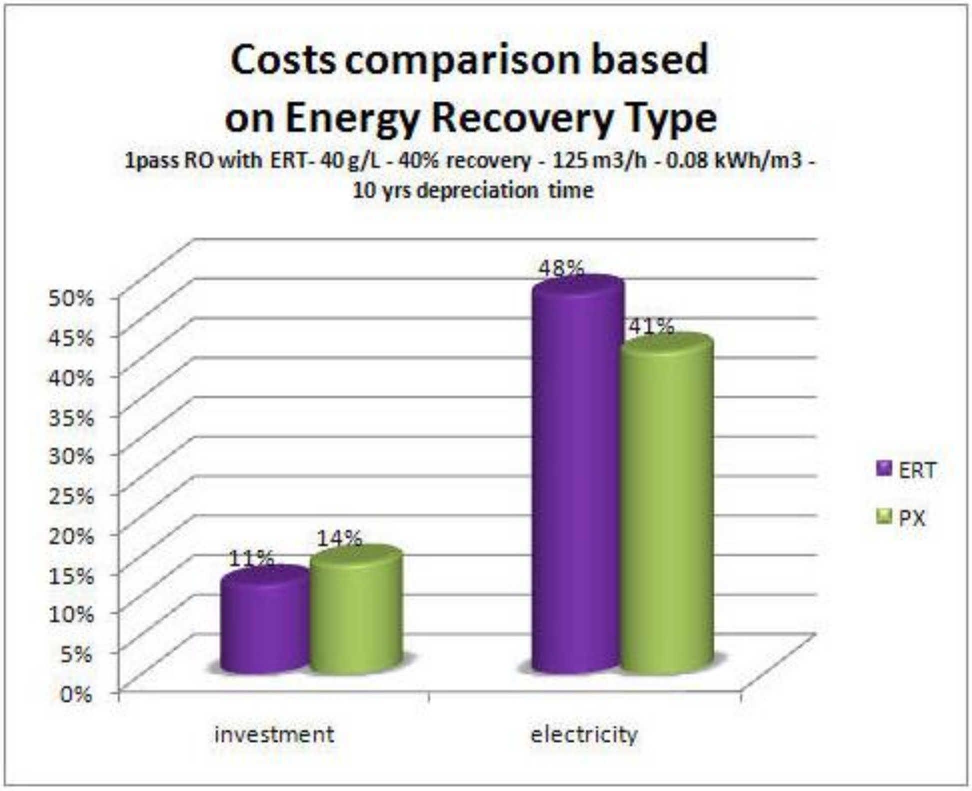


Figure 4: Cost Comparison based on Energy Recovery Type
Source: WWW.Lenntech.com.2011

2.8 Effect of ERDs on Water Cost of Seawater Desalination

The costs of desalinated water from seawater reverse osmosis desalination plants in the past two decades have intensely decreased (approximately from \$2.8 per m3 to \$1.5 per m3). This cost reduction is related to applying energy recovery devices (EDRs) and efficient membranes in the desalination process (Asmerom M. Gilau et al, 2007).

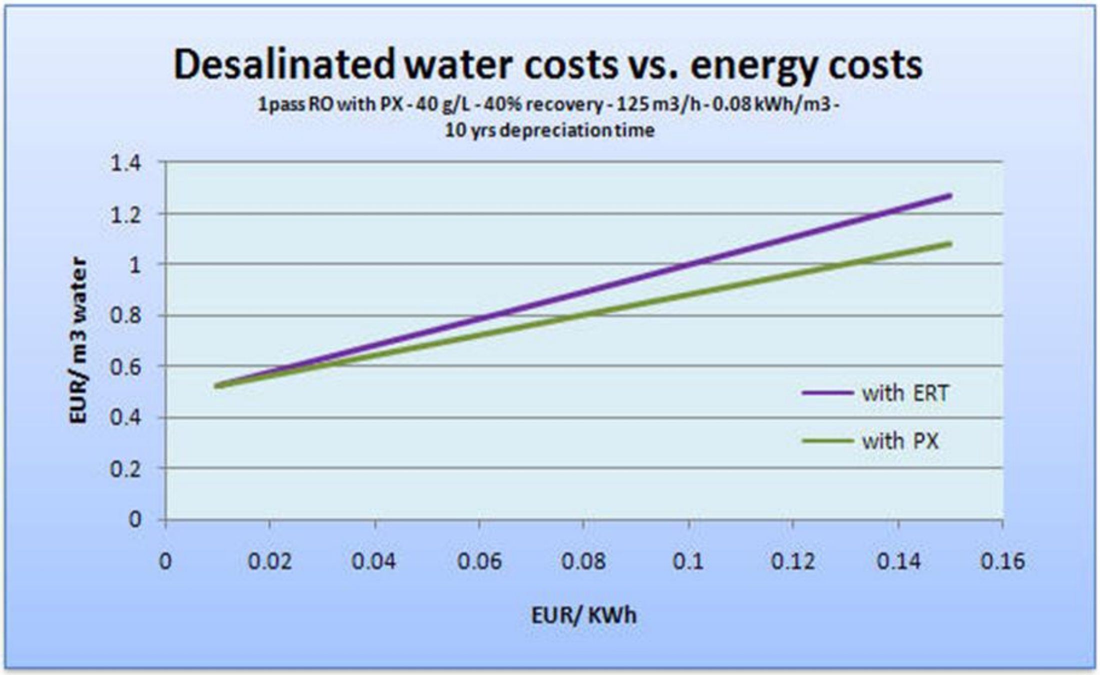


Figure 5: Desalinated Water Costs vs. Energy Costs
Source: WWW.Lenntech.com.2011

Chapter 3

REVERSE OSMOSIS DESALINATION COSTS ANALYSIS

In determining desalination decisions one of the most significant factors is economics: costs and benefits. Nonetheless, it is really hard to analyze and compare different desalination plants costs since the desalination costs are based on plant capacity and type, the region, the raw water quality and capital and labor costs assumptions as well as the period (Yuan Zhou et al, 2003). This chapter discusses factors which affect desalination costs (Younos, 2005).

3.1 Factors Affecting Desalination Costs

Desalination cost is affected by several factors. Generally, desalination implementing cost factors are site specific and are based on several variables. Some of these cost variables are described below (Younos, 2005).

3.1.1 Feed Water Quality

The feed water quality is one of the most critical factors. The energy requirement of desalination treatment is highly dependent on feed water TDS. Feed water with low salinity concentration (e.g. brackish water) needs less energy in comparison to high salinity feed water. Also, the recovery rate of feed water with low salinity is higher so the plant can operate with fewer amounts of anti-scalant chemical.

Therefore, the pre-treatment cost of feed water with lower TDS is much lower than that of feed water with a higher TDS. Because of this fact, it can be seen that seawater desalination cost is greater than brackish due to higher salinity (Younos, 2005).

3.1.2 Plant Capacity

The capacity of a desalination plant is strongly affected by its treatment unit size, pumping and water storage tank size and also water distribution system size. Obviously the initial capital investment cost of high capacity desalination plants is much more than plants with low capacity. However, it should be mentioned that the total unit cost of production of large plants is lower than low capacity plants due to economy of scale.

3.1.3 Site Characteristics

Characteristics of the region in which the desalination plant is located have an effect on the unit production cost of water. For instance, in the determination of desalination cost, land availability and land condition are important factors. Desalination plant location closeness to the source of water and brine discharge point is also an important factor. This closeness considerably reduces the cost of pumping and pipe installation costs. Also, if the desalination plant is an expansion of an existing water treatment plant, costs which are dependent on water intake, pretreatment process, and brine disposal can be significantly reduced in comparison to constructing a new plant. (Younos, 2005).

3.1.4 Regulatory Requirements

These costs are attributed to local or state permits and regulatory requirements (Younos, 2005).

3.2 Implementation Costs of Desalination

The major implementation costs of a desalination plant can be divided into construction costs and annual operation and maintenance (O&M) costs (Younos, 2005).

3.2.1 Construction Costs

Constructions costs consist of direct capital costs and indirect capital costs. In following some direct and indirect capital cost of desalination plant will be described: (Younos, 2005).

3.2.1.1 Direct Costs

- **Land:** The land cost of the project intensely is based on plant ownership (public vs. private) and plant region characteristics. Due to these factors it may vary significantly, from zero to a sum (Younos, 2005).

- **Production Wells:** Construction cost of the well is highly related to the well depth and the capacity of the desalination plant. (Younos, 2005).

- **Structure of Water Intake:** The cost of water intake structures is related to the desalination plant capacity and environmental regulations.

- **Process Equipment:** Different equipment which is used in the desalination process like membranes (water treatment units), pre-treatment and post-treatment units, and cleaning systems are highly dependent on the capacity of the plant and the seawater salinity level (Younos, 2005).

- **Auxiliary Equipment:** Supplementary equipment consists of open water intakes, wells, storage tanks, generators, transformers, pumps, pipes, valves, electric wiring, etc. (Younos, 2005).

- **Buildings:** Building control rooms, workshops, laboratories, and offices for the desalination plant depend on the plant region conditions and its building type (Younos, 2005).

- **Concentrate Disposal:** Plant capacity, desalination plant type, discharge location and environmental regulations are major factors which have an effect on the cost of the brine disposal system (Younos, 2005).

3.2.1.2 Indirect Costs.

- **Freight and Insurance:** Usually this cost is estimated to be 5 percentages of the direct costs (Younos, 2005).

- **Construction Overhead:** Construction overhead costs include labor costs, fringe benefits, field supervision, temporary facilities, construction equipment, small tools, contractor’s profit and miscellaneous expenses. This cost is typically estimated at 15 percent of the direct material and labor costs (Younos, 2005).

- **Owner’s Cost:** The owner’s cost includes land acquisition, engineering design, contract administration, administrative expenses, commissioning and/or startup costs, and legal Fees. It is estimated at approximately 10 percent of direct materials and labor costs (Younos, 2005).

- **Contingency Cost:** This cost is included for possible additional services. It is generally estimated at 10 percent of the total direct costs (Younos, 2005).

3.2.2 Operating and Maintenance Costs

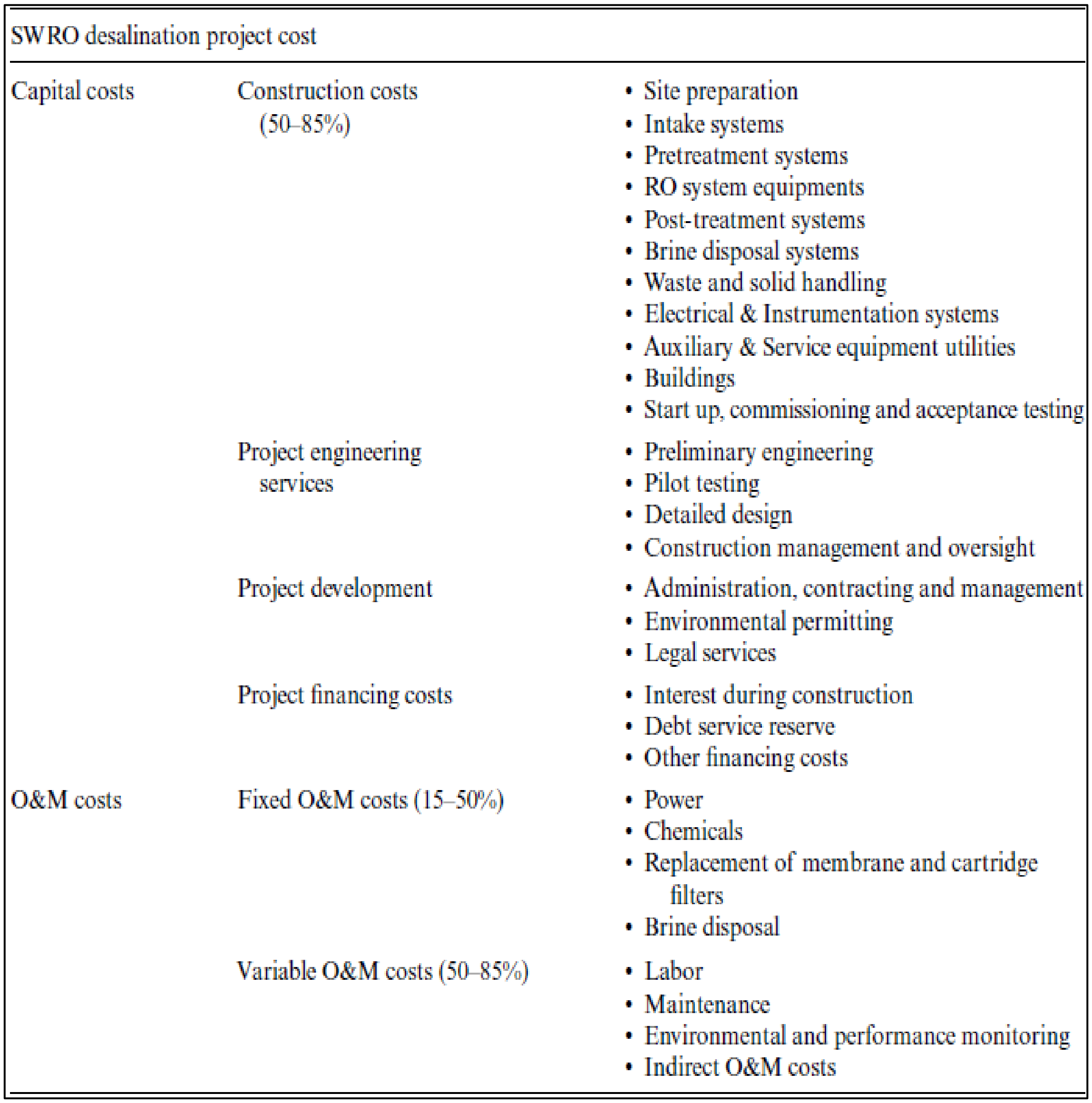
The operating and maintenance (O & M) costs are divided into fixed and variable costs (Younos, 2005).

Fixed Costs: Insurance and amortization costs are considered to be fixed costs. Typically, 0.5% of the total capital cost is considered to be insurance cost. Amortization is typically based on desalination plant life-time and interest rate. Amortization reimburses for the annual interest payments for direct and indirect costs. Generally, the rate which is used for amortization is between 5% and 10 % (Younos, 2005).

Variable Costs: Labor cost, energy consumption cost, chemical cost and maintenance cost are the main variable costs. Costs of labor are based on ownership of plant (public or private) and can be site-specific. Cost of energy is related to inexpensive electricity availability (or other power source). For instance, if the plant is co-located with a power generation plant, it can help to reduce the cost of energy consumption. Level of feed water salinity, cleaning process and pre-treatment and post-treatment degree of feed water determine the amount of chemical usage. The quantity and type of chemicals along with global market prices have an effect on chemicals cost. The greatest portion of maintenance cost is related to the membrane replacement frequency, which depends on water quality.

For feed water with low salinity, the rate of membrane replacement is considered to be 5% annually, and for high salinity seawater this rate is around 20% per year. Maintenance and spare parts cost is usually considered as a percentage of the total capital cost of the project and is determined to be less than 2 percent per year (Younos, 2005).

Table 2: Classification of Costs in SWRO Desalination Plant



SWRO desalination project cost		
Capital costs	Construction costs (50–85%)	• Site preparation • Intake systems • Pretreatment systems • RO system equipments • Post-treatment systems • Brine disposal systems • Waste and solid handling • Electrical & Instrumentation systems • Auxiliary & Service equipment utilities • Buildings • Start up, commissioning and acceptance testing
	Project engineering services	• Preliminary engineering • Pilot testing • Detailed design • Construction management and oversight
	Project development	• Administration, contracting and management • Environmental permitting • Legal services
	Project financing costs	• Interest during construction • Debt service reserve • Other financing costs
O&M costs	Fixed O&M costs (15–50%)	• Power • Chemicals • Replacement of membrane and cartridge filters • Brine disposal
	Variable O&M costs (50–85%)	• Labor • Maintenance • Environmental and performance monitoring • Indirect O&M costs

3.3 Two Main Factors of the Water Production Cost in SWRO Plants

Energy consumption (electricity) and membrane replacement costs are the major factors which affect water production cost. These two factors constitute almost 30 to 50 percent of the total water production cost and 75 percent of the operating cost. It is reported that based on electricity cost, especially for a small capacity plant, 75 to 85% of the total water production cost is electricity consumption (S.A. Avlonitis et al, 2003).

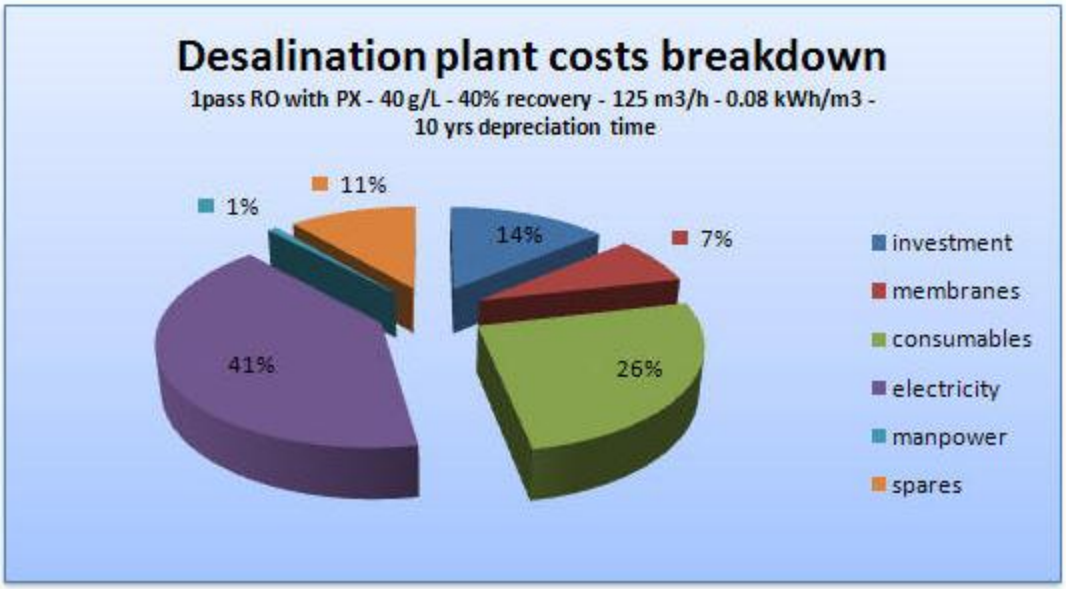


Figure 6: Desalination Plant Costs Breakdown
Source: www.Lenttech.com.2011

3.4 Energy Consumption in SWRO Desalination Method

In a SWRO desalination system, the amount of energy which is required can be expressed as specific energy — the energy required per unit output of permeate — and can be evaluated with following equations:

$$SE = (E_{HP} + E_{BP} + E_{SP}) / Q_P \qquad (1)$$

$$SE = [Q_{HP}(P_{HP} - P_F) / \eta_{HP} + Q_{BP}(P_{HP} - P_{BPI}) / \eta_{PB} + Q_{SP} P_F / \eta_{SP} / Q_P \qquad (2)$$

Where SE is specific energy consumption of SWRO system, E_{HP} is the energy consumption of a high-pressure pump, E_{BP} expresses the energy consumption of the booster pump, E_{SP} is the energy consumption of the supply pump, Q_P is the flow rate of permeate, Q_{HP} is the flow rate of the high-pressure pump, P_{HP} is the outlet pressure of the high-pressure pump, P_F is the feed water pressure to the high pressure pump, η_{HP} is the efficiency rate of the motor and high-pressure pump, Q_{BP} is the flow rate of the booster pump ,P_{BPI} is the inlet pressure of the booster pump, η_{PB} is the efficiency rate of the booster pump and motor, Q_{SP} is the flow rate of the booster pump, and η_{SP} is the efficiency rate of the supply pump and motor. It should be mentioned that for calculating energy consumption of SWRO plants with different ERDs, only the high pressure and booster pumps' energy consumption are considered in the equation. This difference is relatively due to the variation of important requirements in the pretreatment process and supply pumping (Stover, 2006).

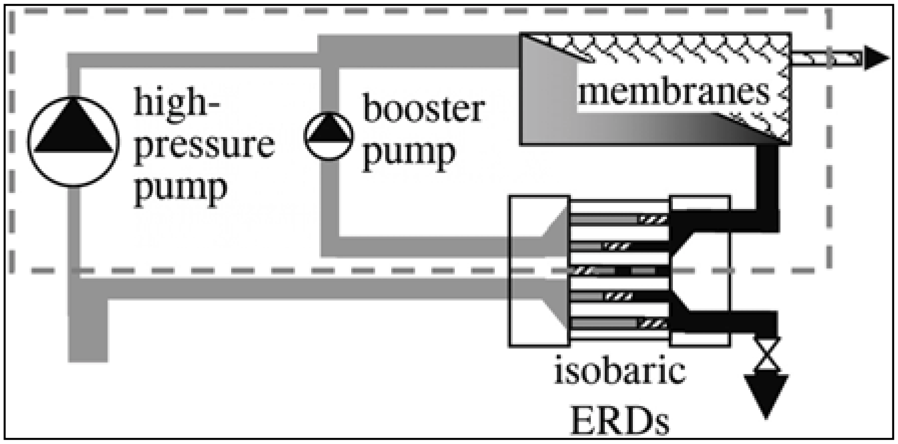


Figure 7: Schematic Diagram of the SWRO System

Several factors have an effect on the energy consumption of seawater desalination plants, such as:

- The feed water concentration
- The desalination method
- The seawater's chemical and physical features
- The existence of an energy recovery system in the plant as well as its type
- The desalination plant location
- The plant capacity (S.A. Avlonitis et al, 2003)

3.5 Cost Trends

As we know, in SWRO desalination plants, the energy consumption cost is one of the major factors in the constitution of its total operating cost and water production cost. During the past decade, due to advance development in sea water desalination technology, the specific energy consumption of desalination plants has been reduced which has caused decreased electricity costs.

This process significantly dropped the total cost of desalination and increased seawater desalination attractiveness for policy makers as an affordable instrument to solve water scarcity (Nir Becker et al, 2010). This downward trend is represented in the following figure (WaterUseAssociation, 2012).

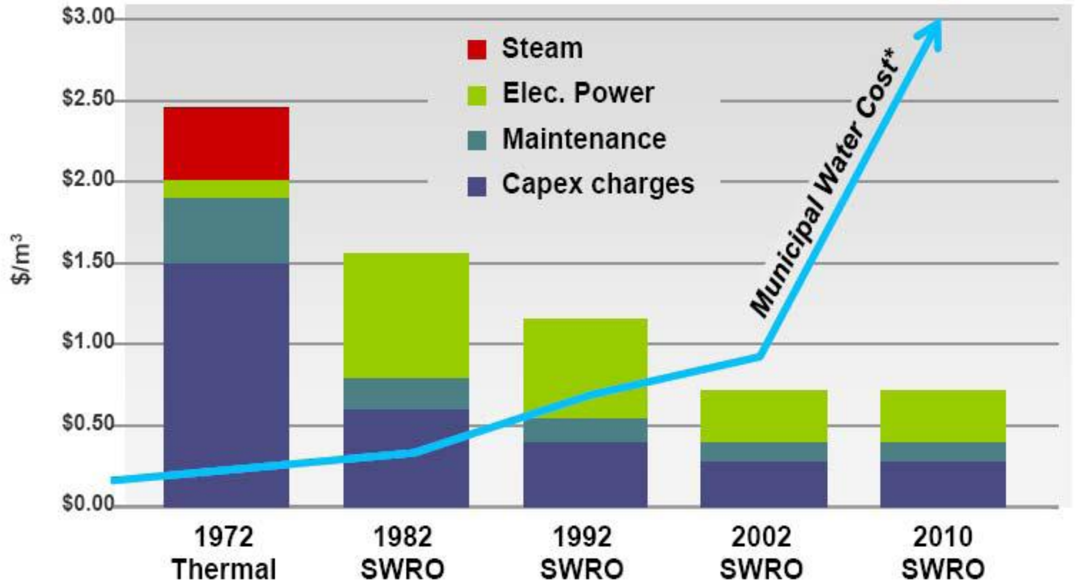


Figure 8: SWRO Cost Trend
Source: Water costs for San Diego, Monterey, Perth, Sydney, and Barcelona

3.6 Model Specification

Our model uses seawater reverse osmosis technology for desalination and for energy savings we applied an isobaric Energy Recovery Device for our model. Isobaric energy recovery devices have considerable benefits for an SWRO plant. As mentioned before, isobaric devices have unlimited capacity in comparison to centrifugal devices. These devices decrease costs of high-pressure pumps, have high efficiency rates in recovering the energy, and they are flexible in operation. Among isobaric energy recovery devices the PX Pressure Exchanger is commercially available and offers the following advantages:

No customization requirement

Easy operation (easy startup, easy shutdown)

Maintenance -free

High efficiency
Low pulsation
Long life

These advantages in PX design and operational characteristics create incredible growth and success in sea water reverse osmosis desalination process and make it the best choice for an energy recovery device in the desalination process (ERI, 2012).

For our model we chose Px-260 which is a new generation of pressure exchanger energy recovery device. The PX-260 device can manage brine flow rates of 50–59 m3/hr (220 to 260 gpm) which is equivalent to 41 to 48 m3/hr (181 to 211 gpm) permeate flow rates when the operating recovery rate is 45%. It should be mentioned that for attaining considered capacity, the PX- 260 units may be used together in multiples, exactly like all other ERI PX® units. When we can operate with these manifold units in parallel, it means that we can manage different seawater reverse osmosis train sizes with PX technology and no limitation exists for this technology. For example, in one plant with a 240,000 m3/day (63 MGD) capacity, a 65-Series PX Pressure Exchanger technology has been installed. Generally speaking, PX technology is well suited for even higher desalination plant capacity. Due to the positive displacement principle which is applied in the PX Pressure Exchanger (PX®) technology, costs of water production are reduce by approximately 60%.

3.6.1 Raw Water Supply System

Raw water quality of desalination plant is a fundamental factor during the operational life of a plant and it is not exaggeration to say that it can also put the whole project in danger and can increase costs of operating and maintenance. For designing and improving the raw water intake system and membrane pre-treatment systems for seawater desalination plants, enough time and resources should be spent. Doing hydro-geological studies on the expected region which will be the water supply source is the first step. In our model we use surface water sources. It is necessary to determine the water salinity review yearly because the levels of water temperature and water PH can change seasonally. For membrane treatment evaluation some water elements should be considered such as:

Table 3: Water Quality Analysis

Parameter
Calcium
Magnesium
Sodium
Potassium
Ammonia
Strontium
Barium
Iron
Manganese
Carbonate
Bicarbonate Alkalinity
Sulfate
Chloride
Nitrate
Fluoride
Silica
Carbon Dioxide
Hydrogen Sulfide
Total Dissolved Solids
Temperature
pH
Silt Density Index

Surface water intake systems should be located where the water variation is low and the water is collected above seabed. The feed water salinity in this case (the Mediterranean seawater characteristics) is high (TDS between 38,000 and 40,000 ppm at a temperature ranging between 16 and 25 degrees Celsius) (Bellot, 2004).

To prevent bio-fouling problems, the seawater intake system needs periodic maintenance and disinfection. The plant desalination process facilities should be designed with sufficient isolation valves, access for pulling pumps, instruments of diverting disinfection flushing water so chlorinated water is not directed to the RO plant. Most operational problems of seawater desalination plants are due to feed water intake systems. Therefore, it is obligatory for the system to be monitored and repaired constantly.

3.6.2 Physical Pre-treatment Facilities

The process of pre-treatment in SWRO plants includes many steps and barriers to keep large particles in the raw water from reaching the membrane. Both physical water pre-treatment and chemical water pre-treatment are utilized to keep the membranes from fouling.

The cartridge filter is the industry standard for the reverse osmosis pretreatment process. It contains pressure-rated housing, usually stainless steel, which consists of numerous disposal filter elements. The filter elements are typically string-wound polypropylene or melt brown elements, 2 ½ in diameter by 30 or 40 long. They can have rating from 1 to 20 microns; usually 5 micron is used in the RO industry.

The elements of a filter can extensively change the efficiency of the desalination process, and therefore can extensively affect desalination costs. The cartridge filter is in place as a last line defense to protect the membranes and RO feed pumps from occasional upsets or particulate matter that may enter the raw water feed from line break or other maintenance. Changing or replacing the cartridge filter elements is moderately expensive and also it is labor intensive.

3.6.3 System Design

In our model, feed water is transferred from the sea to the plant desalination system through a 1200 mm diameter pipeline and at the intake there should be screen to avoid the entrance of fish and sea plants to the pipeline. The next step is chlorination of the feed water with sodium hydrochloride and PH adjustment with sulphuric acid. After this, the seawater is pumped to the main building for the desalination process.

After that, for coalescence and flocculation of the sweater colloids, injecting ferric chloride and polyelectrolyte is necessary. Then the seawater is filtered through six gravity dual media which are made of gravel, silica and anthracite for elimination of all solid matter above a certain size. After these processes, the filtered feed water is pumped to polypropylene wound cartridge filters.

The significant role of these filters is to prevent membrane fouling by guaranteeing that no particles above a standard size can reach the membranes. After these pre-treatment processes, the high pressure pumps will pressurize seawater to the membranes where the seawater is desalinated (Bellot, 2004).

After passing the water through the membranes for the desalination process, the produced water should be transferred to ground storage tanks for adding lime and carbon dioxide to adjust the product water PH and to decrease the water hardness. After finishing this post-treatment process, the water is ready to distribute.

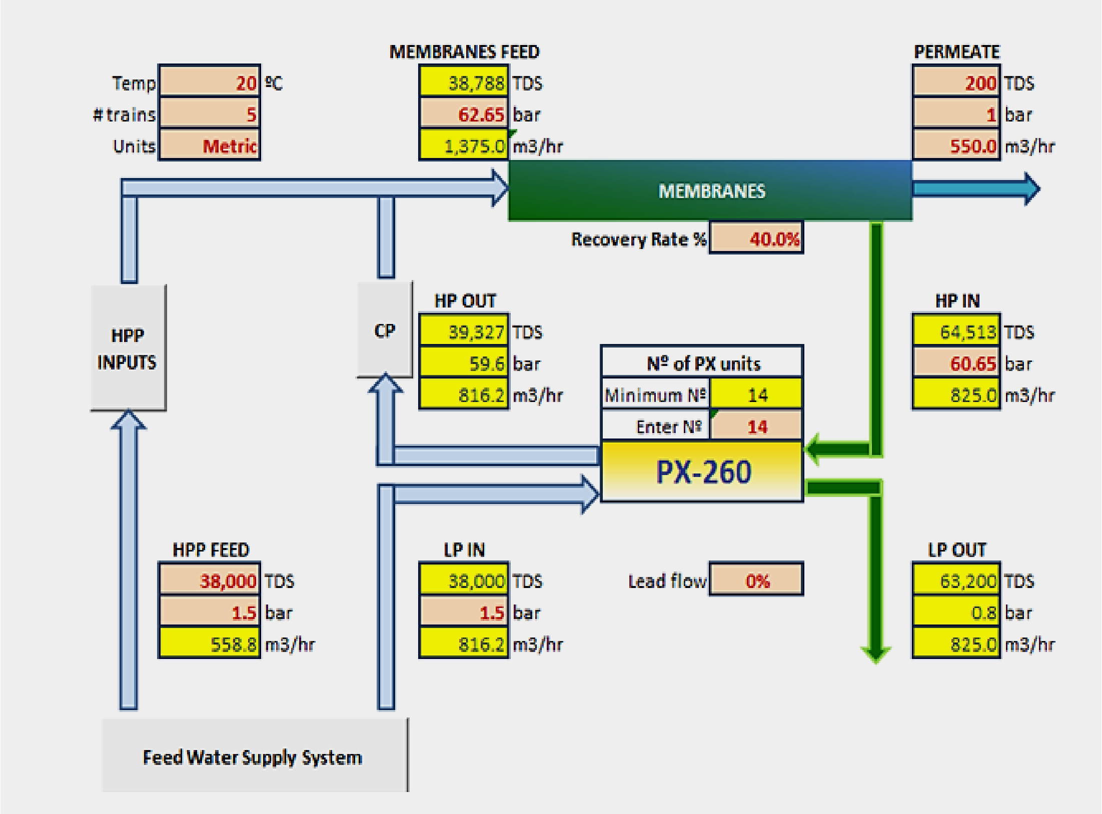


Figure 9: SWRO Desalination Plant Process Diagram

To reach the proposed capacity of large plants like the plant capacity in this study, several RO or membrane trains are required. For achieving the purpose of our study, we have 5 RO trains and each of them has a capacity of 13200m^3 per day (this means that the total daily capacity of our plant is 66000 m^3/ day). The number of reverse osmosis membranes is approximately 15 and the recovery rate is 40 %. In Figure 9, our SWRO desalination plant process diagram is illustrated.

Chapter 4

FINANCIAL ANALYSIS OF THE LEVELIZED COST OF WATER (LCOW)

4.1 Financial Analysis from Perspective of Independent Water Producer (IWP)

During the past two decades the cost of desalinated water from seawater reverses osmosis desalination plants has decreased rapidly. This cost reduction is related to applying energy recovery devices (EDRs) in seawater desalination process.

The levelized cost of water (LCOW) allows one to make a comparison of water generation technologies on the basis of average costs per cubic meter of water produced. The performance of an investment in a water project can be considered from different perspective. In this study we evaluate the LCOW analysis from the independent water producer (IWP) perspective under base case scenario (desalination plants without energy recovery device) and incentive case scenario (desalination plants with energy recovery device). This is will allow to determinet the cost effectiveness of applying EDRs in seawater desalination plants and to evaluate the financial attractiveness of a water project.

Cost of Water: To calculate a levelized cost of water (LCOW), the revenue stream of a water project is discounted using a standard rate (or possibly the project's IRR) to yield a PV. This PV is levelized to an annual payment and then divided by the project’s annual water output to yield a value in cents per kWh. The LCOW is often used by water policy analysts and project evaluators to develop first-order assessments of a project’s attractiveness. The levelized cost of water defines the stream of revenue that minimally meets the requirements for equity return and minimum debt coverage ratio. In this chapter we will discuss the levelized cost of water as a financial criterion to evaluate project viability.

4.2 Scenarios

In this study two scenarios are considered under different sets of assumptions. Results are obtained for each one of them separately:

4.2.1 Scenario I: Specific Energy Consumption of Reverse Osmosis Desalination Plants without Energy Recovery Device Installation

The chief purpose of this scenario’s analysis is to determine the specific energy consumption and operation costs associated with the project without considering the addition of an energy recovery device to the desalination plant. The levelized cost of water is calculated at the plant gate. It should be noted that no interruption or shut down is considered for plant operating times and in this scenario all distributional aspects like distribution cost and leakage are eliminated due to the assumption that water will be sold at the gate. The prices of electricity are assumed as project inputs regardless of any peak/off-peak hour considerations.

4.2.2 Scenario II: Specific Energy Consumption of Reverse Osmosis Desalination Plants with Energy Recovery Device Installation

In this scenario the main aim is to calculate the specific energy requirements of the desalination process in this study as well as to calculate the levelized cost of water while considering an energy recovery device for the plant. We want to determine the effectiveness of installing ERDs on the energy consumption of the project and its operating cost.

4.3 The Energy Consumption Comparison between Two Scenarios

The energy consumption of our project (for a daily capacity of 66,000 m3/day) before installation of the energy recovery device (PX-260) is 1590.48 KWh/hr per train. This amount of energy consumption is calculated by considering the energy consumption of high-pressure pumps, booster pumps' energy consumed and feed water supply pumps' energy consumed. It is expected that after installation of an energy recovery device this amount will be reduced to 1480.09 KWh/hr per train, due to the elimination of the feed water supply pumps' energy consumed. This is relative because of the pretreatment variations and supply pumping requirements. Now for achieving the required energy per unit of permeates output, we should calculate the specific energy consumption of the project (SEC). For attaining the specific energy consumption of the project, the total energy requirement should be divided by the project permeate flow rate (550 m3/hr per train).

Therefore the SEC of scenario I (without energy recovery device) is calculated by dividing 1590 KWh/hr energy requirement per train by the permeate flow rate (550 m3/hr) per train which results in a specific energy consumption of around 2.89 KWh/m3 for each train. For scenario II (with energy recovery device) the specific energy consumption is approximately 2.69 KWh/m3 per train. This amount is the result of dividing 1480.09 KWh/hr energy requirements per train by the permeate flow rate (550 M3/hr per train). As you can see, by installing an energy recovery device, a 0.20 KWh/hr energy saving for each train will reduce the energy consumption cost. The results for the energy consumption of both two scenarios are illustrated below:

Table 4: Specific Energy Consumption without ERDs

Electricity Consumption: scenario I		
Energy requirement	1590.48	(KW/hr.)
Permeate Flow Rate	550	m3/hr.
SEC Before ERD	2.89	kWh/m3

Table 5: Specific Energy Consumption with ERDs

Electricity Consumption: scenario II		
Energy requirement	1480.09	(KW/hr.)
Permeate Flow Rate	550	m3/hr.
SEC After ERD	2.69	kWh/m3

4.4 Levelized Cost of Production

The primary metric of the financial performance is the levelized cost of water (LCOW). Levelized cost is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt hour cost (in real dollars) of water over an assumed financial life of the project.

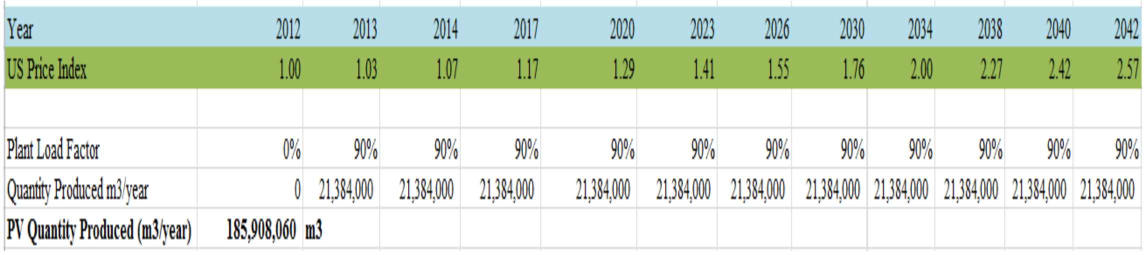
LCOW (levelized cost of water) is the constant unit cost (per kWh or MWh) of a payment stream that has the same present value as the total cost of a generating plant over its life.

4.4.1 Levelized Cost Scenario I (without ERDs)

For each scenario in our project, we calculated the levelized cost of water production and we expected that in scenario II (with energy recovery device) this cost would be reduced due to cost reduction of energy consumption which is the main part of operating cost. In the following tables the calculation of unit total cost of production and unit variable cost of production are illustrated. For calculating the unit total cost of production, the present value of the total cost of the project should be divided by the present value of quantity produced.

To calculate the unit variable cost of production the present value of the variable cost should be divided by the present value quantity produced. For scenario I (without energy recovery device) in the following table we calculated the quantity produced by the plant with the plant load factor of 90% (this percentage is one of the project assumptions). The quantity produced is estimated by multiplying the plant load factor by the yearly project design capacity which is 23,760,000 m3/year. Therefore the quantity produced by our plant is 21,384,000 m3/year. For calculating the levelized cost of production we need the present value of the quantity produced, which the PV of quantity produced with 11% expected rate of return is approximately 185,000,000 m3/year.

Table 6: Quantity Produced, Scenario I



Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Plant Load Factor	0%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Quantity Produced m3/year	0	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000
PV Quantity Produced (m3/year)	**185,908,060**	**m3**										

The second step for calculating levelized cost of production is estimating the present value of the total cost and the present value of the variable cost of the project. In the following table the yearly total and variable costs of the project for scenario I (without energy recovery device) are shown. It can be seen in the year 2012 Scenario I has approximately 66,000,000 U.S. $ investment cost and in following years from 2013-2042 it has an approximate yearly operating cost between 19 -20 million U.S $ (in real terms).

For calculating the present value of total cost we considered the years 2012-2042. The PV at an 11% expected rate of return for operating cost of each year from 2013-2042 will add to the investment cost of year 2012. The PV of the total cost for scenario I (without ERDs) is approximately 236 million U.S. $. It should be mentioned that for calculating the present value of the variable cost for scenario I which is approximately 169 million U.S $, the operating cost of the project from 2013-2042 will be considered and the investment cost will not be included. In following tables you can see that the amount of the unit total cost of production is around 1.2677 $ /m3 and the variable unit cost of production is around 0.91 $/m3 (PV cost divided by PV quantity). The calculation of the levelized cost of production for scenario I (plant with daily capacity of 66,000 m3/day, without energy recovery device) is illustrated below:

Table 7: Total Cost of Project (Scenario I)

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Expenditures												
Investment Cost:												
Land	1,195,097	0	0	0	0	0	0	0	0	0	0	(1,195,097.49)
Building (Including Labor During Construction)	41,482,583	0	0	0	0	0	0	0	0	0	0	(6,503,399.79)
Machinery & Equipment	16,130,000	0	0	0	0	0	0	0	0	0	0	(581,395)
Professional services	6,633,845	0	0	0	0	0	0	0	0	0	0	0
Total fees	1,500,000	0	0	0	0	0	0	0	0	0	0	0
Total Investment Cost	**66,941,525**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**(8,279,893)**
Operating Cost:												
Electricity power cost	0	10,306,305	10,357,836	10,513,982	10,672,482	10,833,371	10,996,685	11,218,274	11,444,328	11,674,937	11,791,978	11,910,192
Chemical Dosage	0	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600
Labor	0	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000
Membrane replacement cost	0	0	0	25000	0	0	0	0	0	0	0	25,000
Cartridge filter cost	0	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Operation Insurance cost	0	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Inlet system chemicals USD	0	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Pump mtce/replacement USD	0	0	0	0	0	0	0	0	0	0	0	25,000
Administration USD	0	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000
Management fee USD	0	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891
External support USD	0	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112
Solids disposal USD	0	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
Water quality monitoring	0	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Spare Part Cost U.S/YEAR	0	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708
Downtime Operating Maintenance Cost USD/Year	0	40,080	40,280	40,888	41,504	42,130	42,765	43,627	44,506	45,403	45,858	46,317
Total Operating cost	**0**	**19,132,696**	**19,184,428**	**19,366,180**	**19,500,296**	**19,661,811**	**19,825,761**	**20,048,211**	**20,275,144**	**20,506,650**	**20,624,146**	**20,792,820**
Change in accounts payables	0	(515,315)	(18,555)	(18,835)	(19,119)	(19,407)	(19,700)	(20,097)	(20,502)	(20,915)	(21,125)	(21,336)
Change in cash balance	0	(229,200)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)
Total Cash Outflow (-)	**66,941,525**	**18,388,180**	**19,158,765**	**19,340,238**	**19,474,070**	**19,635,297**	**19,798,954**	**20,021,007**	**20,247,535**	**20,478,628**	**20,595,915**	**12,484,485**

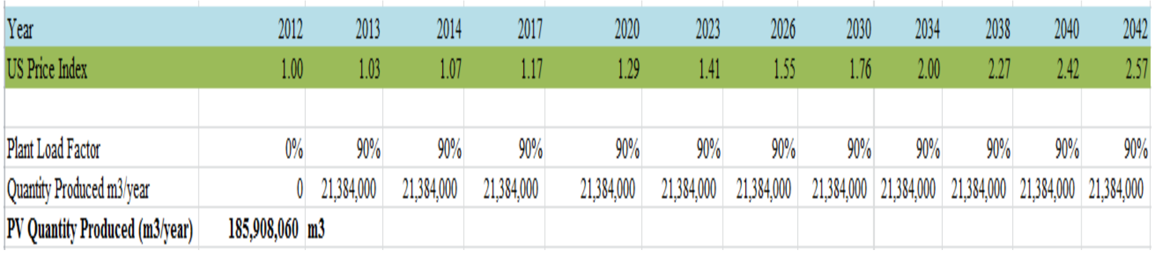
Table 8: Levelized Cost Calculation (Scenario I)

PV Quantity Produced	**185,908,060**
PV of Total Cost (real)	**235,668,912**
Real Unit Total Cost of Production (PV Cost/ PV quantity)	**$1.2677**
PV Quantity Produced	**185,908,060**
PV of variable cost (real)	**168,727,387**
Unit variable cost of production	**$0.91**

4.4.2 levelized Cost Scenario II (with ERDs)

For calculating the levelized cost of production in scenario II (with energy recovery device), it should be mentioned that the PV quantity produced is as same as scenario I (approximately 185,000,000 m3/year), because the load factor is the same (90%) and the design capacity of plant is also as the same as scenario I (23,760,000 m3/year). The following table shows the results:

Table 9: Quantity Produced, Scenario II



Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Plant Load Factor	0%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Quantity Produced m3/year	0	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000	21,384,000
PV Quantity Produced (m3/year)	**185,908,060**	**m3**										

For calculating the present value of the total cost and variable cost, the process is the same as scenario I. As you can see in following table, in year 2012 the investment cost of the project is approximately 72 million U.S $ which is more than in scenario I.

This difference is due to the installation cost of an energy recovery device in our project. But you can see that in following years 2013-2042 the average operating cost of the project is around 17 -19 million U.S$ /year. This amount is less than the average cost of operation in scenario I.

Table 10: Total Cost of Project (Scenario II)

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Revenues												
Gross Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Sales Tax	0	0	0	0	0	0	0	0	0	0	0	0
Net Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41580000	41580000	41580000
Change in accounts receivables	0	(7,484,400)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)
Asset Liquidation receipts (Residual):												
Land	0	0	0	0	0	0	0	0	0	0	0	
Building	0	0	0	0	0	0	0	0	0	0	0	
Total cash Inflow (+)	**0**	**34,095,600**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**
Expenditures												
Investment Cost:												
Land	1,195,097	0	0	0	0	0	0	0	0	0	0	(1,195,097)
Building (Including Labor During Construction)	41,482,583	0	0	0	0	0	0	0	0	0	0	(6,503,400)
PX Pressure Exchanger® Energy Recovery Device	2,100,000	0	0	0	0	0	0	0	0	0	0	0
Machinery & Equipment	18,880,000	0	0	0	0	0	0	0	0	0	0	(581,395)
Professional services	7,167,345	0	0	0	0	0	0	0	0	0	0	0
Total fees	1,500,000	0	0	0	0	0	0	0	0	0	0	0
Total Investment Cost	**72,325,025**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**(8,279,892.63)**
Operating Cost:												
Electricity power cost	0	9,590,960	9,638,915	9,784,223	9,931,721	10,081,443	10,233,422	10,439,631	10,649,995	10,864,598	10,973,515	11,083,525
Chemical Dosage	0	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600
Labor	0	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000
Membrane replacement cost	0	0	0	25000	0	0	0	0	0	0	0	25,000
Cartridge filter cost	0	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Operation Insurance cost	0	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Inlet system chemicals USD	0	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Pump mtce/replacement USD	0	0	0	0	0	0	0	0	0	0	0	25,000
Administration USD	0	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000
Management fee USD	0	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891
External support USD	0	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112
Solids disposal USD	0	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
Water quality monitoring	0	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Spare Part Cost U.S/YEAR	0	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625
Downtime Operating Maintenance Cost USD/Year	0	37,298	37,485	38,050	38,623	39,206	39,797	40,599	41,417	42,251	42,675	43,103
Total Operating cost	**0**	**18,441,487**	**18,489,628**	**18,660,501**	**18,783,573**	**18,933,877**	**19,086,447**	**19,293,458**	**19,504,640**	**19,720,077**	**19,829,418**	**19,989,855**
Change in accounts payables	0	(479,548)	(17,267)	(17,528)	(17,792)	(18,060)	(18,332)	(18,702)	(19,079)	(19,463)	(19,658)	(19,855)
Change in cash balance	0	(229,200)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)
Total Cash Outflow (-)	**72,325,025**	**17,732,739**	**18,465,254**	**18,635,866**	**18,758,674**	**18,908,710**	**19,061,008**	**19,267,649**	**19,478,454**	**19,693,507**	**19,802,653**	**11,683,000**

In scenario II (with ERDs), the present value of total cost, like scenario I, is calculated by taking the PV of the operating cost from 2013-2042 plus the investment cost of year 2012. The result will be approximately 235 million U.S$. For calculating the variable cost the investment cost will be eliminated. Thus the PV of operating costs from 2013-2042 with an 11% rate of return will be considered (around 162 million U.S$). The following table shows the total and variable cost of production for scenario II (plant capacity of 66,000 m3/day):

Table 11: Levelized Cost Calculation (Scenario II)

PV Quantity Produced	**185,908,060**
PV of Total Cost (real)	**234,836,763**
Real Unit Total Cost of Production (PV Cost/ PV quantity)	**$1.2632**
PV Quantity Produced	**185,908,060**
PV of variable cost (real)	**162,511,737**
Unit variable cost of production	**$0.87**

Computing the levelized cost of water for product is an important calculation when setting water sale price. It gives you a benchmark for the selling price of water, so you can sell your product to cover your costs.

It is explained above that key inputs to calculating levelized costs include capital costs, power costs and fixed and variable operations and maintenance (O&M) costs. In this project as can be seen in table 11, the total cost of production in scenario II (with ERDs) was reduced from 1.2677 $/m3 to 1.2632 $/m3. Also, the unit variable cost of production decreased from 0.91 $/m3 to 0.87$/m3.

This reduction in the unit cost of production is due to installation of energy recovery devices which decrease the energy consumption of the project. Energy consumption cost is the main factor in the operating cost of desalination plants, therefore when it decreases, the total operating cost of the project for scenario II (with ERDs) will be decreased and the levelized cost of water also will be reduced. This means that for scenario I (without ERDs) the minimum price of water which must be sold to cover project costs is 1.2677 $/m3 and in scenario II it decreases to 1.2632 $/m3 because the cost of project is less than scenario I. So with lower water price, it is still possible to cover project costs.

4.5 Sensitivity Analysis

Sensitivity analysis was performed to assess how the LCOW may change with the variations of different input parameters. The analysis is important for specifying the inputs that have the most effect on the LCOW. The analysis was conducted for two types of inputs: specific energy consumption and electricity tariffs.

4.5.1 Specific Energy Consumption

One of the critical factors in determination of the unit cost of production is project energy requirement. A plant with a higher energy requirement has a higher unit cost. It has been explained before that the specific energy consumption of scenario I (without ERDs) is 2.89 KWh/m3 per train for a plant with design capacity of 66,000 m3/day. This amount in scenario II (with ERDs) is decreased to 2.69 KWh/m3 per train, due to the energy savings of installing an energy recovery device.

In following tables, financial sensitivity of specific energy consumption on the unit cost of project at **0.15 U.S$ /m3 electricity tariff** for both scenarios are illustrated:

Table 12: Sensitivity of LCOW to SEC (with electricity tariffs 0.15$)

	Without ERDs	Unit Total Cost	Unit variable cost of production
		$1.27	$0.91
	1.00	0.94	0.58
	1.50	1.03	0.67
Specefic Energy consumption (SEC)	2.00	1.12	0.76
	2.59	1.22	0.86
	2.69	1.23	0.87
Electricity Tariff (0.15$)	**2.89**	**1.27**	**0.91**
	3.00	1.29	0.93
	3.50	1.37	1.01
	4.00	1.46	1.10
	4.50	1.55	1.19
	5.00	1.63	1.27
	5.50	1.72	1.36
	6.00	1.81	1.45
	6.50	1.89	1.53
	7.00	1.98	1.62
	7.50	2.07	1.71

	With ERDs	Unit Total Cost	Unit variable cost of production
		$1.26	$0.87
	1.00	0.97	0.58
	1.50	1.06	0.67
Specefic Energy consumption (SEC)	2.00	1.14	0.75
	2.59	1.25	0.86
Electricity Tariff (0.15$)	**2.69**	**1.26**	**0.87**
	2.89	1.30	0.91
	3.00	1.32	0.93
	3.50	1.40	1.01
	4.00	1.49	1.10
	4.50	1.58	1.19
	5.00	1.66	1.27
	5.50	1.75	1.36
	6.00	1.84	1.45
	6.50	1.92	1.53
	7.00	2.01	1.62
	7.50	2.09	1.71

The sensitivity analysis in table 9 is intended to show how a percentage change in a specific energy consumption (with electricity tariffs 0.15 U.S$/M3) changed the LCOW of project. As it is seen in this table, there is a direct relationship between SEC and the unit total cost of production and the unit variable cost of production. However, any change in SEC affects the unit variable's cost of production more than the unit total cost of production.

For example, in scenario I (without ERDs), when the SEC decreased by 7 % (from 2.89 KWh/m3 to 2.69 KWh/m3), the reduction in the unit variable cost of production is 4.4% (from 0.91 KWh/m3 to 0.87 KWh/m3) and the unit total cost of production decreased 3.2% (from 1.27 KWh/m3 to 1.23 KWh/m3). In scenario II (with ERDs), by a 3.72% reduction in SEC (from 2.69 KWh/m3 to 2.59 KWh/m3), the unit total cost is reduced by 0.8% and the unit variable cost of production is decreased by 1.15%.

In this section, the financial sensitivity of specific energy consumption on the unit cost of production of the project at **0.10 U.S$/m3 electricity tariff for** both scenarios is illustrated:

You can see in following table that, in scenario I (without ERDs) by 33% reduction in the electricity tariff (from 0.15 $/m3 to 0.10 $/m3), the unit **total cost of production** decreased almost 13% ((from **1.2677 $/m3** (with electricity tariff **0.15$/m3**) to **1.10 $/m3** (electricity tariff: **0.10$/m3**)). This reduction also occurred in the **unit variable cost of production** by 18 % ((reduction from **0.91 $/m3** (with electricity tariff: **0.15 $/m3**) to **0.74$/m3** (with electricity **tariff 0.10$/m3**)).

Table 13: Sensitivity of LCOW to SEC (with electricity tariffs 0.10$)

	Without ERDs	Unit Total Cost	Unit variable cost of production
		$1.10	$0.74
	1.00	0.89	0.52
	1.50	0.94	0.58
Specefic Energy consumption (SEC)	2.00	1.00	0.64
	2.59	1.07	0.71
	2.69	1.08	0.72
Electricity Tariff (0.10$)	**2.89**	**1.10**	**0.74**
	3.00	1.12	0.76
	3.50	1.17	0.81
	4.00	1.23	0.87
	4.50	1.29	0.93
	5.00	1.35	0.99
	5.50	1.40	1.04
	6.00	1.46	1.10
	6.50	1.52	1.16
	7.00	1.58	1.22
	7.50	1.63	1.27

	With ERDs	Unit Total Cost	Unit variable cost of production
		$1.11	$0.72
	1.00	0.91	0.52
	1.50	0.97	0.58
Specefic Energy consumption (SEC)	2.00	1.03	0.64
	2.59	1.10	0.71
Electricity Tariff (0.10$)	**2.69**	**1.11**	**0.72**
	2.89	1.13	0.74
	3.00	1.14	0.75
	3.50	1.20	0.81
	4.00	1.26	0.87
	4.50	1.32	0.93
	5.00	1.37	0.99
	5.50	1.43	1.04
	6.00	1.49	1.10
	6.50	1.55	1.16
	7.00	1.60	1.22
	7.50	1.66	1.27

You can see above that, in scenario II (with ERDs), by reducing the electricity tariff from 0.15 $/m3 to 0.10 $/m3, the unit **total cost of production** decreased from **1.2632 $/m3** (with electricity tariff **0.15$/m3**) to **1.11 $/m3** (electricity tariff: **0.10$/m3**).

This reduction also occurred in the **unit variable cost of production**. The unit variable cost of production in scenario II (with ERDs) was reduced from **0.87 $/m3** (with electricity tariff: **0.15 $/m3**) to **0.72$/m3** (with electricity **tariff 0.10$/m3**).

4.5.2 Electricity Tariff: Electricity cost is also one of the critical inputs of the project that have a considerable effect on the financial viability of the project. In this project the base case electricity cost is 0.15 US$/m3. In following tables we want to examine the effect of electricity tariffs on the unit cost of production for scenario I (without ERDs) with SEC of 2.89 KWh/m3 and scenario II (with ERDs) with SEC of 2.69 Kwh/m3 for plant with design capacity of 66,000 m3/day.

Table 14: Sensitivity of LCOW to Electricity Tariff

	Without ERDs	Unit Total Cost	Unit variable cost of production
		1.27	$0.91
	0.06	0.97	0.61
	0.07	1.00	0.64
Industrial electricity tariff $ per kWh	0.08	1.04	0.68
	0.10	1.10	0.74
	0.12	1.17	0.81
(SEC 2.89 KWh/m3)	**0.15**	**1.27**	**0.91**
	0.16	1.30	0.94
	0.18	1.37	1.01
	0.20	1.44	1.08
	0.22	1.50	1.14
	0.24	1.57	1.21
	0.26	1.64	1.28
	0.28	1.70	1.34
	0.29	1.74	1.38
	0.30	1.77	1.41

	With ERDs	Unit Total Cost	Unit variable cost of production
		1.26	0.87
	0.06	0.98	0.60
	0.07	1.02	0.63
Industrial electricity tariff $ per kWh	0.08	1.05	0.66
	0.10	1.11	0.72
	0.12	1.17	0.78
(SEC 2.69 KWh/m3)	**0.15**	**1.26**	**0.87**
	0.16	1.29	0.91
	0.18	1.36	0.97
	0.20	1.42	1.03
	0.22	1.48	1.09
	0.24	1.54	1.15
	0.26	1.60	1.22
	0.28	1.67	1.28
	0.29	1.70	1.31
	0.30	1.73	1.34

4.6 The PX Pressure Exchanger Cost Saving

It should be mentioned that in the operating cost section, due to installation of an energy recovery device in the desalination plant, the energy requirement as well as energy consumption cost will be reduced. Since the cost of energy consumption is one of the important cost factors of the operating cost of desalination, by reducing the cost of energy consumption, the operating cost will decrease. This will reduce the whole desalination plant cost. It should be stated that the specific energy consumption (SEC) of scenario I (without ERDs) is 2.89 KWh/m3 per train, while this amount in scenario II (the project with energy recovery device) is decreased to 2.69 KWh/m3 per train. It is obvious that by utilizing the energy recovery device in scenario II (with ERDs) 0.20 KWh/m3 is saved. This means that for our project with a design capacity of approximately 23 million m3/year, the amount of energy savings per year will be calculated by multiplying 0.20 KWh/m3 energy savings by the yearly plant capacity (23,760,000m3/year).

The amount of energy savings for our project will be 4,768,963 KWh/m3/year. To calculate the energy cost savings of our project with ERDs, the amount of energy savings per year will be multiplied by the electricity tariff (which is 0.15 U.S$/m3). Therefore, as you can see in the following table, the amount of Px energy cost savings for our project is around 715,344 U.S$/year.

Table 15: PX Energy Saving

Energy Saving Per kwh/m3 Total	**0.20**
Energy Saving kwh/m3/year (5 trains)	**4,768,963**
Energy Cost Saving , 5 train/year	**715,344**

For evaluating PX operating cost savings, we should compare the PV of the operating cost of project for both scenarios. In the following tables you can see the operating cost savings of the project due to the energy recovery device:

Table 16: Total OPEX (Both Scenarios)

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
YEARLY TOTAL OPEX U.S Real (Scenario I)	0	19,132,696	19,184,428	19,366,180	19,500,296	19,661,811	19,825,761	20,048,211	20,275,144	20,506,650	20,624,146	20,792,820
YEARLY TOTAL OPEX U.S Real (Scenario II)	0	18,441,487	18,489,628	18,660,501	18,783,573	18,933,877	19,086,447	19,293,458	19,504,640	19,720,077	19,829,418	19,989,855

Table 17: PX Total Operating Cost Saving

PV total operating cost without ERD	**$169,965,478**
PV total operating cost with ERD	**$163,707,175**
Operating cost saving during life of project	**$6,258,303**

As you see, the PV of the total real operating cost of scenario I (without ERDs) is 169,965,478 U.S$, and the PV of total operating cost of scenario II (with ERDs) is 163,707,175 U.S$. The results show that with installation of ERDs for our project we will have approximately 6 million dollars operating cost savings during the life of the project per train.

4.7 Financial Simulation Results

We estimated that the LCOW for the base case scenario (desalination plant without ERDs) is 1.2677 $/m3 and the LCOW for the incentive scenario (desalination plant with ERDs) is 1.2632$/m3. It is obvious that this reduction of LCOW is possible by decreasing the specific energy consumption of the plant. This SEC reduction (2.89 KWh/m3 for scenario I to 2.69 KWh/m3 for scenario II) results from the utilization of the energy recovery device in the operation of the plant. As previously mentioned, by utilizing the energy recovery device, the specific energy consumption and levelized cost of production as well as the operating cost of the plant will decrease. In our project we decided to use scenario II (with ERDs) in order to take advantage of the energy recovery device in energy and cost savings of the plant. It should be mentioned that the estimated total investment cost for this project with an energy recovery device is higher than that of the project without an energy recovery device. However, the analysis shows that the reduced cost of energy consumption, which is the main part of the operating cost of the desalination process, will considerably reduce the unit variable cost of production. The money saved by utilizing this device through energy savings will cover the increased investment cost.

Chapter 5

NET PRESENT VALUE AND FINANCING SCENARIOS

The first component of integrated analysis of this project is the financial analysis, which is used to determine the financial feasibility and sustainability of the project. The significant outputs from this section (financial analysis part) are the total and variable levelized cost of water, the debt service capacity ratio for scenario II (with ERDs) and the sensitivity analysis. In this section the cash flow statement from the banker's point of view and the owner's point of view for scenario II is also included.

5.1 Assumptions and Specifications

Gathering the financial parameters required some assumptions in order to analyze the future expected cash flows.

Timing of the Project: The project life is 30 years which starts in 2012. After the construction work, estimated to be completed in 2013, the desalination plant operations will start immediately. 360 full operation days (8640 hours/year) annually are assumed for the analysis.

Working Capital: Accounts payable is 5% of the total cost of electricity and the desired cash balance is equal to 20% of the total labor cost. Accounts receivable makes up 18% of the sale revenue.

Taxes and Inflation Rates: In this project the import and corporate tax are zero and for easy calculation value-added tax is also assumed to be zero as well as personal income tax. The US inflation rate in this study is 3% in 2011, while the domestic (Turkish) inflation rate is 8% .The initial US$ exchange rate is taken at 1.8 TL/US$. For obtaining a nominal exchange rate, all essential adjustments for relative inflations are made yearly.

Depreciation: For the depreciation of the project equipment, the straight line method is applied. The expected useful life of the project building is 50 years while the pumps should be replaced every 15 years and the membranes' useful life is approximately 5 years (20% replacement rate). The filters should be replaced at the end of each operating year. It should be mentioned that the useful life of the energy recovery device (PX 260) for scenario II is approximately 25 years.

Interest on Loan: To obtain this study purpose, to calculate real interest rate on the loan, the Turkish risk premium is used[1]. The nominal interest rate which is charged on the loan in this study is 9.84 %[2]. The loan repayment period is 10 years.

In Appendix 1 you can see the parameter table in the project model that is predicted for both scenarios.

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[1] This is depending on the assumption that it is a Turkish business that undertakes this project. The risk premium would change according the country of the enterprise borrowing the funds.

[2] "This rate is obtained by adding Risk Premium of turkey (4%, source: www.finnvera.fi) to an assumed project specific risk of 2.3% (to obtain the real interest rate) and then adjusting it for inflation using the following formula:
Nominal Interest Rate = Real Interest Rate + (Real Interest Rate*US Inflation) + US Inflation

5.2 Project Cost and Financing

The estimated total investment cost for scenario II (with ERDs) it is almost 72,325,025 US$. These costs are associated with a plant which is designed for capacity of 66000 m3/days with 5 RO (reverse osmosis) trains, and the project life is 30 years. Table 18 represents the investment cost components for scenario II (with energy recovery device). It is obvious that in scenario II the total investment cost is more than in scenario I because of the energy recovery device installation. But it should be mentioned that in the following part the results show that the cost of energy consumption, which is the main cost of the desalination process, will be considerably reduced and the remaining capital can cover this increase of the investment cost. The following Table represents the estimated cost of the various components in calculating the total investment cost of the project.

Table 18: Project Cost for Scenario II (with ERDs)

Investment Costs	**With ERD**
Land Cost	1,195,097
Buildings, plant & equipment cost	39,836,583
Total fees	1,500,000
Equipment (pumps cost, RO membranes, membrane cleaning system, cartridge filter)	18,880,000
LABOR COST (during construction)/USD	1,646,000
PROFESSIONAL SERVICES (% of capital cost)	7,398,345
PX Pressure Exchanger® Energy Recovery Device	2,100,000
TOTAL	**72,325,025**

5.3 Operating and Maintenance Cost:

In this project with the capacity of 23,760,000 m3 per year, the amount of total yearly OPEX for both scenarios are shown below, approximately 700,000 U.S dollar difference between them. Thus, scenario II (with ERDs) has 700,000 U.S $ reduction in its operational costs each year due to the installation of ERDs. Energy cost is one of the most important factors in the operating costs of desalination plants, that can reduced by the installation of energy recovery devices in desalination plants. The average energy consumption savings for plants after applying an energy recovery device is approximately 700,000 U.S$ per year (nearly equal to the operating cost savings per year) and around 6 million US$ energy cost savings during the life of project (30 years) for the entire desalination system in this project.

This reduction in energy consumption also has a considerable effect on the operating costs of the project, approximately 700,000 US$ reduction in average operating costs. This means that there will be around 6 million US$ operational cost savings for the plant during the project. It is obvious that the amount of savings in the energy part and the operating cost part are not exactly the same. This difference is due to some costs of the energy recovery device installation that makes the energy savings a little more than the operating cost savings. The results for both scenarios are illustrated in following table:

Table 19: Operating and Maintenance Cost of Both Scenarios

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
Yealy Total OPEX U.S$ (Scenario I) Real	**0**	**19,132,696**	**19,184,428**	**19,366,180**	**19,500,296**	**19,661,811**	**19,825,761**	**20,048,211**	**20,275,144**	**20,506,650**	**20,624,146**	**20,792,820**
Yearly Total OPEX U.S$ (Scenario II) Real	**0**	**18,441,487**	**18,489,628**	**18,660,501**	**18,783,573**	**18,933,877**	**19,086,447**	**19,293,458**	**19,504,640**	**19,720,077**	**19,829,418**	**19,989,855**
Total Opex Saving	0	691,208.78	694,799.41	705,679.38	716,723.37	727,933.85	739,313.33	754,753.26	770,504.32	786,572.77	794,728.01	802,965.00
Average Saving/Year		**745,787**										
NPV Opex Saving (During Life of Project)		**$6,258,303.05**										
Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
Total Energy Cost USD (Scenario I) Real		**10,306,305**	**10,357,836**	**10,513,982**	**10,672,482**	**10,833,371**	**10,996,685**	**11,218,274**	**11,444,328**	**11,674,937**	**11,791,978**	**11,910,192**
Total Energy Cost USD (Scenario II) Real		**9,590,960**	**9,638,915**	**9,784,223**	**9,931,721**	**10,081,443**	**10,233,422**	**10,439,631**	**10,649,995**	**10,864,598**	**10,973,515**	**11,083,525**
Total Energy Cost Saving		**715,344**	**718,921**	**729,759**	**740,760**	**751,927**	**763,263**	**778,643**	**794,333**	**810,339**	**818,463**	**826,668**
Average Energy Cost Saving		**769,711**										
NPV of Energy Cost Saving During the Life of Project		**$6,467,168.12**										

5.4 Cash Flow Results:

An important source of information about the project’s cash flow is its cash flow statement, a central part of the financial analysis. When the project’s financial cash flow statement is completed, its potential viability can be assessed. The financial cash flow statements change among different points of view. In this study we applied the cash flow statement from the banker’s and owner’s points of view. In the banker’s point of view the banker would like to know if the net cash flow is sufficient to repay the loans from different financing arrangements. This starting point for a credit analysis is the net cash flow from the total investment. The Debt Service Capacity Ratio is used to provide this information for the bankers. The cash flow statement from owner’s point of view is applicable since the owner of a project examines the incremental net cash flow from the investment relative to what could have been earned in the absence of the project and evaluates the financial feasibility of project while considering financial present value of project (Arnold C. Harberger, 2010).

Present Value (PV): Present Value (PV) is the sum of all years’ discounted after-tax cash flows. The PV method is a valuable indicator because it recognizes the time value of money. Projects whose returns show positive PVs are attractive.

Debt Service Coverage Ratio (DSCR*):* Ratio of net operating income to total debt service (Installments). Financiers will require that a project meet a minimum debt service coverage ratio (DSCR) of 1.5-2.0.

5.4.1 Scenario II (with Energy Recovery Device)

In this scenario, two cash flow statements from the owner’s and the banker’s points of view are utilized to evaluate the feasibility of the project from both points of views.

5.4.1.1 Cash Flow Statement (Banker’s Point of View)

As mentioned before, by using the cash flow statement from investment (banker’s) point of view, the debt service capacity ratio can be generated. For evaluating debt service capacity ratio as one of the key factors in evaluating the project ability to pay its operating expense and evaluating the financial viability of project, we should divide present value (PV) of annual net cash flow by PV of annual debt repayment. Cash flow statement of banker’s point of view and loan schedule tables of scenario II is illustrate bellow:

Table 20: Cash Flow Statement, Banker’s Point of View, (Scenario II)

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Revenues												
Gross Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Sales Tax	0	0	0	0	0	0	0	0	0	0	0	0
Net Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41580000	41580000	41580000
Change in accounts receivables	0	(7,484,400)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)
Asset Liquidation receipts (Residual):												
Land	0	0	0	0	0	0	0	0	0	0	0	
Building	0	0	0	0	0	0	0	0	0	0	0	
Total cash Inflow (+)	**0**	**34,095,600**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**
Expenditures												
Investment Cost:												
Land	1,195,097	0	0	0	0	0	0	0	0	0	0	(1,195,097)
Building (Including Labor During Construction)	41,482,583	0	0	0	0	0	0	0	0	0	0	(6,503,400)
PX Pressure Exchanger® Energy Recovery Device	2,100,000	0	0	0	0	0	0	0	0	0	0	0
Machinery & Equipment	18,880,000	0	0	0	0	0	0	0	0	0	0	(581,395)
Professional services	7,167,345	0	0	0	0	0	0	0	0	0	0	0
Total fees	1,500,000	0	0	0	0	0	0	0	0	0	0	0
Total Investment Cost	**72,325,025**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**(8,279,892.63)**
Operating Cost:												
Electricity power cost	0	9,590,960	9,638,915	9,784,223	9,931,721	10,081,443	10,233,422	10,439,631	10,649,995	10,864,598	10,973,515	11,083,525
Chemical Dosage	0	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600
Labor	0	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000
Membrane replacement cost	0	0	0	25000	0	0	0	0	0	0	0	25,000
Cartridge filter cost	0	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Operation Insurance cost	0	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Inlet system chemicals USD	0	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Pump mtce/replacement USD	0	0	0	0	0	0	0	0	0	0	0	25,000
Administration USD	0	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000
Management fee USD	0	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891
External support USD	0	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112
Solids disposal USD	0	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
Water quality monitoring	0	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Spare Part Cost U.S/YEAR	0	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625
Downtime Operating Maintenance Cost USD/Year	0	37,298	37,485	38,050	38,623	39,206	39,797	40,599	41,417	42,251	42,675	43,103
Total Operating cost	**0**	**18,441,487**	**18,489,628**	**18,660,501**	**18,783,573**	**18,933,877**	**19,086,447**	**19,293,458**	**19,504,640**	**19,720,077**	**19,829,418**	**19,989,855**
Change in accounts payables	0	(479,548)	(17,267)	(17,528)	(17,792)	(18,060)	(18,332)	(18,702)	(19,079)	(19,463)	(19,658)	(19,855)
Change in cash balance	0	(229,200)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)
Total Cash Outflow (-)	**72,325,025**	**17,732,739**	**18,465,254**	**18,635,866**	**18,758,674**	**18,908,710**	**19,061,008**	**19,267,649**	**19,478,454**	**19,693,507**	**19,802,653**	**11,683,000**
Net Cash Flow (before Tax)	**(72,325,025)**	**16,362,861**	**22,882,672**	**22,712,059**	**22,589,251**	**22,439,215**	**22,286,918**	**22,080,277**	**21,869,472**	**21,654,419**	**21,545,273**	**29,664,925**
Corporate Tax	0	0	0	0	0	0	0	0	0	0	0	0
Real Net Cash Flow (after Tax)	**(72,325,025)**	**16,362,861**	**22,882,672**	**22,712,059**	**22,589,251**	**22,439,215**	**22,286,918**	**22,080,277**	**21,869,472**	**21,654,419**	**21,545,273**	**29,664,925**

Table 21: Annual Loan Repayment, Scenario II

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
US Price Index	1.00	1.03	1.07	1.10	1.13	1.17	1.21	1.25	1.29	1.33	1.37
Interest Rate	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%
Beginning debt		21,697,508	19,527,757	17,358,006	15,188,255	13,018,505	10,848,754	8,679,003	6,509,252	4,339,502	2,169,751
Loan Disbursements	21,697,508										
Interest accrued		2,134,115	1,920,703	1,707,292	1,493,880	1,280,469	1,067,057	853,646	640,234	426,823	213,411
Principal Repayment		2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76	2,169,750.76
Interest Paid		2,134,115	1,920,703	1,707,292	1,493,880	1,280,469	1,067,057	853,646	640,234	426,823	213,411
Total Annual Loan Repayment	**0.00**	**4,303,866**	**4,090,454**	**3,877,043**	**3,663,631**	**3,450,220**	**3,236,808**	**3,023,397**	**2,809,985**	**2,596,574**	**2,383,162**

The total loan repayment starts from 2013 -2022, because the loan with an interest rate of 9.84% should be repaid during 10 years (this is one of the project's assumptions). So during these years the amount of net cash flow should be enough to cover the loan disbursement. It is obvious that the amount of the total annual loan repayment of scenario II (with ERDs) is higher than scenario I. It should be mentioned that the loan amount of the project under both scenarios is assumed to be 30% of the total investment cost. So when the investment cost of scenario II due to buying energy recovery device is higher than scenario I (without energy recovery device), it is obvious that annual loan repayment of scenario II is more than that of scenario I. in this situation, the net cash flow of scenario II should also be more than scenario I to cover the higher annual loan repayment. As it shown above in the cash flow statement of scenario II, the amount of net cash flow for scenario II is also more than scenario I (you can see cash flow statement of scenario I in the Appendix). This increased amount of net cash flow is due to the reduced operating costs of scenario II. For evaluating the sufficiency of net cash flow of project to cover its liability, the debt service capacity ratio should be considered. In the following table you can see the ratio of debt capacity for scenario II (with ERDS):

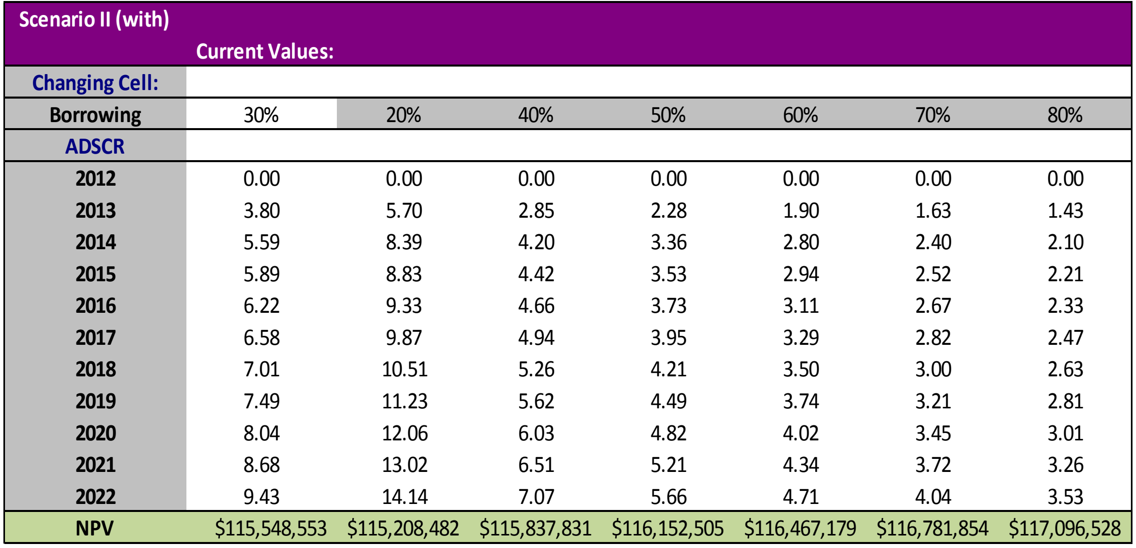
Table 22: Debt Capacity Ratio (scenario II)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Real Net Cash Flow (After Tax)	(72,325,025)	16,362,861	22,882,672	22,834,376	22,785,839	22,712,059	22,688,035	22,638,767	22,589,251	22,539,489	22,464,477
Annual Loan Repayment as an outflow (-)	0.00	4,303,866	4,090,454	3,877,043	3,663,631	3,450,220	3,236,808	3,023,397	2,809,985	2,596,574	2,383,162
Interest Rate (Real)	6.4%										
PV Annual Net Cash Flows (NCF)	**0**	**167,929,022**	**204,134,966**	**181,252,294**	**158,417,918**	**135,632,079**	**112,920,019**	**90,231,984**	**67,593,217**	**45,003,966**	**22,464,477**
PV Annual Debt Repayment	**0**	**26,502,242**	**29,131,273**	**25,040,819**	**21,163,777**	**17,500,146**	**14,049,926**	**10,813,118**	**7,789,721**	**4,979,736**	**2,383,162**
Annual Debt Service Coverage Ratios	**0**	**3.80**	**5.59**	**5.89**	**6.22**	**6.58**	**7.01**	**7.49**	**8.04**	**8.68**	**9.43**
Debt Service Capacity Ratio	**0**	**6.34**	**7.01**	**7.24**	**7.49**	**7.75**	**8.04**	**8.34**	**8.68**	**9.04**	**9.43**

In comparison with scenario I (you can see debt service capacity ratio for scenario I in the Appendix), in some years, the debt service capacity ratio of scenario II (with ERDs) is less than scenario II, but as a whole, the net cash flow of scenario II is sufficient to cover its liability.

It should be noted that the financial structure in this project is composed of 70% equity and 30% loan. This financial structure has an influence on the viability of the project. In table 23 the impact of different leverage rates on the financial NPV of the project and the ADSCR for scenario II (with ERDs) is illustrated:

Table 23: Impact of Different Leverage Rates on Project NPV and ADSCR (Scenario II)



Scenario II (with)							
	Current Values:						
Changing Cell:							
Borrowing	30%	20%	40%	50%	60%	70%	80%
ADSCR							
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	3.80	5.70	2.85	2.28	1.90	1.63	1.43
2014	5.59	8.39	4.20	3.36	2.80	2.40	2.10
2015	5.89	8.83	4.42	3.53	2.94	2.52	2.21
2016	6.22	9.33	4.66	3.73	3.11	2.67	2.33
2017	6.58	9.87	4.94	3.95	3.29	2.82	2.47
2018	7.01	10.51	5.26	4.21	3.50	3.00	2.63
2019	7.49	11.23	5.62	4.49	3.74	3.21	2.81
2020	8.04	12.06	6.03	4.82	4.02	3.45	3.01
2021	8.68	13.02	6.51	5.21	4.34	3.72	3.26
2022	9.43	14.14	7.07	5.66	4.71	4.04	3.53
NPV	$115,548,553	$115,208,482	$115,837,831	$116,152,505	$116,467,179	$116,781,854	$117,096,528

5.4.1.2 Cash Flow Statement (owner's point of view)

As mentioned before, each scenario includes two cash flow statements under banker's and owner's point of view. The result of the cash flow statement from the investment (banker's) point of view was explained in previous section. Now the result of cash flow statement from owner's point of view for scenario II (with energy recovery device) will be explained. The financial cash flow statements from the owner's point of view will be generated to evaluate the feasibility of the project while considering the financial NPV of the project for the owner of the project. It helps the owner to make a decision about accepting or rejecting the project. The cash flow statement from the owner's point of view for scenario II is illustrated in the following table:

Table 24: Cash Flow Statement, Owner’s Point of View, Scenario II

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Revenues												
Gross Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Sales Tax	0	0	0	0	0	0	0	0	0	0	0	0
Net Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Change in accounts receivables	0	(7,484,400)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)
Asset Liquidation receipts (Residual):												
Land	0	0	0	0	0	0	0	0	0	0	0	
Building	0	0	0	0	0	0	0	0	0	0	0	
Total cash Inflow (+)	**0**	**34,095,600**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**
Expenditures												
Investment Cost:												
Land	1,195,097	0	0	0	0	0	0	0	0	0	0	(1,195,097)
Building (Including Labor During Construction)	41,482,583	0	0	0	0	0	0	0	0	0	0	(6,503,400)
PX Pressure Exchanger® Energy Recovery Device	2,100,000	0	0	0	0	0	0	0	0	0	0	0
Machinery & Equipment	18,880,000	0	0	0	0	0	0	0	0	0	0	(581,395)
Professional services	7,167,345	0	0	0	0	0	0	0	0	0	0	0
Total fees	1,500,000	0	0	0	0	0	0	0	0	0	0	0
Total Investment Cost	**72,325,025**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**(8,279,893)**
Operating Cost:												
Electricity power cost	0	9,590,960	9,638,915	9,784,223	9,931,721	10,081,443	10,233,422	10,439,631	10,649,995	10,864,598	10,973,515	11,083,525
Chemical Dosage	0	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600
Labor	0	1,182,672	1,220,518	1,341,477	1,474,423	1,620,546	1,781,150	2,020,315	2,291,595	2,599,302	2,768,319	2,948,326
Membrane replacement cost	0	0	0	25,000	0	0	0	0	0	0	0	25,000
Cartridge filter cost	0	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Operation Insurance cost	0	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Inlet system chemicals USD	0	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Pump mtce/replacement USD	0	0	0	0	0	0	0	0	0	0	0	25,000
Administration USD	0	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000
Management fee USD	0	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891
External support USD	0	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112
Solids disposal USD	0	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
Water quality monitoring	0	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Spare Part Cost U.S/YEAR	0	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625	361,625
Downtime Operating Maintenance Cost USD/Year	0	37,298	37,485	38,050	38,623	39,206	39,797	40,599	41,417	42,251	42,675	43,103
Total Operating cost	**0**	**18,478,159**	**18,564,146**	**18,855,978**	**19,111,996**	**19,408,423**	**19,721,597**	**20,167,773**	**20,650,235**	**21,173,379**	**21,451,737**	**21,792,182**
Change in accounts payables	0	(479,548)	(17,267)	(17,528)	(17,792)	(18,060)	(18,332)	(18,702)	(19,079)	(19,463)	(19,658)	(19,855)
Change in cash balance	0	(229,200)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)
Total Cash Outflow (-)	**72,325,025**	**17,769,411**	**18,539,771**	**18,831,343**	**19,087,097**	**19,383,256**	**19,696,157**	**20,141,964**	**20,624,049**	**21,146,809**	**21,424,972**	**13,485,327**
Net Cash Flow (before Financing & Tax)	**(72,325,025)**	**16,326,189**	**22,808,154**	**22,516,583**	**22,260,828**	**21,964,670**	**21,651,768**	**21,205,961**	**20,723,876**	**20,201,117**	**19,922,954**	**27,862,599**
Financing												
Add Loan Disbursement	21,697,508	0	0	0	0	0	0	0	0	0	0	0
Less loan Repayment	0	4,303,866	4,090,454	3,450,220	2,809,985	0	0	0	0	0	0	0
Net cash Flow after Financing (before Tax)	**(50,627,518)**	**12,022,324**	**18,717,700**	**19,066,363**	**19,450,843**	**21,964,670**	**21,651,768**	**21,205,961**	**20,723,876**	**20,201,117**	**19,922,954**	**27,862,599**
Corporate Tax	0	0	0	0	0	0	0	0	0	0	0	0
Real Net Cash Flow	**(50,627,518)**	**12,022,324**	**18,717,700**	**19,066,363**	**19,450,843**	**21,964,670**	**21,651,768**	**21,205,961**	**20,723,876**	**20,201,117**	**19,922,954**	**27,862,599**
FNPV @ ROE:	11%	**$115,548,553**										
FIRR:		**34%**										

From the cash flow statement from the owner's point of view, we can see that the financial NPV of the project for scenario II at 11% expected rate of return is approximately 115 million U.S$. This is more than the financial NPV of scenario I (you can see the project's FNPV of scenario I in appendix). It is obvious that due to the installation of an energy recovery device, the FNPV of project increased, because the operating costs of the project decreased dramatically due to decreased energy consumption cost which is the main part of desalination costs.

5.5 Financial Sensitivity Analysis Results

To identify the variables' effects on the project's financial performance, we apply sensitivity analysis. Typically it is essential to emphasize only the uncertain variables that contribute to the riskiness of the project in a significant way. In this section we want to assess the effect of water sale tariff and cost overrun on the net present values of scenario II. The sensitivity analysis results are defined in following.

5.5.1 Water Tariff

The important point which should be considered during the evaluation of this project is that the water tariff is assumed to be 1.94 U.S$/m3 (this tariff is calculated from average of water tariffs around the world). Water tariffs, beside other variables, have a significant impact on the feasibility of the project. In the following table the impact of different water tariffs on the project's FNPV is illustrated:

Table 25: Sensitivity of Project NPV to Water Tariffs and Leverage Rate (with)

		Borrowing						
	NPV	20%	30%	40%	50%	60%	70%	80%
Water Tariff	1.94	115,233,879	115,548,553	115,863,228	116,177,902	116,492,576	116,807,251	117,121,925
	1.90	107,174,463	107,489,137	107,803,811	108,118,486	108,433,160	108,747,834	109,062,509
	1.80	89,040,776	89,355,450	89,670,125	89,984,799	90,299,473	90,614,148	90,928,822
	1.70	70,907,089	71,221,764	71,536,438	71,851,112	72,165,787	72,480,461	72,795,136
	1.60	52,773,403	53,088,077	53,402,751	53,717,426	54,032,100	54,346,775	54,661,449
	1.55	43,706,559	44,021,234	44,335,908	44,650,582	44,965,257	45,279,931	45,594,606
	1.50	34,639,716	34,954,390	35,269,065	35,583,739	35,898,414	36,213,088	36,527,762
	1.40	16,506,029	16,820,704	17,135,378	17,450,053	17,764,727	18,079,401	18,394,076
	1.30	(1,627,657)	(1,312,983)	(998,309)	(683,634)	(368,960)	(54,285)	260,389
	1.20	(19,761,344)	(19,446,670)	(19,131,995)	(18,817,321)	(18,502,646)	(18,187,972)	(17,873,298)

The results show that with increasing water tariffs, the NPV of the project at the 11% expected rate of return in scenario II will be improved (also you can see the sensitivity of the project's NPV to water tariffs and leverage rates for scenario I in appendix).

5.5.2 Cost Overrun

Beside various reasons, like technical deficiencies and mismanagement, cost over-run in the construction schedule of projects is one of the most important factors that can damage the project's performance. In the following table the significant effects of cost over-run on the project for scenario II (with ERDs) with a total investment cost of around 72 million U.S$ are illustrated:

Table 26: Sensitivity of project NPV to Cost Over-Run (with)

	With ERDs	NPV @ 11%
		$115,548,553
	0%	**115,548,553**
	5%	112,665,248
Cost Over-run (% of Total Investment cost)	10%	109,781,943
Total Investment Cost: 723,25,025	15%	106,898,639
	20%	104,015,334
	25%	101,132,029
	30%	98,248,724
	35%	95,365,419
	40%	92,482,114
	50%	86,715,504
	60%	80,948,895
	70%	75,182,285
	80%	69,415,675
	90%	63,649,066
	100%	57,882,456

You can see above, in scenario II (with ERDs) with increasing the cost overrun, the NPV of project which is one of the feasibility criteria, considerably decrease. These changes are due to an increase in the total investment cost of the project which simultaneously affects the NPV of the project (the sensitivity of project NPV to cost over-run for scenario I is explained in appendix 5-1).

5.6 CONCLUSION

In this study the levelized cost of water and the specific energy consumption of seawater reverse osmosis desalination were evaluated for the base case scenario (seawater reverse osmosis desalination plant without ERDs) and the incentive scenario (seawater reverse osmosis desalination plant with ERDs).

The specific energy consumption of the plant was estimated to be 2.89 KWH/M3 for the base case scenario and 2.69 KWh/m3 for the incentive scenario. This reduction in energy requirement of the desalination plant is due to the installation of an energy recovery device in this plant.

A remarkable reduction in the LCOW (from 1.2677 KWh/m3 to 1.2632 KWh/m3) of the proposed plant is also achievable by installation of an energy recovery device in the seawater reverse osmosis desalination plant.

The sensitivity analysis of the LCOW to specific energy consumption and electricity tariffs was also performed in this study to assess how the LCOW may change with the variations of different input parameters. Changes in a specific energy consumption (with electricity tariffs 0.15 U.S$/M3) will change the LCOW of project. There is also a direct relationship between the SEC and the unit total cost of production and unit variable cost of production. Electricity cost is also one of the critical inputs of the project that has a considerable effect on the financial viability of the project. By decreasing the electricity tariffs of the project, the levelized cost is also reduced and by increasing the electricity tariff this cost will also be increased.

It should be mentioned that by installing an energy recovery device, the energy requirements of desalination process will decrease in the plant and by this energy consumption cost reduction, the operating cost will decrease which reduces the whole desalination plant cost.

After choosing the second scenario (desalination plant with ERDs) for our project the financial analysis (for scenario II) from owner’s perspective and banker’s perspective were performed to determine the financial feasibility and sustainability of the project under this scenario. Although the investment cost of project with ERDs was higher than the project without ERDs, it was financially feasible due to higher total operating cost savings in the desalination plant and lower total unit cost of production and the variable cost of production.

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APPENDIX

Appendix 5-1: Cash Flow Results for Scenario I (without Energy Recovery Device)

A 5-1.1 Cash Flow Results

In this section we apply cash flow statement from banker's and owner's point of view for scenario I (without energy recovery device). In the banker's point of view the banker would like to know if the net cash flow is sufficient to repay the loans from different financing arrangements. To provide this information for bankers, the Debt Service Capacity Ratio is applied. The cash flow statement from owner's point of view is used to evaluate the financial feasibility of the project considering the financial PV of project.

A 5-1.1.1 Scenario I (without energy recovery device)

In this scenario just like scenario II, two cash flow statements from the owner's and the banker's point of view are used to evaluate the feasibility of the project from both point of view.

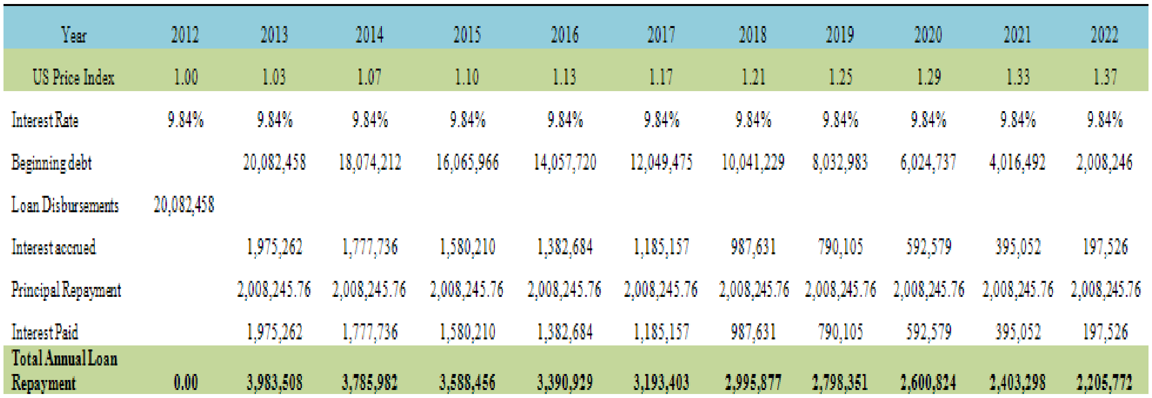
A 5-1.1.1.1 Cash Flow Statement (banker's point of view)

For evaluating the debt service capacity ratio in this scenario, we should use the cash flow statement (from banker's point of view, scenario I) and annual debt repayment (from loan schedule table of scenario I). Similar to scenario II, the present value (PV) of the net cash flow should be divided by the PV of annual debt repayment. The cash flow statement of banker's point of view and loan schedule tables of scenario I, is illustrated below:

Table 27: Cash flow statement, banker’s point of view, (Scenario I)

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Revenues												
Gross Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Sales Tax	0	0	0	0	0	0	0	0	0	0	0	0
Net Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41580000	41580000	41580000
Change in accounts receivables	0	(7,484,400)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)
Asset Liquidation receipts (Residual):												
Land	0	0	0	0	0	0	0	0	0	0	0	
Building	0	0	0	0	0	0	0	0	0	0	0	
Total cash Inflow (+)	**0**	**34,095,600**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**
Expenditures												
Investment Cost:												
Land	1,195,097	0	0	0	0	0	0	0	0	0	0	(1,195,097.49)
Building (Including Labor During Construction)	41,482,583	0	0	0	0	0	0	0	0	0	0	(6,503,399.79)
Machinery & Equipment	16,130,000	0	0	0	0	0	0	0	0	0	0	(581,395)
Professional services	6,633,845	0	0	0	0	0	0	0	0	0	0	0
Total fees	1,500,000	0	0	0	0	0	0	0	0	0	0	0
Total Investment Cost	**66,941,525**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**(8,279,893)**
Operating Cost:												
Electricity power cost	0	10,306,305	10,357,836	10,513,982	10,672,482	10,833,371	10,996,685	11,218,274	11,444,328	11,674,937	11,791,978	11,910,192
Chemical Dosage	0	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600
Labor	0	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000	1,146,000
Membrane replacement cost	0	0	0	25000	0	0	0	0	0	0	0	25,000
Cartridge filter cost	0	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Operation Insurance cost	0	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Inlet system chemicals USD	0	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Pump mtce/replacement USD	0	0	0	0	0	0	0	0	0	0	0	25,000
Administration USD	0	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000
Management fee USD	0	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891
External support USD	0	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112
Solids disposal USD	0	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
Water quality monitoring	0	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Spare Part Cost U.S/YEAR	0	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708
Downtime Operating Maintenance Cost USD/Year	0	40,080	40,280	40,888	41,504	42,130	42,765	43,627	44,506	45,403	45,858	46,317
Total Operating cost	**0**	**19,132,696**	**19,184,428**	**19,366,180**	**19,500,296**	**19,661,811**	**19,825,761**	**20,048,211**	**20,275,144**	**20,506,650**	**20,624,146**	**20,792,820**
Change in accounts payables	0	(515,315)	(18,555)	(18,835)	(19,119)	(19,407)	(19,700)	(20,097)	(20,502)	(20,915)	(21,125)	(21,336)
Change in cash balance	0	(229,200)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)
Total Cash Outflow (-)	**66,941,525**	**18,388,180**	**19,158,765**	**19,340,238**	**19,474,070**	**19,635,297**	**19,798,954**	**20,021,007**	**20,247,535**	**20,478,628**	**20,595,915**	**12,484,485**
Net Cash Flow (before Tax)	**(66,941,525)**	**15,707,420**	**22,189,160**	**22,007,687**	**21,873,855**	**21,712,629**	**21,548,972**	**21,326,918**	**21,100,390**	**20,869,298**	**20,752,011**	**28,863,441**
Corporate Tax	0	0	0	0	0	0	0	0	0	0	0	0
Real Net Cash Flow (after Tax)	**(66,941,525)**	**15,707,420**	**22,189,160**	**22,007,687**	**21,873,855**	**21,712,629**	**21,548,972**	**21,326,918**	**21,100,390**	**20,869,298**	**20,752,011**	**28,863,441**

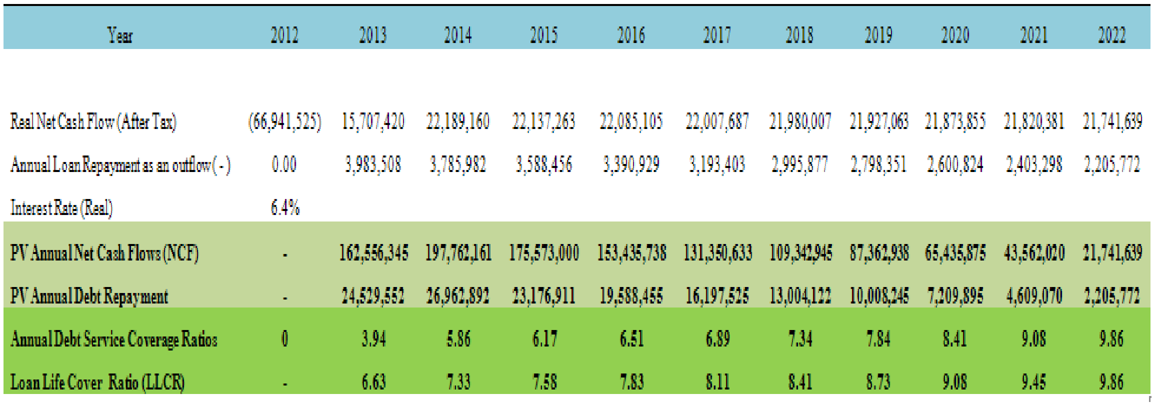
Table 28: Annual Loan Repayment, Scenario I



Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
US Price Index	1.00	1.03	1.07	1.10	1.13	1.17	1.21	1.25	1.29	1.33	1.37
Interest Rate	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%	9.84%
Beginning debt		20,082,458	18,074,212	16,065,966	14,057,720	12,049,475	10,041,229	8,032,983	6,024,737	4,016,492	2,008,246
Loan Disbursements	20,082,458										
Interest accrued		1,975,262	1,777,736	1,580,210	1,382,684	1,185,157	987,631	790,105	592,579	395,052	197,526
Principal Repayment		2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76	2,008,245.76
Interest Paid		1,975,262	1,777,736	1,580,210	1,382,684	1,185,157	987,631	790,105	592,579	395,052	197,526
Total Annual Loan Repayment	**0.00**	**3,983,508**	**3,785,982**	**3,588,456**	**3,390,929**	**3,193,403**	**2,995,877**	**2,798,351**	**2,600,824**	**2,403,298**	**2,205,772**

The total loan repayment in this scenario like scenario II (with ERDs), should be repaid in 10 years (2013-2022) with an 9.84% interest rate, starting from 2013 -2022. During these years the amount of net cash flow for covering loan disbursement should be enough to cover its liability, so the debt service capacity ratio should be considered. In following table you can see the ratio of debt capacity for scenario I (without ERDS):

Table 29: Debt Capacity Ratio (scenario I)



Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Real Net Cash Flow (After Tax)	(66,941,525)	15,707,420	22,189,160	22,137,263	22,085,105	22,007,687	21,980,007	21,927,063	21,873,855	21,820,381	21,741,639
Annual Loan Repayment as an outflow (-)	0.00	3,983,508	3,785,982	3,588,456	3,390,929	3,193,403	2,995,877	2,798,351	2,600,824	2,403,298	2,205,772
Interest Rate (Real)	6.4%										
PV Annual Net Cash Flows (NCF)	**-**	**162,556,345**	**197,762,161**	**175,573,000**	**153,435,738**	**131,350,633**	**109,342,945**	**87,362,938**	**65,435,875**	**43,562,020**	**21,741,639**
PV Annual Debt Repayment	**-**	**24,529,552**	**26,962,892**	**23,176,911**	**19,588,455**	**16,197,525**	**13,004,122**	**10,008,245**	**7,209,895**	**4,609,070**	**2,205,772**
Annual Debt Service Coverage Ratios	**0**	**3.94**	**5.86**	**6.17**	**6.51**	**6.89**	**7.34**	**7.84**	**8.41**	**9.08**	**9.86**
Loan Life Cover Ratio (LLCR)	**-**	**6.63**	**7.33**	**7.58**	**7.83**	**8.11**	**8.41**	**8.73**	**9.08**	**9.45**	**9.86**

For calculating the debt service capacity ratio of scenario I (without ERDs), the net cash flow is coming from real cash flow statement with banker’s point of view and annual loan repayment is coming from the loan schedule table of scenario I which is shown above .

After calculating the PV of the annual net cash flow and the PV of the annual debt repayment with a 6.4% interest rate, these two numbers should divided by the ratios of each year for scenario I, is illustrated above.

In this scenario like in scenario II (with ERDs) the financial structure of the project is composed of 70% equity and 30% debt (foreign loan). By altering this structure, the project feasibility can also change. In the following tables the impact of different borrowing rates on the project NPV and ADSCR for scenario I (without ERDs) are shown:

Table 30: impact of different leverage rates on project feasibility (without ERDs)

Scenario I (without)								
	Current Values:							
Changing Cell:								
Borrowing	30%	20%	30%	40%	50%	60%	70%	80%
ADSCR								
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	3.94	5.91	3.94	2.96	2.37	1.97	1.69	1.48
2014	5.86	8.79	5.86	4.40	3.52	2.93	2.51	2.20
2015	6.17	9.25	6.17	4.63	3.70	3.08	2.64	2.31
2016	6.51	9.77	6.51	4.88	3.91	3.26	2.79	2.44
2017	6.89	10.34	6.89	5.17	4.13	3.45	2.95	2.58
2018	7.34	11.01	7.34	5.50	4.40	3.67	3.14	2.75
2019	7.84	11.75	7.84	5.88	4.70	3.92	3.36	2.94
2020	8.41	12.62	8.41	6.31	5.05	4.21	3.60	3.15
2021	9.08	13.62	9.08	6.81	5.45	4.54	3.89	3.40
2022	9.86	14.79	9.86	7.39	5.91	4.93	4.22	3.70
NPV	$114,646,136	$114,329,487	$114,620,739	$114,911,990	$115,203,242	$115,494,494	$115,785,745	$116,076,997

A 5-1.1.1.2 Cash Flow Statement (owner's point of view)

in this scenario like scenario II (with ERDs), the financial cash flow statements with owner's point of view will be generated to evaluate the feasibility of project (under scenario I) with considering financial NPV of project for owner of project. As mentioned before it is necessary for the project owner to make a decision about accepting or rejecting of project. The cash flow statement from the owner's point of view for scenario I, is illustrated in following table:

Table 31: Cash flow statement, owner’s point of view, Scenario I

Year	2012	2013	2014	2017	2020	2023	2026	2030	2034	2038	2040	2042
US Price Index	1.00	1.03	1.07	1.17	1.29	1.41	1.55	1.76	2.00	2.27	2.42	2.57
Revenues												
Gross Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Sales Tax	0	0	0	0	0	0	0	0	0	0	0	0
Net Sales	0	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000	41,580,000
Change in accounts receivables	0	(7,484,400)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)	(232,074)
Asset Liquidation receipts (Residual):												
Land	0	0	0	0	0	0	0	0	0	0	0	
Building	0	0	0	0	0	0	0	0	0	0	0	
Total cash Inflow (+)	**0**	**34,095,600**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**	**41,347,926**
Expenditures												
Investment Cost:												
Land	1,195,097	0	0	0	0	0	0	0	0	0	0	(1,195,097)
Building (Including Labor During Construction)	41,482,583	0	0	0	0	0	0	0	0	0	0	(6,503,400)
Machinery & Equipment	16,130,000	0	0	0	0	0	0	0	0	0	0	(581,395)
Professional services	6,633,845	0	0	0	0	0	0	0	0	0	0	0
Total fees	1,500,000	0	0	0	0	0	0	0	0	0	0	0
Total Investment Cost	**66,941,525**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**(8,279,893)**
Operating Cost:												
Electricity power cost	0	10,306,305	10,357,836	10,513,982	10,672,482	10,833,371	10,996,685	11,218,274	11,444,328	11,674,937	11,791,978	11,910,192
Chemical Dosage	0	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600	5,847,600
Labor	0	1,182,672	1,220,518	1,341,477	1,474,423	1,620,546	1,781,150	2,020,315	2,291,595	2,599,302	2,768,319	2,948,326
Membrane replacement cost	0	0	0	25,000	0	0	0	0	0	0	0	25,000
Cartridge filter cost	0	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Operation Insurance cost	0	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Inlet system chemicals USD	0	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Pump mtce/replacement USD	0	0	0	0	0	0	0	0	0	0	0	25,000
Administration USD	0	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000	254,000
Management fee USD	0	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891	448,891
External support USD	0	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112	77,112
Solids disposal USD	0	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
Water quality monitoring	0	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Spare Part Cost U.S/YEAR	0	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708	334,708
Downtime Operating Maintenance Cost USD/Year	0	40,080	40,280	40,888	41,504	42,130	42,765	43,627	44,506	45,403	45,858	46,317
Total Operating cost	**0**	**19,169,368**	**19,258,945**	**19,561,657**	**19,828,720**	**20,136,357**	**20,460,910**	**20,922,526**	**21,420,740**	**21,959,952**	**22,246,465**	**22,595,147**
Change in accounts payables	0	(515,315)	(18,555)	(18,835)	(19,119)	(19,407)	(19,700)	(20,097)	(20,502)	(20,915)	(21,125)	(21,336)
Change in cash balance	0	(229,200)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)	(7,107)
Total Cash Outflow (-)	**66,941,525**	**18,424,852**	**19,233,283**	**19,535,715**	**19,802,494**	**20,109,843**	**20,434,103**	**20,895,323**	**21,393,131**	**21,931,930**	**22,218,234**	**14,286,811**
Net Cash Flow (before Financing & Tax)	**(66,941,525)**	**15,670,748**	**22,114,643**	**21,812,211**	**21,545,432**	**21,238,083**	**20,913,822**	**20,452,603**	**19,954,795**	**19,415,996**	**19,129,692**	**27,061,115**
Financing												
Add Loan Disbursement	20,082,458	0	0	0	0	0	0	0	0	0	0	0
Less loan Repayment	0	3,983,508	3,785,982	3,193,403	2,600,824	0	0	0	0	0	0	0
Net cash Flow after Financing (before Tax)	**(46,859,068)**	**11,687,240**	**18,328,661**	**18,618,807**	**18,944,607**	**21,238,083**	**20,913,822**	**20,452,603**	**19,954,795**	**19,415,996**	**19,129,692**	**27,061,115**
Corporate Tax	0	0	0	0	0	0	0	0	0	0	0	0
Real Net Cash Flow	**(46,859,068)**	**11,687,240**	**18,328,661**	**18,618,807**	**18,944,607**	**21,238,083**	**20,913,822**	**20,452,603**	**19,954,795**	**19,415,996**	**19,129,692**	**27,061,115**
FNPV @ ROE:	11%	**$114,646,136**										
FIRR:		**36%**										

From this cash flow statement from the owner's point of view, we can see that the financial NPV of the project for scenario I at an 11% expected rate of return is approximately 114 million U.S$. The financial NPV of project for this scenario is positive; it means that this project from the owner's point of view is financially feasible. But it is expected that financial NPV of scenario II will be more than this, due to cost reduction in operating expenses, because of the installation of an energy recovery device in the plant.