MEDRC Series of R & D Reports
MEDRC Project: 13-CoE-030

Life Cycle Assessment of RO Water Desalination System Powered by Different Electricity Generation Alternatives

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Water and Environmental Engineering, An-Najah National University, Nablus- Palestine

The Middle East Desalination Research Center
Muscat
Sultanate of Oman
Date: 26/11/2017

Dedication

To the spirit of our prophet Mohammed

Blessings and Peace be upon him

To my son, friend and soulmate (Mustafa)

To my beloved Mother, Nawal, for her endless Support, Genuine love & Care

To my Father, Abdelfattah, to whom I owe debt that I can never repay

To my sisters (Aysha & Ghufran)

To my beloved uncle (AbdulNaser)

To my dearest husband, who has been a constant source of support and encouragement. I am truly thankful for having you in my life, with light of hope and support (Mohammad)

To my family in Law (Mustafa, Huda, Battol, Balqees, Omar & the little angle (Osama))

To all of them,

I dedicate this work

Thank you all

For being a great source of support, inspiration and encouragement

Acknowledgments

Initially, I would like to thank Allah for blessing me with the opportunity to contribute to the research community through this research thesis.

I would like to thank both my university supervisors Dr. Hamdallah A. Bearat and Dr. Mohammed Alsayed for giving me strong support, inspiration, encouragement and guidance during the thesis.

Thanks also to my external examiner Dr. Afif Hasan and my internal examiner Dr. Abdelrahim Abusafa.

Thanks to Dr. Hasan Jawad from AlQuds University for his support.

Also big thanks to my family that has been very understanding and supportive during this thesis.

Special thanks to Al-Najah National University my second home.

I would like to thank the Palestinian Water Authority (PWA) and the Middle East Desalination Research Center for the financial and moral support that they gave me to complete my research.

Finally, I would like to thank everybody who was important to the successful realization of thesis, as well as expressing my apology that I could not mention personally one by one.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

Life Cycle Assessment of RO Water Desalination System Powered by Different Electricity Generation Alternatives

أقر أن ما اشتملت عليه الرسالة هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد وأن هذه الرسالة أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة بحثية أو علمية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Signatur **التوقيع:**

Date: **التاريخ: 2017/11/26**

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List of Abbreviations

ADF	**Abiotic Depletion Factor**
Ah	**Ampere hour**
AP	**Acidification Potential**
AW	**Annual Worth**
BWRO	**Brackish Water Reverse Osmosis**
°C	**Celsius**
CFC-11	**Trichlorofluoromethane**
CML	**Center of Environmental Science of Leiden University**
donums	**1000 square meter**
EC	**Electrical Conductivity**
GHG	**Green House Gasses**
GWP100	**Global Warming Potential for Time Horizon 100 years**
HP	**High pressure Pump**
HTP	**Human Toxicity Potentials**
IA	**Inventory analysis**
IPCC	**Intergovernmental Panel on Climate Change**
ISO	**International Organization for Standardization**
JDECO	**Jerusalem District Electricity Co**
kWh	**kilo watt hour**
kWp	**kilo watt peak**
LCA	**Life cycle assessment**
LCI	**Life cycle inventory**
LCIA	**Life cycle impact assessment**
L/c/d	**liter per capita per day**
MEDRC	**Middle East Desalination Research Centre**
MED	**Multi Effect Distillation**
MJ	**Megajoule**
MSF	**Multi Stage Flash**
NIS	**New Israeli Shekel**
NP	**Nutrification potential**
PA	**Positional analysis**
POCP	**Photochemical Ozone Creation Potential**
ppm	**part per million**
PWA	**Palestinian Water Authority**
RO	**Reverse Osmosis**
S/m	**Siemens per meter (Electrical Conductivity unit)**

SWRO	**Sea Water Reverse Osmosis**
TDS	**Total Dissolved Salts in ppm**
USA	**United States of America**
Wp	**Watt Peak**
WHO	**World Health Organization**
WMO	**World Meteorological Organization**

List of Symbols

Ae	**Membrane area per elements**
C_{Ah}	**Capacity in Ampere hour**
DO	**Dissolved oxygen**
DOD	**Depth of discharge**
E_d	**Energy consumption per day**
$E_{P.V}$	**Generator daily energy**
J	**Flux**
ne	**Number of elements**
P_{PVG}	**Generator power peak**
PER	**Primary energy requirement**
pH	**Potential of hydrogen**
Q_f	**Feed flow**
Q_p	**Permeate flow**
TH	**Total hardness**

Life Cycle Assessment of RO Water Desalination System Powered by Different Electricity Generation Alternatives

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Abstract

This study will contribute to reduce the shortage of fresh water in Al-Murashahat area by using Al-Fashkha springs water source and applying the best water desalination technology from environmental and cost aspects. This will be through designing RO system which serves the area and choosing the best energy source by evaluating them in terms of their life cycle assessment.

In this study a life cycle analysis was performed on three RO desalination systems. The first system is RO system operated by PV (RO-PV system). The second system is RO system operated by electricity generated from coal (RO-coal electricity system). The third system is RO system operated by electricity generated from natural gas (RO-natural gas electricity system). The open LCA software, Ecoinvent database was used, and the CML baseline LCIA method was chosen for the evaluation of systems impact on its 10 categories for functional unit of 50 m^3/day.

For all systems, it was found that the water distribution process contributes most to the overall environmental impact followed by the operation process. Across all impact categories the RO-PV system has the least environmental impact, however the RO-coal electricity system has the largest

environmental impact.

The cost of water produced from RO system operated by electricity generated from coal or natural gas is lower than the cost of water produced from RO-PV system, where the cost of $1m^3$ water produced by RO-PV system calculated to be 1.80 $\$/m^3$, however the cost of $1m^3$ water produced by RO-electricity systems calculated to be 1.27 $\$/m^3$.

Chapter One

Introduction

1.1 General background

Millions of people have no access to a secure source of fresh water. Nevertheless, since many arid regions have plentiful saline water, water desalination is a reasonable alternative. There are several challenges posed by water desalination. On one hand, the process energy requirement is high, especially in the developing countries or remote areas, where electricity is required. On another hand, the environmental and technical problems associated with desalination imply higher process cost to dispose of the waste water (brine) and to avoid adverse metal corrosion of infrastructure and equipment. Since most arid regions have renewable energy sources, water desalination seems an interesting route, or even the only way to offer a secure source of fresh water, at reasonable cost [1, 2].

Palestine is one of these areas. Indeed, fresh water resources are limited, and most of Palestinian people do not obtain the 100 Liter of fresh water per person per day to meet the average consumption level which is the minimum amount recommended by the WHO [3]. Therefore, it becomes urgent to find new water resources, including desalination. But, as mentioned above, the process needs energy (mainly fossil fuels), which is expensive. It affects negatively the environment and it is non-sustainable. Thus, using renewable energy in water desalination and addressing the environmental and technical problems due to salts (or brine) could offer some adequate solution.

In Palestine, the most available source of renewable energy is solar energy, especially in the Jordan Valley region. It has 350 sunny days a year, which is about 2800 h/year where the annual average daily solar radiation intensity is about 5.4 kWh/m^2-day [4]. Moreover, Al-Aghwar is located in the Jordan Valley near the Dead Sea, where there is abundance of saline water and solar energy. In Palestine there is a 100 -110 million cubic meter per year of potential saline water (brackish water, containing 1,000 to 10,000 ppm of total dissolved solids [TDS] [5]) resources available and discharged to the Dead Sea [6, 7]. In addition, the brackish water is not deep, which decreases the pumping expenses. So, Al-Agwar is a suitable Palestinian area to apply a project of desalination using renewable energy.

The need for electricity to desalinate salty water is about 1.5-2 kWh/m^3 [8]. This amount can be obtained through the use of solar energy. So, the challenge is to find a technology that is able to exploit existing resources in Palestine. Reversed osmosis (RO) system found to be the least aggressive water desalination technology for the environment depending on the previous studies [9,10]; thus in this research the RO desalination technology was considered apart from all other technologies. Life Cycle Assessment (LCA) approach is chosen in this research since it is a suitable approach for evaluation of the sustainability and the impacts of a product or process life cycle [11].

1.2 Problem statement

As a need for a new water resource that meets the water consumption, RO desalination technology seems to be a suitable alternative as explained above. Therefore, it is important to evaluate the RO system, considering the environmental and economic effects of the system. Since the process energy requirement is high, the evaluation will be for RO system based on three different sources of energy which are PV, electricity generated from coal and electricity generated from natural gas, through a scientific methodology. In this study, the three alternatives are environmentally-compared using the life cycle assessment (LCA) tool.

1.3 Significance of the study

This study will contribute to solve the shortage of fresh water in AL-Murashahat area by using Al-Fashkha springs water source and applying the best water desalination alternative from environmental and economic aspects. This will be through designing RO system which serves the area and choosing the best energy source by evaluating them in terms of their Life Cycle Assessment.

1.4 Objectives of the study

- Designing RO water desalination system depending on Al-Fashkha springs water characteristics (i.e. brackish water) and the water needs of AL-Murashahat area.
- Evaluating RO water desalination system from economic and environmental points of view based on three different electricity

generation alternatives which are PV, electricity generated from coal and electricity generated from natural gas.

1.5 Thesis organization

The work done in this thesis is summarized in five chapters: Introduction chapter discusses the objectives of this study, then explains life cycle assessment (LCA) and RO water desalination technology, and discusses previous studies which have been conducted by using LCA approach in the evaluation of similar cases. Study Area chapter shows the location and characterizations of the case study for this project. Methodology presents technical, economical, and environmental analysis that are employed to get the results. Results and discussion chapter discusses and interprets the results obtained. That includes both economic analysis results and environmental impact analysis results. Conclusions and recommendations chapter includes a critical commentary covering the results of the study, and the most important recommendations.

1.6 Life cycle assessment

More than 30 years ago, life cycle assessment (LCA) was developed as a tool for analyzing environmental burdens. LCA technique is used for planning, finding out the weak points in the life cycle of services and products and evaluating the potential environmental impacts of each alternative. Results of the LCA assist decision-makers to select the most appropriate product or process from an environmental point of view. LCA provides a wide view on environmental impacts through [12]:

- “Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.”

The LCA approach consists of four linked phases: goal and scope definition, inventory analysis, impact assessment, and interpretation [12], which is the methodology to be adopted by this research, as will be explained in the Methodology Chapter.

1.6.1 Elements of life cycle assessment

The internationally accepted principles and guidelines for LCA methodology are defined in ISO standards 14040 and 14044. These standards define the process of performing an LCA [13].

Four different phases can be differentiated:

1.6.1.1 Goal and scope definition

This phase defines the LCA purpose and method of using life cycle environmental impacts by the decision-makers and targeted audience [11]. The following items must be specified in this phase: the expected products or services of the study, desired outcome depending on the intended use of the study, and how the results should be displayed in a meaningful and usable manner [14].

1.6.1.2 Inventory analysis

The life cycle inventory analysis (LCI) is the second phase of LCA. LCI is a process of quantifying energy and raw material requirements and environmental releases associated with each stage for the entire life cycle of a product, process, or activity [13]. Life cycle inventory phase involves collecting and processing the necessary data to meet the goals of the defined study and to evaluate environmental impacts or potential improvements. The level of accuracy and detail of the data collected is reflected throughout the remaining of the LCA process. Life cycle inventory analyses can assist an organization in comparing products or processes by evaluating environmental factors. Furthermore, inventory analyses can assist policy-makers, by helping the government improve environmental regulations and manage resources use [14].

1.6.1.3 Impact assessment

The life cycle impact assessment (LCIA) is the third phase of LCA. It translates the results of the inventory analysis into environmental impacts (e.g. global warming, acidification, ozone depletion, depletion of resources, eutrophication, etc.). The aim of this phase is to assess the human health and the eventual environmental impacts quantified by the inventory [13,14].

1.6.1.4 Interpretation

Life cycle interpretation is the last phase of the LCA process. It includes identification, quantification, checking, and evaluating the results of the inventory and impact phases, then the final conclusions and recommendations are communicated in relation to the objectives of the study [14].

ISO has defined the following two objectives of life cycle interpretation:

• Analyze results, explain limitations, reach conclusions and provide recommendations based on the findings of the previous phases of the LCA, and to report the results of the life cycle interpretation in a transparent method.

• Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, depending on goal and scope of the study [14].

These four phases can be represented as shown in Fig.1.1

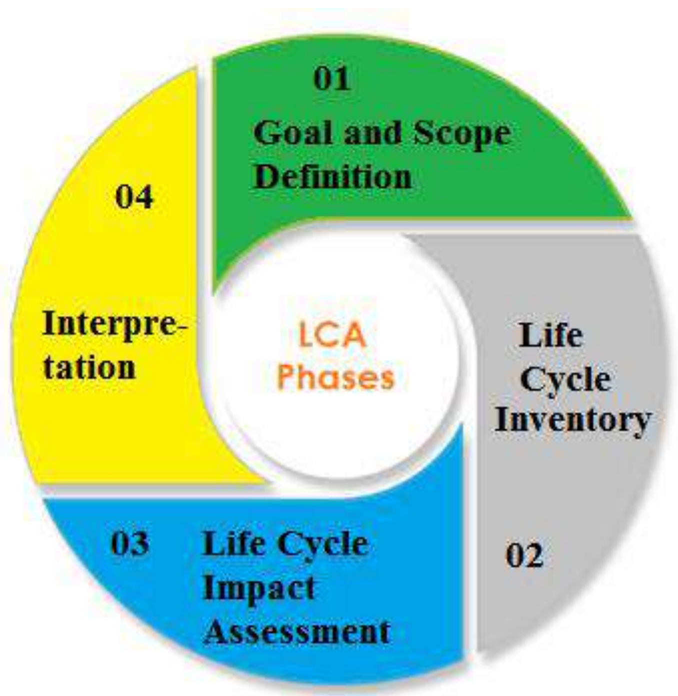

Fig. 1.1: Life cycle assessment (LCA) phases

1.6.2 Life cycle impact assessment methods

Life cycle impact assessment (LCIA) converts ‘inventoried’ flows into simpler indicators. In an LCIA, basically two methods are followed [15]:

- Problem-oriented method (Midpoints):

In the problem-oriented method, flows are classified into environmental themes to which they contribute. Themes covered in most LCIA studies are greenhouse effect (or climate change), natural resource depletion, stratospheric ozone depletion, acidification, photochemical ozone creation, eutrophication, aquatic toxicity and human toxicity. This method aims to simplify the complexity of hundreds of flows into a few environmental indicators [16].

- Damage-oriented method (Endpoints)

  The damage-oriented methods also start by classifying a system flows into various environmental themes, but they model the damage of each environmental theme according to its effect on human health, ecosystem health or damage to resources [16].

  To calculate impact assessment results, the environmental research centers developed several methods, which are CML 2001, Cumulative energy demand, Ecoindicator 99, Ecological footprint, Ecological scarcity 1997 and 2006, Ecosystem damage potential (EDP), EPS 2000, IMP ACT 2002+, IPCC 2001, ReCiPe (Midpoint and Endpoint approach), TRACI, and USEtox. CML baseline has been used in this study [16].

1.6.3 CML method

CML (Center of Environmental Science of Leiden University) suggested a set of impact categories and characterization for the impact assessment stage. There are two versions of CML method: a 'baseline' method with 10 impact categories; and an extended method with 'all impact categories'. In this study CML baseline method has been used [16,17].

The 10 baseline indicators are category indicators at "mid-point level" "(problem-oriented approach)" and are detailed below:

1. Acidification

Acidifying substances cause a wide range of impacts on soil, ground water, surface water, ecosystems, organisms, materials and buildings. Acidification Potential (AP) for emissions to air is calculated with the adapted RAINS 10 model, describing the fate and deposition of acidifying substances. AP is expressed as kg SO_2 equivalents / kg emission. The time span is eternity. The indicator applies at local scale and continental scale [16,18].

2. Climate change

Climate change is related to emissions of greenhouse gases to air. Climate change can result in adverse effects upon ecosystem health, human health and material welfare. For development of characterization factors, the characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission. The geographic scope of this indicator is at global scale [16,18].

3. Depletion of abiotic resources

It is concerned with protection of human health, human welfare and ecosystem health. This impact category is related to extraction of minerals and fossil fuels due to inputs in the system. For each extraction of minerals and fossil fuels, the Abiotic Depletion Factor (ADF) is determined (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale [16].

4. Eutrophication

Eutrophication includes all impacts due to excessive levels of macro-nutrients in the environment caused by releases of nutrients to air, water and soil. Eutrophication is known also as nitrification. Nitrification potential (NP) is based on the stoichiometric procedure of Heijungs (4292), and expressed as kg PO_4 equivalents per kg emission. Time span is eternity and the indicator applies at local scale and continental scale [16,18].

5. Fresh water aquatic eco-toxicity

This category refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. Eco toxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. Characterization factors are expressed as 1,4-dichlorobenzene equivalents/kg emissions. The indicator applies at global, continental, regional and local scale [16,18].

6. Human toxicity

This impact category concerns effects of toxic substances on the human environment. Characterization factors and Human Toxicity Potentials (HTP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. Health risks of exposure in the working environment are not included. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale [16,18].

7. Marine eco-toxicity

Marine eco-toxicity category indicator refers to impacts of toxic substances on marine ecosystems.

8. Ozone layer depletion

A larger fraction of UV-B radiation reaches the earth surface, as a result of ozone layer depletion. This can have harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. This impact category is output-related and at global scale. World Meteorological Organization (WMO) has developed the characterization model which defines ozone depletion potential of different gases (kg CFC-11 equivalent/ kg emission). The time span is infinity [16,18].

9. Photo-oxidant formation

It is the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and which also may damage crops. This problem is also indicated with "summer smog".

Photochemical Ozone Creation Potential (POCP) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission. Winter smog is outside the scope of this category [16,18].

10. Terrestrial eco-toxicity

This category indicator refers to impacts of toxic substances on terrestrial ecosystems.

1.7 Desalination technologies

Numerous technologies have been developed to desalinate salty water effectively in order to produce fresh water (water with low concentration of salt) and another product with high concentration of remaining salts (the brine or concentrate) [19].

Desalination is the process of removing salts from brackish/seawater to provide clean water for drinking, industry and irrigation [20]. According to the principles of the processes used in the desalination technique, the desalination technologies can be classified into three main categories [21]:

- Thermal/distillation processes
- Membrane processes
- Chemical processes

The selection of a desalination process depends on site conditions, including the salt content of the feed water, the quality of water required by the end user, economics and local engineering experience and skills [19].

Desalination technologies that are based on thermal and membrane processes are the dominating technologies used for desalinating brackish and seawater on the commercial scale. Chemical based desalination technologies are used on the smaller scale to end up producing very high quality water mainly for industrial purposes [21].

In this research the RO desalination technology was adopted. For the brackish water, the energy consumption in RO technology is the lowest compared with all other desalination technologies. Therefore it's suitable to be used with PV, especially in small pilot project. Furthermore it is the cheapest technology compared with all other desalination technologies. Thus, it is the most used technology around the world [22].

Reverse osmosis

Reverse osmosis technology uses pressure on solutions with concentrations of salt to force fresh water to move through a semipermeable membrane (microscopic strainer), leaving the salts behind. The amount of desalinated water that can be gained varies between 30% and 85% of the volume of the input water, depending on three main factors, the initial water quality, the quality of the product, and the technology and membranes involved [19]. This filtering process removes 95% to 99% of dissolved salts and inorganic material. Reverse osmosis is the finest level of filtration available and supplies clean, safe and healthy water.

An RO system is made up of the following four basic components: pretreatment, high-pressure pump (which generates the pressure required to enable the water to pass through the membrane), membrane assembly, and post treatment [19]. Figure 1.2 shows the RO desalination plant flow chart.

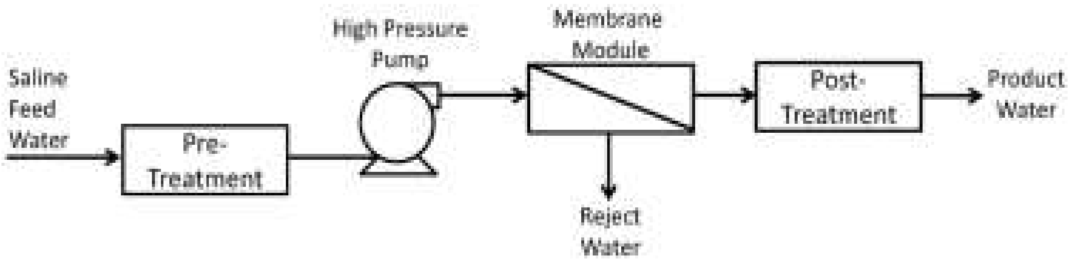

Fig. 1.2: RO desalination plant flow chart [23]

Membranes have four modules which are plate and frame module, hollow fiber module, spiral wound module and tubular module. Mainly, they are manufactured in two configurations; the spiral wound and hollow-fine fiber. The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the semi-permeable membranes [19]. Figure 1.3 shows RO desalination membrane elements (spiral-wound).

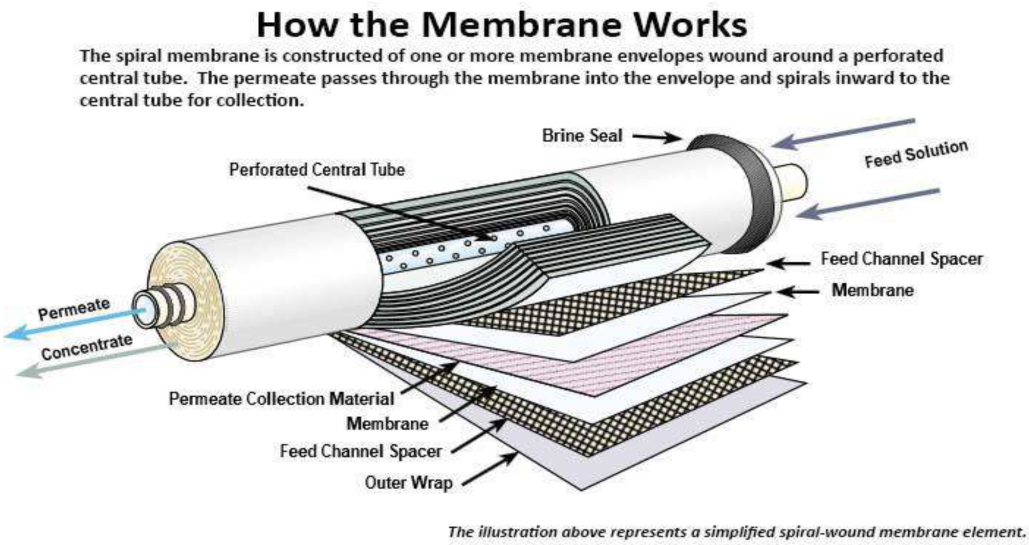

Fig. 1.3: RO desalination membrane elements (spiral-wound) [24]

The two key performance parameters of a RO process are permeate flux and salt rejection. The flux and rejection of a membrane system are mainly influenced by variable parameters including pressure, temperature, recovery and feed water salt concentration [25].

Advantages of Reverse Osmosis technology [21]

- Quick and cheap to build
- Simplicity in operation and maintenance
- Can be used for a large range of flow rates
- Easy expandability and increasing the system capacity
- High space/production capacity ratio, ranging from 25,000 to 60,000 L/day/m^2
- Low energy consumption
- Contaminants removal
- Low usage of cleaning chemicals

Disadvantages of Reverse Osmosis technology [21]

- RO membranes are relatively expensive and have a life expectancy of 2-5 years
- It is necessary to maintain an extensive spare parts inventory
- There is a possibility of bacterial contamination
- The plant operates at high pressures

RO technologies are developed continuously to reduce the cost of membranes materials, enhance membranes recovery ratios and biofouling resistance [19].

1.8 Literature review

Several studies have been conducted to study different desalination technologies with different cases using LCA process.

A study conducted in 2005 by Raluy et al [26] discussed the life cycle assessment of desalination technologies incorporated with renewable energies. The researchers have used the LCA technique of different desalination technologies; Multi-Stage Flash, MultiEffect Distillation and Reverse osmosis integrated with different renewable energy; wind energy, photovoltaic energy and hydro-power. The purpose of the study is to find out the technology providing lower environmental load by establishing a broad perspective in an objective way. The software SimaPro 6.0 has been used as the LCA analysis tool, and three different evaluation methods-CML2 baseline 2000, Eco-Points 97 and Eco-Indicator 99-have been applied [26].

This study has shown that desalination technologies powered by renewable energy can provide substantial benefits in the next future which are: supplying water needs to distant regions where climate characteristics are favorable (high insolation, high wind potential, waterfalls) and also reducing the environmental releases for desalting saline water sources. As a result, solar, wind and hydro-power utilization in sunny, windy areas can act as a direct alternative to fossil fuels to supply the required electric power to the desalination plant. Renewable energies can reduce the environmental impacts of produced water by desalination plants. CO_2 emissions are significantly reduced in percentage for the three technologies, and SO_x is the lowest one in Multi-Stage Flash and Multi Effect Distillation [26].

Another study conducted in 2006 by the same team of researchers [27] discussed life cycle assessment comparison between MSF, MED and RO desalination technologies. The software SimaPro 6.0 has been used to conduct the analysis and is structured as established phases by the standard ISO 14000 for LCA. Despite the analysis is general and not very detailed, the study results are sufficient to obtain a general view about the less aggressive desalination technology for the environment and to represent the systems by applying different evaluation methods (CML 2 baseline 2000, Ecopoints 97 and EI 99) [27].

The study indicated that desalination based on RO has lower environmental impact than thermal desalination. This result is further reinforced if the energy source is changed to renewable energies and also if the reduction of energy consumption of RO is achieved with the new energy recovery systems. However, thermal desalination technologies can present a great potential or environmental impact reduction when it is integrated with other production process [27].

A study conducted in 2008 by Muñoz and Fernández-Alba [28] discussed reducing the environmental impacts of reverse osmosis desalination by using brackish groundwater source. The purpose of the study is to find out the environmental effects of using brackish groundwater instead of sea water in reverse osmosis desalination. A comparison between two water production plants using Life Cycle Assessment (LCA) methodology has been performed. The brackish groundwater alternative is based on a plant located in

Almeria (southern Spain), while the sea water alternative is based on literature data [28].

The results show that the key life-cycle issue of brackish groundwater desalination is electricity consumption, despite this issue the life-cycle impacts for brackish groundwater are found to be almost 50% lower than sea water resources. Eventual local impacts provoked by brine discharge are also found to be lower, due to a reduced content of salts. The researchers recommended giving the first priority for brackish groundwater resource as an input for reverse osmosis desalination when and wherever possible [28].

A published paper by Zhou et al in 2011 [29] discussed the environmental life cycle assessment of reverse osmosis (RO) desalination and the effect of using Life Cycle Impact Assessment (LCIA) methods on the results. The purpose of this study is to find out the environmental impacts variances of RO desalination due to using different LCIA methods. An RO desalination plant in the United States was selected in the LCA using a generic LCIA method, CML 2, and an US-specific method; TRACI (i.e. Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts). Input and output flows of the RO desalination plant were based on the previous study. Life cycle inventory (LCI) used was adopted from the Ecoinvent Database with specific US datasets [29].

This study has shown that the selection of the LCIA method depends on two main factors which are; the feature of the inventories available and the specific concerns in the area if there is any. For this study, neither the

CML2 nor TRACI method is the perfect option for LCA of a RO desalination plant in the US. Furthermore the researchers recommended to further improve the current TRACI method by completing the missing important indicators to better match the RO desalination in the US, since the current TRACI used less data requirement [29].

Another paper published also in 2011 by the latter team [10] discussed environmental life cycle assessment of brackish water reverse osmosis desalination for different electricity production models. The main purpose of this study is to assess the importance of electricity production models based on the environmental impacts from a brackish water reverse osmosis (BWRO) plant. Life cycle assessment (LCA) is used to compare the environmental loads of a BWRO plant with three different electricity production models in the United States, Singapore, and Spain. The input and output flows of BWRO plants are based on the previous studies [10].

The results highlight Singapore, the country that relatively has lower environmental impact in most impact categories due to uniqueness of fuel mixes for electricity generation which has a high percentage of natural gas in the fossil fuel matrix. Furthermore, this study provides the first reference to conduct LCA of BWRO plant in Southeast Asia which helps policy-makers in planning their strategies to relieve environmental impacts of the RO desalination process. It also indicates that regardless of using brackish water with low salinity or the seawater with high TDS the most of the environmental impacts of RO plants are associated with energy consumption. The conclusions obtained from this study could be further extended to other medium-salinity BWRO or SWRO plants as long as it is an energy-dominated process [10].

And another paper published in 2014 by this same team of researchers [30] discussed life cycle assessment for desalination. The study reviews more than 30 desalination LCA studies since 2000 and indicates two main issues which need more improvement. The first is feasibility, covering three elements that support the application of the LCA to desalination, including accounting methods, supporting databases, and life cycle impact assessment approaches. The second is reliability, addressing three fundamental aspects that drive uncertainty in results, incomplete system boundary, non-representative database, and the omission of uncertainty analysis [30].

The research found that life cycle impact assessment can be improved farther by developing two important characteristics of desalination system which are the brine disposal and freshwater savings. The current assessment models used to convert those characteristics into corresponding impacts need more improvement. This indicates an area requiring more research efforts to represent more accurate results [30].

Another paper was published in 2012 by Jijakli et al [9].This study compared three desalination options for water supply in off-grid areas, and evaluated their environmental impacts. The three options are a solar still, a photo-voltaic (PV) powered reverse osmosis (RO) unit and water delivery by truck from a central RO plant. A comprehensive environmental modeling of the three systems has been carried out using life cycle analysis (LCA) [9].

The researchers indicate that energy generation and materials usage are critical parameters when a comparison between the three options has been made. PV-RO is found to have the least environmental impact. This study provides decision makers with insight into renewable energy desalination for clean water production [9].

Another research was conducted in 2014 by Shahabi et al [31]. This paper assesses life cycle Greenhouse Gas (GHG) emissions of a Seawater Reverse Osmosis (SWRO) desalination plant and assesses its performance using three power supply alternatives. A Life Cycle Assessment (LCA) analysis is conducted for a plant located in Perth, Western Australia (WA). Input and output flows of SWRO plant are based on previous studies and Perth desalination plants. Power supply alternatives are "100% WA grid", "100% wind energy" and "92% wind energy plus 8% Photovoltaic (PV) solar energy" [31].

Results indicate that desalination plants powered by renewable energy achieve 90% reduction of GHG emissions compared to the plant powered by WA grid electricity. For the plants powered by renewable energy, the highest contribution goes to chemical use in the operational phase (60%) followed by the construction phase (17%). On the other hand for the plant powered by fossil fuel based grid electricity, electricity use in the operational phase is found to be responsible for more than 92% of its GHG releases. Furthermore results indicate that any improvement in fuel mixes in grid electricity generation can reduce environmental impacts [31].

Another research was conducted in 2016 by Cherif et al [32]. In this paper the researchers performed a study of the life cycle assessment (for a period of 20 years) depending on embodied energy of a water pumping and desalination process powered by a hybrid photovoltaic wind system. In this study the embodied energy according to ISO standards has been used as environmental indicator. Embodied energy is calculated for a photovoltaic subsystem, a wind turbine subsystem and a hydraulic process (water pumping, water storage and a desalination process). A life cycle assessment evaluation has been carried out for three types of photovoltaic module: mono-crystalline, polycrystalline and amorphous silicon in the photovoltaic subsystem, and for three motor-pumps, two stages of pressure vessel and three water tanks in the hydraulic process. In addition, the amounts of the primary energy requirement for different industrial PV modules and for different industrial wind turbines have been calculated [32].

The results of life cycle analysis show that the embodied energy for 20 years life time of 1m^3 of permeate water is around 2.2 MJ/m^3. It is also found that the embodied energy of 1 m^2 wind turbine is around 2409 MJ/m^2 and the embodied energy of 1 m^2 mono-, poly-, and amorphous silicon solar panels is 4779 MJ/m^2, 3815 MJ/m^2 and 2462 MJ/m^2, respectively [32].

The researchers in previous studies had focused in finding the least environmental impact associated with each case. The conclusions obtained from previous studies are; the environmental impact of a system using brackish water is lower than sea water, the key life-cycle issue of brackish groundwater desalination is electricity consumption, desalination based on RO has the lowest environmental impact, desalination technology powered by renewable energy is reducing the environmental releases, finally any improvement in fuel mixes in desalination plants powered by grid electricity generation can reduce environmental impacts.

The results from previous studies were used to achieve the objectives of this study. This study aims to reduce the shortage of fresh water in AL-Murashahat area by using Al-Fashkha springs water source and applying the best water desalination alternative from environmental and economic aspects. Choosing the best water desalination technology from environmental aspect was the first challenge, in this study RO desalination technology has been selected because it has the lowest environmental impact based on previous studies results. The second challenge was choosing the best energy source for the selected desalination technology (RO). It was found from previous studies that any improvement in fuel mixes in desalination plants powered by grid electricity generation can reduce environmental impacts, also desalination technology powered by renewable energy is reducing the environmental releases, this indicates an area requiring more research efforts to represent more accurate results, which has been developed in this study by using three different electricity generation alternatives which are PV, electricity generated from coal and electricity generated from natural gas, and evaluating them in terms of their Life Cycle Assessment in order to choose the best energy source.

Chapter Two

Study Area

Jordan Valley area (Al-Agwar) is a suitable area to apply a project of desalination by renewable energy. The case study for this project will be Al- Fashkha springs where the desalination plant will be; the beneficiary of permeate water will be Al-Murashahat area.

2.1 Geography

Al- Fashkha springs are located on the northwestern shore of the Dead Sea at the foot of the escarpment cliff, and is 6.5 kilometers long and about 3 kilometers south of Qumran Wadi. The springs, which are 10 springs, emerge at 390 meters below sea level. The study area is located in the eastern aquifer, which is one of the three aquifers in West bank (The Western Aquifer, the Eastern Aquifer, and the Northeastern Aquifer). It has an area of 3,079.5 km^2, where Al- Fashkha springs are located in Nar Catchments, which has a length of 25.78 km and drains towards the Dead Sea [33, 34].

Fig. 2.1: Location map of the study area [34]

2.2 Topography and geology

Al-Fashkha springs means the "split" or "cloven" spring. Its name comes from its location in the Dead Sea Valley rift, and from the springs that emerge there (out of the layer of conglomerate that fills the valley). That is, the water emerges out of the rock much like the blood out of the wound in a head hit by a stone [33].

Topography is a unique feature of the area. It is noticeable that the topography of the region changes. It inclines gently from attitude of -100 meters in the west to less than -300 meters in the eastwards to Sea level in the area of the Dead Sea [34].

Certain areas of the escarpment cliff on the western edge of the Dead Sea Valley are outlets for water flowing from the west. The water flows to the cliff through an aquifer (water-bearing layer) consisting of limestone and dolomite rocks. It crosses the faults and emerges from the conglomerate layer in the sediment of the Dead Sea Valley. The study area is located in the eastern aquifer, which mainly consists of carbonate sedimentary rocks with deeply incised valleys draining to the east [34].

2.3 Climatology

Jordan Valley area is dominantly a Mediterranean, it is characterized by arid to semi-arid climate which are controlled by low annual rainfall, low soil moisture conditions and very high potential evapotranspiration levels. The study area has warm low rain winter and hot dry summer. The average temperature is around 40°C in summer and around 15°C in winter. The winds are commonly from the west and southwest, which are from the Mediterranean Sea, and have a moderating influence in the summer weather. Intermittent winds coming from the south and east over the desert are cold and dry in the winter, and dusty and sizzling in the spring. The study area is characterized by low amount of rainfall. The rainfall amount decreases eastwards with rainfall gradient changes from more than 150 to less than 100 mm/year in the area of the Dead Sea. The mean annual rainfall is approximately 100 mm/year, of which about 60% falls in the three months of December, January and February [34].

2.4 Soil and land use

2.4.1 Soil

Al- Fashkha springs area is mainly composed of continental sediments. These create clastic material (clay, sand and gravel) deposited in fan channels with some intercalations of lacustrine sediments (clay, gypsum and aragonite) of the *Lisan* formation and younger Holocene sediments [35]. In the Jordan Valley; the main rock type are *Lisan* marls. They are deposits of a former inland lake and consist of loose *diluvial* marls. The *Lisan* marl soils are generally of a rather light nature, their clay content varies from approximately 10 to 20%. High concentration of calcium carbonate content is present, which varies between 25 and 50%. Where there is no possibility for irrigation, the *Lisan* marls are covered with a very sparse growth of halophytic plants. In the eastern slopes region, the main soil types are the semi-desert soils, the secondary soil types are the mountain marls. For the semi-desert soils, the formation of sand and gravel is characteristic of desert weathering [35].

2.4.2 Land use

Al-Fashkha springs area is considered as natural reserve area, it is managed and controlled by the Israeli Nature and Parks Authority. The land surrounding the springs is mainly covered by shrub plants.

The natural reserve of Ein Al Fashkha is considered as the lowest natural reserve in the world, the reserve is divided into three sections: the northern section which is called the “closed reserve”, the central section, which is called the “visitors reserve”, and the southern section, which is called the “hidden reserve”.

- Northern section (closed reserve) has an area of 2,700 donums, it is closed to the public and used by scientists and researchers.
- Central section (visitors reserve), has an area of 500 donums, it is open to the public and features a series of pools for swimming filled with natural spring water.
- The southern section (hidden reserve), has an area of 1,500 donums, it is open to the public only when visiting on an organized group tour or a specially licensed private tour guide [34,36].

  Photos taken by the researcher of Al-Fashkha springs in closed reserve area are provided in Appendix (A).

2.5 Water resources: quantity and quality

Certain areas of the escarpment cliff on the western edge of the Dead Sea Valley are outlets for water flowing from the west. The water flows to the cliff through an aquifer (water-bearing layer) consisting of limestone and dolomite rocks. It crosses the faults and emerges from the conglomerate layer in the sediment of the Dead Sea Valley. The study area is located in the eastern aquifer, it has an area of 3,079.5 km^2 and mainly consists of carbonate sedimentary rocks with deeply incised *wadis* draining to the east [34].

Surface water depends mainly on the quantity and duration of rainfall during the wet season. It includes mainly the Jordan River along with its tributaries and *wadis* flowing from the central mountains towards the Jordan Valley. The source of the spring water in the reserve is rain that falls on the Hebron Mountains, where Al- Fashkha springs are located in Nar Catchments, which has a length of 25.78 km and drains towards the Dead Sea. The rainwater seeps downward, dissolving salts along the way, and emerges in the oasis along the shore, at the foot of the cliff above the level of the Dead Sea aquifer [34].

The water quality of these springs largely depends on the surrounding geological formation. In particular, the main source of salinity affecting the springs are the saline layers deposited along the shoreline of the Dead Sea, through which fresh groundwater passes as it emerges to the surface. As such, salinity levels vary according to the degree of solubility [34].

The Dead Sea retreat has a significant impact on the location of the springs: The Dead Sea is a very low lake (425 m below sea level, and continues to change). The water level decreases at an average rate of about one meter per year. It is one of the saltiest lakes in the world, and its water has high density due to its high salinity. Therefore it does not mix with the fresh water of the springs, but rather becomes a kind of “foundation” on which the fresh spring water floats [36].

The springs have a discharge rate of 90-117 million cubic meters per year. [1] Available records show that Al-Fashkha springs have relatively high values of Total Dissolved Solids (TDS) ranging from 1,500 to 5,000 mg/L and making them brackish, as well as a high content of chloride and other constituents. The test done at PWA laboratory in 2014 for Al-Fashkha springs water gave the following average results: TDS (2087 mg/L), Salinity (1700 mg/L) and EC (0.0381 S/m). These results show that the water of Al- Fashkha Springs is considered as brackish water [34].

During the site visit done by the researcher and supervisors with Dr. Hasan Jawad from AlQuds University, three water samples from Al-Fashkha Springs have been taken and tested on February 2016 by Dr. Hasan at AlQuds University laboratory.

The test results for Al-Fashkha springs water gave the following results: TDS (2410 mg/L) and EC (0.0528 S/m) the full results are provided in Appendix (B).

2.6 Beneficiary of permeate water (Al-Murashahat area)

Al-Murashahat area is a residential square belonging to Aqabat Jabr camp in Jericho. It has 300 residents, 50 houses and a mosque. There are three agricultural ponds and three water tanks for Aqabat Jabr camp and some residents work in the sheep trade [37]. The average per capita consumption of water is 89 liters per day [38].

Chapter Three

Methodology

Developing new feasible and environmentally friendly water desalination technologies became one of the most important Palestinians priorities. So, this thesis will study the prospects of optimal utilization of PV in RO water desalination technology. This will be done by implementing ISO 14000 standard [39] life cycle assessment (LCA) methodology; in general by four steps. Firstly, goal and scope definition, are designed to obtain the required specifications for the LCA study. Secondly, inventory analysis, which includes collecting all data of the unit processes within a product system and relates them to the functional unit of the study. Thirdly, impact assessment phase aims at making the results from the inventory analysis (IA) more understandable and more manageable in relation to human health, the availability of resources, and the natural environment. Finally, the interpretation phase, which aims to evaluate the results from the inventory analysis or impact assessment and compare them with the goal of the study defined in the first phase [40, 41].

Figure 3.1 describes the overall methodology which was used in this research.

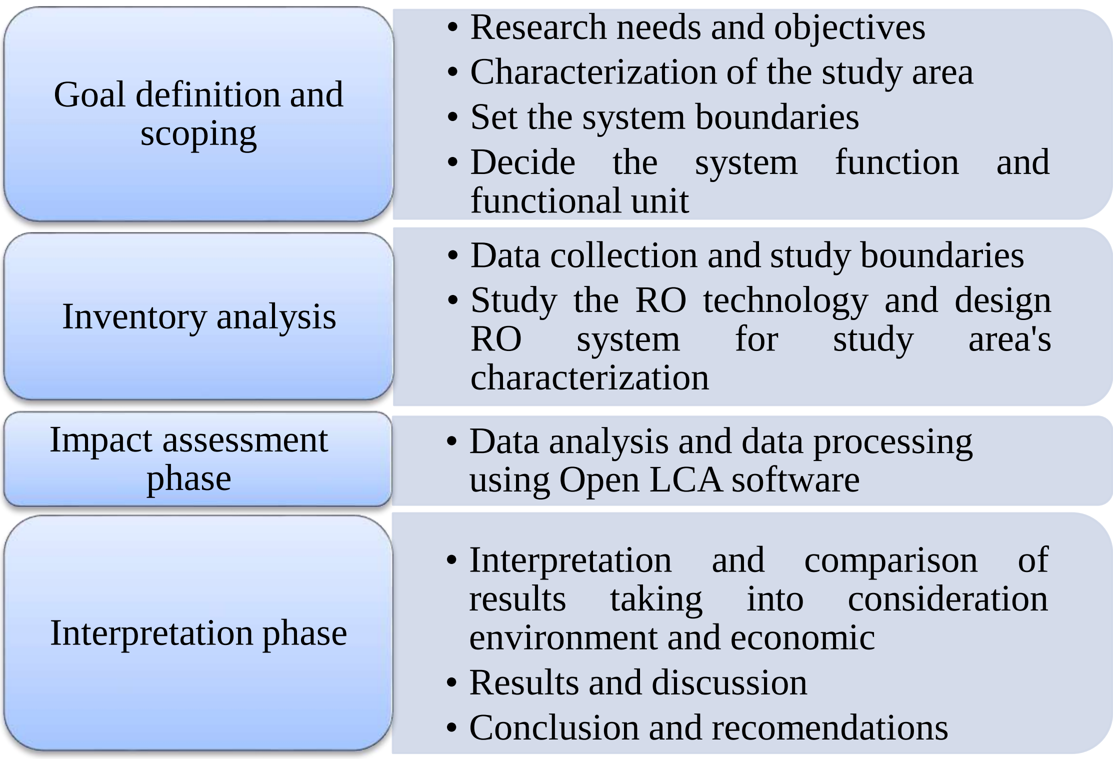

Fig. 3.1: Thesis methodology

3.1 Goals and scope

3.1.1 LCA objective

One of the purposes of using the life cycle assessment is to compare any two or more products and/or services achieving similar functions [32]. LCA used in this study considers RO system designed for Al-Fashkha springs operated by three different energy sources. The first system is RO system operated by PV (RO-PV system with batteries). The second system is RO system operated by electricity generated from coal (RO-coal electricity system). The third system is RO system operated by electricity generated from natural gas (RO-natural gas electricity system). The RO system designed depends on Al-Fashkha springs characterizations and to meet the needs of Al-Murashahat area. The main aim of this study is to determine which of the three systems is the best environment-friendly and economically feasible. It also aims to determine which phase of each system accounts for the highest impact on the environment.

3.1.2 Expected audience

This LCA provides valuable results about RO systems from an environmental and financial perspective to many beneficiaries including graduate students, researchers, government agencies (e.g. Palestinian Water Authority (PWA), Jericho Municipality and The Communal Committee of Aqabat Jabr Camp) and the sponsor of this study (i.e. MEDRC Water Research Organization). Furthermore, RO system designed to meet the demand of the 300 residents in Al-Murashahat area which is considered as pilot study. The results can be extended to larger scale use to serve thousands of residents.

3.2 System boundaries

3.2.1 Conceptual boundaries

RO system consists of three main processes, figure 3.2 shows the three main processes, which are hydraulic process (capital requirements such as tanks, HP pump and RO membranes), operation process and transportation of water process (water distribution by delivery truck of 10m^3) with different life cycle phases have been analyzed: manufacturing and transportation. In other words, it considers material inflow and outflow, from raw material extraction (i.e. cradle), to use phase, unfortunately it couldn’t reach the disposal phase (i.e. grave) due to lack of information. The considered system is essentially metallurgical components that require energy and heat intensive processing, which entails greenhouse gas emissions. To account for this fact, the embodied energy of metallurgical components, the energy required to manufacture the components, is explicitly considered on the LCA. The environmental impact associated with transporting systems and the required components is considered. The environmental impact associated with power consumption during the operational process was explicitly accounted for by multiplying the rated power of components consuming power times their total hours of operation. The start-off point for the analysis of the system operations will be a storage salted water tank and the cut-off point will be delivery of desalinated water to community (i.e. Al-Murashahat area). Insulation, packaging and piping materials are considered outside the system boundary and are not accounted for. Figures 3.2, 3.3 and 3.4 show the boundaries of the three systems.

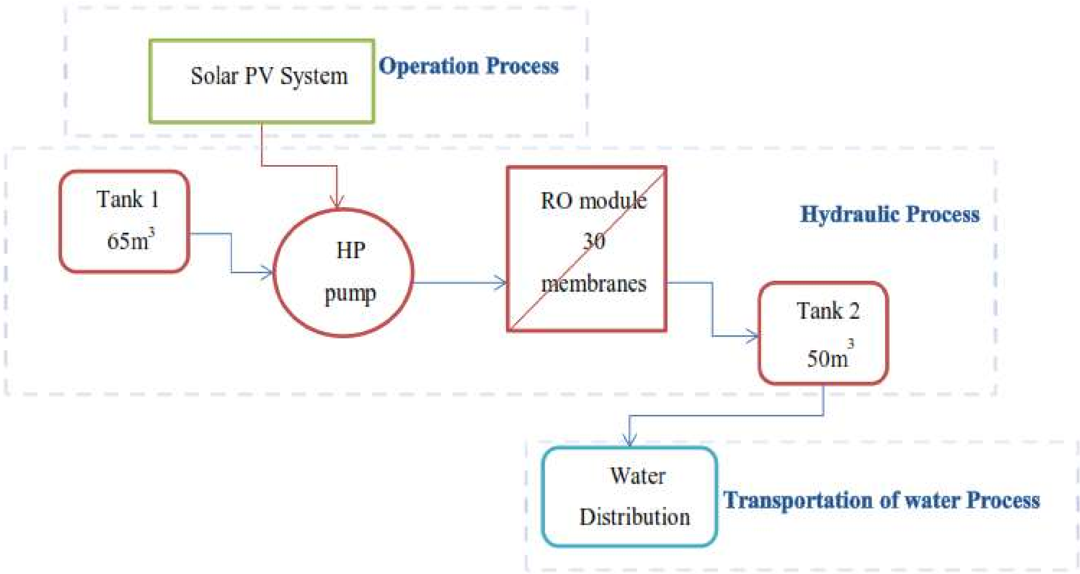

Fig. 3.2: LCA system boundaries of RO-PV system

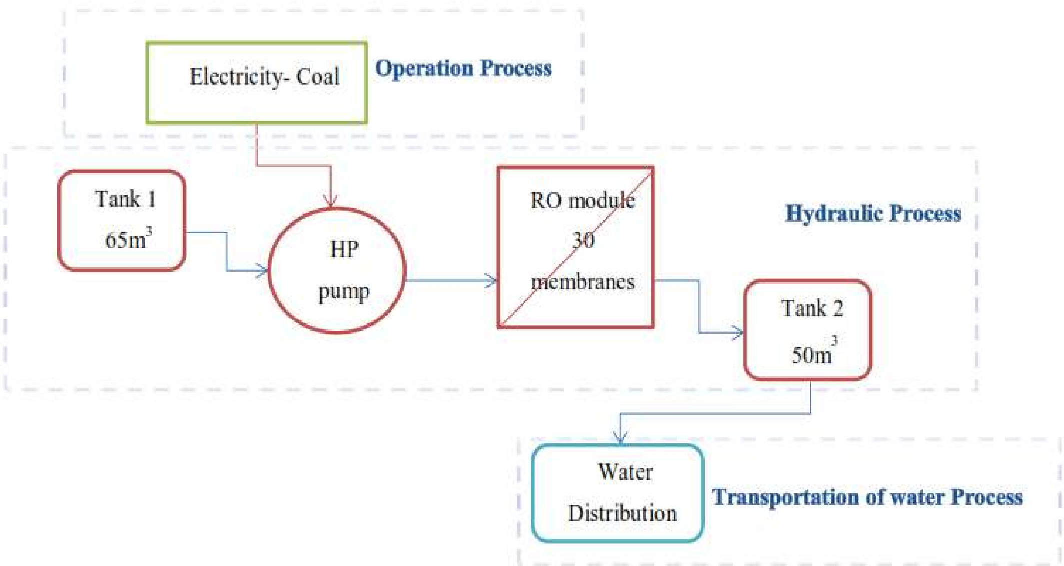

Fig. 3.3: LCA system boundaries of RO-coal electricity system

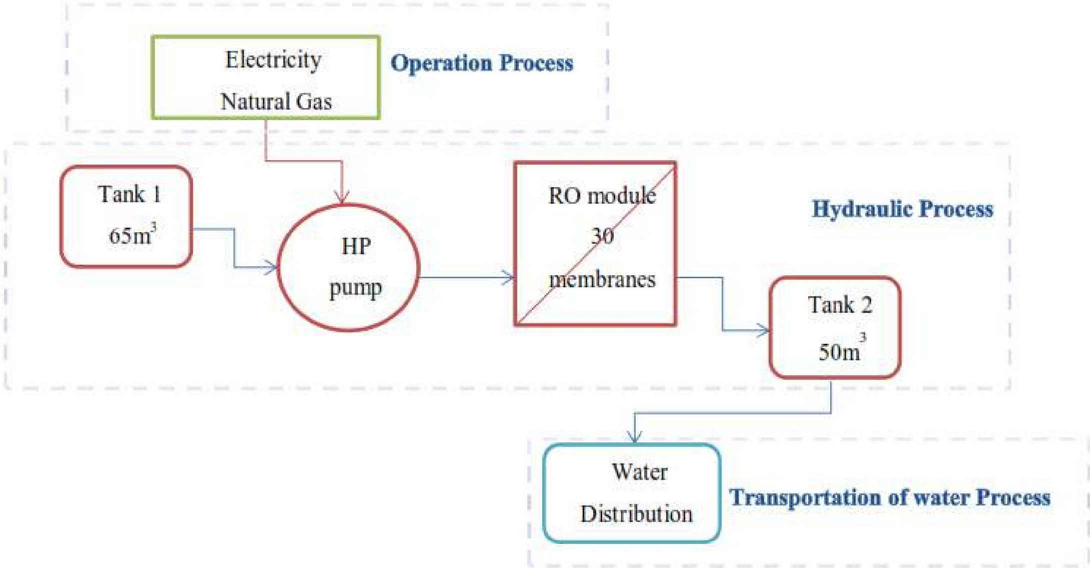

Fig. 3.4: LCA system boundaries of RO-natural gas electricity system

3.2.2 Geographical boundaries

The area study is Al-Fashkha springs, Palestine. The geographical boundaries were extended to include countries where some components and systems are manufactured and imported from. The RO membrane is produced in Germany and is shipped directly to Ashdod port in Israel. The pump is produced in USA and is shipped to Ashdod port. In RO-PV system the PV module is produced in China and the batteries is produced in Germany and are shipped to Ashdod port too. Both RO-coal electricity system and RO-natural gas electricity system are not generated locally and imported from Israel. The coal is produced in South Africa and the natural gas is produced in North Africa and then shipped to Ashdod port.

3.2.3 Temporal boundaries

An average life time of the system was assumed to be 20 years, according to previous studies in this field [32,9].

3.3 Function and functional unit

The function of the systems is desalinated water. The beneficiary of desalinated water will be Al-Murashahat area with 300 residents. Based on the average per capita consumption of water of 89 liter per capita per day, the required water demand calculated to serve this small community for the coming 20 years to be 50m^3/day taking into consideration 2.5% annual increase of population. This serves as the LCA functional unit of the RO systems.

3.4 RO system design

The RO system designed depends on Al-Fashkha springs water characteristics (founds on Appendix B) and to meet the expected water demand of Al-Murashahat area for the coming 20 years, which is calculated to be 50m^3/day. The system is assumed to be operated for 10 hours per day. The water temperature is 27.3 C^o. The design done by LewaPlus software program from LANXESS Engineering, for more information about full design details refer to Appendix (C) [42].

The RO system includes a set of RO membrane elements, housed in pressure vessels that are arranged in a design manner. A high-pressure pump is used to feed the pressure vessels. The RO system is operated in crossflow filtration mode, not in dead end mode, because of the osmotic pressure of rejected solute.

The RO system is usually designed for continuous operation and the operating parameters (permeate flow rate and recovery rate) are constant with time. Figure 3.5 illustrates the material balance of a typical RO system. The feed flow is divided to permeate and concentrate flow [42].

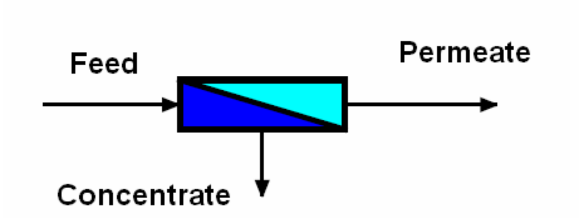

Fig. 3.5: Material balance of RO system [42]

3.4.1 Single-Module System

An RO membrane system consists of RO elements arranged in pressure vessels. The arrangement of the RO system can be single or double pass with the specific geometry of the pressure vessel arrangement described in stages, and with pressure vessels inside a stage arranged in what is called an array. Inside the pressure vessel, the elements are connected sequentially in series format with up to eight elements per pressure vessel.

The concentrate of first element becomes the feed to the second, and so on. The product water tubes (center pipe) of all elements are coupled, and connected to the module permeate port. In a single-module RO system, the system recovery rate is approximately 50%. This value is applicable to standard single pass seawater desalination systems.

To achieve the recovery rate higher than 50%, concentrate recirculation is applied. In this system configuration, part of concentrate is recycled and added to the suction side of the high-pressure pump, thus increasing the feed flow rate (shown in Figure 3.6). A high fraction of the concentrate being recycled helps reduce single hydraulic element recovery, and thus, reducing the risk of membrane fouling or scaling. On the other hand, concentrate recirculation has disadvantages of larger high-pressure feed pump, higher energy consumption and permeate quality decrease [42].

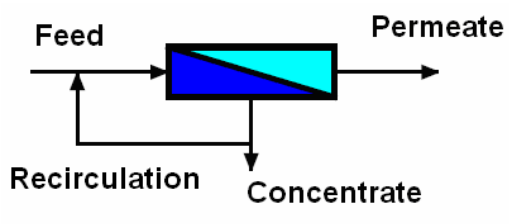

Fig. 3.6: Single module system with concentrate recirculation [42]

3.4.2 Single-Stage System

In a single-stage system, two or more vessels are arranged in parallel. Feed, concentrate and permeate lines from the parallel pressure vessels are connected to the corresponding manifolds. The single-stage system operates in the same way as a single module system. Single-stage system is typically used where the recovery rate does not exceed 50% to 60%, e.g., in seawater desalination [42].

3.4.3 Multi-Stage System

Systems with more than one stage are used for higher system recovery rates without exceeding the single element recovery limit. Usually two stages will be applied for recovery rate up to 75-80%. To compensate for the permeate which is removed and to maintain a uniform feed cross flow rate in each stage, the number of pressure vessels per stage decreases in the flow direction. In a typical two-stage system (shown in Figure 3.7), the ratio of vessel number is 2:1 (upstream: downstream) [42].

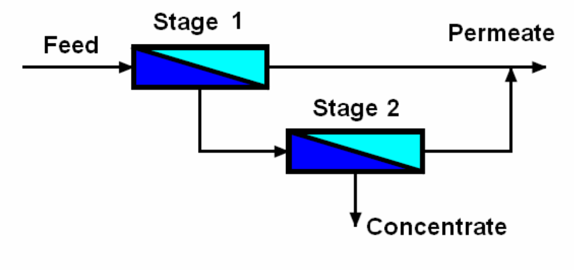

Fig. 3.7: Example of 2nd stage system [42]

The relation between recovery rate and the stage number is as follows [42]:

- 1 stage : < 50-60%
- 2 stage : < 75-80%
- 3 stage : < 85-90%

The following calculations have been made manually to double check the design [43.44]:

- Permeate Flow for the Plant= 50 m^3/day
- Operation will be for 10 hours
- So, Permeate Flow (Q_p)= 5 m^3/hr
- Temperature= 27.3 C^o
- PH= 6.73
- Brackish water plants usually operate at 75% and some up to 90% recovery [42], assumed recovery = 80%

$$R = \frac{Q_p}{Q_f} \qquad 3.1$$

Where:

R : assumed recovery

Q_p : permeate flow (capacity)

Q_f : feed flow

So, Q_f = (5/0.80) = 6.25 m^3/hr

When conversion has to be higher than 50% a second stage is necessary [7]. The number of vessels in the next stage is about 50% of the previous one; because the ratio feed flow to permeate flow at the entrance of the next stage is the same [43].

Total number of elements follows from [43]:

$$ne = \frac{A}{Ae} \qquad 3.2$$

$$A = \frac{Q_p}{J} \qquad 3.3$$

Where:

ne : number of elements

A : total required membrane area

Ae : membrane area per element

Q_p : permeate flow (capacity)

J : flux

Average permeate flux= 21.10 L/m^2/h (refer to Appendix (C))

A= 5/0.0211= 236.97 m^2

Ae = 7.9 m^2 (refer to Appendix (D))

ne= 236.97/7.9= 29.996= 30 elements (membranes)

Each vessel with six elements (refer to Appendix (C));

No of vessels= 30/6= 5

The RO plant will be two stages, the first stage with 3 vessels and the second stage with 2 vessels, which is matching the software design.

RO membrane type selected is spiral wound element the LEWABRANE RO B085 LE 4040 (40 inch length and 4 inch diameter), which is known of highest performance at lowest feed pressure and thereby of lowest energy consumption. The data sheet is found in Appendix (D) [45].

The high pressure pump type CRN5-20 from Grundfos company, power 5.5 kW was found to be the most suitable one for the RO system depends on the design. The data sheet is found in Appendix (E.1) [46].

Fig. 3.8: High pressure pump type CRN5-20 from Grundfos company

3.5 PV system design

The RO desalination system is powered by a PV system. The design of the PV system including the PV generator and the storage battery system. Determining the peak power of the PV generator depends on the daily electric load to be supplied and on the annual average of daily solar radiation in the area.

In order to determine the PV generator supply size the following data must be given [4]:

- Peak sun hours (PSH)= 5.4
- Safety factor of K= 1.15
- Operation will be for 10 hours

PV generator sizing

The key elements which will be used for the design are:

- Load rated power =5.5 kW
- Energy consumption per day E_d = 55 kWh/day
- The required nominal DC voltage for the system = 48 V_{DC}

1) The selection of the inverter size should be 25-30% bigger than total power of the load. The selected inverter for this site which is rated at an

output power of 5.5kW is a “Studer” inverter “XTH 8000-48” with a rated input voltage of $48V_{DC}$, apparent output power of 7000VA, and an efficiency (η_{inv}) of 96%. The data sheet is found in Appendix (E.2).

Fig. 3.9: Studer XTH 8000-48

2) The selection of a suitable charge regulator is the next step, where “BlueSolar charge controller MPPT 150/70” is used. The nominal output voltage is 48 V, the maximum input voltage is 150 volt PV open circuit voltage is 150 V, the maximum solar array input power is 4000W and the efficiency ($\eta_{C.R}$) at full load is 97.5%. The data sheet can be found in Appendix (E.3).

Fig. 3.10: BlueSolar charge controller MPPT 150/70

The following equation has been used in order to calculate the peak power for the PV generator.

$$E_{P.V} = \frac{E_d}{\eta_{inv} \times \eta_{C.R}} \qquad 3.4$$

Where:

$E_{P.V}$: generator daily energy

E_d : energy consumption per day

η_{inv} : inverter efficiency

$\eta_{C.R}$: charge regulator efficiency

So, $E_{P.V}$ = 55/ (0.96*0.975) = 59 kWh/day

$$P_{PVG} = \frac{E_{P.V} \times K}{PSH} \qquad 3.5$$

Where: P_{PVG} is the generator power peak

So, P_{PVG}= (59* 1.15) / 5.4 = 12.6 kW_p

3) The selection of the proper PV modules. The selected PV module is “P-type monocrystalline cells, YLM series” which is a crystalline module with MONO cells. The number of cells connected in series is 60 cells, and the dimensions are (1.640 * 0.990) = 1.62 m^2 area, rated at 280 W_P (P_{mpp}), 31.4 VDC (V_{mpp}), and 8.91A (I_{mpp}). The open circuit voltage $V_{O.C}$ is 39.3 V and the short circuit current $I_{S.C}$ is 9.38A. The efficiency of the module is 17.2%, all specifications are found in Appendix (E.4).

Fig. 3.11: P-type monocrystalline PV modules

Calculate the number of modules

The following equation has been used in order to calculate the number of PV modules:

$$\text{No. of modules} = \frac{P_{PVG}}{\text{P of one module}} \quad 3.6$$

No. of modules= (12.6*1000)/280 = 45 modules.

Since there are 2 C.R then we have 2 arrays: 24 modules for the first array and 21 modules for the second array.

No. of strings in the first array= 24/3= 8 strings (in parallel).

Which means 3 modules in series at each string.

No. of strings in the second array = 21/3= 7 strings (in parallel).

Which also means 3 modules in series at each string.

Battery block sizing:

The storage capacity for this system is considerably large. This is why the selected type should be a reliable, strong, and high quality block battery. The "OPzS solar.power" single cell battery is vented stationary battery with liquid electrolyte (diluted sulphuric acid). Due to the tubular plates technology "OPzS solar.power" batteries offer an extreme high cycling expectancy. The excellent cycling behavior of "HOPPECKE OPzS solar.power" tubular plate batteries is based on the around protection of positive mass by using of gauntlets. "HOPPECKE OPzS solar.power" batteries are optimal for application in sectors with high charge and discharge operation load like solar or off-grid applications, in partial during particle state of change operations, with 80% depth of discharge DOD, and 90% efficiency (η_{Batt}) Appendix (E.5).

Fig. 3.12: "HOPPECKE OPzS solar.power" batteries

Calculating the watt hour capacity for the block battery

The following equation has been used in order to calculate the capacity in Amper hour for the block battery:

$$C_{Ah} = \frac{E_d}{DOD \times \eta_{inv} \times \eta_{Batt} \times V_{system}} \quad 3.7$$

Where:

C_{Ah} : capacity in Ampere hour

E_d : energy consumption per day

DOD : depth of discharge

η_{inv} : inverter efficiency

η_{Batt} : batteries efficiency

V_{system} : voltage for the system

So, C_{Ah} = (55*1000)/ (0.80*0.96*0.90*48)

C_{Ah} = 1657.7 Ah\day

The calculations will be for two autonomy days, so:

C_{Ah} 2 Days = 2* 1657.7 = 3315.5 Ah

The selected battery cells for this site will be “11 OPzS solar.power 1670, 2V”, with C10/1.80 V and Amper hour capacity of 1255.8 Ah at 2V.

The number of battery strings is 3315.5 /1255.8 = 2.6, so 3 strings (in parallel)

The number of cells per string = 48/2= 24 battery cell (in series)

The total number battery cells = 3*24 = 72 batteries

The watt hour capacity of the battery bank will be= 3*1255.8*48= 180835

Wh.

Table 3.1 shows the design summary for PV system.

Table 3.1: Summary of PV system design

Component	Value
Load Rated power kW	5.5
E_d kWh/day	55
E_{PV} kWh/day	59
P_{PVG} kW_P	12.6
No. calculated PV modules	45
No. actual PV modules	45
No. arrays	2
No. strings 1^{st} arrays/2^{nd} arrays	8/7
$V_{OC.PVG}$ Volts	39.3
$I_{SC.PVG}$ Amperes	9.34
Ampere hour capacity C_{Ah} 2 days Ah	3315.5
Watt hour capacity C_{AW} Wh	1255.8
No. battery strings	3
No. batteries in series	24
No. batteries	72

Figure 3.13 shows the components of PV system which are PV arrays, batteries, inverter and charge controller, the connection between all components and the arrangement of PV modules and batteries.

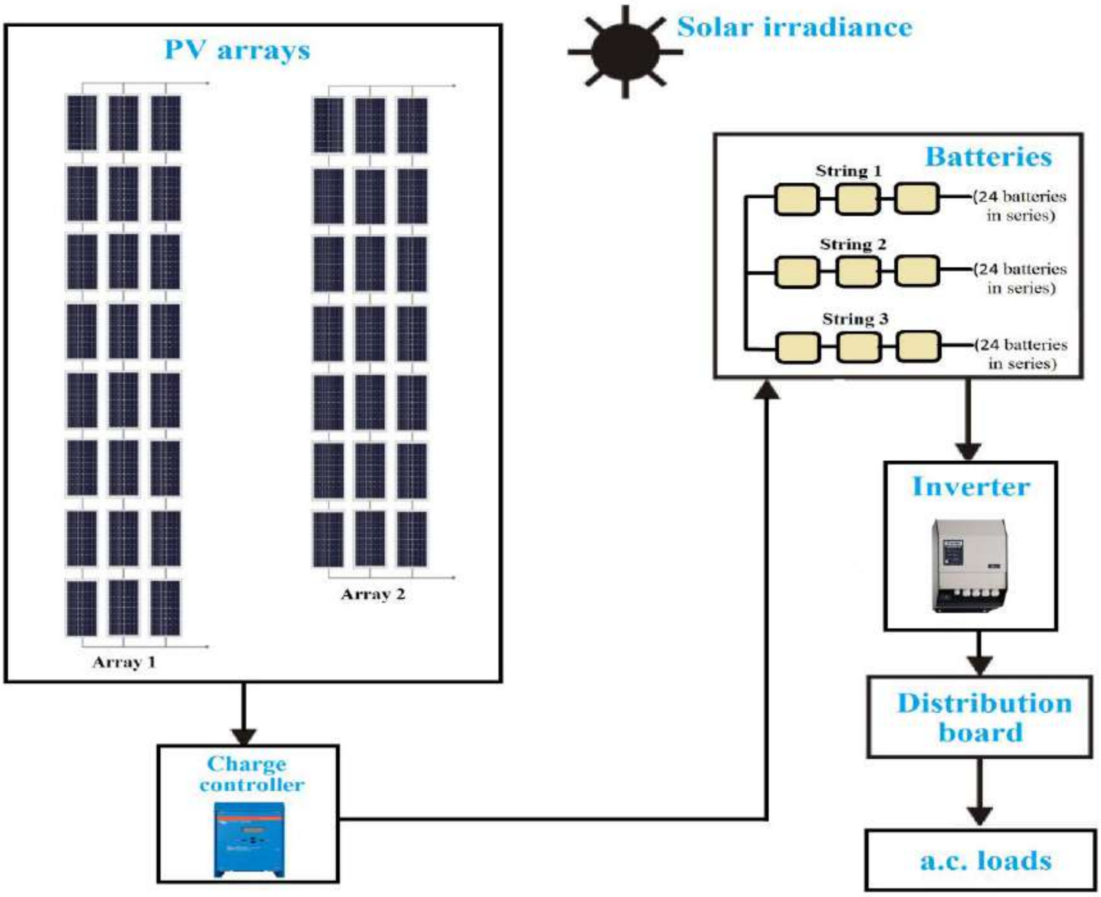

Fig. 3.13: PV system components and connections

3.6 Economic analysis

Detailed cost estimate including initial and running costs for different components of the three RO systems (i.e. RO-PV system, RO-coal electricity system and RO-natural gas electricity system) will be calculated based on the local market prices.

Then, a comparison for the cost of producing 1m^3 of water between the three RO systems will be made to determine the lowest cost between the three RO systems.

The key elements which will be used for economic analysis are:

- Permeate flow for the plant= 50 m^3/day
- Electricity needs per day= 75 kWh
- Life time of project is 20 years

3.7 Impact assessment

Through a literature study, required data for materials and design specifications for the three systems were obtained using openLCA (version 1.4.2) [47,48] and the EcoInvent 3.1 databases [49] consisting of materials, emissions and the impact assessment method CML (Institute of Environmental Sciences) [50] have been used to perform life cycle impact analysis. Global supply chains for products are also present in the database.

According to the CML method, the environmental impact is quantified on 10 impact categories [50]:

- Acidification potential
- Climate change
- Depletion of resources
- Eutrophication
- Freshwater aquatic eco toxicity
- Human toxicity
- Marine aquatic eco-toxicity

- Ozone layer depletion
- Photochemical oxidation
- Terrestrial eco-toxicity

The inventory process was the biggest challenge. Data of the systems were collected from manuals, manufacturer data sheets and published scientific papers, in order to know the exact mass of materials, energy and other sources used to build each system. The detailed systems inventories are shown in results and discussion chapter.

3.7.1 Life cycle assessment processes

RO system consists of three main processes which are hydraulic process (capital requirements), operation process and transportation of water process (water distribution) with different life cycle phases have been analyzed: manufacturing and transport.

3.7.1.1 Manufacturing

For the three main processes of RO system, data of the amount of power, metals, energy, plastics and electronics have been collected from manufacturer's manuals, sheets, and scientific papers [32, 45, 46, 51, 52]. Ecoinvent 3.1 database has been used to provide a comprehensive picture of the size of elements, raw materials, natural sources inputs, and to calculate the environment impacts [49].

3.7.1.2 Transport

Only shipping by sea or ocean from country of origin port to Ashdod port is considered in this phase. To determine the distance between ports, SEA-Distance Organization website has been used [53]. Ecoinvent 3.1 database has been used in this phase to provide complete results [49].

For more information, the detailed systems inventories are shown in results and discussion chapter.

Chapter Four

Results and Discussion

All results which were obtained after applying the previous methodology are listed and discussed in this chapter, including economic analysis results and environmental impact analysis results.

4.1 Economic assessment

This section discusses the initial and running costs of the three RO systems (i.e. RO-PV system, RO-coal electricity system and RO-natural gas electricity system) based on the local market prices.

The key elements which will be used for economic analysis are:

- Permeate flow for the plant= 50 m^3/day
- Electricity needs per day= 75 kWh
- Life time of project is 20 years

To compare the cost between RO-PV system and RO-electricity system (coal or natural gas) the following calculations have been made:

Calculate the cost of RO-PV system

In this section the annual worth for RO-PV system and the cost of 1 m^3 water produced by RO-PV system will be calculated.

Table 4.1 shows the prices of each component of RO-PV system, total capital cost, operating and maintenance cost, and salvage value. In this study salvage value is suggested to be 10% of total capital costs while operating and maintenance cost is assumed to be 6% of total capital costs.

Table 4.1: Incomes and out-comes for RO-PV system

Component	Quantity (No)	Unit price ($)	Life time year	Total price ($)
RO system components cost				
RO membranes	30	400	5	12,000
HP pump	1	22,000	10	22,000
Rest of RO system	1	56,000	20	56,000
Tank (65m^3)	1	9,500	20	9,500
Tank (50m^3)	1	7,500	20	7,500

RO system capital cost				107,000
Operating and maintenance cost= 6% of capital cost				6,420
Salvage value suggested to be 10% of capital cost				10,700
Operated by PV				
PV system	1	25,000	20	25,000
Batteries	72	470	5	33,840
PV capital cost				58,840
Operating and maintenance cost= 6% of capital cost				3,530
Salvage value suggested to be 10% of capital cost				5,884

The cash flow chart will show the incomes money and out-comes money for RO-PV system over 20 years as represented in Figure 4.1.

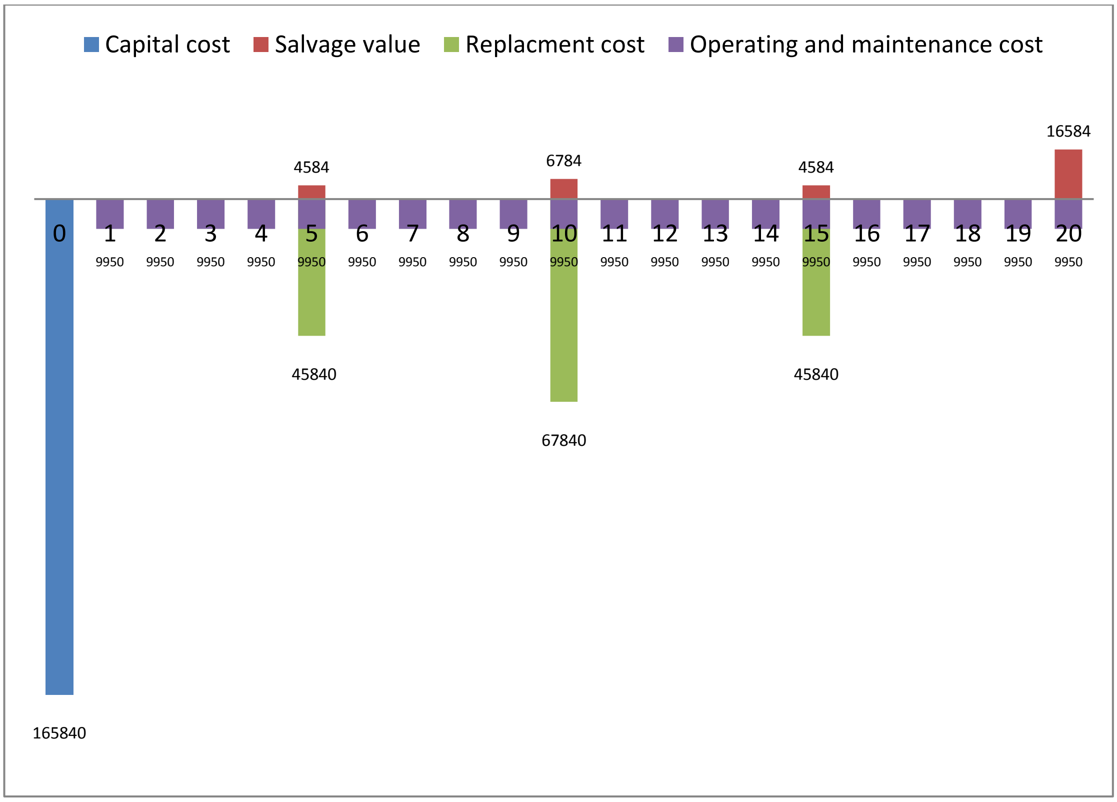

Fig. 4.1: Cash flow chart for RO-PV system

The annual worth (AW) for RO-PV system has been calculated, assuming the interest rate of 10%.

$AW_{Total}=AW_{RO\ membranes} + AW_{HP\ pump} + AW_{Rest\ of\ RO\ system} + AW_{Tank\ 65m3} + AW_{Tank\ 50m3} + AW_{PV\ system} + AW_{Batteries}$

4.1

AW_{Total}= 12000 (A/P,10%,5) + 22000 (A/P,10%,10) + 56000 (A/P,10%,20) + 9500 (A/P,10%,20) + 7500 (A/P,10%,20) + 25000 (A/P,10%,20) + 33840 (A/P,10%,5)

Annual worth for RO-PV system= 32,794.5 $

In order to calculate the cost of 1 m^3 water produced by RO-PV system:

Total daily cost of RO-PV system= 32,794.5 $ /365 days=89.85 $/day

The daily water production 50 m^3/day, then

Total cost of 1 m^3 water produced by RO-PV system=89.85/50=1.8 $/m^3$.

Calculate the cost of RO-electricity system (coal or natural gas)

The electricity price is fixed from the source (i.e. Electricity Company) regardless it generated from coal or natural gas.

The prices and cost details for RO system components shown in Table 4.1 are constant for the three systems, the only difference is in the operation (source of energy), operated by PV in RO-PV system and operated by electricity in RO-electricity systems (coal or natural gas). The electricity price is 0.5 NIS/kWh [54], which is fixed in RO-electricity systems (coal and natural gas). In this study the salvage value is suggested to be 10% of total capital costs while operating and maintenance cost is assumed to be 6% of total capital costs and the used conversion rate US$/NIS is 3.5.

The cash flow chart will show the incomes money and out-comes money for RO- electricity system over 20 years.

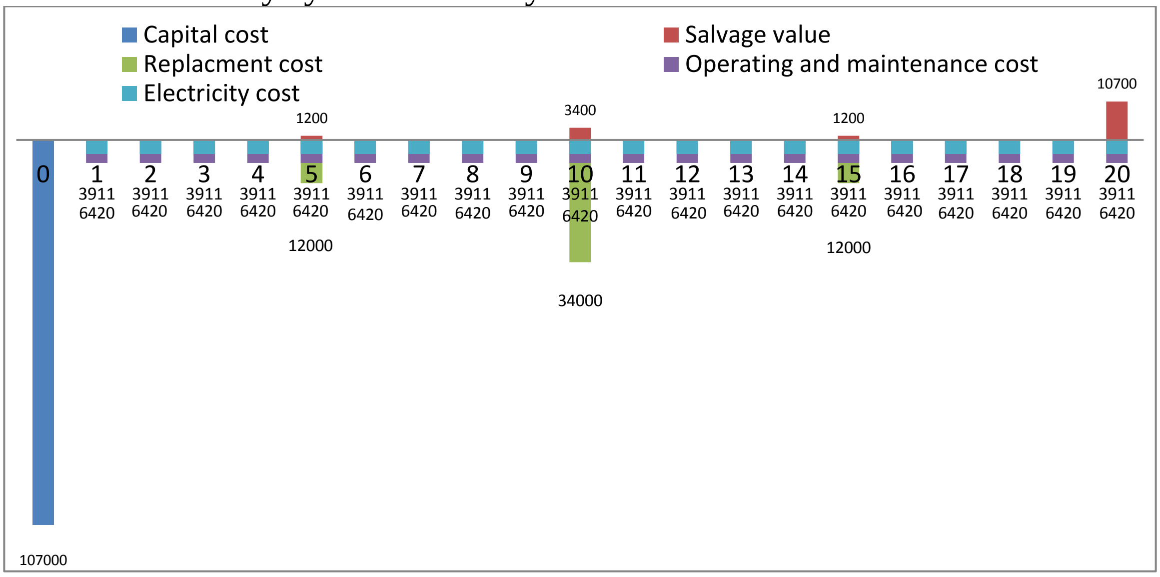

Fig. 4.2: Cash flow chart for RO-electricity systems

To compare the cost between RO-PV system and RO-electricity system (coal or natural gas) the same calculations have been repeated for RO-electricity systems, assuming the interest rate of 10%.

$AW_{Total}=AW_{RO\ membranes}+AW_{HP\ pump}+AW_{Rest\ of\ RO\ system}+AW_{Tank\ 65m3}+AW_{Tank\ 50m3}+AW_{electricity}$ 4.2

$AW_{Total}=$ 12000 (A/P,10%,5) + 22000 (A/P,10%,10) + 56000 (A/P,10%,20) + 9500 (A/P,10%,20) + 7500 (A/P,10%,20) + 3911

Annual worth for RO- electricity systems= 23,255 $

In order to calculate the cost of 1 m^3 water produced by RO-electricity system:

Total daily cost of RO-electricity system = 23,255/365=63.71 $/day

Total cost of 1 m^3 water produced by RO-electricity system

=63.71/50=1.27 $/m^3$.

Calculation of water distribution cost

In this study, the distribution of water using delivery trucks has been assumed due to political and financial reasons that prevent using pipeline system which are: the pipeline route between Al- Fashkha springs and Al-Murashahat area is controlled by Israel and the cost of construction of the pipeline system will be high due to the long distance of the route (i.e. 25km).

Cost of water delivery truck (10m^3) to Al-Murashahat area = 250 NIS, which was found from calling delivery truck drivers from nearby regions.

Then cost of 1m^3 =250/10= 25 NIS/m^3 which is equal 7.14 $/m^3**.**

In conclusion the total cost of 1 m^3 water produced by RO-PV system is calculated at 1.8 $/m^3. In comparison, the total cost of 1m^3 water produced by RO-electricity system is calculated at 1.27 $/m^3 (coal or natural gas). Changing the electrical power source in RO-electricity systems such as coal or natural gas has no cost impact because the electricity price is fixed from the electricity company. The cost of water produced by RO-electricity systems (coal or natural gas) is lower than the cost of RO-PV system, this is due to the high cost of PV batteries in RO-PV system. Furthermore, the cost of delivery between Al-Fashkha springs to Al-Murashahat area by trucks is calculated at 7.14 $/m^3, this is constant for all three systems.

4.2 Systems inventories

RO system consists of three main processes which are hydraulic process (capital requirements), operation process and transportation of water process (water distribution) with different life cycle phases have been analyzed: manufacturing and transport.

4.2.1 RO system hydraulic process

4.2.1.1 RO membrane

- Manufacturing:

4" membrane (B085 FR 4040) from LANXESS company [45]

Weight= 4.2 kg

Energy in production for 20 years (PER) [32]:

$$PER(MJ) = 5224.7 \times Q_P \qquad (4.3)$$

Where Q_P is the permeate water= 50 m^3/day

So, PER= 261235 MJ

Table 4.2: Composition of dry 4″ membrane elements [51]

Components	4" membrane mass of material (kg)	Type of material
Outer casing	0.6	Fiberglass with polyester resin
Membrane sheet	1.2	Polyester (PET) base with polysulfone (PSf) supporting layer and polyamide (PA) active layer
Feed spacer	0.35	Polypropylene (PP)
Permeate spacer	0.45	Polyester (PET)
Tube and end caps	1.2	Acrylonitrile butadiene styrene (ABS)
Glued parts	0.4	Polyurethane glue

- Transport:

From Germany to Ashdod port= 6617.196 km [53]

4.2.1.2 Pump

- Manufacturing:

High pressure pump (CRN5-20) from GRUNDFOS company [46].

Weight= 69.1 kg

Power required by pump= 5.5 kW

Energy in production for 20 years (PER) [32]:

$$PER\ (MJ) = 684.87 \times P_2 \times 2 \tag{4.4}$$

Where P_2 is Power required by pump= 5.5 kW

So, PER = 7533.57 MJ

Table 4.3: Materials amount of HP pump [32]

Mass of material (kg)	Type of material by percentage
58.735	85% Stainless steel
3.455	5% Cast iron
3.455	5% Copper
3.455	5% iron

- Transport:

From USA to Ashdod port= 9911.904 km [53]

4.2.1.3 Tanks

- Manufacturing:

Tank1= 62.5 m^3, assumed to be 65 m^3 based on local market available sizes.

Tank2= 50 m^3

Weight for tank= 4.2 kg/m^3 [32]

Energy in production for 20 years [32]:

$$PER\ (MJ) = 371.61 \times (V_1 + V_2) \quad 4.5$$

Where V_1, V_2 are the volumes of Tank1, Tank2 which are $65m^3$, $50m^3$ respectively.

So, PER =42735.15 MJ

Table 4.4: Materials amount of tanks [32]

Mass of material for Tank1 (kg)	Mass of material for Tank2 (kg)	Type of material by percentage
218.4	168	80% PVC
54.6	42	20% Fiber reinforced plastic

- Transport:

Tanks from local manufacture have been used.

4.2.2 RO system operation process

4.2.2.1 PV system

- Manufacturing:

P-type (monocrystalline cells YLM series), refer to Appendix (E.4)

Number of modules= 45

Weight for each module= 18.5 kg

OPzS solar.power) batteries type), refer to Appendix (E.5)

Number of batteries= 72

Weight for each battery= 25.2 kg

Energy in production for batteries for 20 years [52]:

PER (MJ) = 31 MJ/kg

So, PER = 224986 MJ

Table 4.5: Materials amount of battery [52]

Mass of material (kg)	Type of material by percentage
6.3	25% Lead
8.82	35% Lead oxides
2.52	10% Polypropylene
2.52	10% Sulfuric acid
4.03	16% Water
0.504	2% Glass
0.252	1% Antimony

- Transport:

Transport of PV system from China to Ashdod port= 12575.08 km [53]

Transport of batteries of PV system from Germany to Ashdod port= 6617.196 km [53]

4.2.2.2 Electricity- natural gas:

Include extraction and transportation of natural gas and power plant operation (electricity generation)

To calculate the volume of natural gas needs:

Power required for the system per day= 75kWh

The efficiency of the power plant (μ) = 0.35

So;

The power input= 75/0.35= 214.3 kWh

Heating value= 37.3 MJ/m^3

$$\text{The volume of natural gas} = \frac{\text{Power input}}{\text{Heating value}} \qquad 4.6$$

The volume of natural gas= (214.3× 3.6)/37.3

The volume of natural gas needs per day= 21m^3

Transport of natural gas from North Africa to Ashdod port= 2950.236 km [53]

4.2.2.3 Electricity- coal:

Include mining and transportation of coal and power plant operation (electricity generation)

To calculate the volume of natural gas needs:

Power required for the system per day= 75kWh

The efficiency of the power plant (μ) = 0.35

So;

The power input= 75/0.35= 214.3 kWh

Heating value= 23.9 MJ/kg coal

By applying equation 4.6:

The weight of coal = (214.3× 3.6)/23.9

The weight of coal needs per day= 32.3 kg

Transport of coal from South Africa to Ashdod port= 10128.59 km [53]

4.2.3 RO system water distribution process

Transport water from Al- Fashkha springs to Al-Murashahat area by delivery truck of 10m^3, where the distance between them is 25 km. Furthermore, the permeate water per day is 50m^3, and the delivery truck size is 10m^3, the required number of delivery trucks per day will be 5 trucks.

4.3 Environmental impact assessment

The CML base line method (Institute of Environmental Sciences) has been used to obtain the environmental impacts of the main process of three RO systems by the LCA phases for this study which are manufacturing and transport. The detailed systems inventories for the three RO systems shown in section 4.2 have been used as a base to assess the impact of each system.

Figure 4.3 shows the environmental impacts For the RO-PV system during the three processes of the life of the system (i.e. hydraulic process, operation process and water distribution process). It seems that the water distribution process has the major impacts on the CML method 10 categories (i.e. acidification potential, climate change, resources depletion, eutrophication, freshwater aquatic eco toxicity, human toxicity, marine aquatic eco-toxicity, ozone layer depletion, photochemical oxidation and terrestrial eco-toxicity). Operation process (PV process) also contributes significantly in the system life cycle impact. Hydraulic process does not contribute significantly as in the case of water distribution and operation processes.

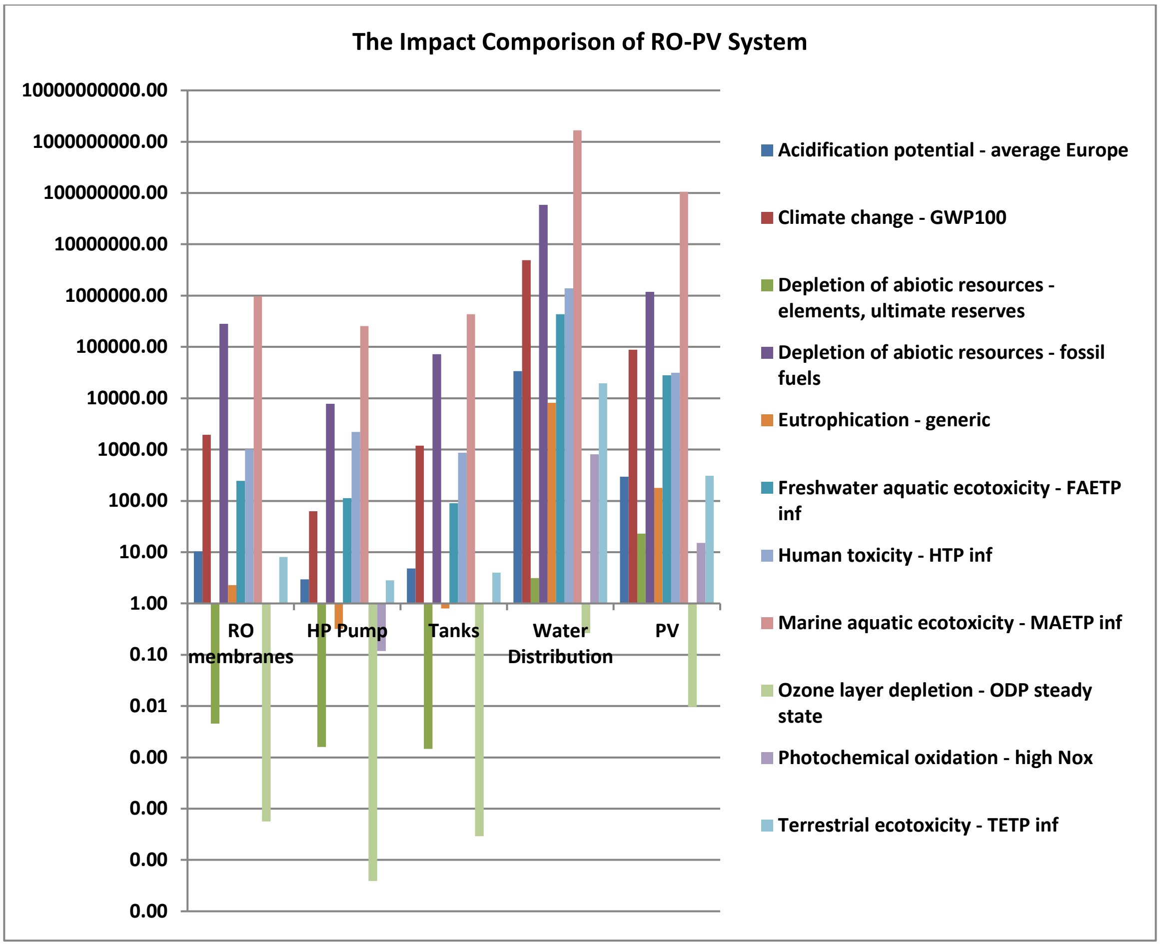

Fig. 4.3: The impacts of all processes together for RO-PV system

Figures 4.4, 4.5, and 4.6 show the impacts of each process alone for three systems. In hydraulic process, the RO membranes have the largest value for most of impacts except human toxicity category, where the highest impact is a result of the high pressure pump. This is due to the large mass and high amount of energy used in manufacturing of RO membranes which are also replaced each 5 years of the system life. The tanks have relatively large mass but a less impacts on the system because it has been assumed not to be replaced for the 20 years. The significant result in Figure 4.3 is the high values of marine aquatic ecotoxity, depletion of abiotic resources–fossil fuels and climate change for water distribution process and that because of using delivery water trucks (5 trucks per day for 20 years).

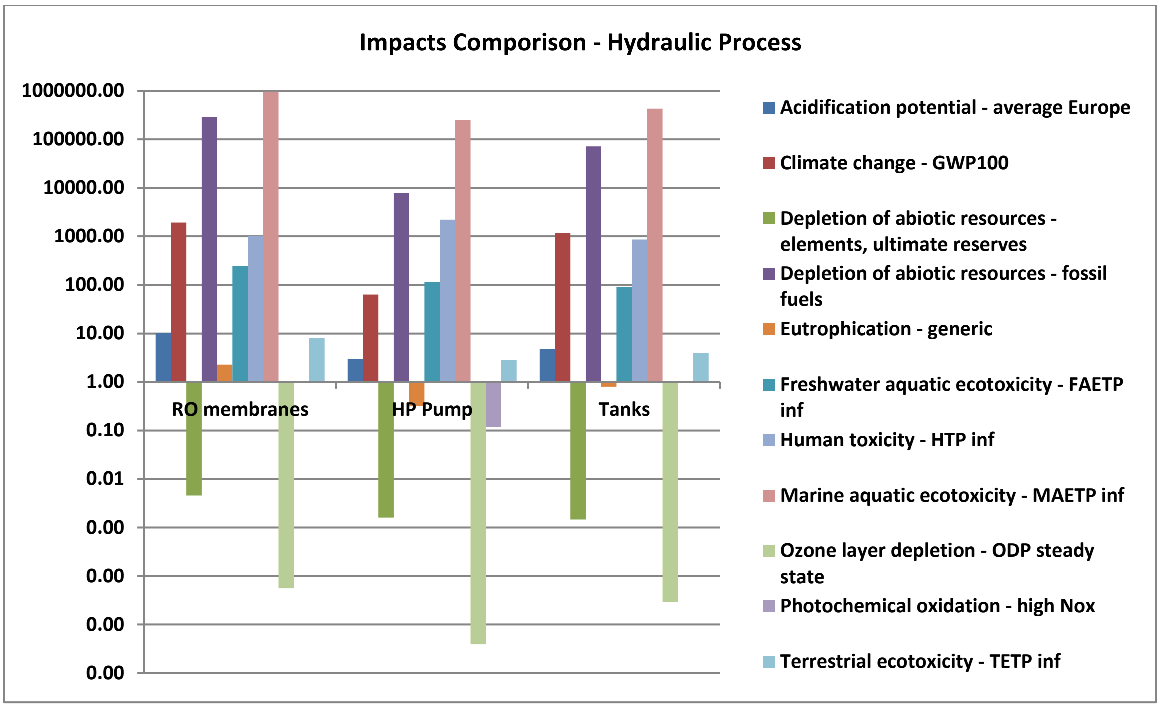

Fig. 4.4: The impacts of all components of hydraulic process

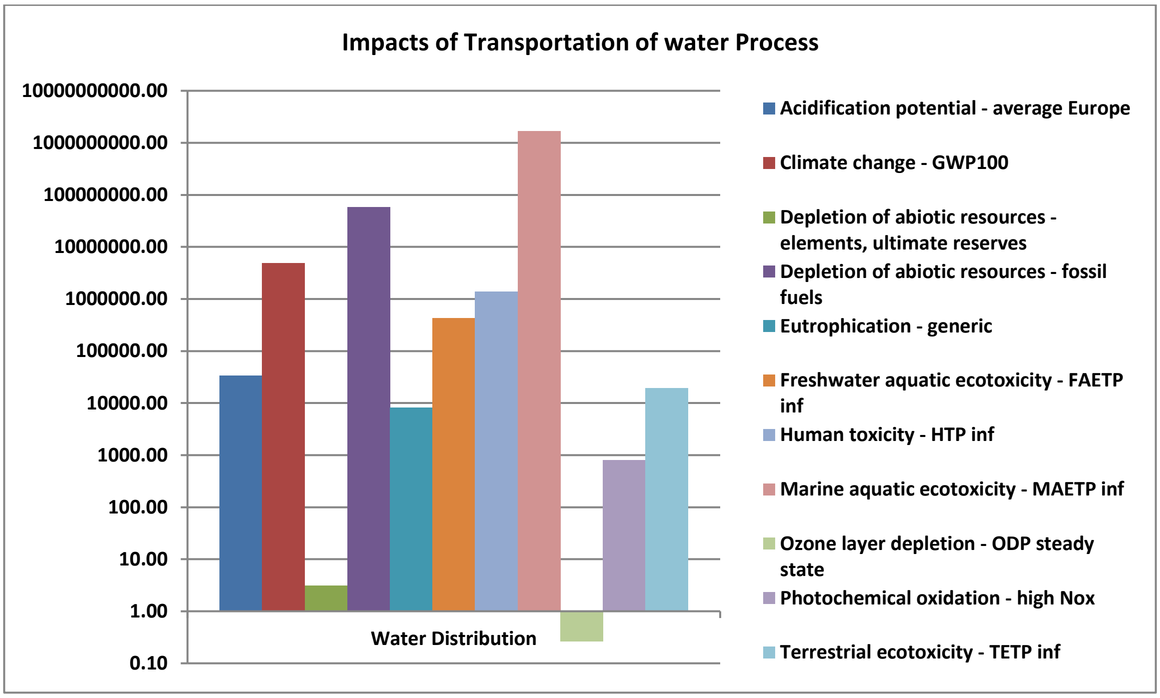

Fig. 4.5: The impacts of water distribution process

Figure 4.6 shows the operation process for the three systems. The operation process differs between the three systems and plays an important role in RO system. The majority of categories in the coal electricity reveal the biggest impact values. This is due to the large amount of energy consumption and the source of the energy used (i.e. coal power station). That is also clear in Figure 4.7 which shows the comparison of the whole processes impacts of the systems. The high values of the RO-coal electricity system impacts in comparison to the RO-natural gas electricity system give us a clear indication about the extensive damage caused by burning of coal compared to gas. But for the comparison between RO-PV system and RO-natural gas electricity, the high values of the most impacts belong to natural gas system except depletion of abiotic resources–elements, eutrophication-generic and freshwater aquatic ecotoxicity, despite that they are closed values that because of the manufacturing of PV system components.

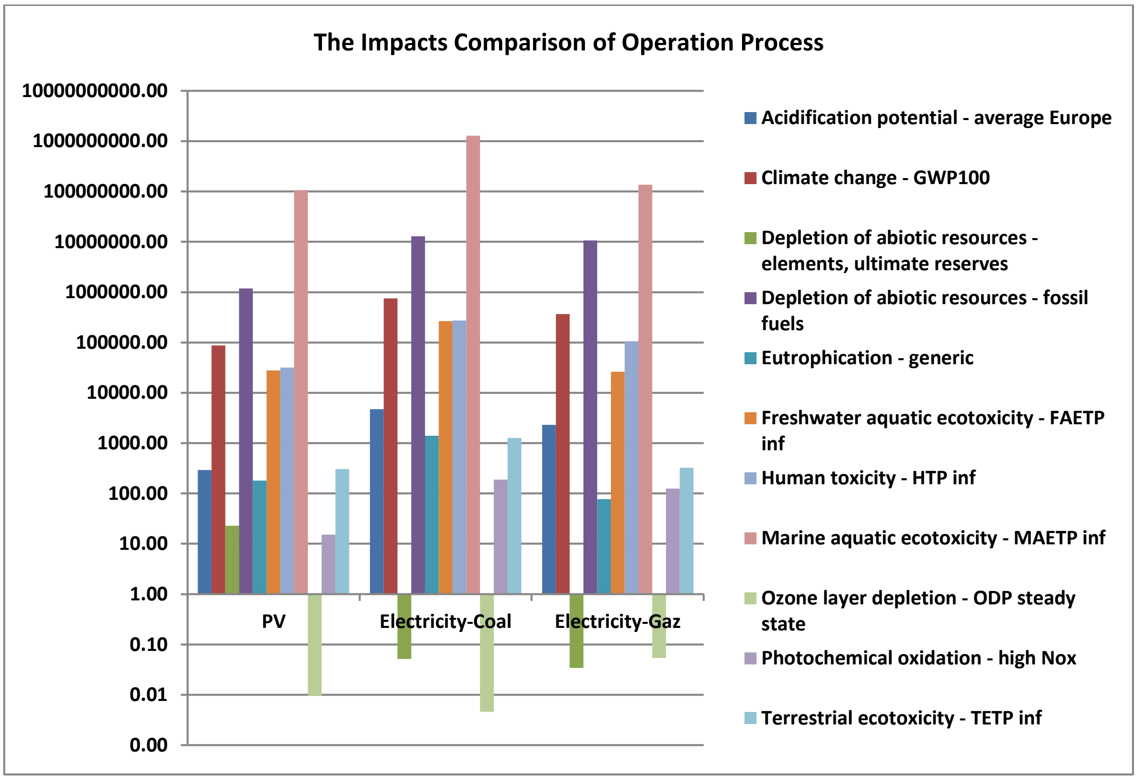

Fig. 4.6: The impacts of operation process in the three systems

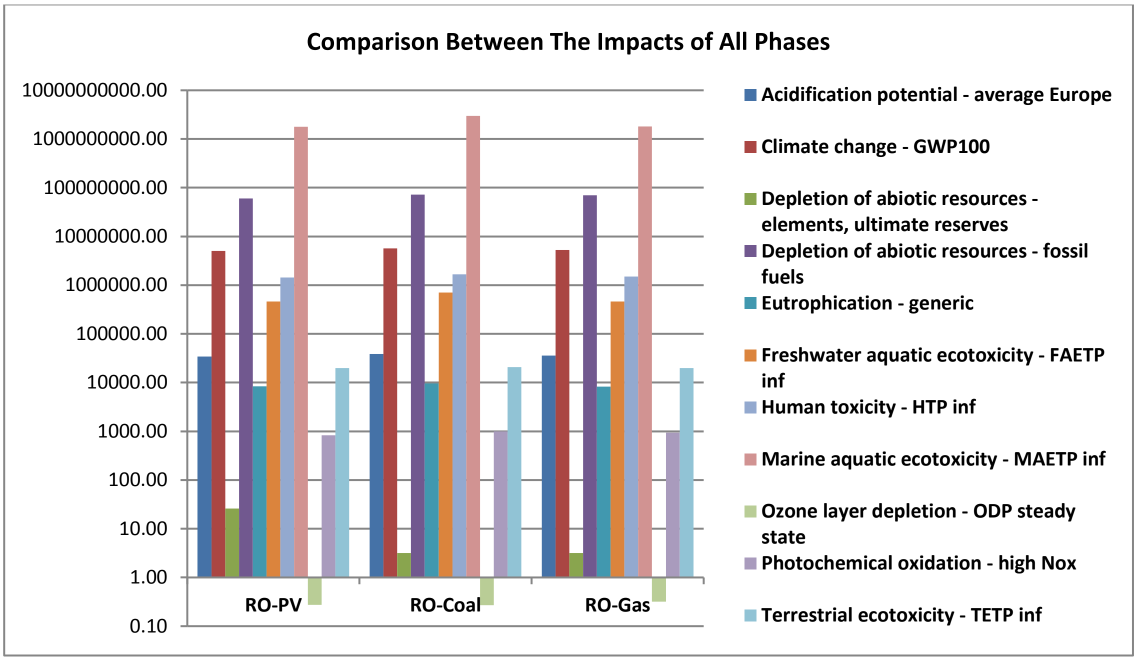

Fig. 4.7: Comparison between the impacts of all processes in the three systems

Appendix (F) contains the impact on each CML damage subcategory of all processes.

Figures 4.8, 4.9 and 4.10 altogether give a clear idea about the contribution of each process as a percentage. Figure 4.8 shows the contribution of hydraulic process life cycle impacts for each system which is small contribution and values are very closed in all systems. The impact values of depletion of abiotic resources – fossil fuels comes from RO membranes, human toxicity comes from high pressure pump and photochemical oxidation comes from tanks are the highest impact values among the hydraulic process in the three systems. The impacts of depletion of abiotic resources – fossil fuels comes from RO membranes are 0.47%, 0.39% and 0.41% for RO-PV system RO-coal electricity and RO-natural gas electricity, respectively. The impacts of human toxicity comes from high pressure pump are 0.15%, 0.13% and 0.15% for RO-PV system RO-coal electricity and RO-natural gas electricity respectively. Finally the impacts of photochemical oxidation comes from tanks are 0.15%, 0.13% and 0.15% for RO-PV system RO-coal electricity and RO-natural gas electricity respectively.

Figure 4.9 shows the significant effect of the water distribution process for the three systems in all impacts. 99.08% of acidification potential impact for the RO-PV system comes from the water distribution process, 98.25% of ozone layer depletion impact of the RO-coal electricity system comes from the water distribution process and for RO-natural gas Electricity 99.03% of eutrophication-generic comes from the water distribution process. Furthermore, other important impacts like climate change and human toxicity have also a huge effect of the water distribution process for the three systems. 98.19%, 86.69% and 93% of climate change impact of RO-PV system, RO-coal electricity and RO-natural gas electricity respectively also comes from the water distribution process. 98.7%, 99.8% and 99.8% of human toxicity impact of the RO-PV system, RO-coal electricity and RO-natural gas electricity respectively comes from the water distribution process.

Figure 4.10 shows that 87.96% of depletion of abiotic resources – elements impact comes from the operation process for the RO-PV system, 43.53% of marine aquatic ecotoxicity impact for the RO-coal electricity also comes from the operation process and 16.99% of ozone layer depletion impact for the RO-natural gas electricity comes from the operation process. If the water distribution process eliminated from the systems, the operation process will be the main contributor of the life cycle assessment for the three systems.

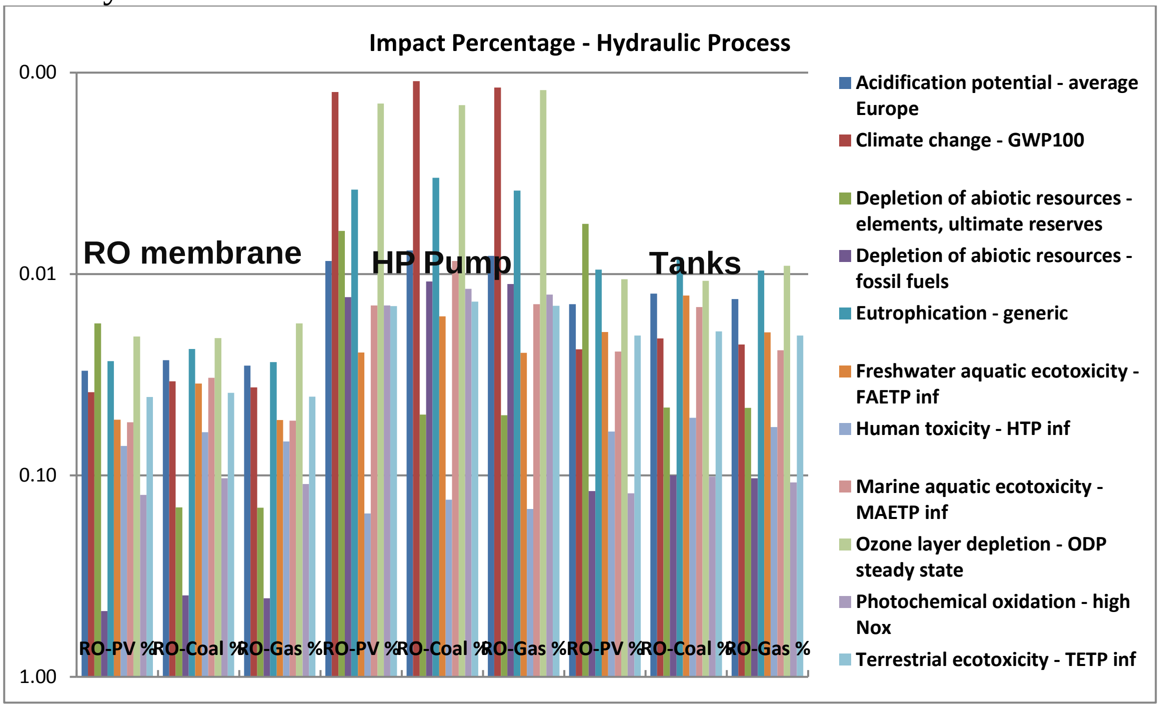

Fig. 4.8: Percentage of hydraulic process contribution in the three systems life cycle's impact

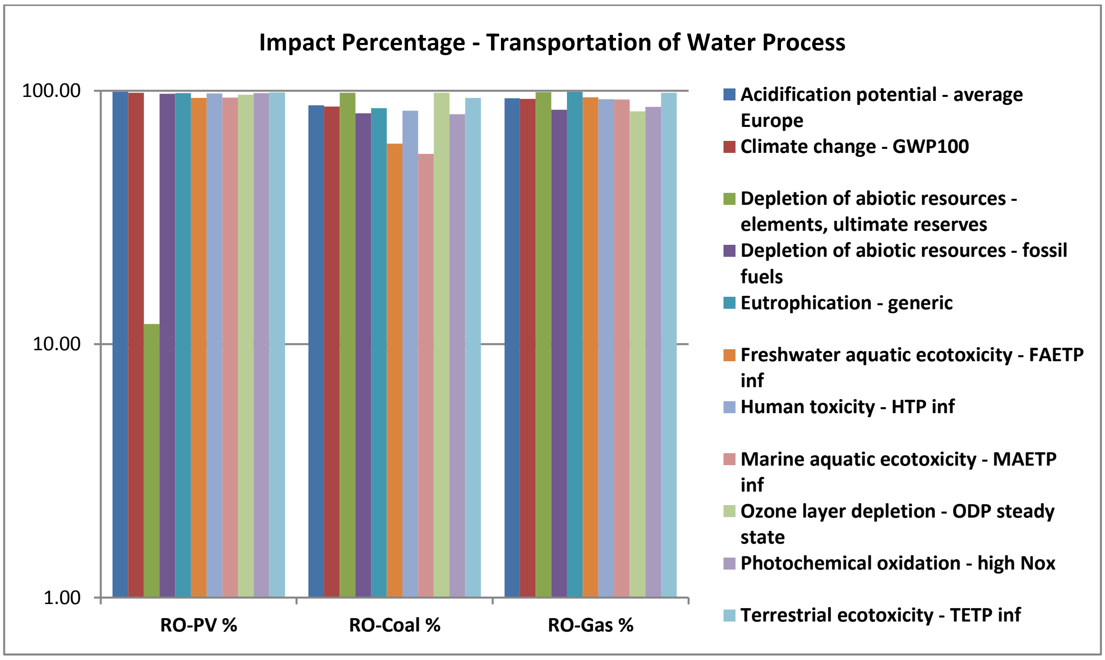

Fig. 4.9: Percentage of transportation process contribution in the three systems life cycle's impact

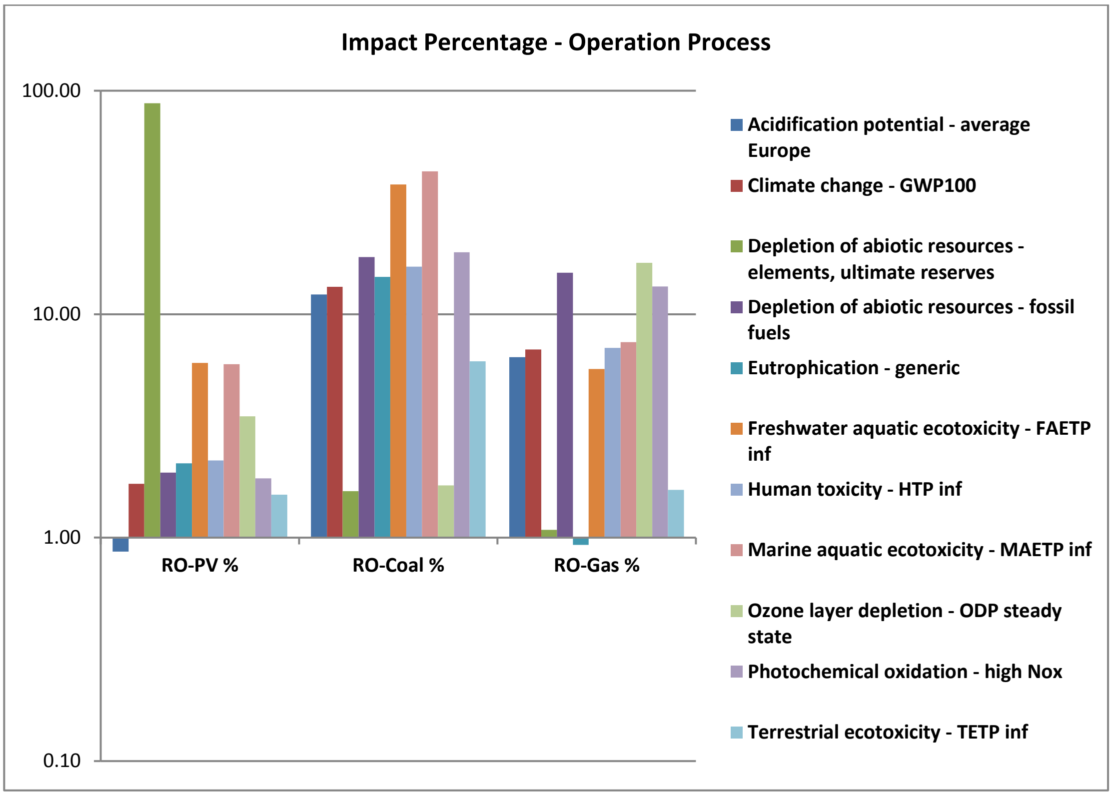

Fig. 4.10: Percentage of operation process contribution in the three systems life cycle's impact

In conclusion, RO-PV system is the most environmental friendly when it's compared with RO-electricity systems. Changing the electrical power source in RO-electricity systems such as coal and natural gas has a significant environmental impact of the systems working on electricity.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

In this study a life cycle analysis was performed on three RO desalination systems. The openLCA software version 1.4.2, Ecoinvent 3.1 database was used, and the CML baseline LCIA method was chosen for the evaluation of all systems impact on its 10 categories.

For all systems, it was found that the water distribution process contributes most to the overall environmental impact followed by the operation process, that because of using delivery water trucks (5 trucks per day for 20 years). If the water distribution process is eliminated from the systems, the operation process will be the main contributor of the life cycle assessment for the three systems. Across all impact categories the RO-PV system has the least environmental impact. However the RO-coal electricity system has the largest environmental impact, this is due to the large amount of energy consumption and the used source of the energy (i.e. coal power station).

The three systems recorded high results in marine aquatic eco-toxicity indicator. The RO-PV system seems the most friendly to the ozone layer. The highest impacts of human toxicity come from the RO-coal electricity system.

In conclusion the total cost of $1m^3$ water produced by RO-PV System calculated to be 1.8 $\$/m^3$, however the total cost of $1m^3$ water produced by RO-electricity systems calculated to be 1.27 $\$/m^3$ (coal or natural gas). The cost of water produced by RO-electricity systems (coal or natural gas) is lower than the cost of RO-PV system, this is due to the high cost of PV batteries in RO-PV system. Furthermore, the cost of water distribution between Al-Fashkha springs to Al-Murashahat area by delivery trucks for $1m^3$ calculated to be 7.14 $\$/m^3$, which is constant for the three systems.

RO-PV system is the most environment friendly when it's compared with RO-electricity systems. Furthermore, changing the electrical power source in RO-electricity systems such as coal and natural gas can significantly affect the environmental impact of the systems working on electricity.

5.2 Recommendations

Based on the outcome of this research, the following can be recommended:

- This research is considered as a pilot study, to choose the most environment friendly source for RO small water desalination plant which produces 50 m^3 of permeate water per day that serves 300 residents in Al-Murashahat area. In the future, further research is required to take this study to the next level and to extend it to larger scale to serve thousands of residents.
- Cost remains a significant issue when it comes to the feasibility and market penetration of renewable energy powered desalination systems. A detailed cost analysis that should capture accurate future expectations and economies of scale would greatly contribute to the feasibility analysis.
- Paying attention to water distribution type. Using delivery trucks has the worst environmental impact and considered the bulk of the cost. Hence additional study should be conducted to apply the best water distribution alternative that should be considered to minimize these impacts.
- Priority should be given to the development of desalination technology (Reverse Osmosis) based on the use of renewable energy sources that meet sustainability and environmental requirements.

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APPENDICES

APPENDIX (A): Site Photographs

(Al Fashkha Springs Nature Reserve)

A.1 Site Photographs of Al Fashkha Springs

Photo 1: Site visit with Dr. Hasan Jawad from AlQuds University

Photo 2: Sign of Ein Al Fashkha Nature Reserve

Photo 3: A student from AlQuds University taking water samples from Ein Al Fashkha

Photo 4: Water sampling at Ein Al Fashkha

Photo 5: Ein Al Fashkha running spring

Photo 6: The Dead Sea area close to Ein Al Fashkha

APPENDIX (B): The Test Results for Al-Fashkha Springs Water

B.1 The test results for Al-Fashkha springs water samples tested on February 2016

Table B.1: Water test results for Al-Fashkha springs

Parameter	Sample # 1	Sample # 2	Sample # 3
Temp (°C)	27	31.3	27.3
TDS (g/L)	2.05	0.31	2.41
EC (mS/cm)	4.39	0.65	5.28
pH	7.61	6.31	6.73
DO (mg/L)	0	5.9	6.18
Cl (mg/L)	1411	137	1870
HCO_3 (mg/L)	183	100	171
F (mg/L)	0.22	0.24	0.2
SO_4 (mg/L)	77	49	69
NO_3 (mg/L)	28	27	29
Na (mg/L)	446	60	701
K (mg/L)	44	10	48
Mg (mg/L)	153	27	155
Ca (mg/L)	208	50	286
TH (mg/L)	1150	250	1350
Sr (meq/L)	0.03	0.01	0.04
Ba (meq/L)	0.003	0.001	0.002
B (meq/L)	0.05	0.02	0.06

APPENDIX (C): RO Design Results by LewaPlus Software Program

C.1 The design details using LewaPlus software program from LANXESS Engineering

Lewabrane® | **LewaPlus** | LANXESS Energizing Chemistry

1 / 2016-04-13 / BWRO-ALfashkah

2016-05-09 00:11:04 Module Reverse Osmosis | 2/10

Water analysis of feed

Water source:	ALfashkah springs - Dead sea		
Water type:	Brackish well	Country: United States	
Source flow rate:	6.25 [m^3/h]	Date of sampling: 2016-04-13	

Cations	Original Unit	[mg/l]	[meq/l]	**Anions**	Original Unit	[mg/l]	[meq/l]
Na	701.00000 [mg/l]	701.00000	30.49152	Cl	1870.00000 [mg/l]	1870.00000	52.75035
Ca	286.00000 [mg/l]	286.00000	14.27146	SO_4	69.00000 [mg/l]	69.00000	1.43660
Mg	155.00000 [mg/l]	155.00000	12.74671	CO_3	0.10940 [mg/l]	0.10940	0.00365
K	48.00000 [mg/l]	48.00000	1.22762	HCO_3	171.00000 [mg/l]	171.00000	2.80236
Sr	0.04000 [ppm CaCO3]	0.03505	0.00080	NO_3	29.00000 [mg/l]	29.00000	0.46774
Ba	0.00200 [meq/l]	0.13734	0.00200	F	0.20000 [meq/l]	3.80000	0.20000
NH_4	0.00000 [mg/l]	0.00000	0.00000	SiO_2	0.00000 [mg/l]	0.00000	0.00000
Fe(II)	0.00000 [mg/l]	0.00000	0.00000	B	0.06000 [meq/l]	0.64860	0.06000
Mn	0.00000 [mg/l]	0.00000	0.00000	PO_4	0.00000 [mg/l]	0.00000	0.00000
H+		0.00019	0.00019	OH-		0.00215	0.00013
Sum C			58.74011	Sum A			57.66070
+ Na		0.00000	0.00000	+ Cl		38.26699	1.07946

Others

Temperature	27.30 [°C]	Turbidity	0.00 [NTU]	Fe (total)	0.00 [ppm]
pH	6.73	SDI	0.00	Free chlorine	0.00 [ppm]
CO_2	40.14 [mg/l]	TSS	0.00 [ppm]	H_2S	0.00 [ppm]
		TOC	0.00 [ppm]		

Summary

TDS	3372.00 [ppm]
Conductivity	6236.42 [µS/cm]
Osmotic pressure	243.56 [kPa]
Ionic strength	0.072

Comments

System parameters

Water type	Brackish well
Temperature	27.30 [°C]
Recovery	80.00 [%]
Hydraulic recovery	80.00 [%]
Pump discharge pressure	1518.39 [kPa]
Feed flow	6.25 [m^3/h]
Feed flow to stage 1	6.25 [m^3/h]
Permeate flow	5.00 [m^3/h]
System permeate flow	5.00 [m^3/h]

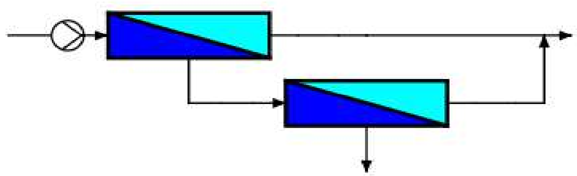
System configuration

Pass	1 / 1
Number of stages / elements	2 / 30
Permeate blending	No
Permeate recirculation	No
Concentrate recirculation	No
Energy recovery device	No

pH adjustment

pH	6.73
Chemical	
Dosing (100%)	0.00 [mg/l]

Design of pass 1



Membrane parameters

Default membrane age	5.00 [a]
Average membrane age	5.00 [a]
Flux decline ratio	10.00 [%]
Salt passage increase	10.00 [%/a]
Average permeate flux	21.10 [l/m^2/h]
Permeate salinity	145.81 [mg/l]
Permeate conductivity	287.10 [µS/cm]

Stage		1	2
Element type		RO B085 FR 4040	RO B085 LE 4040
Vessels / Elements per vessel		3 / 6	2 / 6
Feed pressure	[kPa]	1418.39	1286.55
Concentrate pressure	[kPa]	1286.55	1229.10
Permeate pressure	[kPa]	0.00	0.00
Permeate flux	[l/m^2/h]	26.96	12.30
Feed flow rate per vessel	[m^3/h]	2.08	1.21
Concentrate flow rate per vessel	[m^3/h]	0.81	0.62

Composition and scaling of pass 1

Composition		Feed Raw water	Feed Treated	Feed Blended	Concentrate	Permeate	Permeate Final
Ions		[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Na		701.000	701.000	701.000	3360.911	38.298	38.298
Ca		286.000	286.000	286.000	1404.884	5.529	5.529
Mg		155.000	155.000	155.000	761.388	2.997	2.997
K		48.000	48.000	48.000	213.511	7.607	7.607
Sr		0.035	0.035	0.035	0.172	0.001	0.001
Ba		0.137	0.137	0.137	0.676	0.002	0.002
NH_4		0.000	0.000	0.000	0.000	0.000	0.000
Fe(II)		0.000	0.000	0.000	0.000	0.000	0.000
Mn		0.000	0.000	0.000	0.000	0.000	0.000
Cl		1908.267	1908.267	1908.267	9235.275	75.170	75.170
SO_4		69.000	69.000	69.000	344.051	0.551	0.551
CO_3		0.109	0.109	0.109	3.974	0.000	0.000
HCO_3		171.000	171.000	171.000	824.599	6.729	6.729
NO_3		29.000	29.000	29.000	107.716	8.130	8.130
F		3.800	3.800	3.800	18.254	0.179	0.179
SiO_2		0.000	0.000	0.000	0.000	0.000	0.000
B		0.649	0.649	0.649	0.767	0.619	0.619
PO_4		0.000	0.000	0.000	0.000	0.000	0.000
CO_2		40.137	40.137	40.137	40.137	40.137	40.137
TDS	[mg/l]	3371.997	3371.997	3371.997	16276.177	145.812	145.812
pH		6.730	6.730	6.730	7.349	5.399	5.399
Conductivity	[µS/cm]	6236.420	6236.420	6236.420	28202.208	287.099	287.099
Osmotic pressure	[kPa]	243.565	243.565	243.565	1095.652	11.969	11.969
LSI		-0.225	-0.225	-0.225	1.734	-4.126	-4.126

Scaling		Feed water
$CaSO_4$	[% Sat.]	2.01
$BaSO_4$	[% Sat.]	80.72
$SrSO_4$	[% Sat.]	0.02
SiO_2	[% Sat.]	0.00
CaF_2	[% Sat.]	417.67
$Ca_3(PO_4)_2$		0.00
LSI		-0.23
SDSI		-0.41
Scaling		**Concentrate**
$CaSO_4$	[% Sat.]	14.99
$BaSO_4$	[% Sat.]	565.30
$SrSO_4$	[% Sat.]	0.12
SiO_2	[% Sat.]	0.00
CaF_2	[% Sat.]	82824.47
$Ca_3(PO_4)_2$		0.00
LSI		1.73
SDSI		1.03
Scaling		**Permeate**
LSI		-4.13
RI		13.65
CCPP		-80.48

Stage details for pass 1

		Stage 1		Stage 2	
Composition		**Concentrate**	**Permeate**	**Concentrate**	**Permeate**
Ions		[mg/l]	[mg/l]	[mg/l]	[mg/l]
Na		1780.628	21.838	3360.911	92.438
Ca		734.126	3.132	1404.884	13.415
Mg		397.865	1.697	761.388	7.270
K		118.044	4.428	213.511	18.065
Sr		0.090	0.000	0.172	0.002
Ba		0.353	0.001	0.676	0.006
NH_4		0.000	0.000	0.000	0.000
Fe(II)		0.000	0.000	0.000	0.000
Mn		0.000	0.000	0.000	0.000
Cl		4869.432	42.699	9235.275	181.977
SO_4		178.355	0.310	344.051	1.342
CO_3		0.916	0.000	3.974	0.001
HCO_3		435.704	3.828	824.599	16.273
NO_3		66.021	4.958	107.716	18.565
F		9.665	0.102	18.254	0.433
SiO_2		0.000	0.000	0.000	0.000
B		0.756	0.581	0.767	0.744
PO_4		0.000	0.000	0.000	0.000
CO_2		40.137	40.137	40.137	40.137
TDS	[mg/l]	8591.956	83.575	16276.177	350.531
pH		7.099	5.159	7.349	5.770
Conductivity	[µS/cm]	15290.007	168.652	28202.208	667.966
Osmotic pressure	[kPa]	593.370	6.932	1095.652	28.281
LSI		0.940	-4.921	1.734	-2.911

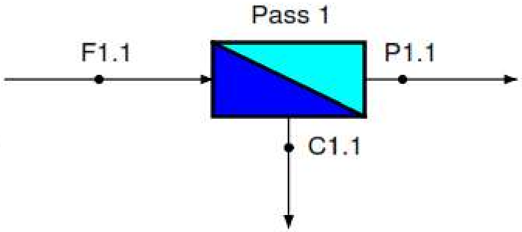
Element details for pass 1 (18)

Stage 1	Age	Recovery	Beta	Permeate Flux	Permeate Flow	Permeate TDS	Concentrate Flow	Concentrate TDS	Feed Flow	Feed TDS
# Element	[a]	[%]		[l/m²/h]	[m³/h]	[mg/l]	[m³/h]	[mg/l]	[m³/h]	[mg/l]
1 RO B085 FR 4040	5.0	12.73	1.11	33.56	0.27	40.12	1.82	3857.67	2.08	3372.00
2 RO B085 FR 4040	5.0	13.53	1.12	31.15	0.25	52.90	1.57	4452.96	1.82	3857.67
3 RO B085 FR 4040	5.0	14.39	1.12	28.64	0.23	69.45	1.35	5189.44	1.57	4452.96
4 RO B085 FR 4040	5.0	15.22	1.13	25.92	0.20	90.83	1.14	6103.95	1.35	5189.44
5 RO B085 FR 4040	5.0	15.87	1.14	22.92	0.18	122.66	0.96	7231.17	1.14	6103.95
6 RO B085 FR 4040	5.0	16.13	1.14	19.60	0.15	172.12	0.81	8591.96	0.96	7231.17

Stage 2	Age	Recovery	Beta	Permeate Flux	Permeate Flow	Permeate TDS	Concentrate Flow	Concentrate TDS	Feed Flow	Feed TDS
# Element	[a]	[%]		[l/m²/h]	[m³/h]	[mg/l]	[m³/h]	[mg/l]	[m³/h]	[mg/l]
1 RO B085 LE 4040	5.0	14.55	1.12	22.24	0.18	149.10	1.03	10028.63	1.21	8591.96
2 RO B085 LE 4040	5.0	13.42	1.11	17.54	0.14	215.55	0.89	11548.78	1.03	10028.63
3 RO B085 LE 4040	5.0	11.69	1.10	13.22	0.10	318.74	0.79	13033.79	0.89	11548.78
4 RO B085 LE 4040	5.0	9.57	1.08	9.56	0.08	479.61	0.71	14361.21	0.79	13033.79
5 RO B085 LE 4040	5.0	7.39	1.06	6.68	0.05	730.18	0.66	15456.84	0.71	14361.21
6 RO B085 LE 4040	5.0	5.42	1.04	4.53	0.04	1122.03	0.62	16276.18	0.66	15456.84

Overview of system design

Recovery rates		[%]
Pass 1	Recovery	80.00
	Hydraulic recovery	80.00
System	Recovery	80.00



List of element types

Type	Count
RO B085 FR 4040	18
RO B085 LE 4040	12

Pass 1

Feed pressure	1418.39 [kPa]
Concentrate pressure	1229.10 [kPa]

		Flow	TDS	Conductivity	pH
	Position	[m^3/h]	[mg/l]	[µS/cm]	[-]
Feed	F1.1	6.25	3372.00	6236.42	6.73
Permeate	P1.1	5.00	145.81	287.10	5.40
Concentrate	C1.1	1.25	16276.18	28202.21	7.35

Scaling Pass 1			[% Sat.]
Concentrate		$CaSO_4$	14.99
$Ca_3(PO_4)_2$	0.00	$BaSO_4$	565.30
LSI	1.73	$SrSO_4$	0.12
SDSI	1.03	SiO_2	0.00
		CaF_2	82824.47

System power consumption

System capacity	120.0 [m^3/d]	Total motor power	3.63 [kW]
System recovery	80.0 [%]	Specific power consumption	0.73 [kWh/m^3]

Power consumption in pass 1

High pressure pump	
Pump flow	6.25 [m^3/h]
Pump suction pressure	50.00 [kPa]
Required feed pressure	1418.39 [kPa]
Additional pump pressure	100.00 [kPa]
Pump discharge pressure	1518.39 [kPa]
Pump efficiency	78.00 [%]
Motor efficiency	90.00 [%]
Motor power	3.63 [kW]

APPENDIX (D): RO Membranes Data Sheet

D.1 RO B085 LE 4040 membrane data sheet

PRODUCT INFORMATION
LEWABRANE® RO B085 LE 4040

Lewabrane®

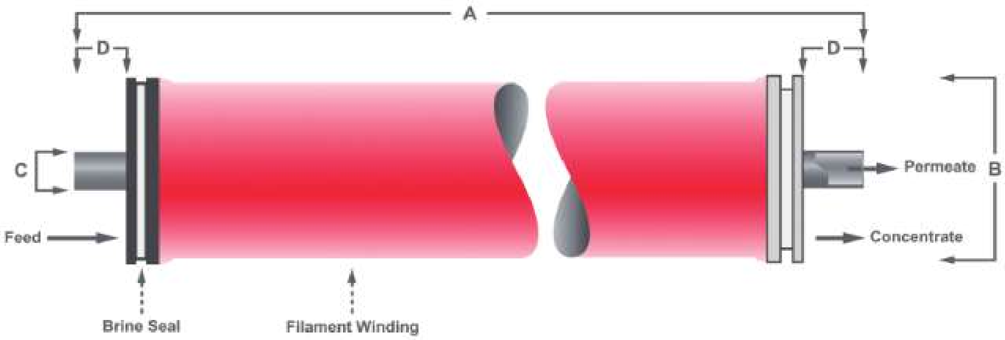
The Lewabrane® RO B085 LE 4040 elements are spiral wound, composite polyamide membrane elements of higher permeability than standard pressure RO membranes. These RO membranes are characterized by a lower operating feed pressure than HR, HF and FR type membranes, and result in a lower energy consumption, hence the terminology of LE (Low Energy). These RO membranes are designed for industrial and potable water treatment applications, such as the treatment of brackish and low salinity waters.

General Information

	Metric units	US units
Feed spacer thickness	0.86 mm	34 mil
Membrane area	7.9 m^2	85 ft^2
Salt rejection, av.	99.5 %	99.5 %
Salt rejection, min.	99.0 %	99.0 %
Permeate flow rate, av.	7.4 m^3/d	2000 gpd
Permeate flow rate, min.	5.9 m^3/d	1550 gpd

Element is tested under the following conditions: applied pressure 10.3 bar (150 psi), NaCl concentration 2000 mg/l, operating temperature 25 °C (77 °F), pH 7 and recovery rate 15 %.

Element Dimension



	A (Length)	B (Diameter)	C (OD)	D (Length)
Metric Units	1016 mm	100 mm	19 mm	26 mm
US Units	40 inch	3.9 inch	0.75 inch	1.05 inch

This document contains important information and must be read in its entirety.

LANXESS
Energizing Chemistry

Lewabrane®

Application Data

	Metric units	US units
Operating pressure, max.	41 bar	600 psi
Operating temperature, max.	45 °C	113 °F
Feed water SDI, max.	5	5
Feed flow, max.	4.0 m^3/h	18 gpm
Concentrate flow, min.	0.6 m^3/h	3 gpm
pH range during operating	2 - 11	2 - 11
pH range during cleaning	1 - 12	1 - 12
Pressure drop per element, max.	1.0 bar	15 psi
Pressure drop per vessel, max.	3.5 bar	50 psi
Chlorine concentration, max.	0.1 ppm	0.1 ppm

Additional Information

- Treat RO Elements with care; do not drop the element.
- Each RO Element is wet tested, preserved in a 1% weight sodium bisulfite solution, and vacuum packed in oxygen barrier bags.
- During storage, avoid freezing and direct sunlight. The temperature should be below 35 °C (95 °F).

After Installation

- Keep the RO Elements wet, and use a compatible preservative for storage duration longer than 7 days.
- During the inital start up, discharge the first permeate to drain for 30 min.
- Permeate back pressure should not exceed feed pressure at any time.
- Consider cleaning, if the pressure drop increases by 20% or water permeability decreases by 10%.
- Use only chemicals which are compatible with the membrane.
- For additional information consult the Lewabrane® technical information available at www.lpt.lanxess.com.

LANXESS Deutschland GmbH
BU LPT
D-50569 Köln

www.lpt.lanxess.com

LANXESS
Energizing Chemistry

Edition: 2016-01-14
Previous Edition: 2016-01-06

APPENDIX (E): Data Sheets

E.1 High pressure pump data sheet

GRUNDFOS

Company name:
Created by:
Phone:

Date: 9/16/2017

Position	Count	Description
	1	**CRN 5-20 A-P-G-E-HQQE**

Product photo could vary from the actual product

Product No.: 96084853
Vertical, non-self-priming, multistage, in-line, centrifugal pump for installation in pipe systems and mounting on a foundation.

The pump has the following characteristics:
- Impellers, intermediate chambers and outer sleeve are made of Stainless steel, DIN W.-Nr. 1.4401.
- Pump head cover and base are made of Stainless steel, DIN W.-Nr. 1.4408.
- The shaft seal has assembly length according to EN 12756.
- Power transmission is via cast iron split coupling.
- Pipework connection is via PJE (Victaulic) flanges/couplings.

The motor is a 3-phase AC motor.

Liquid:

Pumped liquid:	Water
Liquid temperature range:	253 .. 393 K
Liquid temperature during operation:	293 K
Density:	998.2 kg/m³

Technical:

Speed for pump data:	3467 rpm
Rated flow:	6.9 m³/h
Rated head:	148.4 m
Primary shaft seal:	HQQE
Approvals on nameplate:	ANSI/NSF61
Curve tolerance:	ISO9906:2012 3B

Materials:

Pump housing:	Stainless steel DIN W.-Nr. 1.4408 ASTM A 351 CF 8M
Impeller:	Stainless steel DIN W.-Nr. 1.4401 AISI 316

Installation:

Maximum ambient temperature:	333 K

GRUNDFOS	Company name: Created by: Phone: Date: 9/16/2017

Position	Count	Description	
		Max pressure at stated temperature:	25 bar / 120 °C
			25 bar / -20 °C
		Flange standard:	PJE (Victaulic)
		Pipe connection:	1 11/16"
		Flange size for motor:	213TC
		Electrical data:	
		Motor type:	132DA
		Rated power - P2:	5.5 kW
		Power (P2) required by pump:	5.5 kW
			5.5 kW
		Main frequency:	60 Hz
		Rated voltage:	3 x 208-230YY/460Y V
		Service factor:	1,15
		Rated current:	19,5-18,1/9,09 A
		Starting current:	1020-1480 %
		Cos phi - power factor:	0,89-0,86
		Rated speed:	3490-3515 rpm
		Motor efficiency at full load:	89.5 %
		Motor efficiency at 3/4 load:	89.7 %
		Motor efficiency at 1/2 load:	88.3 %
		Number of poles:	2
		Enclosure class (IEC 34-5):	55 Dust/Jetting
		Insulation class (IEC 85):	F
		Others:	
		Net weight:	69.1 kg
		Gross weight:	77.2 kg
		Shipping volume:	0.11 m³

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E.2 Studer data sheet

Séries Xtender

Modèle	XTS 900-12	XTS 1200-24	XTS 1400-48	XTM 1500-12	XTM 2000-12	XTM 2400-24	XTM 2600-48	XTM 3500-24	XTM 4000-48	XTH 3000-12	XTH 5000-24	XTH 6000-48	XTH 8000-48
Onduleur													
Tension nominale de la batterie	12Vdc	24Vdc	48Vdc	12Vdc		24Vdc	48Vdc	24Vdc	48Vdc	12Vdc	24Vdc	48Vdc	
Plage de tension d'entrée	9.5 - 17Vdc	19 - 34Vdc	38 - 68Vdc	9.5 - 17Vdc		19 - 34Vdc	38 - 68Vdc	19 - 34Vdc	38 - 68Vdc	9.5 - 17Vdc	19 - 34Vdc	38 - 68Vdc	
Puissance continue @ 25°C	650**/500VA	800**/650VA	900**/750VA	1500VA	2000VA	2000VA	2000VA	3000VA	3500VA	2500VA	4500VA	5000VA	7000VA
Puissance 30 min. @ 25°C	900**/700VA	1200**/1000VA	1400**/1200VA	1500VA	2000VA	2400VA	2600VA	3500VA	4000VA	3000VA	5000VA	6000VA	8000VA
Puissance 3 sec. @ 25°C	2.3kVA	2.5kVA	2.8kVA	3.4kVA	4.8kVA	6kVA	6.5kVA	9kVA	10.5kVA	7.5kVA	12kVA	15kVA	21kVA
Charge maximale	Jusqu'au court-circuit												
Charge asymétrique max.	Jusqu'à Pcont												
* Détection de charge (Stand-by)	2 à 25 W												
Cos φ	0.1-1												
Rendement max.	93%	93%	93%	93%		94%	96%	94%	96%	93%	94%	96%	
Puissance à vide OFF/Stand-by/ON	1.1W/1.4W/7W	1.2W/1.5W/8W	1.3W/1.6W/8W	1.2W/1.4W/8W	1.2W/1.4W/10W	1.4W/1.6W/9W	1.8W/2W/10W	1.4W/1.6W/12W	1.8W/2.1W/14W	1.2W/1.4W/14W	1.4W/1.8W/18W	1.8W/2.2W/22W	1.8W/2.4W/30W
* Tension de sortie	Sinus pur 230Vac (+/- 2%) / 120Vac[1]												
* Fréquence de sortie	50Hz / 60Hz[1] +/- 0.05% (contrôlée par quartz)												
Distorsion harmonique	<2%												
Protection de surcharge et de court-circuit	Déconnection automatique puis 3 essais de démarrage												
Protection de surchauffe	Alarme avant coupure et redémarrage autom.												
Chargeur de batterie													
* Caractéristique de charge	6 étapes : Bulk - Absorption - Maintien - Egalisation - Maintien réduit - Absorption périodique Nombre d'étapes, seuils, courant de fin d'étape et temps entièrement réglables avec la RCC-02/-03												
* Courant de charge maximum	35A	25A	12A	70A	100A	55A	30A	90A	50A	160A	140A	100A	120A
* Compensation de la température	Avec BTS-01 ou BSP 500/1200												
Correction du facteur de puissance (PFC)	EN 61000-3-2												
Données générales	XTS 900-12	XTS 1200-24	XTS 1400-48	XTM 1500-12	XTM 2000-12	XTM 2400-24	XTM 2600-48	XTM 3500-24	XTM 4000-48	XTH 3000-12	XTH 5000-24	XTH 6000-48	XTH 8000-48
* Plage de tension d'entrée	150 à 265Vac / 50 à 140Vac[1]												
Fréquence d'entrée	45 à 65Hz												
Courant max. d'entrée (relais de transfert) / Courant max. de sortie	16Aac/20Aac			50Aac/56Aac									50Aac/80Aac
Temps de transfert (UPS)	<15ms												
Contacts multifonctionnels	Module ARM-02 à 2 contacts en option			Deux contacts indépendants (libres de potentiel 3 points, 16Aac / 5Adc)									
Poids	8.2 kg	9 kg	9.3 kg	15 kg	18.5 kg	16.2 kg		21.2 kg	22.9 kg	34 kg	40 kg	42 kg	46 kg
Dimension h x l x L [mm]	110x210x310			133x322x466						230x300x500			
Indice de protection	IP54			IP20						IP20			
Conformité	Directive CEM 2004/108/CE : EN 61000-6-1, EN 61000-6-3, EN 55014, EN 55022, EN 61000-3-2, 62040-2 Directive basse tension 2006/95/CE : EN 62040-1-1, EN 50091-2, EN 60950-1												
Plage de température de travail	-20 à 55°C												
Humidité relative de fonctionnement	100%			95% sans condensation						95% sans condensation			
Ventilation	Module de ventilation ECF-01 en option			Forcée dès 55°C						Forcée dès 55°C			
Niveau acoustique	<40dB / <45dB (sans / avec ventilation)												
Garantie	5 ans												
Accessoires													
Télécommande RCC-02 ou RCC-03	•	•	•	•	•	•	•	•	•	•	•	•	•
Module Xcom-232i	•	•	•	•	•	•	•	•	•	•	•	•	•
Sets de communication par internet Xcom-LAN/Xcom-GSM	•	•	•	•	•	•	•	•	•	•	•	•	•
Moniteur de batterie BSP	•	•	•	•	•	•	•	•					
Module de com. à distance RCM-10 (3 m)	•	•	•	•	•	•	•	•	•	•	•	•	•
Module à 2 contacts auxiliaires ARM-02	•	•	•										
Module de ventilation ECF-01	•	•	•										
Sonde de temp. de batterie BTS-01 (3 m)	•	•	•	•	•	•	•	•	•	•	•	•	•
Câble de communication 3ph et // CAB-RJ45-8-2	•	•	•	•	•	•	•	•	•	•	•	•	•
Cadre de montage X-Connect										•	•	•	•

* Réglable avec la RCC-02/03

** Valeurs mentionnées uniquement valables avec le module de ventilation ECF-01.

[1] Avec -01 à la fin de la désignation, signifie 120V/60Hz. Disponible pour tous les Xtender sauf l'XTH 8000-48

Sous réserve de modifications.

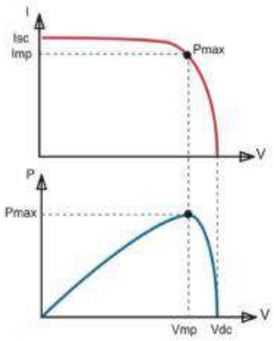
v 1.1.0

E.3 BlueSolar charge controller data sheet

victron energy
BLUE POWER

BlueSolar Charge Controllers MPPT – Overview

www.victronenergy.com



Maximum Power Point Tracking

Upper curve:
Output current (I) of a solar panel as function of output voltage (V).
The Maximum Power Point (MPP) is the point Pmax along the curve where the product I x V reaches its peak.

Lower curve:
Output power P = I x V as function of output voltage.
When using a PWM (not MPPT) controller the output voltage of the solar panel will be nearly equal to the voltage of the battery, and will be lower than Vmp.

Feature highlights

- Ultra-fast Maximum Power Point Tracking (MPPT)
- Advanced Maximum Power Point Detection in case of partial shading conditions
- Load output on the small models
- Battery Life: intelligent battery management by load shedding
- Automatic battery voltage recognition
- Flexible charge algorithm
- Over-temperature protection and power de-rating when temperature is high.

Color Control GX
All Victron Energy MPPT Charge Controllers are compatible with the Color Control GX: The Color Control GX provides intuitive control and monitoring for all products connected to it. The list of Victron products that can be connected is endless: Inverters, Multis, Quattros, MPPT 150/70, BMV-600 series, BMV-700 series, Skylla-i, Lynx Ion and even more.

VRM Online Portal
Besides monitoring and controlling products on the Color Control GX, the information is also forwarded to our free remote monitoring website: the VRM Online Portal. To get an impression of the VRM Online Portal, visit https://vrm.victronenergy.com, and use the 'Take a look inside' button. The portal is free of charge.

Related product: EasySolar
Minimal wiring and an all-in-one solution: the EasySolar takes power solutions one stage further, by combining an Ultra-fast BlueSolar charge controller (MPPT), an inverter/charger and AC distribution in one enclosure.

Model	Load output	Fan	Battery voltage	Display	Color Control GX	Com. port
75/10	Yes	No	12/24	No	Compatible	VE.Direct
75/15	Yes	No	12/24	No	Compatible	VE.Direct
100/15	Yes	No	12/24	No	Compatible	VE.Direct
100/30	No	No	12/24	No	Compatible	VE.Direct
100/50	No	No	12/24	No	Compatible	VE.Direct
150/35	No	No	12/24/36/48	No	Compatible	VE.Direct
150/45-Tr	No	No	12/24/36/48	No	Compatible	VE.Direct
150/45-MC4	No	No	12/24/36/48	No	Compatible	VE.Direct
150/60-Tr	No	No	12/24/36/48	No	Compatible	VE.Direct
150/60-MC4	No	No	12/24/36/48	No	Compatible	VE.Direct
150/70-Tr	No	No	12/24/36/48	No	Compatible	VE.Direct
150/70-MC4	No	No	12/24/36/48	No	Compatible	VE.Direct
150/70	No	No	12/24/36/48	Yes	Compatible	VE.Can
150/85	No	Yes	12/24/36/48	Yes	Compatible	VE.Can

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victron energy
BLUE POWER

E.4 PV modules data sheet

YINGLI SOLAR

YLM
60 CELL
40mm SERIES

YINGLI SOLAR
Power Your Life

IMPROVED POWER
NEVER SETTLE FOR LESS

Choosing the best P-type monocrystalline cells, YLM series modules are making the best out of your system. Trust in the expertise of Yingli and well proven technology.

19.9%
CELL EFFICIENCY

10 YEAR
PRODUCT WARRANTY

0-5W
POWER TOLERANCE

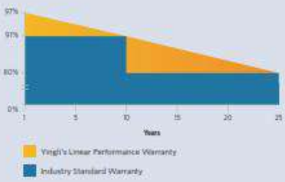
High Power Density
High conversion efficiency and more power output per square meter.

Durability
Durable PV modules, independently tested for harsh environmental conditions such as exposure to salt mist, ammonia and known PID risk factors.

Advanced Glass
Our high-transmission glass features a unique anti-reflective coating that directs more light on the solar cells, resulting in a higher energy yield.

PID Resistant
Tested in accordance to the standard IEC 62804, our PV modules have demonstrated resistance against PID (Potential Induced Degradation), which translates to security for your investment.

25 Years Linear Warranty



Yingli Green Energy
Yingli Green Energy Holding Company Limited (NYSE: YGE), known as "Yingli Solar," is one of the world's leading solar panel manufacturers with the mission to provide affordable green energy for all. Deploying more than 60 million solar panels worldwide, Yingli Solar makes solar power possible for communities everywhere by using our global manufacturing and logistics expertise to address unique local challenges.

YINGLISOLAR.COM

YLM 60 CELL 40mm SERIES

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)							
Module type			YLxxxD-30b (xxx=P_{max})				
Power output	P_{max}	W	290	285	280	275	270
Power output tolerances	ΔP_{max}	W	0 / + 5				
Module efficiency	η_m	%	17.9	17.6	17.2	16.9	16.6
Voltage at P_{max}	V_{mpp}	V	31.9	31.7	31.4	31.2	30.9
Current at P_{max}	I_{mpp}	A	9.08	9.00	8.91	8.82	8.73
Open-circuit voltage	V_{oc}	V	39.9	39.6	39.3	38.9	38.6
Short-circuit current	I_{sc}	A	9.45	9.41	9.38	9.34	9.31

STC: 1000W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3.
Average relative efficiency reduction of 3.0% at 200W/m² according to EN 60904-1.

Electrical parameters at Nominal Operating Cell Temperature (NOCT)							
Power output	P_{max}	W	211.5	207.9	204.2	200.6	196.9
Voltage at P_{max}	V_{mpp}	V	29.1	28.9	28.7	28.4	28.2
Current at P_{max}	I_{mpp}	A	7.26	7.20	7.13	7.06	6.98
Open-circuit voltage	V_{oc}	V	36.8	36.6	36.3	35.9	35.6
Short-circuit current	I_{sc}	A	7.64	7.61	7.58	7.55	7.53

NOCT: open-circuit module operation temperature at 800W/m² irradiance, 20°C ambient temperature, 1m/s wind speed.

THERMAL CHARACTERISTICS

Nominal operating cell temperature	NOCT	°C	46 +/- 2
Temperature coefficient of P_{max}	γ	%/°C	-0.42
Temperature coefficient of V_{oc}	β_{Voc}	%/°C	-0.32
Temperature coefficient of I_{sc}	α_{Isc}	%/°C	0.05

OPERATING CONDITIONS

Max. system voltage	1000V_{DC}
Max. series fuse rating	15A
Limiting reverse current	15A
Operating temperature range	-40°C to 85°C
Max. static load, front (e.g., snow)	5400Pa
Max. static load, back (e.g., wind)	2400Pa
Max. hailstone impact (diameter / velocity)	25mm / 23m/s

CONSTRUCTION MATERIALS

Front cover (material / thickness)	low-iron tempered glass / 3.2mm
Cell (quantity / material / dimensions / number of busbars)	60 / monocrystalline silicon / 156mm x 156mm / 3 or 4
Frame (material)	anodized aluminum alloy
Junction box (protection degree)	≥ IP65
Cable (length / cross-sectional area)	1000mm / 4mm²
Plug connector (type / protection degree)	MC4 / IP68 or YT08-1 / IP67 or Amphenol H4 / IP68

• Due to continuous innovation, research and product improvement, the specifications in this product information sheet are subject to change without prior notice. The specifications may deviate slightly and are not guaranteed.
• The data do not refer to a single module and they are not part of the offer, they only serve for comparison to different module types.

QUALIFICATIONS & CERTIFICATES

IEC 61215, IEC 61730, CE, MCS, ISO 9001:2008, ISO 14001:2004, BS OHSAS 18001:2007, PV Cycle, SA 8000

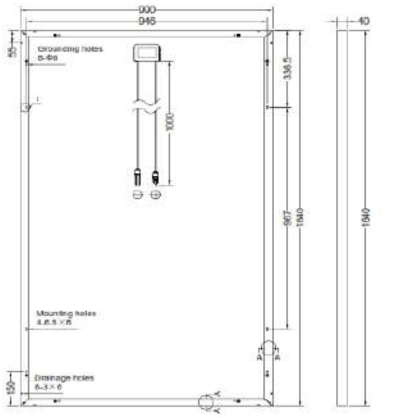
GENERAL CHARACTERISTICS

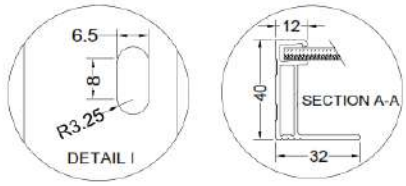
Dimensions (L / W / H)	1640mm / 990mm / 40mm
Weight	18.5kg

PACKAGING SPECIFICATIONS

Number of modules per pallet	26
Number of pallets per 40' container	28
Packaging box dimensions (L / W / H)	1700mm / 1160mm / 1165mm
Box weight	514kg

Unit: mm





Warning: Read the Installation and User Manual in its entirety before handling, installing, and operating Yingli Solar modules.

Yingli Partners:

Yingli Green Energy Holding Co., Ltd.
service@yingli.com
Tel: +86-312-2188055

YINGLISOLAR.COM

E.5 PV batteries data sheet

OPzS solar.power

Vented lead-acid battery for cyclic applications

Motive Power Systems

Reserve Power Systems

Special Power Systems

Service

Your benefits with HOPPECKE OPzS solar.power

- **Highest cycle stability during PSoC[1] operation** - due to tubular plate design with efficient charge current acceptance
- **Maximum efficiency with reduced charging factor** - ready for use of optional elelctrolyte recirculation
- **Maximum compatibility** - dimensions according to DIN 40736-1
- **Higher short-circuit safety even during the installation** - based on HOPPECKE system connectors
- **Extremely extended water refill intervals up to maintenance-free** - optional use of AquaGen® recombination system minimizes emission of gas and aerosols[2]

Typical applications of HOPPECKE OPzS solar.power

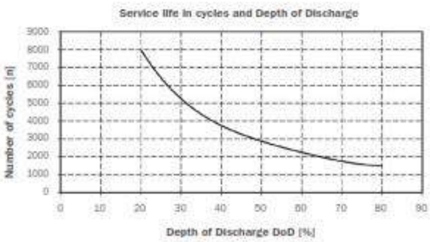
- **Solar-/Off-grid applications**
  Power supply for remote off-grid applications and isolated power networks, drinking water supply systems, healthcare facilities
- **Telecommunications**
  Mobile phone stations
  BTS-stations
  Off-grid/on-grid solutions
- **Traffic systems**
  Signalling systems
  Lighting

HOPPECKE
POWER FROM INNOVATION

Type overview

Capacities, dimensions and weights

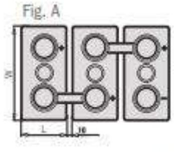
Type	C_{100}/1.85 V Ah	C_{50}/1.85 V Ah	C_{24}/1.83 V Ah	C_{10}/1.80 V Ah	C_5/1.77 V Ah	max. Weight kg	Weight electrolyte kg (1.24 kg/l)	max.* Length L mm	max.* Width W mm	max.* Height H mm	Fig.
4 OPzS solar.power 280	280	265	245	213	182	17.1	4.5	105	208	420	A
5 OPzS solar.power 350	350	330	307	266	227	20.7	5.6	126	208	420	A
6 OPzS solar.power 420	420	395	370	320	273	24.6	6.7	147	208	420	A
5 OPzS solar.power 520	520	490	454	390	345	29.1	8.5	126	208	535	A
6 OPzS solar.power 620	620	585	542	468	414	34.1	10.1	147	208	535	A
7 OPzS solar.power 730	730	685	634	546	483	39.2	11.7	168	208	535	A
6 OPzS solar.power 910	910	860	797	686	590	46.1	13.3	147	208	710	A
7 OPzS solar.power 1070	1070	1002	930	801	691	59.1	16.7	215	193	710	B
8 OPzS solar.power 1220	1220	1145	1063	915	790	63.1	17.3	215	193	710	B
9 OPzS solar.power 1370	1370	1283	1192	1026	887	72.4	20.5	215	235	710	B
10 OPzS solar.power 1520	1520	1425	1325	1140	985	76.4	21.1	215	235	710	B
11 OPzS solar.power 1670	1670	1572	1459	1256	1086	86.6	25.2	215	277	710	B
12 OPzS solar.power 1820	1820	1715	1591	1370	1185	90.6	25.8	215	277	710	B
12 OPzS solar.power 2170	2170	2010	1843	1610	1400	110.4	32.7	215	277	855	B
14 OPzS solar.power 2540	2540	2349	2163	1881	1632	142.3	46.2	215	400	815	C
16 OPzS solar.power 2900	2900	2685	2472	2150	1865	150.9	45.9	215	400	815	C
18 OPzS solar.power 3250	3250	3015	2765	2412	2097	179.1	56.4	215	490	815	D
20 OPzS solar.power 3610	3610	3350	3072	2680	2330	187.3	55.7	215	490	815	D
22 OPzS solar.power 3980	3980	3685	3388	2952	2562	212.5	67.0	215	580	815	D
24 OPzS solar.power 4340	4340	4020	3696	3220	2795	221.2	66.4	215	580	815	D
26 OPzS solar.power 4700	4700	4355	4004	3488	3028	229.6	65.4	215	580	815	D



C_{100}, C_{50}, C_{24}, C_{10} and C_5 =
Capacity at 100 h, 50 h, 24 h, 10 h and 5 h discharge

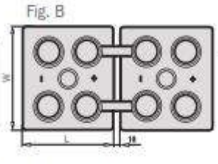
* according to DIN 40736-1 data to be understood as maximum values

Fig. A



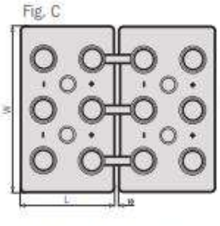
4 OPzS solar.power 280 - 6 OPzS solar.power 910

Fig. B



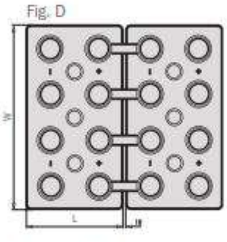
7 OPzS solar.power 1070 - 12 OPzS solar.power 2170

Fig. C

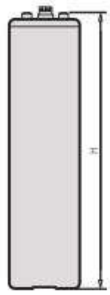


14 OPzS solar.power 2540 - 16 OPzS solar.power 2900

Fig. D



18 OPzS solar.power 3250 - 26 OPzS solar.power 4700



Optimal environmental compatibility - closed loop for recovery of materials in an accredited recycling system

IEC 60896-11
IEC 61427

[1] Partial State of Charge (Teilentladebetrieb)
[2] Similar to sealed lead-acid batteries

HOPPECKE
POWER FROM INNOVATION

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Impact category	Reference unit	RO membranes	HP Pump	Tanks	Water Distribution	PV
Acidification potential - average Europe	kg SO2 eq.	10.28	2.93	4.80	33710.36	294.62
Climate change - GWP100	kg CO2 eq.	1938.42	62.86	1188.82	4937458.19	87627.35
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	0.00	0.00	0.00	3.12	22.86
Depletion of abiotic resources - fossil fuels	MJ	284226.04	7844.88	72149.94	58785877.85	1180626.33
Eutrophication - generic	kg PO4--- eq.	2.26	0.32	0.80	8183.81	179.98
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	245.29	113.73	89.96	435006.01	28056.15
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	1018.08	2200.11	863.05	1390523.76	31600.68
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	968161.00	255000.18	431906.78	1670536705.52	106363070.40
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	0.00	0.00	0.00	0.27	0.01
Photochemical oxidation - high Nox	kg ethylene eq.	1.03	0.12	1.01	809.60	15.23
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	8.04	2.84	3.99	19407.44	306.84

APPENDIX (F): Life Cycle Impact Assessment (LCIA)

Table F.1: Comparison between the impacts of all process altogether

for RO-PV system

Table F.2: Comparison between the impacts of each components in hydraulic process

Impact category	Reference unit	RO membranes	HP Pump	Tanks
Acidification potential - average Europe	kg SO2 eq.	10.28	2.93	4.80
Climate change - GWP100	kg CO2 eq.	1938.42	62.86	1188.82
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	0.00	0.00	0.00
Depletion of abiotic resources - fossil fuels	MJ	284226.04	7844.88	72149.94
Eutrophication - generic	kg PO4--- eq.	2.26	0.32	0.80
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	245.29	113.73	89.96
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	1018.08	2200.11	863.05
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	968161.00	255000.18	431906.78
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	0.00	0.00	0.00
Photochemical oxidation - high Nox	kg ethylene eq.	1.03	0.12	1.01
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	8.04	2.84	3.99

Table F.3: The impacts of transportation process (water distribution)

Impact category	Reference unit	Water Distribution
Acidification potential - average Europe	kg SO2 eq.	33710.36
Climate change - GWP100	kg CO2 eq.	4937458.19
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	3.12
Depletion of abiotic resources - fossil fuels	MJ	58785877.85
Eutrophication - generic	kg PO4--- eq.	8183.81
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	435006.01
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	1390523.76
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	1670536705.52
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	0.27
Photochemical oxidation - high Nox	kg ethylene eq.	809.60
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	19407.44

Table F.4: Comparison between the impacts of each system in operation process

Impact category	Reference unit	PV	Electricity-Coal	Electricity-Gaz
Acidification potential - average Europe	kg SO2 eq.	294.62	4702.75	2315.20
Climate change - GWP100	kg CO2 eq.	87627.35	755040.42	368635.17
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	22.86	0.05	0.03
Depletion of abiotic resources - fossil fuels	MJ	1180626.33	12985568.39	10728073.67
Eutrophication - generic	kg PO4--- eq.	179.98	1407.63	76.60
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	28056.15	267014.40	26283.39
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	31600.68	271989.00	105873.29
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	106363070.40	1288941417.46	135652709.39
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	0.01	0.00	0.05
Photochemical oxidation - high Nox	kg ethylene eq.	15.23	189.50	124.37
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	306.84	1272.55	322.70

Table F.5: Comparison between the impacts of all processes altogether for three systems

Impact category	Reference unit	RO-PV	RO-Coal	RO-Gas
Acidification potential - average Europe	kg SO2 eq.	34023.00	38431.14	36043.58
Climate change - GWP100	kg CO2 eq.	5028275.63	5695688.70	5309283.46
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	25.99	3.18	3.16
Depletion of abiotic resources - fossil fuels	MJ	60330725.04	72135667.11	69878172.39
Eutrophication - generic	kg PO4--- eq.	8367.16	9594.82	8263.78
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	463511.14	702469.39	461738.38
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	1426205.68	1666594.00	1500478.28
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	1778554843.89	2961133190.95	1807844482.88
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	0.27	0.27	0.32
Photochemical oxidation - high Nox	kg ethylene eq.	827.00	1001.26	936.13
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	19729.16	20694.86	19745.01

Table F.6: Hydraulic process- percentage of contribution in the systems life cycle's impact

Impact category	RO membranes			HP Pump			Tanks		
	RO-PV %	RO-Coal %	RO-Gas %	RO-PV %	RO-Coal %	RO-Gas %	RO-PV %	RO-Coal %	RO-Gas %
Acidification potential - average Europe	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
Climate change - GWP100	0.04	0.03	0.04	0.00	0.00	0.00	0.02	0.02	0.02
Depletion of abiotic resources - elements, ultimate reserves	0.02	0.14	0.14	0.01	0.05	0.05	0.01	0.05	0.05
Depletion of abiotic resources - fossil fuels	0.47	0.39	0.41	0.01	0.01	0.01	0.12	0.10	0.10
Eutrophication - generic	0.03	0.02	0.03	0.00	0.00	0.00	0.01	0.01	0.01
Freshwater aquatic ecotoxicity - FAETP inf	0.05	0.03	0.05	0.02	0.02	0.02	0.02	0.01	0.02
Human toxicity - HTP inf	0.07	0.06	0.07	0.15	0.13	0.15	0.06	0.05	0.06
Marine aquatic ecotoxicity - MAETP inf	0.05	0.03	0.05	0.01	0.01	0.01	0.02	0.01	0.02
Ozone layer depletion - ODP steady state	0.02	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.01
Photochemical oxidation - high Nox	0.13	0.10	0.11	0.01	0.01	0.01	0.12	0.10	0.11
Terrestrial ecotoxicity - TETP inf	0.04	0.04	0.04	0.01	0.01	0.01	0.02	0.02	0.02

Table F.7: Transportation phase- percentage of contribution in the systems life cycle's impact

Impact category	RO-PV %	RO-Coal %	RO-Gas %
Acidification potential - average Europe	99.08	87.72	93.53
Climate change - GWP100	98.19	86.69	93.00
Depletion of abiotic resources - elements, ultimate reserves	12.01	98.15	98.68
Depletion of abiotic resources - fossil fuels	97.44	81.49	84.13
Eutrophication - generic	97.81	85.29	99.03
Freshwater aquatic ecotoxicity - FAETP inf	93.85	61.93	94.21
Human toxicity - HTP inf	97.50	83.44	92.67
Marine aquatic ecotoxicity - MAETP inf	93.93	56.42	92.40
Ozone layer depletion - ODP steady state	96.48	98.25	82.98
Photochemical oxidation - high Nox	97.90	80.86	86.48
Terrestrial ecotoxicity - TETP inf	98.37	93.78	98.29

Table F.8: Operation phase- percentage of contribution in the systems life cycle's impact

Impact category	RO-PV %	RO-Coal %	RO-Gas %
Acidification potential - average Europe	0.87	12.24	6.42
Climate change - GWP100	1.74	13.26	6.94
Depletion of abiotic resources - elements, ultimate reserves	87.96	1.61	1.08
Depletion of abiotic resources - fossil fuels	1.96	18.00	15.35
Eutrophication - generic	2.15	14.67	0.93
Freshwater aquatic ecotoxicity - FAETP inf	6.05	38.01	5.69
Human toxicity - HTP inf	2.22	16.32	7.06
Marine aquatic ecotoxicity - MAETP inf	5.98	43.53	7.50
Ozone layer depletion - ODP steady state	3.49	1.71	16.99
Photochemical oxidation - high Nox	1.84	18.93	13.29
Terrestrial ecotoxicity - TETP inf	1.56	6.15	1.63

جامعة النجاح الوطنية

كليـة الدراسات العليـا

تقييم دورة حياة نظام التناضح العكسي لتحلية المياه باستخدام مصادر طاقة كهربائية مختلفة

إعداد

إسراء عبدالفتاح صبيح

إشراف

د. حمدلله بعيرات

د. محمد السيد

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2017

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الملخص

سوف تسهم هذه الدراسة في الحد من النقص في المياه العذبة في منطقة المرشحات وذلك باستخدام مياه ينابيع الفشخة وتطبيق أفضل تقنية لتحلية المياه من النواحي البيئية والتكلفة. وسيتم ذلك من خلال تصميم نظام التناضح العكسي الذي يخدم المنطقة ، واختيار أفضل مصدر للطاقة من خلال تقييمها من حيث تقييم دورة حياتها.

تم في هذه الدراسة إجراء تحليل لدورة الحياة على ثلاثة أنظمة لتحلية المياه باستخدام التناضح العكسي، النظام الاول هو نظام التناضح العكسي باستخدام الطاقة الشمسية ، والنظام الثاني هو نظام التناضح العكسي باستخدام الطاقة الكهربائية الناتجة من الفحم ، أما النظام الثالث هو نظام التناضح العكسي باستخدام الطاقة الكهربائية الناتجة من الغاز الطبيعي. تم استخدام برنامج OpenLCA وقاعدة بيانات Ecoinvent ، ولتقييم الآثار البيئية المترتبة على دورة حياة هذه الأنظمة ، فقد استخدم أسلوب مركز العلوم البيئية في جامعة ليدن، حيث تم تقسيم الآثار البيئية المترتبة إلى10 أثار رئيسية وذلك تم على نظام صمم لينتج 50 متراً مكعباً من المياه المحلاة في اليوم.

وبالنسبة لجميع الأنظمة، تبين أن عملية توزيع المياه تساهم إلى حد كبير في الأثر البيئي العام ثم تليها عملية التشغيل. وفي جميع فئات الآثار البيئية، تبين أن نظام التناضح العكسي باستخدام الطاقة الشمسية له أقل أثر بيئي، بينما نظام التناضح العكسي باستخدام الطاقة الكهربائية الناتجة من الفحم له أكبر أثر بيئي.

إن تكلفة المياه المنتجة من نظام التناضح العكسي باستخدام الطاقة الكهربائية الناتجة من الفحم أو الغاز الطبيعي تعد أقل من تكلفة المياه المنتجة من نظام التناضح العكسي باستخدام الطاقة الشمسية ، حيث أن تكلفة 1متر مكعب من المياه المنتجة من قبل نظام التناضح العكسي باستخدام الطاقة الشمسية هي 1,80 دولار أمريكي ، بينما أن تكلفة 1متر مكعب من المياه المنتجة من نظامي التناضح العكسي باستخدام الطاقة الكهربائية هي1.27 دولار أمريكي.