Technical, Economic, and Environmental Feasibility Analysis of a Small Scale CSP Desalination Plant in Sonora, Mexico

by

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Abstract

The purpose of this study is to evaluate the feasibility of developing a small-scale Concentrated Solar Power (CSP) desalination plant at a coastal community located in the northwestern region of Mexico that does not have a running water system to provide continuous access to fresh water.

Freshwater is considered a scarce resource around the world, especially in these coastal communities located far away from major urban centers and experiencing severe weather conditions. Some of these communities receive fresh water by tank trucks visit them periodically. The rather long time between each visit makes living conditions harsh during summer days.
A literature review was initially conducted to define all the necessary parameters to compare both methods of supplying fresh water, the business as usual and the CSP. Once the variables were identified and included in three categories (technical, economic, and environmental), a case study based on an on-field research was developed to determine the actual input values.

For the technical analysis, we calculated the amount of reflecting surface necessary to generate the heat required to fulfill the desalinated water demand. The economic analysis consisted in computing the costs of each phase of the business as usual method, as well as the costs of the CSP components in that region. The environmental study focused on the CO_2 emissions generated during each process of supplying water.

Analysis of the collected data provided the opportunity to compare the actual process with the proposed CSP and draw an appropriate conclusion based on the results on each of the three categories. From a technical point of view, the location of the community receives the necessary solar resource required for the development of an economically feasible CSP project. At the same time, the community is located near an urban center that will give us access to the technology and human resources required to implement the project. The proposed alternative method of supplying water lessens the environmental impact compared to the actual one by emitting less CO_2 emissions with a lower levelized cost during the lifetime of the desalination plant.

Key words:
Concentrated Solar Power
Desalination

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1. Introduction

This paper provides a technical and economic feasibility assessment of a small scale Concentrated Solar Power (CSP) desalination plant for coastal communities in regions with high direct solar radiation. Our case study is based on the information collected from the Tastiota community in the Hermosillo region of the state of Sonora, Mexico, field research, literature review, and necessary calculations as a proof of concept for the technology. Through the case study we establish the technical requirements for a CSP desalination plant and a comparison of economic and environmental parameters with the business as usual.

Freshwater is a scarce resource in arid regions, especially in coastal communities located far from major urban centers [1]. These communities experience severe hot and dry weather during most of the year, with annual precipitation averages in the Sonoran desert of 76 to 500 mm [2]. Some of these communities, such as Tastiota, receive fresh non-drinkable water extracted from distant wells and distributed by tank trucks that visit the town periodically. The long interval between visits worsens the living conditions during extreme hot summer days.

Palenzuela et al. estimate that as of today, around 25% of the world's population has no access to fresh water, and more than 80 countries are facing water scarcity issues serious enough to impair their economic development [3]. In recent years, water supply reliability was imperiled by climate changes, especially on account of extended drought periods in regions previously unaffected by dry climatic characteristics.

According to the United Nations Organization 2015 World Population Prospects, the worldwide projected total population for year 2030 will be 8.50 billion people, with Africa and Asia being the fastest growing regions [4]. This growth will put a strain on sustainable water and energy supply over medium to long term, which will increase the reliance of a greater number of people on desalinated water to meet part of their growing demand for urban water [5]. Desalination has been recognized as a viable option to meet the increasing demand for fresh water in harsh environments [6]. Moreover, the feasibility and viability of renewable energy sources used for water desalination may become an important policy topic, particularly in a desired low carbon future economy. In a carbon constrained economy scenario, Rowlinson et al. suggest that desalination plants will be a main consideration by several stakeholders and decision makers, including urban planners and energy and water utilities [7]. Therefore, technical feasibility and economic viability of alternative energy sources for desalination plants represent a current relevant area of study.

1.1. Case Study Region

The coast of Hermosillo aquifer is a coastal aquifer located in the hydrologic region number 9 in central Sonora, comprising an area of 1,738.76 km^2. The exploitation of the Costa de Hermosillo aquifer has led to an important economic and social development in the region. Nevertheless, excessive pumping has also created serious problems for both water supply and water quality [8]. Medina et al. define a coastal aquifer as a hydrogeological unit whose basic characteristic is that one of its geographic limits is with the sea or the coastline, generally understood as representing the water discharge from a continental hydrologic basin. According to these authors, coastal aquifers are considered highly sensitive to groundwater extraction because of seawater intrusion whenever the aquifer height gets below sea level, unlike continental aquifers that self-regulate from other freshwater sources, mitigating the impact of overexploitation. The same authors state that this phenomenon occurs due to a hydraulic imbalance resulting from extraction over the recharge rate, having as a consequence a loss of hydraulic head that allows the marine water to penetrate into the aquifer.

According to the State Water Commission, the Sonora's State aquifer of the coast of Hermosillo, has suffered a saline intrusion up to 40 km inland [9]. They adjudge this phenomenon to the region's low meteoric precipitation combined with the over-extraction of groundwater. Other aquifers to the north and south show a front of marine intrusion and a zone of mixing which must be monitored systematically. The advance of this contamination has been accelerated during the last 30 years by population growth and water demand [8].

Communities established across the coast originally obtained their freshwater directly from locally drilled wells. The saline intrusion has contaminated these wells forcing the communities to rely on water delivered by tanker trucks periodically from the urban centers. The water received is suitable for non-consumptive uses only, forcing communities to buy bottled potable water at high rates from unreliable markets nearby. The small size of these communities makes a water distribution system from the city economically unfeasible.

Tastiota is one of these small communities located in the coast of Hermosillo aquifer region. It is an ideal location to implement small-scale CSP desalination options due to both its severe lack of fresh water availability and abundant solar radiation.

2. Materials and Methods

Figure 1 below provides an outline of the methods followed to develop the technical and economic assessment through the Tastiota case study. In the first step gathered data to determine the conditions of the business-as-usual water demand and supply in the community. This data was used to calculate the technical specifications and design the CSP technology that would satisfy the community's demand. Step three used the results to determine the levelized cost of water supply (LCOW) for both the BAU and the proposed CSP technology. Finally, CO_2 emissions for both scenarios were calculated.

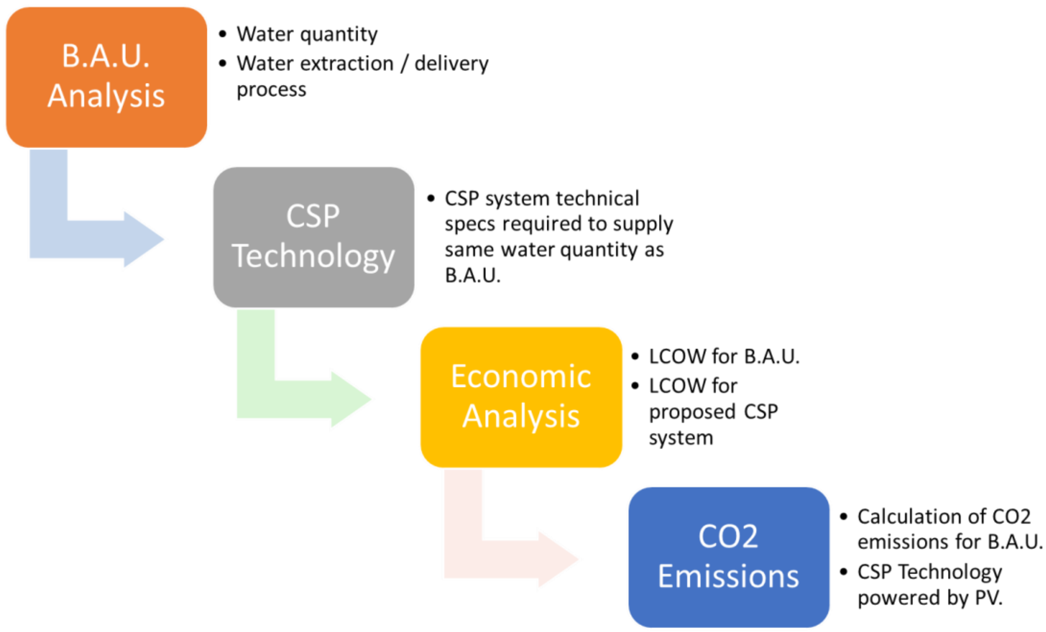

Figure 1. Fresh water supplying system BAU for the Sonora Case.

2.1. Business as Usual Analysis

The most common way of supplying (non-drinkable) water to these coastal communities is shown in Figure 2. The municipal water utility extracts water from several wells with a piping system around the region, which is then delivered to the water treatment plant in the urban area. Once the water is treated, tank trucks transport it to the coastal communities and deposit it in storage reservoirs for consumer access. Each house has its own 1,000 L water tank located on ground level where the tanker truck pours fresh water every week.

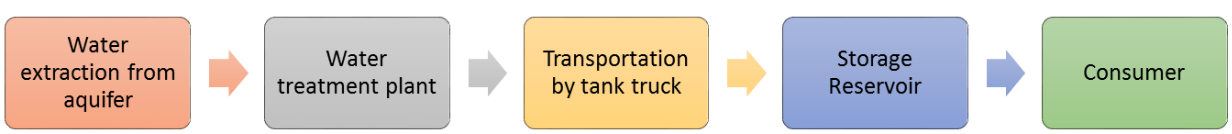

Figure 2. Fresh water supplying system BAU for the Sonora Case.

Four visits to the region were performed during summer 2017 in order to collect data about costs and quantity of water delivered. The first visit consisted of identifying the community water demand, build relationships with various stakeholders and create community engagement through informal meetings with local authorities and inhabitants. In the second visit, we gathered information from the local water company about how much it costs the government to obtain the non-drinkable water that should be transported to the community and how much the local government pays to the transportation company for this service. For the third visit, we focused on the way the non-drinkable water is delivered to the community. We followed the tankers truck route beginning from the well where the water is extracted, up to the community and observed the stops the tanker truck makes at houses. Finally, the fourth visit was done during a delivery day of drinking water. Since the water delivered by the water company is non-drinkable, the intention was to figure out how much drinkable water people in the community buy from a private company that sends a truck filled with water containers approximately every 20 days and how much it costs.

Tastiota community receives 18m^3 of freshwater by tank truck weekly, which means a daily amount of 2.57m^3 of freshwater. This water is not appropriate for human consumption. The community purchases drinkable water from a separate company. Considering one person consumes on average 3.8L and there are 40 people in the community, we add 152L/day of drinking water. This sums up to a total amount of 2,730L or 2.73m^3 of needed distilled water. We decided to calculate a CSP system that can provide them with 3m^3 (3,000 liters) per day of distilled water (1,095m^3 per year) to include the water needed for additional activities currently not covered by the amount of water the community receives (e.g. clean up the fish supply for sale purposes).

2.1.1. Stakeholders description

During the summer visits in Tastiota we gathered data from different stakeholders in order to understand the current process of water delivery, and create engagement with community's residents and other stakeholders that would impact the project's development and outcome. Major stakeholders are:

-Inhabitants of Tastiota: Includes around 40 persons, mostly engaged in fishing as a primary source of income. Community needs fresh water for daily activities and for supporting the economic potential of developing the fishing activity.

-University of Sonora: University of Sonora Solar Energy Lab has facilities near town and can supervise the construction and operation of the desalination plant. We signed an agreement of cooperation with University of Sonora.

-Local authorities: During our visits to the community we kept a permanent contact with the mayor to inform him about any progress. He mentioned that the piece of land suitable for this project development belongs to the government and can be provided for free.

-State authorities: We were able to present and discuss the project with authorities from the State Water Commission, Ecology and Sustainable Development Commission, and Energy Commission. They all showed interest in the project and willingness to support it.

-Technology provider companies: We contacted companies that can provide the necessary heliostats and Linear Fresnel components in order to obtain price quotations. In addition, we received information about Mexican companies that can assemble them.

2.2. CSP and Desalination Technology Analysis

Besides Solar Photovoltaic, which is nowadays the most common solar technology [10], there are many other ways to capture solar energy. One such example is Concentrated Solar Power (CSP), which uses direct solar radiation concentrated onto a small area to generate heat, usually with the purpose of producing electricity. Some of the countries where this technology is being successfully implemented are Algeria, Egypt, Greece, India, Italy, Mexico, Morocco, Spain, and the U.S.A., due to their high levels of direct solar radiation within their borders [11].

In general, the main components of a CSP system are the concentrator, the absorber and the thermal storage. The concentrator consists of a system that uses mirrors or lenses to capture and concentrate a large amount of sunlight, or solar thermal energy, onto a small area. This solar radiation is reflected to the absorber located at the focus point, absorbing the heat and transmitting it to the thermal fluid [11].

CSP technologies can commonly be categorized by the type of receiver they employ, into parabolic troughs, solar towers, dish systems, and linear Fresnel reflectors. As shown in Figure 3, parabolic trough and linear Fresnel are systems that use line focusing to capture solar radiation, while solar tower and dish systems use point focusing.

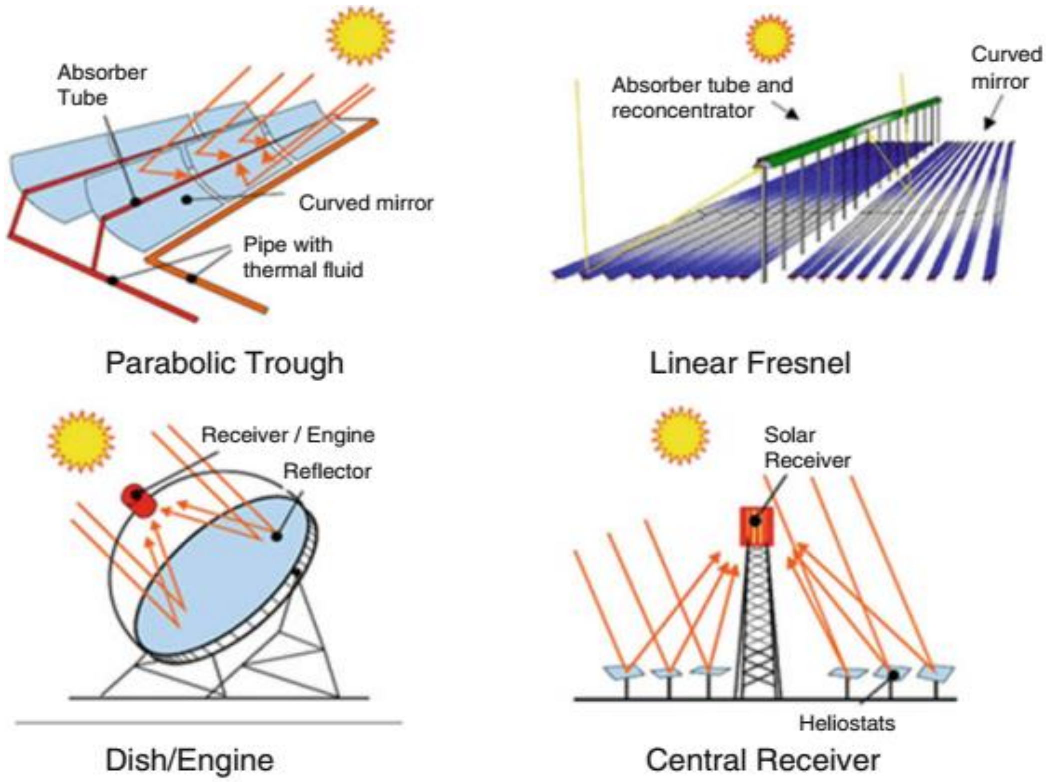

Figure 3. Concentrating Solar Power Technologies. Source: Concentrating Solar Power and Desalination Plants [3].

This project studies the feasibility of implementing a small-scale CSP desalination plant, evaluating the use of a Central Receiver system or a Linear Fresnel system to provide potable water to a community located in a desert region. According to the MENA Regional Water Outlook, Central Receiver and Linear Fresnel systems are in an early stage of development, which leaves open questions about cost, reliability, and scalability for mass production [12]. The fact that there isn't much competition on the market for using the Central Receiver system or the Linear Fresnel system, and the expertise developed at the University of Sonora Solar Energy Lab represent an incentive to determine its feasibility, considering the new advances of the technology.

2.2.1. Central Receiver Systems (CR).

Central Receiver (tower) systems are power plants in which a large field of two-axis tracking mirrors, also called heliostats, reflect direct solar radiation onto a receiver located at the top of a tower. In the receiver, the concentrated solar energy is absorbed by a working fluid, converting the solar energy into thermal energy [13]. The working fluid can be water or steam, molten salts, liquid sodium, or air. This heat transfer is used to generate steam that drives a conventional steam turbine to produce electricity. According to Alexopoulos and Hoffschmidt, concentration factors achieved in CR Systems are high, reaching temperatures of 1,200 °C, and making it feasible to integrate this technology into steam, gas or combined cycle power plants [14].

One of the most attractive attributes of solar towers is that they can store energy. Molten salts are used as thermal storage medium, allowing the system to extend its operating hours or increase capacity during periods when the electricity flowing into the network is at a higher price [13].

2.2.2. Linear Fresnel Systems (LF).

In Linear Fresnel systems, solar radiation is concentrated onto a line and can then be converted to electricity through steam turbines. The large number of mirror segments that constitute the collectors in the LF system can individually follow the path of the sun. The absorber tubes remain static above the mirrors in the center of the solar field. The system can operate with oil, water or molten salts [3].

According to Gunther, the main advantages of LF systems are a simpler design, reduced manufacturing costs and higher land use efficiency compared to the parabolic-trough and central tower [15]. Gunther states that the investment cost of a Fresnel power plant at the same nominal power is lower due to the significant lower investment cost of the solar field, considering the same primarily reflector area [16]. Moreover, he claims that operation and maintenance costs are lower during the lifetime of the project.

The basis for a LF plant is a Rankine cycle, which includes a LF system as heat source, a steam turbine as converter and a steam condenser as heat sink. The solar energy is converted into thermal energy, then to mechanical energy, and finally into electricity. The LF system enables the collection and conversion of solar energy into thermal energy (steam), after which the steam turbine generator converts thermal energy into mechanical energy and mechanical energy into electricity. The steam condenser system cools the residual steam at the outlet of the turbine, collects the resulting condensate and distributes the flow in the system, feeding the LF system with feedwater at the required temperature and pressure [17].

2.2.3. Water Desalination Technologies

There are a variety of technologies available for water desalination, divided into two broad categories: membrane processes and thermal processes. Figure 4 shows a diagram in which the specific process used, either membrane or thermal, fits in the “Desalination Process” box.

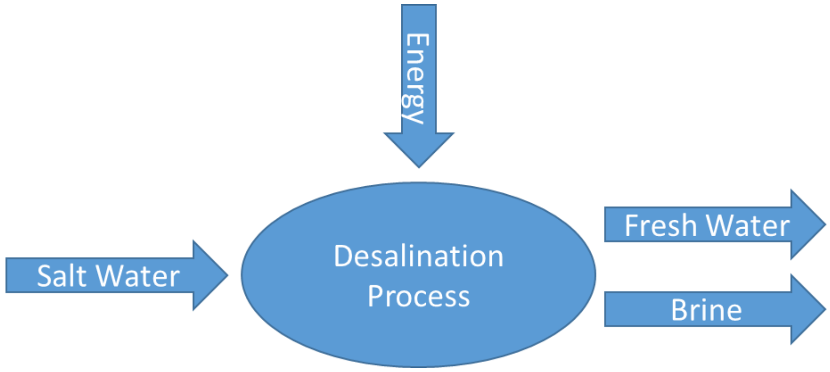

Figure 4. Desalination Basic Process Diagram.

The most commonly used technology is Reverse Osmosis, representing an increasing uptake of membrane processes in installed plants, plants under construction, and proposed plants [18]. Membrane processes drive the saline water through a membrane that acts as a filter and removes the salts, as well as other dissolved solids.

Thermal processes consist in employing different forms of evaporation methods to separate the salts from the water [3]. The two most used thermal processes are Multi Stage Flash (MSF) and Multi Effect Distillation (MED).

This paper considers Single Stage Distillation system. Due to the relative small quantity of fresh water production needed, MSF and MED are not economically sustainable, therefore they are not available to be supplied on the market for small scale plants. The single stage distillation process is considered a good choice for easy operation and when the compact size of a plant is important [19].

2.3. Economic and Environmental Analysis

2.3.1 Economic Analysis

The main role of economics in project development is to provide financial information to the decision-making process. One of the most important steps of this process is to identify all the cost bearing components involved in both systems of supplying fresh water (BAU and CSP desalination plant). In order to ensure an effective and proper comparison between the systems, data was collected and analyzed for the same product quantity and quality attributes. The economic feasibility analysis of the CSP desalination system versus the business as usual is based on the levelized cost of water, without taking into consideration any revenue from potential alternative business models. The main reason underlying this strategy is that the local authorities are willing to support the implementation of the desalination project as long as the total investment and operating cost during the lifetime of the CSP desalination system would be lower than the cost of supplying water through the business as usual method for the same period. Consequently, this paper considered the levelized cost of water as the main driver of a potential investment in the technology.

As per analogy to the levelized cost of energy definition provided by NREL, levelized cost of water can compare the combination of capital costs, operations and maintenance (O&M), performance, and any fuel costs, if the case. In general, a levelized cost represents the total cost to install and operate a particular system divided by its expected life-time output. In other words, the levelized cost provides the average cost of this output, in this case in $/m3. The life-time of the system used as basis for calculations is equal to the life-time of the power source (reflective surface) under normal operational conditions, which according to the standards in the energy industry is around 20 years.

2.3.2 Environmental analysis

We analyze CO_2 emissions because transportation is one of the largest sources of greenhouse gas emissions from human activities (include citation from EPA). From the B.A.U. we identified two sources of emissions:

- Emissions related to the electricity consumption of the water pump used to extract the water from the well;
- Emissions from the tanker truck that delivers the water to the community.

We considered that the CSP desalination system will not generate any CO_2 emissions because the entire system will be powered by the solar PV.
Since the brine resulting from desalination will not be discharged back into the sea, the CSP desalination system will have no impact on the aquatic system. The resulting brine will be dried and turned into salt as by-product to be sold as is or to the cattle industry. Moreover, the sea water will be extracted from a well near the coast, thus avoiding any damage to the water fauna.

3. Calculations

3.1. CSP Required Reflective Surface

The main design parameter for CSP in this application is the amount of energy required to distil the community's daily water demand. The reflective surface area necessary to capture that energy can be calculated through Eq. (1). Calculations for the case study were made considering average values for the variables involved and the geographic location of interest.

$$RS = \frac{EN}{(DNI*EFF)} \quad (1)$$

where:

RS is the reflective surface of CSP collector required in m^2.

EN is the energy necessary to boil the desired amount of water in kWh.

DNI is the Daily average Direct Normal Irradiance received in $kWh/m^2/day$; taken from NREL NSRDB Data Viewer.

EFF is the System optical efficiency, defined as the fraction of incident solar energy absorbed by the receiver from the collector's aperture. This variable depends on the optical properties of the materials involved, the collector's geometry, the receiver alignment to the focal point of the collector, and the tracking precision of the system [20]*. Values for each system were obtained from literature review* [21] [22]*.*

and

$$EN = \frac{\{[(LH + SH) * W] * 1{,}000\}}{3{,}600{,}000}$$

where:

LH is the latent heat required to boil the desired amount of seawater in kJ/L.

SH is the sensible heat required to increase the temperature of the seawater that will be boiled in kJ/L.

W= Amount of water in Liters.

3.2. Economic Parameters

The main components of the levelized cost of water (LCW) are the capital costs at the time of initial investment in case of implementing a new project, which can be different depending on the project requirements, and annual operating costs that are adjusted based on inflation and other assumptions and then discounted back at the time of initial investment or year zero to get the present value of the total investment cost for comparison purposes between different methods of supplying water.

Present value of operating costs is calculated based on the following formula:

$$PV = \frac{FV}{(1+r)^n}$$

where:

PV = present value of a future series of annual cash-flows

FV = future value of the annual cash-flows (adjusted cash-flows)

r = discount rate

n = number of years until future value is received

Discount rate represents the weighted average cost of capital of a proxy company and it is calculated based on the following formula:

$$WACC = \frac{D}{D+E}\,(1-T)\,r_d + \frac{\mathrm{E}}{\mathrm{D}+\mathrm{E}}\,r_e$$

where:

WACC = weighted average cost of capital (discount rate)

D = short term and long term debt of the company (taken from the balance sheet of a proxy public listed company with the same business segment as a new investment project)

E = equity of the company

T = marginal tax rate

Rd = cost of debt

Re = cost of equity

*E = number of shares outstanding * price per share*

$T = \frac{Income\ before\ tax - Income\ after\ tax}{Income\ before\ tax}$ *, both numbers available in the profit and loss statements*

Rd is approximated based on the S&P credit rating of the public listed proxy company that gives the Interest rate spread to treasury above the risk-free rate

*Re is calculated based on the CAPM (Capital Assets Pricing Model) = Beta of equity * Market risk premium + Risk free-rate*

Risk free-rate is based on yield to maturity on the 20-year US Treasury bond as listed by the US Department of Treasury

This research study considered as proxy Veolia Environnement, public listed company, traded on the over-the-counter markets under the code VEOEY, which provides environmental management services, including drinking water treatment and distribution, wastewater and sanitation services, and waste management and energy services. Veolia is currently the global leader in desalination, with 12 million cubic meters of water produced per day.

The public information for Veolia Environnement shows the following input data:
-Per Google Finance: D = $13,350,500,000 (as of 12/31/2016); Number of shares outstanding = 548,300,000; Price per share = 18.52 (as of 04/01/2017); Income before tax = 651,400,000 (as of 12/31/2016); Income after tax = 458,700,000 (as of 04/01/2017); Beta of equity = 0.97 (as of 04/01/2017)

-Per S&P listing: Veolia Environnement has a long-term credit rating of BBB

-Per Bank of America Merrill Lynch: the bond yields and spreads for 2015 fell in the range of 2.8% to 3.7 % for S&P credit ratings above BBB. Since Veolia increased the net income with almost 65% from end of 2015 to end of 2016, showing an improved financial performance, this paper assumes an Interest rate spread to treasury of 2.8%

-Per US Department of Treasury: risk free-rate on the 20-year US Treasury bond is 2.78%

-Per survey performed by ValueWalk for 71 countries, the market risk premium for 2016 in US was 5.3% on average

Additional input data for Mexico:
-Per Mexico National Bank: exchange rate Peso/USD = 0.05 as of 02/28/2017

-Per Mexico National Bank: inflation at the end of 02/2017 was 4.86%, way above the target of 3%. In terms of long-term forecasts (20 years), due to the impact of fuel price liberalization, there isn't currently a reliable source of data, the numbers ranging from 3.6 to 5.0-5.3, for an average of 4 – 4.4. This paper assumes a long-term inflation rate of 4.4%.

The input data and the formulas lead to a discount rate of 5.65%.

The BAU method of supplying water has three main cost components: the cost of transporting the freshwater by tank trucks from the water treatment plant to the community, the cost of acquiring the drinkable water by the community from a different company and the cost of obtaining the freshwater (extraction and treatment) by the municipal utility.
This paper assumes that the long-term evolution of the cost of transporting freshwater to the community is mainly driven by the movements of the diesel price on the market. Consequently, the Mexican Ministry of Finance announced an increase of 16.5% for 2017 in the diesel price. For the following years, due to the liberalization program, the diesel prices should follow the trend in the international / US market. Consequently, according to EIA, the short-term forecast for increase in diesel prices is 4.8%. In terms of long-term projection for Mexico, the assumption would be a stabilization at around 7% (to account for 50% of long-term projected inflation rate).
The cost of acquiring drinkable water by the community has increased historically from 2008 to

2011 by 10% and this paper estimates that the trend will continue.

The cost of obtaining the freshwater by the municipal utility is highly influenced by the gross disbursement of development assistance for water project from the government budget to account for increase in inflation. According to UN data, the annual average official development assistance gross disbursements for water supply and sanitation during 2003-2011 was $12.42 million, representing 27% of the total annual average official development assistance gross disbursements during the same period, leading to an annual average increase in the cost of obtaining the freshwater of around 3.4%.

The cost structure for the CSP desalination plant is the following:

Capital investment costs, that include mainly the power source and the desalination component. Additional smaller costs are related to securing the site during construction, contingency (0.5% of construction cost), and acquisition of the land.

Main operational costs include the labor cost for running the plant and securing the premises, the cost of any spare parts outside warranty (this paper assumes that for the lifetime of the project, this cost is negligible), the cost of any major replacements or refurbishments needed during the lifetime of the project (the warranty on the main project components would cover these costs) and the cost of minerals added to the distilled water. Since distilled water is free of dissolved minerals, it can only meet the required standards for drinking water as long as additional minerals are supplemented. Compared to the amount of the total investment, the cost for adding the minerals for the lifetime of the project is negligible. The calculation of the discounted operational costs doesn’t take into consideration any depreciation, because this is not a cash item and it would diminish the comparability between the BAU and the CSP desalination methods of supplying water.

Security and labor costs are expected to increase with inflation.

Figure 5 shows the main components used in calculating the Levelized cost of water for implementing a CSP desalination plant.

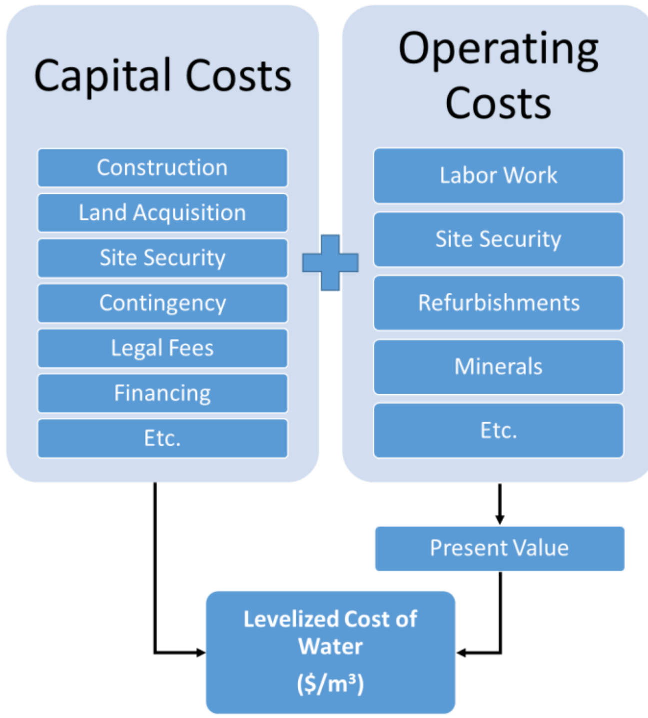

Figure 5. Levelized cost of water for implementing a CSP desalination plant.

3.3. CO_2 Emissions Analysis

For the calculation of CO_2 emissions from the BAU method, we separated the process in two stages: Well to Tanker and Tanker to Consumer.

For the Well to Tanker stage, we visited the facilities of the well where the water is extracted and collected the necessary data. Eq. (2) was used to calculate the well's power consumption per m^3.

$$WC = \frac{TP}{WE} \qquad (2)$$

where:

WC is the amount of energy consumed by the well in kWh/m^3

TP is the well's electricity consumption for a year in kWh

WE is the water extracted at the well in a year in m^3

According to the water delivery records for Tastiota, the town receives 18 m^3 of freshwater every week for 52 weeks in a year, which is equivalent to 936 m^3 of freshwater per year. Since the Mexican power grid is nationally interconnected, we used the national CO_2 emission factor [23] of 0.454 CO_2 tons/MWh to estimate the CO_2 generated for extracting freshwater.

For the second stage, Tanker to Consumer, we followed a methodology proposed by Kecojevic and Komljenovic [24] for diesel trucks, so that we could calculate the emissions of the water transportation. Eq. (3) was used to calculate CO_2 emissions from the tanker truck trips during one year.

$$E = H(FC * CF) \quad (3)$$

where:

E is the amount of emissions in tons CO_2/year.

H is the total number of hours on the road per year in hrs/year.

FC is diesel fuel consumption in L/hr.

and

CF is a conversion factor.

The CSP desalination systems proposed in the different scenarios are considered as zero emissions because their electricity demand will be fulfilled by solar photovoltaic panels.

4. Results

4.1. Reflective Surface Results

The optical efficiency for each system was obtained from literature review, based on general performance data. We considered an optical efficiency of 70% for the Solar Tower system [21] and an optical efficiency of 63% for the Fresnel system [22]. Table 1 shows the results obtained from doing the calculations.

LF System				**CR System**			
Distilled water to obtain	=	3,000.00	L/day	Distilled water to obtain	=	3,000.00	L/day
Latent and sensible heat	=	2,570.00	KJ/L	Latent and sensible heat	=	2,570.00	KJ/L
(LH+SH)*W	=	7,710,000.00	KJ	(LH+SH)*W	=	7,710,000.00	KJ
Energy necessary	=	2,141.67	kWh	Energy necessary	=	2,141.67	kWh
Average daily DNI in the region	=	7.87	kWh/m^2/day	Average daily DNI in the region	=	7.87	kWh/m^2/day
Optical efficiency	=	63%		Optical efficiency	=	70%	
Required reflective surface	=	431.95	m^2	Required reflective surface	=	388.76	m^2

Table 1. Reflective surface calculations.

4.2. Economic Analysis Results

In 2016, the company transporting the water to the community was paid \$135/18 m^3 delivered every week, thus \$7,020 per year. Community was buying daily drinking water at the price of \$43/m^3 on average, leading to an initial yearly cost of \$2,386. The municipal utility was obtaining fresh water at a cost of \$0.6/m^3 (\$561 per year). This leads to a discounted total cost of supplying water of \$223,560 and a levelized cost of water of 11.27\$/m^3.

For Heliostats, the price is considered 145\$/m^2 (market price including installation), while the price for Linear Fresnel is 128.5\$/ m^2. The distillation component is \$30,000 as per the ASPEN PLUS V8.8 Economic Process Analyzer tool rough estimation.

The LF Community Scenario assumes that following the implementation of the CSP desalination plant, the legal responsibility of operating it will be transferred to the local authorities that will employ volunteers from the community to run it on a daily basis.

Table 2 shows the values we considered for the calculations and the obtained results.

Concept	**Scenarios**		
	Heliostats	Linear Fresnel	LF Community
Cost of land (\$)	50	50	0
Construction cost (\$)	86,370	85,521	85,521
First Year Security cost (\$/year)	3,000	3,000	0
Contingency (\$)	432	428	428
First Year Labor cost (\$/year)	7,202	7,202	0
Discounted Total Cost of Implementation (\$)	269,511	268,657	85,948
Total amount of desalinated water (m^3)	21,900	21,900	21,900
LWC (\$/m^3)	12.31	12.27	3.92

Table 2. Economic Scenarios Analysis.

4.3. CO_2 Emissions Results

Table 3 shows the results of estimating CO_2 emissions for both of the defined stages of the BAU water delivery process.

CO_2 Emissions per Year					
Well to Tanker			**Tanker to Consumer**		
-National power grid emissions factor:	0.000454	tons CO_2/kWh	-Trip round distance:	140	kms
			-Duration of trip:	6	hrs
-Total well pump kWh consumption:	965,574	kWh/year	-Diesel Lts consumed per trip:	90	lts
-Total water extracted:	1,866,240	m^3/year	-(FC)= Lts/hr:	15	lts/hr
-kWh per m^3:	0.52	kWh/m^3	-Conversion factor for diesel (CF):	0.00268	
-Water delivered to Tastiota:	936.00	m^3/year	-CO_2= FC x CF =	0.0402	tons CO_2/hr
-kWh consumed for Tastiota:	484.28	kWh	-Hours of trip in a year:	312	hrs/yr
-CO_2 emissions in a year:	0.22	tons CO_2/year	-CO_2 emissions in a year:	12.5424	tons CO_2/yr
Total = 12.76 tons CO_2/yr					

Table 3. Values considered and results of CO_2 emissions.

5. Discussion

The assessment presented in this paper shows that implementation of a CSP desalination plant in Tastiota community can be potentially attractive due to the following reasons: Tastiota region provides abundant solar radiation to justify the technical feasibility of the project, current method of supplying water is unsustainable on a long term and impedes the economic development of the community, there isn't much competition on the market for technologies developed for small scale desalination and the total investment can be financially feasible under certain conditions as outlined in results.

However, there are several areas of interest to be further explored in order to get a more detailed comprehension of the impact and additional benefits that the implementation of this project would have on the community.

One of the additional research to be performed is the management and related costs of the brine resulting after circulating the sea water through the distillation plant. This brine can be poured to a flat surface nearby, where it will dry in evaporation ponds, thus obtaining the salt as by-product, which can be sold as is or to the cattle industry for the feeding production system, and generating extra income for the community.

Another area of further exploration is the mineralization process of the distilled water required to turn part of it into drinking water, including, but not limited to the regulations that drinking water must fulfill for safe consumption and necessary quantity and type of minerals to be added to the distilled water together with its resulting health benefits.
It should also be mentioned that any excess of distilled water generated from the plant can be used to wash the captured fish, thus prolonging its normal consumption time and allowing the community to sell it directly to the market in the cities nearby. This would result in bypassing the intermediaries that kept the acquisition price from community at an artificial low level for increased financial gain.

Ultimately, specific political and administrative systems need to be in place at local authority level to establish a set of best practices and rules to operate the plant by the community and create an environment of fairness in water usage and costs distribution. The timeline and impact of this process is yet to be determined.

6. Conclusions

In conclusion, various water desalination technologies are currently available on the market, but less efforts have been made to develop attractive solutions for small scale applications due to economic constraints. Therefore, the CSP desalination technology presented in this paper is based on the single stage distillation system that ensures an easy operational process and a total investment cost that under certain conditions may put the project on par with the existing method of supplying water while reducing the environmental impact and creating opportunities to increase the living standard in the community.

Out of the mentioned underlying results of this assessment, the economic feasibility stands out as the main driver for getting support from the local authorities to implement the technology. If the community is trained and can successfully operate the distillation plant, the total levelized cost of generating drinking water for the lifetime of the project would be less than the total levelized cost of supplying water under BAU conditions, making it a feasible investment for authorities.

At the same time, implementing this technology would eliminated the water insecurity in the community, which increases substantially during the rainy season when the tanker trucks cannot access the community because of lack of proper infrastructure, delaying the process of distributing water with two or three weeks, and ultimately forcing residents to go by boat to a nearby community to buy more expensive bottled water.

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