WORCESTER POLYTECHNIC INSTITUTE

AN INTERACTIVE QUALIFYING PROJECT

Policy Study of Desalination in Sharjah, UAE

in partial fulfillment of the requirements for the
Degree of Bachelor of Science

Authors
Caitlin KEAN
Sophie KURDZIEL
Robear MANKARYOUS
Sawyer WOFFORD

Sponsors
Mayyada Al BARDAN
Deputy Manager
Waleed El DAMATY
Research Project Engineer

Advisor
Joseph DOIRON

In collaboration with:
American University of Sharjah (AUS)
Sharjah Electricity and Water Authority (SEWA)

January 31, 2021

Contents

Abstract

This report addresses the importance of implementing a comprehensive and sustainable desalination policy in Sharjah, UAE by the Sharjah Electricity and Water Authority (SEWA). Our goal is to create a policy brief that can aid SEWA in the implementation of a desalination policy. The data for the recommendations were collected through analyzing guidelines and policies from around the world, conducting expert interviews, and distributing surveys on various desalination themes. This information helped formulate a policy brief that recommends regulations on desalination technologies, desalination input management, and desalination output management. We hope that SEWA will consider our recommendations to further ensure the economic and environmental prosperity of Sharjah and the Arabian Gulf.

Executive Summary

Arid countries in the United Arab (UAE) utilize desalination as a major source of freshwater. Desalination is the process of converting seawater into freshwater by removing the salt concentration and other dissolved solids. The remaining concentration, known as brine, is released back into the environment, which can negatively affect seawater quality (Badescu et al., 2013). Additionally, the use of combustible sources to power desalination plants has a large carbon footprint due to high energy usage. Thus, administrations in charge of overseeing desalination must implement proper policies to limit these negative effects. One such administration is Sharjah Electricity and Water Authority (SEWA) in Sharjah, UAE, which is seeking to implement a comprehensive desalination policy that limits negative environmental impacts and ensures future economic sustainability. The goal of our project is to assist in the initial ideation and formulation of a policy by presenting a policy brief to SEWA. This policy brief will contain recommendations on key factors that a comprehensive policy must consider.

Methodology

To meet our project goal, we developed the following research objectives:

1. *Identify the main themes of desalination legislation.*
2. *Understand expert opinions on these themes in the context of policy and regulations.*
3. *Formulate a policy brief with recommendations for SEWA that compiles these findings.*

To initiate the methodology, interviews were first conducted with four professors at Worcester Polytechnic Institute (WPI). These professors had backgrounds in desalination or environmental policy and were asked various questions (Appendix A.2) to establish the central themes of desalination policy. Theme identification was achieved by extracting and comparing keywords from the interview transcripts. These themes were then used to guide research on global desalination policy and categorize the policy findings from different regions into sections related by theme. These policies were identified using the FAOLEX database. In addition, SEWA's drafted guidelines were translated and divided amongst the themes. The combination of this global policy research and initial expert guidance provided information to create multiple surveys that were divided amongst the central themes. These surveys were created using WPI's Qualtrics client, and were implemented into a project website.

Experts were identified internationally through online research that was targeted towards university professors and PhD students, research groups, and industry professionals. Over 500 experts were contacted to participate in the surveys. Through the project website, they were able to complete one (or more) 15 minute surveys depending on their areas of expertise. Additionally, experts were able to leave comments, policy suggestions, and questions through this platform. After multiple weeks of data collection, the surveys were manually analyzed for suggestions and recommendations on the various themes presented. All the responses were categorized by the key topics found amongst the surveys, which were then used in collaboration with previous background research to develop the following recommendations.

Findings

The findings from the initial interviews represent the main aspects of desalination that should be covered to ensure a successful policy. The final list of themes are as follows: Desalination Technologies, Desalination Plant Energy Usage, Potable Desalinated Water Quality, Desalination Plant Source Water, Desalination Plant Discharge, Desalination Intake Port Protection from Ship Movement, and Desalination Process Management. Dividing the resulting surveys amongst these themes ensured they could be distributed to specifically qualified experts.

The data obtained from the research, interviews, and surveys helped formulate a policy brief that can be summarized by the findings below.

1. **Focus future desalination investments on reverse osmosis (RO) desalination while phasing out existing distillation-based desalination**
   (a) New advancements in RO desalination polymer membranes can tolerate high salinity and temperatures.

   (b) Distillation-based desalination inhibits the diversification of water and power sources.

   (c) RO desalination can be linked to renewable energy sources, while distillation-based desalination relies on heat from thermal sources.

   (d) Distillation-based desalination relies on heat that is often generated from combustible resources. As SEWA transitions to renewable resources, distillation-based desalination investments will not be economically sustainable.

   (e) The brine from distillation-based desalination is much warmer than that of RO desalination, which can harm marine and contribute to rising seawater temperatures.

2. **Focus future power-generation investments on sustainable processes while phasing out existing combustion-based plants**
   (a) When investing in modern infrastructure to support future energy requirements, neither nuclear or natural gas based power generation are economically viable options.

      i. Nuclear facilities require large initial investments and similar decommissioning costs

      ii. Natural gas is reliant on sensitive non-renewable resources and contributes to greenhouse gas emission.

(b) Modular sustainable energy technologies such as solar and wind power offer many benefits over their non-renewable counterparts that require large facilities.

   i. Modular solutions encourage the steady development of infrastructure compared to the large initial investments required for combustion-based facilities.

   ii. Decentralizing an energy infrastructure ensures network reliability.

   iii. Renewable energy technologies can be implemented to target various attributes of the Arabian Gulf. Solar power can be used to capture energy from the consistent and strong solar insolation experienced in the region, and wind power technologies can be targeted at capturing shamals which is a near continuous source in the spring and summer months.

   iv. Regions with access to fossil fuels are presented with an opportunity to profit off of remaining resources while investing in a power generation infrastructure that can withstand the exhaustion of those resources.

(c) Relying on combustion for power generation and desalination for potable resources, there exists a water and power nexus where both are dependent on exhaustible sources.

(d) The economic benefits from renewable energy sources will outlast future economic investments into depleting fossil fuels. The investment in sustainable and renewable energy resources creates an infrastructure that is reliable and sustainable, even if existing in tandem with combustion power generation. To "secure a sufficient, reliable supply of low-carbon energy and water" (Sharjah Electricity and Water Authority, 2020, p. 13), dependency on fossil fuels needs to be reduced.

3. **Establish frequent reporting and monitoring of source water**

   (a) Water quality guidelines should be set to ensure that source water meets certain standards that promote plant resilience. A regional water board should be established that evaluates the administration of desalination plants. The administration should report data on source water, effluent water, over production of water, and environmental safety. Data collected will provide evidence needed to take action against negative environmental effects. Additionally, fluctuation of source water quality will be detected and recognized to prevent significant damage to the plant.

   (b) Additional research should be conducted to determine the impact of ship movement on the desalination process. This research should find specific information on an acceptable distance for shipping vessels to travel near desalination intake ports.

4. **Develop policy on brine management with environment and economy in mind**

   (a) Zero liquid discharge (ZLD) should be included in the policy as the main technology to eliminate brine. Although ZLD discharge is more expensive to install, the costs of brine management will decrease overtime because it decreases the volume of brine and the carbon footprint of desalination plants. In addition, ZLD makes it easier for desalination facilities to follow restrictions on brine regulations and mixing zones.

(b) Brine should be disposed of through submerged disposal. The brine should be dumped into deep ocean areas where the concentration can be diluted. If the desalination facility is not built near deep waters, long pipes should be installed to deliver the brine near the ocean floor.

Suspended Solids	≤ 50 mg/l
Mixing zone radius from outfall	500 m
Temperature	5 °C
Dissolved Oxygen	5 mg/l or 90% saturation
pH	0.2 pH unit change
Total Dissolved Solids (TDS)	≤5% above ambient conditions
Turbitiy	75 NTU or 20% reduction
Oil and Grease	≤10 mg/l

Figure 1: Mixing Zone Limits adapted from the United Arab Emirates Ministry of Environment & Water (2015, p. 6)

(c) The mixing zone limits in Figure 1 are strict enough to create both a positive impact on the environment and the economy overtime. These limits should be adapted into policy and set by SEWA. The Arabian Gulf can be further protected by increasing sampling beyond Total Dissolved Solids (TDS) limits for toxic chemicals, such as boron. Regions in the Gulf Cooperation Council (GCC) must consider the Arabian Gulf's health as a critical concern if they intend to continue relying on seawater desalination for freshwater.

(d) The brine in mixing zones should be tested frequently throughout the week, if not continuously.

(e) Organisms that live near mixing zones should be sampled to protect marine ecosystems. The minimum amount of collection should be monthly and the maximum should be weekly.

5. Establish water quality guidelines that promote human health and facility sustainability

(a) Implement remineralization as a post-process of desalination.

i. The combination of highly effective water purification seen in RO/distillation based desalination and internal post-remineralization give desalination plants nearly full jurisdiction over water quality.

ii. Desalinated water is generally slightly acidic due to its purified state. Remineralization offers an internal solution to re-balance water pH before distribution to minimize corrosion.

iii. Remineralization techniques offer other benefits, such as introducing concentrations of minerals that benefit human health or even improving the taste of the water.

(b) Target specific contaminants within water quality standards rather than setting general ranges for total dissolved solids.

i. Requiring water to have a low TDS generally relates to high clarity, but does not ensure potability.

ii. Regions that specify general TDS ranges rather than monitoring and setting ranges for specific contaminants risk causing chronic health conditions. Certain concentrations of toxic contaminants can remain undetected under TDS ranges alone.

iii. The World Health Organization (WHO) offers an abundant amount of information on these contaminants and their related health concerns.

iv. Desalination plants should conduct a cost and risk analysis of each possible contaminant from the WHO's guidelines (World Health Organization, 2017) to choose which ones to monitor and regulate.

SEWA should modify their current desalination policy draft and implement it in Sharjah, UAE. This action will set a good example for other regions in the GCC and will allow Sharjah to lead sustainability in the UAE. A policy is vital for the longevity of desalination that will allow for the continuous and sustainable supply of freshwater. The economic and environmental implications of not having an enforced desalination policy are detrimental and potentially irreversible.

Introduction

In arid regions such as the United Arab Emirates (UAE), alternative solutions must be employed to offset the demand of clean drinking water not supplied by natural resources. Beyond the necessity of freshwater for basic human survival, limited access to drinking water in the UAE could constrain future development and hinder economic sustainability (Murad et al., 2007). Freshwater in the UAE is currently collected through three main sources: groundwater, desalinated water, and treated wastewater. As of 2015, groundwater accounts for 51% of the total water supply and is mainly used "by the agriculture, forestry, and public realm amenities sectors" (Saleh et al., 2019, p. 5). Desalinated seawater supplies 40% of the total water supply in the UAE and is mainly used by the domestic and government sectors, and sees less usage in the industrial and commercial sectors. The remaining water supply is from treated wastewater, which accounts for 9% of the total water supply and has seen little to no adoption as a drinking water source (Saleh et al., 2019). Desalination is a critical component to providing freshwater to not only the UAE but all the countries along the Arabian Gulf. However, without proper regulations the desalination process can lead to serious economic and environmental impacts.

Regions in the Gulf Cooperation Council (GCC) that depend on desalination for freshwater must consider the Arabian Gulf's health as a critical concern. Brine, the main byproduct of desalination, can have harmful effects on the environment if not properly discarded due to its chemical pollutants, high salinity, and high temperatures. Possible temperature/salinity increases and pollution can hurt the Gulf's ecosystems and affect its reliability as a resource. Additionally, desalination plants' high energy demands from mostly combustion-based power hinders SEWA from reaching their 2025 vision to "secure a sufficient and reliable supply of low-carbon energy and water" (Sharjah Electricity and Water Authority, 2020, p. 13).

Implementing a policy to protect the environment from the negative aspects of desalination will minimize the future cost of retroactive environmental protection and allow SEWA to achieve its declarations of sustainability. The goal of this project was to create a policy brief to outline the central aspects of desalination that need regulation, which was achieved by creating a set of research objectives that would focus the scope of this project. The methodology derived from these research objectives allowed us to provide recommendations to SEWA. These recommendations included reverse osmosis (RO) vs distillation, energy, source water, brine management, and potable quality. We compiled these suggestions into a policy brief for SEWA and hope that they are considered when SEWA formulates their desalination policy.

Background

The following chapter aims to provide the background information necessary to understand the implications of our concluding policy recommendations. First, this section presents a background on the current leading desalination technologies. Next, it presents information surrounding the Arabian Gulf on the topics of economics, pollution, and its importance to the GCC. Then follows a discussion on the bilateral relationship between desalination and water quality, along with the effects desalination byproducts have on the environment. To conclude this chapter, background information will be given on the importance of environmental policy and regulating energy usage.

2.1 Desalination

2.1.1 Desalination Overview

Increasing population has put potable resources under specific pressure in the UAE, alongside influences of a rapidly increasing economy and the cultural avoidance of recirculated wastewater. This is primarily due to unreliability associated with the natural sources of freshwater in the region. Access to surface water is contingent on the amount of rainfall, so its use as a potable water source is largely restricted to the eastern UAE within the Oman Mountains as the rest of the region receives very scarce rainfall. Groundwater sources, another natural source, come from both renewable and non-renewable aquifers: renewable aquifers occur from shallow alluvial aquifers, while non-renewable aquifers occur in the deep aquifers of the UAE (Murad et al., 2007). With non-renewable sources being more readily available than their renewable counterpart, it is important to diversify water collection strategies while pursuing renewable sources. Additionally, the effects of seawater intrusion on groundwater quality in the northeastern coastal area demonstrated that "seawater intrusion [has] extended about 8 km inland from the coast of the Gulf of Oman", and that groundwater sources may not provide long-term solutions to the issue of freshwater scarcity in the UAE (Sherif et al., 2011, p. 436). This lack of natural resources paired with the pressures of population growth have driven the acceleration of technological innovations relating to freshwater collection. Desalination offers a potable water solution that is accessible and culturally accepted, alongside diversifying existing water resources and establishing a more robust water system to supply their freshwater needs.

Desalination also provides another, often less publicized, benefit over freshwater sources in that it is slowly offsetting the natural balance of freshwater and seawater on Earth. Freshwater only accounts for 3% of the world's water supply, with seawater accounting for the remaining 97% of available water. Of that 3% freshwater only 0.5% is available for use as a potable resource, while the other 2.5% is held in glaciers, atmosphere, soil, and deep-earth aquifers (American River Water Education Center, 2020). Thus, processes that add to the

0.5% of accessible freshwater by taking from another source (such as seawater) are increasing the global supply of freshwater. The process of desalination presents a benefit over the collection of existing freshwater, in that the creation of freshwater from seawater means that current sources of freshwater can be preserved (as they are largely non-renewable). Instead of harvesting/recycling the limited number of freshwater sources in the region, desalination provides a method of converting the abundant seawater on Earth into potable freshwater. The preservation of existing groundwater sources and conversion of abundant seawater are additional benefits to the use of desalination, and promote desalination in regions where groundwater sources are scarce.

An important factor to the success of alternative water production solutions is the quality of the water that feeds these various systems. Fluctuations in water quality can cause the efficiency and productivity of water production plants to fluctuate correspondingly, and could force plants to temporarily shut down. Additionally, the need to adapt to these fluctuations has been an important factor for the UAE to consider to continue its strategic transformation of water systems through the development of water production plants. Desalination has proven to be one of the most reputable solutions to the problem of insufficient natural freshwater sources, and its usage as a primary source of drinking water in the UAE has only been growing. However, a plant's inability to resist large changes in source water quality means that extra consideration must be placed on ensuring the resilience of desalination plants.

2.1.2 Desalination Resilience

The resilience of desalination plants is directly relevant to their operational efficiency and economic viability. Variations in water quality, even if infrequent, can have considerable effects on the capabilities of a desalination plant and directly impact the availability of drinking water for thousands of people. To provide further context, "[c]onsider what a 1% drop in availability means in terms of production: Given that the plant operates 8760 h per year, a 1% drop in availability means that it will no longer be available to produce for just over 87 h per year. Since the plant produces a total of 180,000 l/h, this would cause a loss of more than 15 million liters of desalinated water" (Durán et al., 2020, p. 10). Beyond the commonly discussed environmental protections provided by regulations around water quality, such policies have the potential to increase plant efficiency by decreasing events that impact plant resilience. An increase in plant efficiency promotes environmental protection and ensures that potable water output from desalination plants can remain consistent and resilient to anomalies.

2.1.3 Desalination Methods

Desalination plants utilize multiple technologies to convert seawater into freshwater resources. The top three most common desalination processes that contribute to the UAE's freshwater supply are multi-stage flash (MSF), multiple-effect distillation (MED), and RO.

MSF and MED are both examples of thermal processes that rely on distillation as their main mechanism for purifying seawater, which contribute to 58% and 33% of the UAE's desalinated water supply respectively (Saleh et al., 2019, p. 5). MSF relies on a temperature difference between seawater before and after it is heated by a thermal source, and uses an array of chambers that successively lower temperature and pressure to vaporize water from liquid. MED uses a similar array of chambers to evaporate seawater, but it relies on a temperature difference between seawater and a direct thermal source rather than the temperature difference between heated and non-heated seawater. MED typically is a more efficient desalination method, using less energy than MSF by applying a thin-film evaporation approach.

RO is a technology that entered the desalination industry later than MSF and MED. RO relies on pressurizing its feed water and encouraging it through a semipermeable membrane that removes solutes. It is widely regarded as a cleaner technology because it only requires electrical energy to power its pumps and does not require thermal energy, but it only accounts for 9% of the UAE's freshwater supply (Saleh et al., 2019, p. 5).

Globally, RO has become the standard process for desalination, contributing to around 69% of the global desalination capacity while MSF and MED processes have been phased out, only contributing to 18% and 7% of the global desalination capacity respectively (Saleh et al., 2019, p. 3). The share of desalination technologies between MED, MSF, and RO generally differ among regions due to variances in energy production methods.

2.1.4 Energy Consumption

Desalination is not without its drawbacks, and the different technologies come with their own pros and cons. Both thermal and membrane based desalination facilities demand very high amounts of energy. RO desalination plants can be entirely powered from clean energy sources, as they rely purely on electrical forms of energy without the dependency of thermal sources for distillation. Even though membrane-based desalination processes warrant more straightforward solutions for energy conservation, thermal-based processes also have an abundant amount of solutions to reduce their energy consumption. In the UAE, thermal-based desalination plants are often seen in dual purpose arrangements with combustion-based power plants. These cogeneration plants combine a power plant and a desalination plant, and can exist in a mutual relationship. The power plant produces hot steam which is used as the thermal source for the thermal-based desalination process, while the desalination plant is taking in seawater to act as a cooling agent for the power plant. This arrangement reduces total emissions and introduces a relationship that conserves energy. Other unconventional solutions exist that utilize various technologies to fulfill the thermal energy requirements, such as using solar ponds, a relatively cost-effective method, to capture thermal energy through a pool of saltwater and supply this energy to MED and MSF desalination processes (Younos & Lee, 2020). But, because thermal-based processes are being phased out, less modern innovations are coming from these technologies.

RO desalination plants became the global standard for desalination because they can be entirely powered entirely from clean energy sources. The UAE has already adopted clear strategies to "increase the RO power plants' capacity by building new plants", as RO does not require heat energy and has lower operational costs. This push for membrane-based desalination also assists in decoupling the water and energy industries, because future limitations on non-renewable power generation techniques will not affect the RO desalination plants. But, RO technologies still require vast amounts of energy, so understanding their consumption is critical. Because the carbon footprint from RO facilities is indirect, it is important to understand the effects these plants' energy usage have on the environment. This is achieved with a metric that looks at plant emissions in CO2e. CO2e equates the cost of desalinating one cubic meter of water in terms of greenhouse gas emissions, and puts it in terms of the environmental impact resulting from burning a set amount of CO2. The process of MSF is estimated to use 2.988 $\mathrm{kgCO_2e/m^3}$ of water desalination, MED is estimated to utilize 1.28 $\mathrm{kgCO_2e/m^3}$, and RO is estimated to utilize 2.562 $\mathrm{kgCO_2e/m^3}$ (Saleh et al., 2019, p. 5). This suggests that an RO plant will have larger contributions to greenhouse gas emission than an MED plant if powered exclusively from combustion-based power, meaning the source of energy is critical to limiting emissions when supplying power to desalination plants.

2.2 Arabian Gulf

2.2.1 Arabian Gulf Overview

The Arabian Gulf (more commonly known as the Persian Gulf) is a shallow estuary where freshwater and saltwater mix, with a mean depth of 35 meters (approximately 115 feet). It is connected to the Strait of Hormuz that opens into the Arabian Sea and Indian Ocean. The northern gulf collects freshwater along the Shatt-al Arab River and the Iranian Coast. Observed inflow is approximately 0.2 meters per year, and the circulation of the gulf is controlled by the exchange flow with the Strait of Hormuz. Inflow through the strait is 33.7 meters per year, while the outflow is 32.1 meters per year. The Indian Ocean surface current flows into the gulf year round and has a lower salinity. A small part of the surface current flows out of the Gulf, while the majority mixes with the hypersaline water in the Gulf. There are also shamal winds that travel from the Northwest and have velocities of up to 18 meters per second in the winter and up to 10 meters per second in the summer (Chow et al., 2019).

Due to the high temperatures in the Middle East, shallow waters in the Northern Gulf and the UAE coast rapidly evaporate. This evaporation causes a dense brine to form and leaves the strait as a subsurface gravity current. Subsurface currents are induced by differences in densities of water. This current causes more dense water to sink as the salinity of the sea water increases in that specific location. Evaporation removes between 1.4 meters per year to 2.1 meters per year while precipitation adds between 0.07 to 0.15 meters per year to the Arabian Gulf. The large evaporation rates and minimum river and rain input lead to increasing salinities (Chow et al., 2019). The salinity levels in the gulf are usually between 38-42 psu, and are dependent on the season. The salinity of the water is highest in the summer, while spring trends toward lower salinity levels due to evaporation rates. The lower evaporation levels cause thermal stratification, which is the formation of two distinct layers of water at different temperatures. Thermal Stratification causes the surface salinity to be lower compared to the other seasons (Chow et al., 2019). These high salinities and variance of salinities experienced in the Arabian Gulf can influence desalination plant operation.

2.2.2 Arabian Gulf Economics

The Arabian Gulf not only supplies freshwater through desalination, but is beneficial to the livelihood of its citizens. Nomads living near the Arabian Gulf had historically survived through a nomadic lifestyle of pearling and fishing. Today the demand for seafood has risen as the population of the UAE continues to increase, thanks in part to large economic gains from the oil industry (Evans, 2020). In 2018, 20.7 million barrels of oil per day flowed through the Strait of Hormuz, with oil exports accounting for 25% of the UAE's gross domestic product (Barden, 2019). As the fishing industry continues to grow, the Arabian Gulf continues to experience a rise in salinity levels that "is now too high for many common fish species" (Berdikeeva, 2019, para. 10). This has led to a decreasing wild fish population, causing Arabian Gulf countries to adapt to methods of fish farming. Over 200 hundred fish species have experienced population decline, and 85% of popular fish have gone extinct in the region (such as groupers and rabbit fish) (Berdikeeva, 2019). Against these odds of a declining fish population, the fishing industry still continues to grow under the pressures of increasing human populations and changing dietary preferences. In the UAE, fish farming (also known as aquaculture) is projected to produce 30 tonnes, or 66,138 lbs, of caviar annually. In 2015, aquaculture created 790 tonnes, or 1,742,000 lbs, of sturgeon, tilapia, shrimp, and gilthead seabream (Food and Agriculture Organization of the United Nations, 2016), resulting in 3,000 tons of fish per year (6,000,000 lbs). The industry of fish farming is currently government driven, with little to no private investors (Berdikeeva, 2019). As the reliance on fish farming grows with the increasing human population, there is an increasing importance of protecting the Arabian Gulf from high salinity levels and toxic pollution.

2.2.3 Gulf Cooperation Council

The Arabian Gulf is governed by a council known as the GCC. The GCC was established on May 25th, 1981 and includes the UAE, Kingdom of Saudi Arabia, Kingdom of Bahrain, the State of Qatar, the State of Kuwait, and the Sultanate of Oman (Secretariat General of the Gulf Cooperation Council, 2020a). The GCC aims to facilitate cooperation amongst the countries in terms of economic, communications, education, health, tourism, legislative, and environmental affairs. The Council also seeks to promote research in different sectors across the countries. Specifically, the GCC recognizes the necessity of conserving natural resources and developing solutions for environmental concerns in the Gulf region. The Council aims to address concerns surrounding environmental affairs by developing the necessary legislations and promoting awareness of environmental issues in the community (Secretariat General of the Gulf Cooperation Council, 2020b).

Due to the arid conditions and the rapid development in the region, the GCC countries are prioritizing water security and water conservation. The Council has established a committee of ministers for water conservation from the GCC countries to promote collaboration on issues related to water (Ahmed et al., 2014). Currently, the GCC countries rely on desalination for their water supply. In fact, the GCC countries combined produce 40% of the world's total desalinated water (Asaba, 2020). Because the process of desalination relies on clean source water for efficient operation, the GCC must prioritize policy to protect the Arabian Gulf if its countries are to continue using it as a resource for freshwater.

2.3 Water Quality Influences

2.3.1 Arabian Gulf Pollution

The Arabian Gulf is increasingly becoming more polluted, so to maintain the efficiency of the desalination plants it is important for the GCC to limit the Arabian Gulf's pollution. The major causes of pollution for the Arabian Gulf are oil and gas production, desalination, sea traffic, urban development, and climate change (Chitrakar et al., 2019). Seawater contamination can also present issues for desalination plants, as they cannot operate effectively when the input seawater is heavily contaminated and risk shutdown. The Middle East economy is heavily invested in the oil and gas industry, with an estimated 20,000 oil tankers imported and exported annually. Pollution is also caused by ballast water discharge, or water that is held under ships and provides stability for vessels in rough seas. This ballast water is often from foreign bodies of water and can introduce non-native marine species when flushed from travelling vessels. Another pollutant to the Arabian Gulf is coastal development, with the UAE bordering the Arabian Gulf for more than 700 km. These developments can cause erosion to the coast, along with damage to coastal reefs and naturally occuring seaweed. Human polluters produce carbon dioxide and greenhouse gases, which can change the chemical composition of the Arabian Gulf. An increase in CO2 in seawater causes the pH to decrease, making the seawater more acidic. This change in acidity is causing an increase in algae blooms (Chitrakar et al., 2019), and can impede membrane-based desalination systems by clogging intake filters and compromising membranes.

Beyond the impacts of coastal development, litter left behind at recreation sites such as beaches (metal scraps, plastics, glass bottles, waste paper, discarded nets, plastic sacs and bags, etc.) can cause harm to marine life by trapping them in debris. Additionally, oil spills can affect the safety of swimming waters near recreation sites. Oil spills will appear as tar balls on the beach, making it unsafe to walk on the shore or swim in the ocean. Tar balls are remnants of oil spills that have been weathered to a solid consistency, are dark in color, sticky, and are difficult to remove from contaminated surfaces (Shriadah, 2008). Emirates such as Ras Al-Khaimah, Abu-Dhabi, and Sharjah are largely affected by littering from fishing and shipping industries in comparison to littering on the beach, but such factors should be kept in mind when implementing and enforcing regulations to protect the seawater (Shriadah, 2008). It is important to identify and regulate the pollutants that affect the intake of desalination plants.

2.3.2 Total Dissolved Solids

Desalination converts seawater into freshwater by decreasing the concentration of total dissolved solids (TDS). TDS is the sum of all minerals, salts, organic matter, and metals that are dissolved in a water sample. There can be as many as 70 elements that are dissolved in seawater and brackish water. Nevertheless, 99% of the TDS in seawater is made up of six chemicals: chloride (Cl^{-}), sodium (Na^{+}), sulfate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^{+}) (Younos & Lee, 2020). The average concentration of TDS in seawater is between 30,000-50,000 mg/L,with the Arabian Gulf having 45,000 mg/L. For comparison, freshwater from streams and rivers has a concentration less than 500 mg/L and wastewater has a concentration between 200-500 mg/L. According to the World Health Organization (WHO), TDS levels below 300 mg/L are considered excellent quality while levels above 1200 mg/L should not be used (Younos & Lee, 2020). Higher TDS present health risks and create taste and odor issues, as well as cause scaling in pipes, staining of bathroom fixtures, and corrosion of piping and fixtures. The negative impacts of high TDS concentrations are also applied to the concentrated byproduct of desalination, brine.

2.3.3 Brine

Desalination takes in water of a certain salinity, and divides that source into water with very low salinity, freshwater, and a byproduct with very high salinity, brine. Brine, also known as concentrate, is the largest byproduct of desalination. It is a highly concentrated salt mixture and often contains pretreatment chemicals, cleaning chemicals, and metals from corrosion of pipes. Some of the chemical pollutants contained in the mixture include iron, copper, nickel, zinc, and chromium (Benaissa et al., 2020). Due to these harmful elements, the high temperature and high salinity brine must be disposed of properly to subvert negative environmental effects.

2.3.4 Brine Disposal

The full impact of brine disposal on the environment is still unclear due to multiple studies presenting conflicting information. One study was done on the Mediterrean Coast of Israel, located near two large desalination plants. It was determined that brine had almost no impact on the quality of the nearby seawater (Kress et al., 2020). In another study, brine released at the shoreline or into topographical land depressions resulted in visible harm and destruction of life forms (Badescu et al., 2013). These contradictory findings indicate that the brine disposal location is still important to minimize the potential negative effects it has on the environment, and that more research needs to be done to identify these impacts.

If brine is disposed of in a localized environment where there is limited water flow, the brine solution may not effectively mix and dissipate into water. When brine is discarded into the ground it can cause the soil and groundwater to deteriorate. Additionally, when brine is discharged near a shoreline the life forms that exist around it have been noticeably harmed (Badescu et al., 2013). Benthic communities at the bottom of the sea are affected the most as they can only withstand changes in the salinity levels of ±1000 mg/L. Other species are able to adapt to the temporary change in salinity; however, they cannot withstand long term exposure (Ladewig & Asquith, 2012). Without proper mixing conditions, the brine will disrupt ecosystems and can cause long term damage.

With respect to larger mixing zones, brine has a smaller impact on the environment since there is more capacity for diffusion back into the natural environment. In studies where brine was released in wide bodies of water, the water quality was only affected at the bottom of the ocean with negligible effects in other ocean layers (Kress et al., 2020). The reason for this is the higher density of brine compared to water, meaning once it is released into the ocean it sinks to the bottom with minimal disruption to the sea above. It was hypothesized that the brine would increase salinity and sequentially increase temperature, decrease oxygen concentration, decrease pH, and increase chemical and metal concentrations. However, no significant trends were found in the study when the brine was released into a large body of water (Kress et al., 2020).

As a result of the different findings from each study, it is understood that the effects brine has on its environment are dependent on the disposal location, hydrographical conditions, desalination technology, plant production, and final brine density (Kress et al., 2020). In the study when brine was released at the shoreline, there were noticeable negative effects to water quality and the environment due to the constricted mixing radius of the disposed brine. In the Mediterranean coast study, the brine was discharged further from the shore and resulted in minimal negative effects on water quality and the environment.

After determining a suitable location to dispose of the brine, the disposal technique needs to be considered. There are currently four primary brine disposal techniques. Surface water disposal is one of these techniques, where brine is dumped back into the desalination plant's body of source water, such as oceans and estuarine waters. Although this technique is low cost, if brine is added in close proximity to the desalination plant's intake it can create a positive feedback loop of increasing source water salinity. Submerged disposal is another common technique that transports brine through underwater pipes beneath the surface of the ocean. This method has a high initial investment cost, but has the benefit of disposing the brine away from desalination intake ports (Younos & Lee, 2020). Another technique is deep well injection where concentrate is injected into groundwater aquifers that are not used for drinking. The depths of the well can vary from 0.32 km to 2.57 km below the ground. This method has been known for its reliability and limited negative environmental effects, but it is not feasible in locations where groundwater is limited (Lenntech, n.d.).

New technologies are now being utilized to reuse brine and limit the quantities requiring disposal. One common process is through solar evaporation. Using either evaporation ponds or wind aided intensified evaporation (WAIV), the water is evaporated out of the mixture leaving only the contaminants to be discarded. The ponds can (and have already been) implemented at an industrial scale with low economic cost and simple operation. However, evaporation ponds use substantial amounts of land that can contaminate nearby groundwater sources (Morillo et al., 2014). Another process is phyto-desalination, which uses brine to irrigate plants and crops. Only a selected group of species are suitable for this method with the current technology. zero liquid discharge (ZLD) is a different method that uses the evaporation and crystallization process and aims to reduce the amount of salt in the brine. This technology has high installation costs, but over time can help reduce the expenses of brine management. Membrane distillation is another technology and it is used for high concentrated mixtures like brine. This method has shown promising results including reductions in energy consumption and minimal maintenance. In addition, it eliminates the need for pretreatment of source water. All the different processes help reduce the amount of brine output and thus limit the associated environmental risks (Morillo et al., 2014). These processes are chosen based on the development status, technical complexity, and economic impact to find the best option for the given environment.

2.4 Policy

2.4.1 Importance of Environmental Policy

Environmental policies provide checks and balances to private and public industries, and promote sustainability to ensure a healthy environment for future generations. The main priority for all environmental policies is to protect the health of people and their environment by protecting land, air, and water quality. Environmental policies are also used as preventative measurements to stop catastrophes from happening that may influence habitability. Lack of these policies can have detrimental effects on a community's longevity and health.

The water crisis in Flint, Michigan, USA is an example of how the absence of policy can directly affect a community. The Flint River runs through the city of Flint, Michigan. In the early 1900s, the Flint River was used as a waste disposal site for industries that ranged from car factories to meatpacking plants (Denchak, 2018). By 2011, Flint, Michigan accumulated a twenty five million dollar deficit causing the state to take control. As the economy of Flint was declining, the government needed to make changes in spending. To deal with the economic crisis in Flint, Michigan, the emergency manager cut costs by changing the water supply. The potable freshwater source was switched from Detroit's water to temporarily pumping from the Flint River until a new water pipeline was built. The water in Flint was highly corrosive, causing the lead in aging pipes to infuse the community's drinking water. Scientists at the University of Michigan propose this could have been prevented by adding orthophosphate to treat the water (Christman, 2017). In the future, events like these can be prevented through environmental policies on the local level to sample and monitor source water quality as well as drinking water quality. According to pediatrician Mona Hana-Attish, the lack of treatment caused blood-lead levels in children to double and nearly triple in some neighborhoods. Lead was not the only issue found with the water. A critical form of pneumonia called Legionnaires' disease that was the third largest outbreak in US history, killing twelve and affecting at least eighty-seven people (Denchak, 2018). Future environmental crises can be mitigated through the creation and practice of comprehensive environmental policies.

2.4.2 Abu Dhabi Policy

The UAE has a governing body meant to set guidelines and regulations for the rest of the country known as the Ministry of Environment and Water. This ministry creates strategies for other emirates to follow and implement; however, many emirates also produce their own set of regulations. One emirate with thorough implemented environmental policies is Abu Dhabi. These policies regulate all aspects of water usage in the Emirate whether it be fresh groundwater or desalinated water, as well as many other environmental features. Their groundwater policy sets the standards for groundwater management and monitoring in order to "meet human/ecosystem needs both today and in the future at sustainable levels"

(McDonnell & Fragaszy, 2016, p. 35). They also have a water quality policy with exact limitations for contaminants in potable water and sampling guidelines for suppliers (Shadid & Ali, 2009).

Another policy under Abu Dhabi is their "Seawater Desalination Code." This code sets the standard for every phase of desalination, starting from the construction of the desalination plant until the moment potable water is delivered to the consumer. Once all planning is complete and it is properly made, the code specifies the managing, monitoring, and sampling procedures that must be followed. Each section is important in order to maintain a sustainable business that benefits the citizens of Abu Dhabi without harming the environment. Abu Dhabi has numerous detailed environmental policies and clear guidelines that ensure there are limited negative effects on the environment as a result of desalination.

2.4.3 Regulating Energy Usage

The various forms of desalination all require large amounts of energy in order to operate, and the environmental impact of these energy sources can be significant. In Sharjah, SEWA reports that 82.3% of their energy generation comes from Gas Turbines and 17.3% comes from Steam Turbines (Sharjah Electricity and Water Authority, 2019). "The HAP [hazardous air pollutants(s)] that are present in the exhaust gases from stationary combustion turbines include formaldehyde, toluene, benzene, and acetaldehyde" (Environmental Protection Agency, 2020, p. 13527). Such chemicals may have adverse health and environmental effects, and require regulation to ensure these chemicals remain within safe ranges. The Environmental Protection Agency in the United States "conducted a three-tier screening assessment of the potential adverse environmental risks associated with emissions of these pollutants," and ensured that emissions were within regulations for new Gas Turbines installed in the US (Environmental Protection Agency, 2020, p. 13529).

Renewable sources of energy (such as solar panels) have seen little utilization for powering desalination plants in Sharjah. "Solar thermal energy is one of the most promising applications of renewable energy to seawater desalination," and regulations may be necessary to enforce this transition away from non-renewable energy sources (Kalogirou, 2005, p. 268). Multiple plants have implemented coupling with a solar pond as a thermal energy source for MSF processes, and "other indirect solar desalination pilot plants are implemented at different locations" (Kalogirou, 2005, p. 269). The implementation of regulations surrounding health and environmental impacts of the existing energy sources of desalination in Sharjah can push the transition to these alternative, more renewable, energy sources. Issues arise around the cost of photovoltaic cells (found in solar panels) and the variability of power produced from solar panels and wind turbines. Even in face of these issues, "future water desalination around the world should be increasingly powered by solar, wind and other clean natural resources. Such environmentally friendly systems should be potentially available at economic costs" (Kalogirou, 2005, p. 275). The potential for an increased use of renewable energy sources can further contribute to the increase in water desalination as SEWA transitions away from exhaustible energy sources. This transition to renewables will be important for Sharjah's sustainable and long-term access to freshwater.

Methodology

Sharjah is dependent on seawater desalination to be able to provide clean drinking water to its population. Thus, it is crucial for the Sharjah government, specifically SEWA, to enact a policy for desalination and seawater quality. Our plan is to perform a study and create a policy brief to present to SEWA that emphasizes the importance of implementing a desalination policy. We developed the following research objectives to guide our methodology:

1. *Identify the main themes of desalination legislation.*
2. *Understand expert opinions on these themes in the context of policy and regulations.*
3. *Formulate a policy brief with recommendations for SEWA that compiles these findings.*

3.1 Expert Interviews

In order to identify the main themes of desalination policy, we identified and interviewed experts across multiple fields in order to collect multi-disciplinary information. One important requirement of these experts was their availability due to the state of our project timeline, with interviews scheduled within a week's time. For this reason, the preliminary expert interviews were with professors from Worcester Polytechnic Institute (WPI) who specialized in topics relating to desalination. These experts were asked to provide their opinion on various desalination questions, which was critical for our project group to understand before stages of global desalination research and survey generation.

3.1.1 Identification

First, we were tasked with identifying experts that could provide insightful information to assist the formation of general desalination policy themes. To aid the identification process, we established backgrounds or areas of research that are related to our project, including desalination, water quality and environmental policy. The availability of these experts was also important since the interviews needed to be completed in one week's time. Those who met these criteria consisted of current WPI professors in the Environmental Engineering department and the Global Studies Program. They were discovered through recommendations from our advisor or through their listed research interests on their profile within WPI's directory.

3.1.2 Recruitment

In order to contact and recruit the experts identified within the identification stage, we reached out via email with a project summary and information about what we hoped to seek from them. The previously identified WPI professors were contacted via email, and a time was organized to meet with our team. Those who were able to interview provided the necessary information for our team to proceed with our methodology.

3.1.3 Interview Process

The interviews were all conducted virtually, given the current nature of the pandemic, and were held through Google Meets. Using the Chrome extension Tactiq, all of the closed captions from each individual (interviewers & interviewees) were transcribed from the Google Meets platform and stored in a Google Docs file. This provided the capability to review interviews for critical information post-interview, which ensured a more thorough data analysis. We created a list of questions based on our background research that explored the aspects of desalination that are important to consider when conceiving policy. Our questions can be found in Appendix A.5. These questions were asked to each interviewee and were expected to take around 30 minutes to an hour. Given the various expertise of our interviewees, we received answers that covered all the basic factors of desalination that need to be considered in a policy.

3.1.4 Data from Interviews

The data gathered from these preliminary interviews consisted of the interviewees' responses to our questions and their suggestions of other experts that may be beneficial to our study. We did not have time to interview all WPI professors that fit the criteria; however, these professors were noted as experts that would later be qualified to complete a survey. To process the qualitative data received from the interviews, a pass of coding analysis was done on the interview transcripts that entailed highlighting keywords and important topics for each transcript. This data supplied us with qualitative data about the general topics of desalination, and helped us decide relevant and targeted themes regarding different aspects of desalination policy that would later be used to guide world policy research and survey generation.

3.2 World Policy Research

After interviews were conducted and analyzed, we researched desalination policies and guidelines from around the world. The list below represents a step-by-step plan of how this global policy research was achieved.

1. Created themes from interviews with experts
2. Researched policies and guidelines on desalination from around the world
3. Segmented these policies and distributed sections into a master spreadsheet categorized by theme
4. Received drafted policy from SEWA
5. Translated, segmented, and distributed SEWA's document into the master spreadsheet

3.2.1 Theme Creation

To generate themes from the previous qualitative data analysis, the keywords highlighted within the transcripts were first extracted and compiled into a list that represented the critical aspects of desalination that require policy. Additional keywords from our background were added if we noticed repeated occurrence within our research documents. Our initial list included around twenty themes from our interviews and other research, which was later condensed into around eight themes by cross-referencing and combining transcript keywords. This was done for practicality of guideline research and survey generation with respect to our project timeline. For themes that failed to provide relevant or sufficient guidelines or policies, they were eventually transformed into a broader theme or cut entirely. These themes were too focused around specifics of desalination or lacked representation in current global policy and guidelines.

3.2.2 Guideline Discovery

After a selection of themes was created from our interviews with experts, we searched for world policies and guidelines that contained sections relevant to these themes. Countries were selected based on the following parameters: an existing desalination infrastructure (preferably, one that mimicked the thermal plants of Sharjah), an environment similar to that of the UAE, and a publicly accessible guideline/policy database. Later in the project, we received the guidelines from SEWA that would be included into this process for comparison with other world policies and guidelines. We first looked to the United Nations (UN) for guidelines that would likely correlate with many of the themes we had created. We found that the UN held a vast amount of thematically relevant guidelines, which would contribute to the framework of guideline discovery.

Document discovery was accomplished via the FAOLEX database, which provided filters for specific keywords, themes, countries, and so on. The FAOLEX database proved indispensable for discovering and obtaining a majority of the documents during our research. When FAOLEX presented a newer version of a document, the latest policy or guideline was used to keep our research and recommendations up to date.

3.2.3 Guideline Segmentation

A spreadsheet was made with each row labeled as a different theme and each column assigned to a different region of interest. Discovered policies from each region were then broken down into these individual themes to make comparisons more apparent. This spreadsheet was created in Google Sheets.

3.2.4 SEWA Drafted Policy

The next step in our methods was to collect drafted guidelines from SEWA. Since the guidelines were in Arabic, American University of Sharjah (AUS) students on the project team roughly translated and summarized these documents for presentation to the rest of the team. These guidelines were then segmented into the themes and placed into the master spreadsheet similarly to previous global policies.

3.3 Surveys

Now that our project group was familiar with the themes associated with desalination policy and had excerpts of policies from around the world related by theme, we could evaluate which legislation should be recommended to SEWA. To make these decisions in a qualified manner, surveys were sent out to experts around the globe. Various surveys were made, covering the different themes of desalination policy, and were sent to experts that specialized in fields related to those themes. Catering different surveys to different experts ensured we could obtain the most educated opinions for each survey and allowed the surveys to be shorter and more specific which improves response rate. The process to generate these surveys and find their recipients can be seen below.

1. Created different surveys based on the central themes of desalination policy
2. Researched and contacted experts
3. Distributed surveys to experts
4. Analyzed survey responses

3.3.1 Survey Generation

Surveys were created through Qualtrics via WPI, which allowed us to produce professional looking surveys with templates quickly and spend our time focusing on the content of each survey. Additionally, Qualtrics supports data analysis features that assisted us in analysis of the surveys later on. Our team first decided the formatting for the surveys that could be continuous across each survey. Additionally, a template was made that included common sections that would exist in every survey. This template included an introduction page and project summary, a consent agreement, and a survey submit page. Each project member was assigned 1-2 themes to generate the draft of the surveys for, which was accomplished by using the themes, the world policy comparisons, and the insight gained from our expert interviews. Policies from different regions were posed side by side and experts were asked about their differences relating to environmental and economic impacts. Tables and policy excerpts were used to convey this comparison. Policy locations were kept anonymous to avoid potential regional biases. To preserve the attentiveness of our surveys, we thought of creative ways to implement non-typed responses such as multiple choice, ranking, and agree/disagree questions. The surveys also contained areas of open response, in which the experts could discuss factors that they feel are relevant to this policy brief. Once the drafts were completed for each survey, they entered an editing phase that was conducted by the other project members. It was critical to keep the surveys concise and focused on their designated theme to ensure full responses and mitigate overlapping data between surveys.

3.3.2 Finding Experts

We first identified experts to take the surveys by searching within the WPI faculty directory and WPI's Global Water Resource Center. Although we learned that the website was potentially outdated, we wrote down all the professors names and emails to contact later. We also asked the AUS students to send emails to all their professors who are working on desalination and water quality; we thought professors at AUS were more likely to respond to their own students than ones from another university. In addition, we emailed Mayyada Salem Al Baron of SEWA for experts she thought would be helpful to our policy brief. We also searched online for desalination experts, in pursuit of experts that had an available email address to contact.. It was easier to find experts from universities because their emails were listed in their universities' directories. However, when we first started sending surveys we noticed that professors had relatively low response rates. Thus, we started to broaden our search to include Phd students and masters students that were researching desalination technology. We discovered that most professors had websites for their research groups, which included all their students names, areas of interests, and emails. This additional information allowed us to increase our pool of experts by over two hundred people.

If an expert came from the industry, we used Rocket Reach to find their emails; Rocket Reach is a free website that searches people's names or LinkedIn addresses to find their most recent email addresses. We also searched through LinkedIn by searching with keywords of desalination and water quality. Through this method, we were able to leave messages for different people and give them the links to our surveys. Our professor, Joseph Doiron, was also able to spread the survey by posting the link to our website (website creation is explained later) on his LinkedIn and adding us to the project center LinkedIn group. Through all of these methods of outreach, we were able to reach data saturation for all of our surveys.

3.3.3 Distribution to Experts

Once created and formalized, the surveys were distributed to experts around the world. Our initial batch of surveys was distributed to friends, family, and professors at Worcester Polytechnic Institute. After modifications were made based on feedback from this initial test-group, we began the mass distribution of surveys to our identified experts. We used the "link sharing" feature within Qualtrics to generate a link which would be shared to experts via email. In order to prevent unwanted responses to our survey, we resorted to prompting experts to enter their email address in the survey. This served a dual-purpose of safeguarding against spam replies and providing an avenue of further contact with experts who responded.

Using Microsoft Word, we utilized the "Mail Merge" feature to mass-produce (and automatically send) our emails by importing our spreadsheet of experts created previously. This feature allowed us to choose the survey sent to each expert without needing to type and send every email by hand.The first batches of emails were personally tailored to each expert, in hopes that references to their research or career would increase response rates. After this initial outreach, we created a website to increase our perceived credibility among experts and ease the survey distribution and selection process. The homepage of our project website included a description of our project, background on our project members, and a form to contact us with any comments or questions. On a secondary page, we presented our surveys by theme with a link that would take experts directly to the survey. Although we were initially worried that this would open the floodgates to spam responses, we trusted our ability to filter responses from the email field to ensure that the responses were authentic.

3.3.4 Survey Analysis

Once the surveying period was over, the data from these surveys could be analyzed. Because these surveys gathered qualitative data, the analysis was carried out manually. The surveys were first distributed amongst project members for analysis. The responses were read, analyzed, and summarized into the central topics that encompassed the themes of the survey. The qualitative analysis of these responses can be seen in our findings. Since these surveys were limited in distribution to specific experts, we found it more valuable to inspect each information-dense response instead of resorting to an automatic analysis as would be done with quantitative responses. The specific insights gained from these qualitative responses were more valuable than quantitative information, and provided different perspectives on the questions we strived to answer within our policy brief. Our responses were already "categorized" by nature of the surveys being separated by theme, so we compared responses between multiple experts and extracted similarities and differences between perspectives on a specific prompt. The inclusion of a text response field after quantitative responses allowed experts to elaborate the reasoning behind their responses. It was important to understand how respondents interpreted these multiple choice questions, which the paired qualitative responses allowed for.

3.4 Policy Brief

After compiling all the information from the interviews and surveys, a policy brief was created and presented to SEWA. This entailed discussing the implication of our survey findings and combining these suggestions with our background research to generate a set of recommendations surrounding desalination policy. These recommendations were implemented into a LaTeX policy brief document to present our findings in a familiar format to policy makers. The policy brief is meant to give SEWA recommendations on desalination policy to further ensure the economic and environmental prosperity of Sharjah and the Arabian Gulf.

Findings

In this chapter we discuss our findings, which include the key themes of desalination policy that came from our preliminary interviews and the interviewee responses collected from our surveys. These findings reflect the data necessary to establish a foundation for our future policy recommendation to SEWA, and will be used in collaboration with our background research to formulate our final policy brief.

4.1 Interviews

We conducted interviews with four different WPI professors. We interviewed three professors in the Environmental Engineering department and one in the Environmental Science Policy. The interviews were successful in improving our knowledge of the central themes of desalination policy, but some discrepancies were experienced with our transcription software. It experienced difficulties transcribing the nuances in conversation, especially when responses were non-linear or spoken quickly. But, the software was very successful at capturing overlaid conversation between individuals and keywords within the conversation. The transcripts and their corresponding keyword extraction can be seen below A.3. Each interview gave our project group insightful information on desalination policy, and helped establish themes for our world policy research and following survey generation. The initial and final lists of themes extracted from transcript keywords can be seen below, with the final list excluding themes that were eliminated for practicalities described in our methodology.

4.1.1 Theme List

Themes extracted from transcript keywords:

- Reverse Osmosis
- Thermal Desalination
- Brine Discharge
- Environmental Concerns
- Energy Usage
- Intake Salinity
- Regulation Costs
- Public Health
- Economic Costs

- Process Efficiency
- Source Water Quality
- Potable Desalinated Resources
- Discharge Temperature
- Discharge Mixing Zones
- Climate Change
- Co-generation Plants
- Reverse Osmosis Water Temperature Benefits (Viscosity)
- Brine Management
- Fossil Fuels
- Groundwater Contamination
- Pip Corrosion
- Sustainability
- Wastewater Recirculation

Final themes:

- Desalination Technologies
- Desalination Plant Energy Usage
- Potable Desalinated Water Quality
- Desalination Plant Source Water
- Desalination Plant Discharge
- Desalination Intake Port Protection from Ship Movement
- Desalination Process Management

4.2 Surveys

Below are the findings from our surveys. The surveys and project website were distributed to more than 500 experts, specifically catering each category of survey to experts that specialized in closely related fields. Sixty responses were received over a period of two weeks, establishing a response rate of 12%. The responses are presented in summarized forms that reflect the findings of each survey from the reader's perspective. Raw responses can be seen below in A.6.

4.2.1 Desalination Technologies

Environmental Impacts of Reverse Osmosis

The main negative environmental impact associated with RO is the handling and disposal of brine that results from desalination. Despite this negative impact, RO remains a favored source of potable water over alternative sources such as ground water. It's low energy usage in comparison to other desalination technologies, along with its capability of converting plentiful seawater, earns it high praise amongst experts in our surveys. One expert noted that "[the] Gulf states are very water scarce and... [may] deplete ancient groundwater [sources]. By using RO they avoid that issue." These RO systems must be state of the art; however, utilizing renewable energy where possible and carefully disposing of rejected brine to mitigate the negative environmental impacts. Disposal of rejected brine often occurs via deep underground injection, and should avoid sensitive areas that would inhibit the rapid assimilation of the brine with the receiving water. Such sensitive areas include habitats of fish populations, where increased salinity could damage coral reefs and become toxic for many species of fish. Discharging via properly designed outfalls with diffusers "allow[s] [the] salinity of the discharge to be dissipated to less than 10% of the ambient seawater salinity within 300 m from the discharge", an expert noted in the survey. The design of these diffusers is site specific and the ratio of dilution can vary, but all methods should promote the rapid mixing of brine and seawater offshore. The promotion of ZLD technologies can help minimize the return of high-salinity concentrate into the sea, alongside improving the energy efficiency and reducing carbon footprint. Additionally, there is ongoing research around the extraction of minerals from the brine stream (recovering beneficial components).

In addition to the potential effects of brine disposal, RO can rely on energy that is produced through renewable methods to achieve sustainability and environmental friendliness. Although the energy consumption associated with RO is significantly less than thermal methods, it is still high relative to other methods of obtaining potable water. Thus, the carbon footprint associated with RO desalination plants remains a pertinent factor and should be lessened where possible. For RO plants that utilize coal for a source of electricity, an expert clarifies that the "impact... [on] the atmosphere" could be avoided via "renewable sources of energy [that are] linked to reverse osmosis." The coupling of energy sources and RO plants can be a key factor in reducing carbon footprint and promoting sustainability.

Economic Cost of Reverse Osmosis

The steady supply of freshwater is needed for steady economic growth. Desalinated water keeps industries running and is crucial for communities. Using RO coupled with pretreatment of feed solution, potable water production is fast and cost effective. It's cost effective because "the energy costs for operating an RO plant are much smaller than the revenue generated from selling treated water," with the energy consumed ranging from "0.5 - 2 kWh per cubic meter water produced." Thus, the UAE will likely generate a large revenue from selling the desalinated water.

Even though RO is one of the most cost effective desalination methods, the energy cost to run the plants is still high. RO is expensive due to the high electrical demand for high pressure pumps used to overcome the "osmotic pressure of sea water" (3-4 kWhr per cubic meter). There are recovery techniques that can be put into place, but they only help with approximately 40% of the savings. Furthermore, "increased energy efficiency can reduce the pumping costs, as RO requires very high pressures." This can include using solar, wind, or pressure retarted osmosis to mitigate the energy costs. The costs can also be mitigated by encouraging private sectors to invest in RO and encourage them to develop innovative solutions.

Environmental Impacts of Thermal Solutions

One of the main reasons thermal solutions are used over membrane solutions is the robustness of operation associated with their acceptance of feed-water. However, thermal solutions have a larger negative impact on the environment. One negative impact is the energy needed to power thermal desalination. The large amount of energy needed to power the facilities increases the carbon footprint. However, these negative impacts can be improved by "replacing the old MSF or coupling the steam generating machine with solar panels instead of steam boiler." The facilities can also integrate waste heat or geothermal energy to decrease the negative impact on the environment. Many experts reason that the only way to decrease the energy usage is to switch thermal desalination to RO.

Thermal-based desalination also creates brine that "usually has a higher concentration of metals, including copper." The brine also has a higher salinity and temperature compared to the source water. The temperature and salinity can be mitigated by discharging "high salinity brine into deep ocean areas with higher dilution factor may offset these issues." Better pretreatment and reduction of discharge from plant to nearby water treatment can be used to improve the environmental impact of thermal desalination. With thermal desalination, extensive research should be done on the ecosystem where brine is disposed and it should be away from sensitive habitats and fish populations.

Economic Cost of Thermal Solutions

By itself, thermal plants are more energy intensive than RO plants. The economic cost can be improved by integrating waste heat or geothermal energy. Waste energy can offset the cost and make it economically viable. However, many experts expressed that there is nothing that can be done to mitigate the cost of thermal desalination. One expert expressed that "thermal desalination technology has no future outside of the Middle East and even there it is likely to be replaced by membrane desalination - it is not cost competitive." Another expert wrote that desalination facilities "Need to decarbonise water production. I suggest replacing fossil-driven thermal processes with renewables-driven RO."

Desalination Technology for Arabian Gulf

The Arabian Gulf has relied on thermal desalination due to the higher salinity of the water, thus needs to consider salinity factors when switching to membrane based solutions. Some experts claim that thermal desalination should continue to be used in the Middle East due to its ability to handle fouling and scaling issues. One expert explained that "RO is the most attractive desalination technology because of its low energy consumption, but as the salinity of the source water increases, the energy efficiency and applicability of RO decreases altogether, favoring thermal systems." Thermal desalination is also less prone to unexpected failures, which means the desalination facilities will not be shut down as often.

A solution to the Middle East might be a hybrid of thermal and membrane based desalination. This hybrid would aim to increase the water production and lower costs. The usage of the facilities would depend on the salinity of the source water: "Using RO for desalination to its effective salinity limit of 70,000 mg/L would most likely be the most energy efficient (and cost efficient). For the RO brine, a thermal desalination technology could be used to treat water with high salinity (greater than 70,000 mg/L) with the integration of waste heat or another form of low-grade thermal energy to power the technology." This solution would decrease the amount of brine disposed and increase water production.

Another solution to the high temperature and salinity of the Arabian Gulf is to use newer membranes that work better at targeting higher salinity. Older RO membranes such as RO polyamide struggle in the region, but modern RO membranes have been developed to target higher salinities. Additionally, new membrane technologies such as membrane distillation (MD) can be considered as a solution. MD is beneficial because it can handle higher source water salinities and minimizes the brine produced and returned to the Arabian Gulf. Switching to RO will be exponentially important as the Arabian Gulf switches renewable energy. Currently, thermal desalination is coupled with power generators, which will no longer be possible when the power generators do not produce as much energy: "Without the extra energy from the power generators, thermal technologies become extremely poor economically. Hence in the long-term the move towards RO and reduction of thermal desalination in the region is inevitable."

Membrane and thermal-based desalination are not the only solutions to water scarcity. One expert noted that "vapor compression desalination has the energy efficiency of reverse osmosis and the robustness of thermal processes. Furthermore, it can recover so much water [that] there is zero liquid [brine] discharged."

4.2.2 Desalination Plant Energy Usage

Nuclear Power as a Principal Source

Nuclear power generation supplies great amounts of energy with relatively small environmental impact. For a set amount of energy, the volume of mined uranium is much less than the amount of coal/oil needed to produce the same amount of energy. Additionally, the current global warming crisis is stemmed from the concentrations of CO2 in the atmosphere which fossil fuel processing directly contributes to. Nuclear power does not directly contribute directly to depositing CO2 into the atmosphere. Some aspects of the process still have a carbon footprint, but they are indirect contributors. The waste from nuclear power generation is much less pressing when compared to global climate change, but still requires resources to manage properly. The processes involved with spent fuel disposal and nuclear plant decommissioning or maintenance require strict management that can have large impacts on human health if mismanaged. The carcinogenic nature of the waste makes the byproducts from nuclear plants more directly threatening to human health than those that come with fossil fuel based plants, which comparatively have more direct environmental impact. Additionally, this concern on human health from nuclear power also arises in general plant operation. The existence of nuclear power plants in a region can be viewed as a threat to the habitability of that area if the plant experiences failure, while coal/oil based plants have minimal risks of immediately and largely influencing habitability.

Nuclear power plants require very different financials than coal/oil based power plants. They require large investments at the beginning and ending of the plant's operation time and much smaller costs during normal operation. Capital investments required to construct the plant and decommission costs are very high, but the comparatively low cost of fuel and maintenance compared to coal/oil helps the plant operate more cost-efficiently. This generally sets nuclear plants to be profitable over fossil fuel based plants, but the rare and unexpected possibilities of leaks or plant operation issues can push this balance quickly to favor fossil fuels. Nuclear power is viewed as a long term investment, and because of this is more present in regions that experience geopolitical stability.

Natural Gas as a Principal Source

Natural gas has become the most efficient way to generate energy from fossil fuels. When utilized as a fuel for combustion power plants, natural gas releases much less CO2 as a byproduct into the atmosphere than coal or oil. Nonetheless, because global climate change requires reducing greenhouse gas emissions, natural gas still has a large negative impact on the environment. There are technologies to reduce natural gas's carbon emissions such as carbon capture and sequestration, but these processes cost money and still require the disposal of whatever the output state of carbon is. But, because this reduces the amount of CO2 being released into the atmosphere, these technologies still present benefits.

Natural gas exists in a variable market that is heavily reliant on availability and competition. Natural gas is very difficult to transport and is most prominently used as a fossil fuel source in regions that have natural resources to tap into. When available, natural gas can be used (in plants accustomed to dirtier fossil fuels such as oil or coal) as a source to greatly reduce that plant's environmental impact. Additionally, adopting natural gas as a source further helps diversify a plant's operational capabilities, which is imperative for plants that are dependent on unreliable fossil fuel sources. Because fossil fuel sources are limited, and competition for these resources are rapidly increasing, they can not be considered a sustainable option while investing in power infrastructure.

Comparing Nuclear Power and Natural Gas as a Principal Source for Desalination

When comparing power generation from nuclear processes and natural gas sources, there are large risks associated with both processes. Nuclear power often requires massive and immediate investments with respect to long term planning, and in cases can prove to become a liability on human health with the potential for meltdowns, leaks, or malfunctions. Due to this, these plants have strict operational lifetimes that require huge sums of money to decommission. Additionally, national security reasons can make uranium sources hard to import or trade. On the other hand natural gas and other forms of fossil fuels are strictly dependent on a source with increasing utilization and declining availability. Fossil fuels are exhaustible sources that deem all reliant existing infrastructure irrelevant when exhausted. Neither process for power generation establishes a sustainable model that has minimal risk of preserving their investment. Because desalination is fully reliant on energy production and is the leading contributor to potable freshwater in the UAE, collapse of the energy generation infrastructure ensures the subsequent collapse of the potable freshwater infrastructure.

Considerations in Exploring Alternative Energy Sources from Fossil Fuels

Fossil fuels are non-renewable and non-sustainable sources of energy. One expert noted "oil will eventually be depleted, depriving the region of its income and energy source". "The life of any source needs to be considered", and security of supply is important for long-term economic stability. Because these sources are actively being depleted, it is important to take action before they are depleted or become economically unviable. Regions with current access to oil should utilize associated profits to invest in a new energy infrastructure with long-term geopolitical and economic stability in mind. There are many alternative solutions to power generation that accomplish this by relying on sustainable processes. Another expert noted, "in the Arabian Gulf countries, solar energy seems to be most viable as there is consistent strong solar insolation throughout the year." Other experts propose power generation from wind energy as a very viable option. These options also establish regions as energy-independent and provide predictable economic stability within their infrastructure. Experts additionally stress that moving away from combustion-based power generation towards renewable resources can vastly reduce a region's environmental repercussions. Power plants utilizing combustion directly and largely contribute to the global climate trends being observed by releasing CO2. Continuing to invest in this technology undermines long-term global sustainability with irrevocable damages to the environment.

4.2.3 Potable Desalinated Water Quality

Regulation of Water Contaminants

Regulations that restrict contaminant concentration in potable water sources are very dependent on the quality of the source water and the pre-existing pollutants in that source water. Local polluters can introduce contaminants in certain regions that other regions will not experience, which introduces the divide in the two main perspectives of implementing environmental policy: Reactive implementation and precautionary implementation. Reactive implementation relies on events or new studies to suggest revisions or new regulations to an adaptive legislation, but often does not recognize related environmental and health issues until after their observed impacts. Precautionary implementation uses other regions' policies and studies to build a more robust policy that is better suited to prevent health and environmental damage before it occurs. Precautionary implementations require much more monitoring, sometimes for pollutants that have very low chances of ever existing in the water supply, prioritizing human and environmental health over expenditures.

Regions often generalize water contaminants with regulations on TDS rather than setting ranges for each contaminant. Using TDS as a regulation method is very vague, and can often allow toxic contaminants through the restrictions. Different contaminants have different levels of toxicity, a set concentration for all combined contaminants does not ensure safe drinking water. But, setting regulations requires regular monitoring to meet those water quality standards. Hence it is impractical to set regulations for every possible contaminant. The WHO potable water quality standards consider the practical toxicity, and use a precautionary implementation on their regulations to set ranges for pollutants that have been observed to affect human health. But, many regions still lack the technological and financial abilities to monitor all the contaminants identified by the WHO. Full surveillance of water quality is impractical, which is why regions often implement legislation that considers the cost of monitoring each contaminant with respect to the potential human health impacts while prioritizing region-specific contaminants.

Additionally, legislators that devise the restrictions on potable water contaminants often take the availability of monitoring and treatment technologies into consideration before setting ranges for each contaminant. This ensures that the region can achieve their own regulations, but can also allow different regions to have vastly different regulations for water quality (leaving some nations to have objectively better water quality with respect to health).

Groundwater and Desalination as a Principal Source of Potable Freshwater

Groundwater should be prioritized as the principal source of potable freshwater because it is a renewable, natural, and inexpensive source. However, other sources are forced to act as the dominant source when groundwater fails to supply a region. In certain regions, the unreliabilities related to groundwater renewability can force desalination as the principal source. For example, the fluctuations in the rate of supply from groundwater sources can cause desalinated sources to be prioritized for periods of time, allowing groundwater sources to replenish. Additionally, water quality often impairs groundwater sources. Contaminants can quickly push groundwater sources outside their potable water quality concentration limits which requires dilution or treatment to fix.

When natural renewable sources can no longer be relied on to supply a region with potable freshwater, desalination offers a reliable solution. Although costly, desalination can establish a freshwater source with relatively stable and reliable yield rates. Additionally desalination can be used to supplement natural resources, and can be used to aid these sources when contamination occurs. Often, desalinated water can be used to dilute these contaminated sources to assist the concentrations back within quality standards.

Groundwater sources are generally cleaner than surface water sources and therefore usually require less monitoring. But, many water quality factors still have to be closely considered to ensure safe potable sources. Groundwater can be contaminated with viruses, parasites, and minerals with adverse health effects. Shallow groundwater sources can be polluted from both artificial and natural processes, such as pesticides from agricultural runoff and pollutant intake from seawater intrusion.

With desalinated potable sources, different forms of health concerns arise. Because the process of desalination removes all contaminants, including natural minerals that are essential for good human health, it is important to re-evaluate water quality after desalination. In many cases, minerals are added back to these sources to mimic natural groundwater. Desalination and postliminary re-mineralization is a potable freshwater source that offers near-complete control to water quality.

Wastewater as a Principal Source of Potable Freshwater

Wastewater treatment and recirculation as a source of potable freshwater has many benefits over desalination. Wastewater treatment is cheaper, more energy efficient, more sustainable, and more environmentally friendly. Sewage has lower salinity than seawater, and is generally easier to treat. Wastewater treatment requires less resources, and relies on an already existing byproduct of society rather than introducing additional waste into a region such as brine from desalination. Brine is expensive to store and requires resources that are not already established, while wastewater management resources already exist and only need to be modified to support wastewater treatment. However, wastewater reuse (like desalination) also requires strong regulation on output when considering potable sources. The largest inhibitor paired with the adoption of wastewater treatment technologies is the societal acceptance of the process.

4.2.4 Desalination Plant Source Water

Economic Impact of Controlling Different Measures of Source Water

The process of monitoring source water is in itself an economic cost to the desalination plant; however, it will prevent expenses from facility repairs later on. This reporting confirms that there is limited contamination in the source water making the rest of the process more efficient by limiting the amount of wasted water. In addition, it will improve the reliability and quality of the plant. Poor quality source water will lead to reduced efficiency and more waste generation which will increase the overall desalination process cost. If the analytical cost is a concern, it could be lowered if samples from multiple plants are combined and tested at a central laboratory.

Thermal and Membrane Desalination Considerations

The thermal and membrane desalination technologies are affected differently by source water. Thermal desalination is less sensitive to fouling and scaling than membrane desalination. Suspended solids in the source water have a greater effect on the performance of membrane desalination too. These factors must be considered when creating regulations depending on the type of technology being used.

4.2.5 Desalination Plant Discharge

Environmental Impact of Different Discharge Limits

Regulations on brine discharge are adapted to protect the seawater quality. The stricter the recommendations are, the smaller the environmental cost. According to one of the experts in the survey, "As per the guidelines, the permissible limit for contaminants and other parameters are low. Hence, it may have a lesser effect with the ecosystem." Thus, when creating a policy with just the environment in consideration, tighter regulations are more beneficial for the ecosystem and environment.

Experts recommended Sharjah's guidelines on mixing zone limits (Figure 1) have a positive impact on the economy and environment. On the other hand, California's guidelines were viewed as lenient and having a negative impact on the environment. Experts suggest that wider ranges on mixing zone limitations can cause harm to the environment.

Economic Impact of Different Discharge Limits

Short-term, lenient parameters are more cost effective because "the maintenance cost [is] quite low and profitable." Tighter parameters on discharge limits are beneficial for long term desalination operation. In addition, the economic costs of discharge can be mitigated through pre-treatment. This pre-treatment includes ZLD units; ZLD decreases the volume of discharge. If there is less brine, then the cost to manage the brine decreases. Thus, ZLD helps to decrease the cost of brine management and makes it easier for facilities to follow tighter parameters.

Factors to Consider When Setting Discharge Limits

In the survey, we asked experts to address additional factors that need to be included to mitigate the effects of discharge. The important factors include location of discharge, identification of sensitive ecosystems, flow rate, and trace contaminants. One expert expressed the importance of separating the chemicals: "the discharge[d] water needs to be character[ized] for chemical constituents. Then, the required measurement needs to segregate the waste based on the chemical functionality." This method allows policies to be set for the chemicals pertaining to the water region. These chemical constituents will be different for each desalination plant.

Parameters vary on whether they are set as static restrictions or percentages from the current state of ambient water. The responses were split on how to record these parameters. Those in favor of percentages believe that "Percentages are used as standard parametric value to assess the water quality and other constituents." Yet, the experts in favor of static restrictions agree that percentages are less related to ecosystem protection. Thus, when making a policy for environmental protection, static restrictions should be used as parameters, and standard policies for larger regions should rely on percentages.

Most experts agree that there should be policies set on discharge distances from desalination facility intake. This distance should be set vertically from the desalination facility instead of horizontally. The vertical distance should reach deep into the ocean. This ensures that the brine does not mix with the surface level, affecting the marine ecosystem and desalination plants.

All experts agreed that there should be testing for how often data should be collected about marine life living near brine deposits; however, experts disagreed with how often it should occur. Half of the experts claimed monitoring should occur monthly, while the other half stated data collection should occur weekly. Their explanation for weekly monitoring was the constant variability of seawater conditions. One expert claimed, "The flow dynamics of seawater is [an] unsteady state, thus it is necessary to maintain the data for every week."

Future Goals for Discharge

The future goals for discharge revolve around the reduction of brine management's carbon footprint. This can be reduced by investing in ZLD. Additionally, hybrid membrane processes can be attempted to limit the amount of brine. An example of this process is a forward osmosis (FO) coupled with RO. Forward osmosis has a lower total energy and better fouling resistance, which reduces the carbon footprint of the desalination facility.

4.2.6 Desalination Intake Port Protection from Ship Movement

Why There Was a Lack of Responses

This survey received a limited amount of responses. As such, the findings reported from this survey may not adequately represent collective expert opinion on this topic. The survey received limited responses either due to lack of research in this area or lack of expert qualification. This means desalination policy should stress for research to be done on ship movement before new desalination facilities are built.

Factors to Consider

From the survey we know that there should be regulations on how close ports are to desalination facilities. This is because ports contaminate the water quality and that can have a negative effect on the source water near desalination plants. In our survey, we asked if there should be a set distance for how close large vessels can come to desalination facilities. The one answer found was 100 km (60 miles). This answer seems too large to be practical. It would limit the amount of travel through the GCC countries because transportation and accessibility need to be considered when building a desalination facility.

4.2.7 Desalination Process Management

Environmental Impact of Process Management

Regulations of process management can prevent negative environmental effects. With proper monitoring techniques and guidelines, there will be a sufficient amount of data to predict the potential environmental impacts; however, monitoring alone will not prevent harsh effects. In this survey, one expert noted that "understanding the operating conditions can help for environmental impacts...just knowing the information isn't enough." A positive impact on the environment will come from evidence based decisions.

Consistent Data Collection

The data collection from management needs to be both consistent and accurate. Some policies require the desalination plants to provide only the forecast data. This data is a prediction of the future based on the past collections. Using forecast data would not be sufficient and as one expert said, "The forecast data changes from time to time and it is inconsistent." Instead, periodic control and regular reporting would be a better measure of conditions within the plant. This process helps make the best decisions for environmental conservation and economic considerations. This approach can be time consuming due to the amount of reporting required. This can be solved with the use of automated processes that can manage constant monitoring. With this technology there will be more accurate data that can be collected as frequently as necessary.

Maintain a Sustainable and Flexible Monitoring Schedule

The process management procedure will vary between each plant but the guideline should still be specific. A detailed procedure will be helpful for the plant to produce accurate data, but it should still allow for some flexibility. If the conditions were to change at a plant, it is important that they can adapt their management as well while maintaining the given regulations.

Sampling Discharge

Sampling the discharge from desalination is necessary to regulate. Regulations or monitoring practices that are lenient can negatively impact the desalination process and marine life. The sampling should be frequent and cover many conditions in order to be effective. The important parameters that should be monitored through sampling are flow, CBODs, suspended solids, pH, fecal coliform, chlorine residual, ammonia nitrogen, total phosphorus, total nitrogen, dissolved oxygen, and boron and other toxic elements. A reasonable sampling frequency is between one to three days per week, depending on the parameter. There are some parameters that do not require more than one day per month: for example, total nitrogen. The limits of these parameters must be set based on the environment as not all places have the same surrounding conditions.

Discussion

The objective of this section is to analyze our findings while highlighting important recommendations that will be included in the policy brief. Our recommendations include using RO over distillation technology, investing in sustainable technology, testing source water quality, managing discharge limits, and testing potable quality. These topics were divided into three sections: desalination technology, desalination input management, and desalination output management. These three sections highlight the important aspects that should be included in a comprehensive desalination policy and will aid in making desalination technology both economically and environmentally sustainable.

5.1 Desalination Technology

5.1.1 Reverse Osmosis vs Distillation

Based on background research, interviews, and survey responses from experts, RO is the recommended desalination technology over it's thermal-based predecessors (such as MSF and MED). Current implementations of RO around the world present a variety of benefits in the forms of reduced energy usage and brine impact on the environment, along with further capabilities of co-generation with renewable energy sources. RO is already the global standard for desalination and is the suggested future for desalination plants in Sharjah. The adoption and implementation of RO will be a key enabler for Sharjah to become carbon neutral and advance SEWA's goals of a sustainable energy future. While some arid climate guidelines have pointed to the proven robustness of thermal-based processes in extreme temperatures, this claim is made with respect to older RO polyamide membrane technologies, and that optimizations to membranes have already increased their temperature resilience. Additionally, RO as a desalination technology depends on physics that benefit with the warmer source water experienced in the Arabian Gulf. As water becomes warmer it becomes less viscous, which promotes the water to permeate through RO membranes at faster rates. Experts suggest that warmer source water is a great benefit to RO desalination. Other recommendations targeted scenarios where RO processes struggle with higher salinity experienced in source waters. Distillation is considered a more reliable process for purifying water with higher concentrations of contaminants. A hybrid process exists if access to new membrane technologies with high-salinity resilience are not available; water below a certain salinity is treated with RO and a thermal-based process is used to treat the remaining high-salinity water. These restrictions and influences become location or site specific and can, in occasions where RO membranes may struggle, promote thermal-based processes. Additionally, this hybrid configuration can promote the transition to RO from thermal-based processes because it does not require the immediate dismantling of existing thermal plants. RO is currently the leading global desalination technology which comes with the highest rate of technological research. New RO membranes are constantly being developed, some specifically targeting higher salinity source waters.

5.1.2 Economic Impact

As Sharjah begins moving towards a renewable energy future, the transition to RO becomes inevitable. As fossil fuel based power generation declines, thermal-based desalination plants will become less and less economically viable because they will no longer be able to exist in co-generation configurations with combustion power plants. With thermal-based plants, a nexus exists where desalination is reliant on fossil fuels (directly or indirectly through combustion-based power plants if paired in co-generation configurations). This is establishing two of society's most important assets as dependable on exhaustible resources, meaning if the market of fossil fuels drastically changes, both resources can potentially collapse. RO gains another advantage over thermal-based solutions in this regard, as RO relies purely on electrical energy and diversifies its water resources from nonrenewable energy. Additionally, it has the smallest relative energy consumption when compared to the other leading desalination technologies. Experts in our surveys stated that "thermal-based desalination systems... are much less energy-efficient than RO thus the economic cost is greater in regards to energy consumption." Additionally, experts also noted that "thermal desalination technology is going to be always more costly [than] RO membrane separation of fresh water from the salt in seawater..." and that "[e]conomic costs can be mitigated by replacing thermal desalination with membrane desalination." While the economic cost of thermal plants can be offset by the utilization of waste heat energy, RO systems have demonstrated economic and environmental benefits across the globe. Further investments in distillation-based desalination are high risk assets of outdated technologies that are reliant on declining energy resources, and should only be used to supervise the conversion to RO systems.

5.1.3 Environmental Impact

RO is not without its own environmental challenges as the rejected brine must be properly managed and disposed of. Along with the environmental impact of brine, the utilization of non-renewable energy sources would only further degrade the environment. These environmental impacts can be mitigated and improved through a variety of measures. Brine discharge methods can be properly designed to promote rapid assimilation with the receiving seawater and dissipating the salinity via diffusers before mixing. When deciding locations for disposal, the brine should avoid sensitive habitats and fish populations. SEWA should pursue ZLD, recovering chemicals from rejected brine, and creating useful products from brine that would otherwise go unused. One such use for reject brine is in the irrigation of halophyte plants which had "succeeded in turning an environmental problem... into a source of new economical activities" (Sánchez et al., 2015, p. 1). Thermal desalination also produced brine at a higher temperature than RO, which can harm marine life and raise seawater temperature. RO discharges brine at seawater ambient temperature, which avoids the negative effects of high temperature brine. Experts also voiced their concerns over the use of fossil-driven thermal processes, and heavily recommended renewable-driven RO as a sustainable replacement. When RO might not be economically feasible, experts recommended the integration of "low-grade waste heat or geothermal plants to power thermal-based desalination systems."

The recommendations emphasized that thermal plants "simply [use] more energy... than RO plants", and that little could be done on the energy-consumption front other than to "replace the capacity with RO". These factors are region specific and further research should be carried out on designing and implementing RO plants when possible, given their lower negative environmental impact. While RO does provide some difficulties in implementation specific to arid climates, the relative benefits over thermal solutions warrant active pursuit.

5.2 Desalination Input Management

5.2.1 Energy Usage

Desalination, regardless of the mechanisms driving the process, utilizes substantial amounts of energy that need to be taken into consideration to minimize the indirect carbon footprint of these facilities. The transformation to renewable energy sources needs to be prioritized for any developed country with financial and geopolitical stability. Such regions that experience relative security in power generation because of their access to large portions of the global fossil fuel supply are presented with an opportunity that other regions cannot rely on. For these regions, there exists the ability to profit off of remaining fossil fuels while building a power generation infrastructure that can withstand the exhaustion of those resources. Modular and sustainable energy generation technologies that currently exist such as solar and wind power encourage the steady development of infrastructure rather than the massive and immediate investments required to develop nuclear power and combustion plants. One expert pointed out, “in the Arabian Gulf countries, solar energy seems to be most viable as there is consistent strong solar insolation throughout the year.” Another solution that considers the geography of regions residing on the Arabian Gulf is to capture wind power from shamals, which are almost continuous sources of energy in the spring and summer months. These regions can continue to supplement their sustainable energy infrastructure while capitalizing off of dwindling nonrenewable resources, and can be prepared for the future when these sources expire. Continuing to invest in fossil fuels while cognisant of their impending depletion is proving poor capitalization of existing resources when alternative investments exist that promote the longevity of the economy. This dependence of power generation solely on an exhaustible resource can lead to economic collapse once the resource is fully exhausted. With relying on combustion for power generation and desalination for potable resources, there exists a water and power nexus where both are dependent on exhaustible sources. Because desalination is reliant on immense supplies of energy, if that supply becomes unstable, entire supplies from the water and energy sectors can collapse simultaneously. With investment in sustainable and renewable energy resources comes infrastructure reliability and stability, even if existing in tandem with combustion power generation. To “secure a sufficient, reliable supply of low-carbon energy and water” (Sharjah Electricity and Water Authority, 2020, p. 13), dependency on fossil fuels needs to be reduced.

5.2.2 Source Water

The second component of desalination intake is the source water. There should be regulations on sampling and monitoring this water, as it can have direct effects on the efficiency of the desalination plant. Proper regulations will increase desalination efficiency, reducing energy wasted on filtering out additional contaminates. It is recommended that turbidity and temperature are tested continuously to provide accurate, up-to-date data. Additional source water parameters, such as salinity, chloride, and alkalinity, are also important to sample; however, they require less frequent reporting.

Desalination plants should have an efficient process management schedule to account for all the reporting and sampling of effluent and receiving water. Proper implementation of this process will limit negative environmental effects from desalination as it allows for evidence based decision making. There should be periodic control and reporting rather than forecast data to have the most accurate data presented. One way to accomplish this is implementing an automated sampling process. Process management should also be reporting data on the overproduction of water. This will help production to adjust to the different needs of the different daily and seasonal fluctuations.

The shipping industry is suspected to have a negative impact on desalination feedwater. As vessels travel past intake ports, their byproducts, such as ballast water, can easily mix with and contaminate the source water. Currently there is limited research on the effect this has on desalination plants, so more research should be put into this topic to understand how to best prevent the negative effects of ship movement. One topic worth researching is the allowable distance a large vessel should travel near a desalination intake plant. This information could be implemented by all countries in the GCC to benefit the source water quality of all desalination plants in the region.

5.3 Desalination Output Management

5.3.1 Brine Management

Policies on brine management should center around protecting the surrounding environment and communities using the potable water. One major focus for brine management policy is brine disposal, which should include both ZLD and submerged disposal. We recommend ZLD be included in the policy as the main technology to eliminate brine. Although ZLD discharge is more expensive to install, the cost of brine management will decrease overtime because it decreases the volume of brine and the carbon footprint of desalination plants. ZLD also makes it easier for desalination facilities to follow restrictions on brine regulations and mixing zones. Additionally, submerged disposal should be used to dispose of brine. Submerged disposal allows brine to be discharged into the deep ocean where the concentrate can be diluted. Since the mean depth of the Arabian Sea is only 35 meters, long pipes may need to be installed to deliver the brine to the ocean floor. The lower the brine is below the surface, the smaller impact it has on the intake of desalination facilities and the marine environment.

We recommend the guidelines address the parameters to set on mixing zone limits. According to experts, the limits presented by SEWA in Figure 1 are strict enough to create both a positive impact on the environment and the economy overtime. The proposal set low permissible limits which allowed for a smaller effect on the ecosystem. These limits should be adapted into policy and enforced by SEWA. The Arabian Gulf can be further protected by increasing sampling beyond TDS limits for toxic chemicals. Some of these important parameters included flow, CBODs, suspended solids, pH, fecal coliform, chlorine residual, ammonia nitrogen, total phosphorus, total nitrogen, and dissolved oxygen. Other toxic chemicals, like boron, should also be considered. Regions in the GCC must consider the Arabian Gulf's health as a critical concern if they intend to continue relying on seawater desalination as a potable source.

It was an unanimous opinion amongst experts that sampling the brine once a month is too lenient. Instead, it is recommended that these parameters are tested frequently throughout the week if not continuously. Throughout the year, the ranges on these parameters are subject to change due to seasonal fluctuations and this should be reflected in the sampling guidelines. These guidelines will also change depending on the region and the surrounding conditions of the desalination plant. Most importantly, collecting the sampling data will maintain the desalination plant's efficiency and will minimize harm to the aquatic environment. Along with Brine, it's important to sample marine life that lives near ecosystems. It was a consensus that data should be collected on marine life, with an emphasis on gathering statistics as much as possible. The minimum rate of collection should be monthly and the maximum rate should be weekly. The reasons to collect samples weekly is the unsteady fluctuation of seawater. Frequent sampling of both brine and marine life will increase the quality and durability of the Arabian Gulf near brine disposal sites.

5.3.2 Potable Quality

Water quality experts recommend precautionary approaches when developing potable water quality policies and regulations. The potential for liabilities on human health that come with unregulated drinking water resources greatly outweigh the costs associated with monitoring and post-treatment water quality correction. Small unregulated changes in water quality can affect human health in unexpected ways, such as incidents with water pipe corrosion. Because distillation and reverse osmosis are very effective at removing contaminant concentrations from their source waters, water quality deterioration often occurs after the process of desalination. Purified water is especially corrosive because it is lacking common minerals to balance pH and can accelerate transport pipe wear which ends up affecting drinking water quality, which is a very large concern for desalination plants. Health crises due to pipe corrosion are the most common forms of potable water contamination because they occur externally from the water processing plants. If internal processes are not created to mitigate these effects and balance water pH, such as employing remineralization after purification, long-term public health effects can develop. Remineralization techniques offer other benefits, such as introducing concentrations of minerals that benefit human health or even improve the taste of the water. The combination of highly effective water purification seen in RO and distillation based desalination and internal post-remineralization give desalination plants nearly full jurisdiction over the water supply's quality.

Other health concerns generally happen within the water processing procedure, typically relating to the quality guidelines set or the corresponding monitoring techniques. Specifically, TDS is most often monitored and restricted incorrectly. Regions that specify general TDS ranges rather than monitoring and setting ranges for specific contaminants risk causing chronic health conditions, because toxins in water do not all rely on the same concentrations to become toxic. Requiring water to have a low TDS generally relates to high clarity, but does not ensure potability. Fortunately, because potable water quality relates to human health, there is a significant amount of research established by the World Health Organization (2017) that most nations can use as guidelines for their monitoring process and water quality standards. There is a balance of utilizing WHO guidelines and disregarding contaminants with very low probabilities of concentration, as monitoring and meeting these standards can be expensive. Plants with limited budgets or technological resources are forced to evaluate risk with monitoring costs, and may not monitor certain contaminants recommended by the WHO because of their miniscule concentrations. But, these decisions should be based on the scientific evaluation of contaminant concentrations and exposure periods, and should not be used to justify setting general ranges for TDS.

Conclusion

SEWA should modify their current desalination policy draft and implement it in Sharjah, UAE that considers the following factors: desalination technology, desalination input management, and desalination output management. The policy brief in Appendix A.1 summarizes our discussion chapter, and presents the findings in an accessible format to SEWA. We hope SEWA considers our policy brief when creating their own policy. This action will set a good example for other regions in the GCC and will allow Sharjah to lead sustainability in the UAE. Ideally, it will foster collaboration amongst these countries to maintain the health of the Arabian Gulf. Implementing a policy is vital for the longevity of desalination and will allow for the continuous and sustainable supply of fresh water. The economic and environmental implications of not having an enforced desalination policy are detrimental and potentially irreversible.

6.1 Future Considerations

SEWA's mission statement highlights the importance of educating the youth on sustainability and the environment. One of SEWA's strategies is to "[l]aunch awareness drives targeting the students of the schools and universities and all community categories under the theme: With conservation, we are all beneficiaries" (Sharjah Electricity and Water Authority, 2015, para. 5). This suggests that SEWA has long term goals of adopting wastewater treatment to support their future potable resources, but is limited by their population's acceptance of the process. Our findings indicate that wastewater treatment offers many benefits over seawater desalination, including lower operational costs due to energy efficiency, higher economic sustainability, and lower environmental impacts. If SEWA plans to utilize these economic benefits associated with implementing wastewater recirculation, alleviating skepticisms surrounding wastewater circulation among the people of Sharjah is of utmost importance.

The following sentiment is from three American University of Sharjah students who share their experience with SEWA's education initiatives:

- Zahraa Al Dawood, Sharjah, AUS, 4th year civil engineering
- Maryam Bin Hammad, Dubai, AUS, 4th year civil engineering
- Ruba El Mootassem, Sharjah, AUS, 5th year civil engineering

American University of Sharjah - Student Perspective

"Growing up, we were aware that the UAE lacks fresh water supply and relies heavily on desalination for drinking water. However, we had minimal experience learning about alternatives to desalination or the water scarcity in the country. Additionally, prior to starting this project, we were not aware of the implications of desalination on the environment or the constraints of the process. It was through the WPI-AUS initiative that we became more aware of these circumstances.

We personally have not been exposed to any of SEWA's educational campaigns despite studying in Sharjah. Taking this into account, we think it is necessary to educate the youth about water treatment and conservation in the country. SEWA could launch educational campaigns across schools (public and private) and universities in Sharjah to promote awareness on water scarcity and water treatment methods. SEWA could also educate students about reclaimed water and its treatment methods to challenge existing cultural misconceptions.

Though we are skeptical about reclaimed water as an alternative, we believe that awareness and education can tackle cultural misconceptions. This is why school students are an ideal group to educate: educating students about reclaimed water would be more effective in changing the public opinion. Beyond informative campaigns, one specific way SEWA could educate students is through competitions. These competitions could concern topics related to water conservation and treatment, which would incite the students' interest in the future of water in the UAE.

SEWA could also collaborate with universities like AUS to host educational workshops for university students, high school students, and employees at AUS."

This insight from AUS students can be used to reflect on and improve SEWA's initiatives to educate Sharjah's future generations on topics of water conservation. These initiatives are critical if SEWA intends to transition to wastewater recirculation. Investing time into the younger generation's education will aid in environmental impact awareness and promote the acceptance of future water conservation efforts.

Bibliography

Ahmed, A.-E.-W., Murbati, W. M. A., Ruwaili, N. A. A., Oraif, A. S. A., Oraif, A. A., Arafati, A. A., Nasrullah, A., Bahow, M. R. A., Anzi, S. M. A., Rashidi, M., & Moosa, S. Z. A. (2014). *Desalination in the GCC - the history, the present & the future* (2nd). The Cooperation Council for the Arab States of the Gulf. Retrieved December 14, 2020, from http://opil.ouplaw.com/view/10.1093/law:epil/9780199231690/law-9780199231690-e604

American River Water Education Center. (2020, July 23). *Water facts - worldwide water supply* [Bureau of Reclamation]. Retrieved October 16, 2020, from https://www.usbr.gov/mp/arwec/water-facts-ww-water-sup.html

Asaba, B. (2020, February 24). *GCC countries are leading the world in desalination with around 40% of the total world desalinated water* [Utilities Middle East]. Retrieved December 14, 2020, from https://www.utilities-me.com/news/15070-gcc-countries-are-leading-the-world-in-desalination-with-around-40-of-the-total-world-desalinated-water

Badescu, V., Ciocanea, A., Cathcart, R. B., & Finkl, C. W. (2013). Desalination brine disposal by submerged pipes in the red sea. *Journal of Coastal Research*, *29*(6A), 81–92. Retrieved September 15, 2020, from http://www.jstor.org/stable/43215784

Barden, J. (2019, June 20). *The strait of hormuz is the world's most important oil transit chokepoint* [Today in Energy]. Retrieved December 14, 2020, from https://www.eia.gov/todayinenergy/detail.php?id=39932

Benaissa, M., Rouane-Hacene, O., Boutiba, Z., Habib, D., Guibbolini-Sabatier, M. E., & Risso-De Faverney, C. (2020). Ecotoxicological effects assessment of brine discharge from desalination reverse osmosis plant in Algeria (South Western Mediterranean). *Regional Studies in Marine Science*, *39*, 101407. https://doi.org/10.1016/j.rsma.2020.101407

Berdikeeva, S. (2019, October 27). *The rise of fish farming in over-fished Gulf Nations* [Inside Arabia]. Retrieved November 24, 2020, from https://insidearabia.com/the-rise-of-fish-farming-in-over-fished-gulf-nations/

California Environmental Protection Agency. State Water Resources Control Board. (2015). Water quality control plan: Ocean waters of California. https://www.waterboards.ca.gov/water_issues/programs/ocean/docs/cop2015.pdf

Chitrakar, P., Baawain, M. S., Sana, A., & Al-Mamun, A. (2019). Current status of marine pollution and mitigation strategies in arid region: A detailed review. *Ocean Science Journal*, *54*(3), 317–348. https://doi.org/10.1007/s12601-019-0027-5

Chow, A. C., Verbruggen, W., Morelissen, R., Al-Osairi, Y., Ponnumani, P., Lababidi, H. M. S., Al-Anzi, B., & Adams, E. E. (2019). Numerical prediction of background buildup of salinity due to desalination brine discharges into the northern Arabian Gulf. *Water*, *11*(11), 2284. https://doi.org/10.3390/w11112284

Christman, J. (2017, August 8). *Scientists conclude Flint crisis could have been prevented.* [The Center for Water Security and Cooperation]. Retrieved December 14, 2020, from https://www.ourwatersecurity.org/single-post/2017/08/08/Scientists-conclude-Flint-crisis-could-have-been-prevented

Denchak, M. (2018, November 8). *Flint water crisis: Everything you need to know* [Natural Resources Defense Council]. Retrieved December 14, 2020, from https://www.nrdc.org/stories/flint-water-crisis-everything-you-need-know

Durán, O., Aguilar, J., & Capaldo, A. (2020). Evaluating maintenance strategies using a resilience index in a seawater desalination plant. *Desalination*, 114855. https://doi.org/10.1016/j.desal.2020.114855

Egypt Environmental Affairs Agency. (1995). *Promulgating the executive regulations of the law for the environment*. http://extwprlegs1.fao.org/docs/pdf/egy4986E.pdf

Egypt Environmental Affairs Agency. (2001). The national environmental action plan of Egypt 2002/17. Environment at the center of modernizing Egypt.

Electricity & Co-Generation Regulatory Authority. (2011). *Seawater desalination code.* [Report No. 7561A01/FICHT-7235220-v22]. https://www.ecra.gov.sa/ar-sa/ECRARegulations/Codes/Documents/swdc%20-%20final%20nov%202011%20-%20protect.pdf

Environmental Protection Agency. (2020, March 9). Rules and regulations. *Federal Register* (46th ed., pp. 13524–13546). Retrieved November 4, 2020, from https://www.govinfo.gov/content/pkg/FR-2020-03-09/pdf/2020-02714.pdf

Evans, G. (2020, March 24). *Persian Gulf* [Encyclopædia Britannica]. Retrieved December 14, 2020, from https://www.britannica.com/place/Persian-Gulf

Food and Agriculture Organization of the United Nations. (2016, February). *Fishery and aquaculture country profiles - the United Arab Emirates* [Fisheries Division]. Retrieved December 14, 2020, from http://www.fao.org/fishery/facp/ARE/en

Illinois Environmental Protection Agency. Division of Water Pollution Control. (2016). National pollutant discharge elimination system. [Report Number: SAK: FRB: 16010401.bah]. https://www.minooka.com/wp-content/uploads/2016/11/2016-NPDES-Permit-IL0055913-1.pdf

Kalogirou, S. A. (2005). Seawater desalination using renewable energy sources. *Progress in Energy and Combustion Science*, *31*(3), 242–281. https://doi.org/10.1016/j.pecs.2005.03.001

Kress, N., Gertner, Y., & Shoham-Frider, E. (2020). Seawater quality at the brine discharge site from two mega size seawater reverse osmosis desalination plants in Israel (Eastern

Mediterranean). *Water Research*, *171*, 115402. https://doi.org/10.1016/j.watres.2019.115402

Ladewig, B., & Asquith, B. (2012). Disposal to surface water. *Desalination Concentrate Management* (pp. 21–30). Springer. https://doi.org/10.1007/978-3-642-24852-8_4

Lenntech. (n.d.). *Brine deep well injection* [Water Treatment Solution]. Retrieved December 12, 2020, from https://www.lenntech.com/processes/brine-deep-well-injection.htm

McDonnell, R., & Fragaszy, S. (2016, December). *Groundwater use and policies in Abu Dhabi* (IWMI Project Report No. 13). http://gw-mena.iwmi.org/wp-content/uploads/sites/3/2017/04/Rep.13-Groundwater-use-and-policies-in-Abu-Dhabi-Emirate.pdf

Morillo, J., Usero, J., Rosado, D., El Bakouri, H., Riaza, A., & Bernaola, F.-J. (2014). Comparative study of brine management technologies for desalination plants. *Desalination*, *336*, 32–49. https://doi.org/10.1016/j.desal.2013.12.038

Murad, A. A., Al Nuaimi, H., & Al Hammadi, M. (2007). Comprehensive assessment of water resources in the United Arab Emirates (UAE). *Water Resources Management*, *21*(9), 1449–1463. https://doi.org/10.1007/s11269-006-9093-4

Republic of Singapore. National Climate Change Secretariat. (2012). *National climate change strategy 2012.* [Report Number: SAK: FRB: 16010401. bah]. http://extwprlegs1.fao.org/docs/pdf/sin178015.pdf

Saleh, L., Zaabi, M. a., & Mezher, T. (2019). Estimating the social carbon costs from power and desalination productions in UAE. *Renewable and Sustainable Energy Reviews*, *114*, 109284. https://doi.org/10.1016/j.rser.2019.109284

Sánchez, A., Nogueira, I., & Kalid, R. (2015). Uses of the reject brine from inland desalination for fish farming, spirulina cultivation, and irrigation of forage shrub and crops. *Desalination*, *364*, 96–107. https://doi.org/10.1016/j.desal.2015.01.034

Secretariat General of the Gulf Cooperation Council. (2020a, August 12). *About GCC* [The Cooperation Council for the Arab States of the Gulf]. Retrieved December 14, 2020, from https://www.gcc-sg.org/en-us/AboutGCC/Pages/StartingPointsAndGoals.aspx

Secretariat General of the Gulf Cooperation Council. (2020b, August 12). *Cooperation in the field of human and environment affairs* [The Cooperation Council for the Arab States of the Gulf]. Retrieved December 14, 2020, from https://www.gcc-sg.org/en-us/CooperationAndAchievements/Achievements/CooperationinthefieldofHumanandEnvironmentAffairs/Pages/EnvironmentalCooperation.aspx

Shadid, J., & Ali, N. (2009, July). The Water Quality Regulations 2009 (S. Nemer, L. Hill, & C. Hannan, Eds.). Retrieved October 30, 2020, from http://extwprlegs1.fao.org/docs/pdf/uae92144.pdf

Sharjah Electricity and Water Authority. (n.d.). Environmental and social impact assessment (ESIA) study report. [Report No. ESC/SHJ/SEWA-ESP/P695/EISA/REV.02]. https://www.jbic.go.jp/ja/business-areas/environment/projects/pdf/60826_2.pdf

Sharjah Electricity and Water Authority. (2015, August 4). *The declaration of Sharjah city of conservation*. Retrieved December 11, 2020, from https://www.sewa.gov.ae/en/content.aspx?P=4JVpzOgumWxxDeo5mu1mhQ==

Sharjah Electricity and Water Authority. (2019). *Statistical reports 2019*.

Sharjah Electricity and Water Authority. (2020, February 5). *SEWA Vision 2025*. https://www.sewa.gov.ae/uploads/pdfs/SEWAVISION2025.pdf

Shemer, H., & Semiat, R. (2017). Sustainable RO desalination. Energy demand and environmental impact. *Desalination*, *424*, 10–16. https://doi.org/10.1016/j.desal.2017.09.021

Sherif, M., Mohamed, M., Kacimov, A., & Shetty, A. (2011). Assessment of groundwater quality in the northeastern coastal area of UAE as precursor for desalination. *Desalination*, *273*(2), 436–446. https://doi.org/10.1016/j.desal.2011.01.069

Shriadah, M. A. (2008). Beach littering along the coast of the United Arab Emirates, 7.

Singapore Public Utilities Board. (2019, July). Singapore drinking water quality (July 2019 - June 2020). Retrieved November 6, 2020, from https://www.pub.gov.sg/Documents/Singapore_Drinking_Water_Quality.pdf

United Arab Emirates. Ministry of Environment and Water. (2010). *United Arab Emirates water conservation strategy*. http://extwprlegs1.fao.org/docs/pdf/uae147095.pdf

United Arab Emirates Ministry of Environment & Water. (2015, November 2). Tanzim 'iidarat tasrif almiah almurtajieat min mahattat altahliyat 'iilaa albahr [Organizing the management of the discharge of returned water from desalination plants to the sea].

World Health Organization. (2017). *Guidelines for drinking-water quality* [OCLC: 975491910]. https://apps.who.int/iris/rest/bitstreams/1080656/retrieve

World Health Organization. Public Health and the Environment. (2007). *Desalination for safe water supply: Guidance for the health and environmental aspects applicable to desalination*. https://www.who.int/water_sanitation_health/gdwqrevision/desalination.pdf

Younos, T., & Lee, J. (2020). Desalination: Concept and system components. In V. S. Saji, A. A. Meroufel, & A. A. Sorour (Eds.), *Corrosion and fouling control in desalination industry* (pp. 3–27). Springer International Publishing. https://doi.org/10.1007/978-3-030-34284-5_1

Appendix

A.1 Policy Brief

Policy Brief

WPI & AUS | December 14, 2020 | Sharjah, UAE

Regulating the Future of Desalination

Presented to the
Sharjah Electricity and Water Authority

The Sharjah Electricity and Water Authority (SEWA) is pursuing guidelines and policies on the topic of desalination to better improve the operational and economical efficiency of their desalination plants. Regulation is necessary to promote desalination as a sustainable resource and to reduce resultant impacts on the environment.

INTRODUCTION

SEWA is seeking to implement a policy surrounding seawater desalination. There is draft policy but it has not yet been implemented or enforced. Environmental policies surrounding desalination are vital to minimize negative environment effects and allow for the greatest economic gain and stability. Both the environmental and economic effects can directly impact SEWA and the people of Sharjah.

Countries in the Gulf Cooperation Council (GCC) that depend on desalination for freshwater must consider the Arabian Gulf's health as a critical concern. Brine, the main byproduct of desalination, can have harmful effects on the environment if not properly discarded due to its chemical pollutants, high salinity, and high temperatures. Possible temperature/salinity increases and pollution can hurt the Arabian Gulf's ecosystems and affect its reliability as a resource. Additionally, desalination plants' high energy usage from mostly combustion-based power hinders SEWA from reaching their 2025 vision to "secure a sufficient and reliable supply of low-carbon energy and water" (Sharjah Electricity and Water Authority, 2020, p. 13).

Implementing a policy to protect the environment from the negative aspects of desalination will minimize the future cost of retroactive environmental protection and allow SEWA to achieve its goals of sustainability. This policy brief will outline the central aspects of desalination that need regulation. These factors include: desalination technology, input management, and output management.

APPROACHES

Policies and guidelines were analyzed around the globe pertaining to desalination and water quality, and gathered data from experts' opinions to help Sharjah's policy go from a draft to law. After a stage of initial research, interviews were conducted with four professors at Worcester Polytechnic Institute (WPI). These professors had a background in desalination or environmental policy and were asked to provide their opinion on various questions to help guide research on global desalination policy. The themes established from these interviews were then used to categorize policy from regions around the world employing desalination. These policies were identified using the FAOLEX database. In addition, SEWA's drafted guidelines were translated and divided amongst the themes. The combination of this global policy research and initial expert guidance provided information to create multiple surveys that were divided amongst the central themes of desalination policy. These surveys were created using WPI's Qualtrics client, and were implemented into a project website.

Experts were identified internationally through online research that was targeted towards university professors and PhD students, research groups, and industry professionals. Over 500 experts were contacted to participate in the surveys. Through the project website, they were able to complete one (or more) 15 minute surveys depending on their areas of expertise. Additionally, experts were able to leave comments, policy suggestions, and questions through this platform. After multiple weeks of data collection, the surveys were analyzed manually for suggestions and recommendations on the various themes presented. All the responses were categorized by the key topics found amongst the surveys, which were then used in collaboration with previous background research to develop the following recommendations.

RECOMMENDATIONS

1. Focus future desalination investments on reverse osmosis (RO) desalination while phasing out existing distillation-based desalination

(a) New advancements in RO desalination polymer membranes can tolerate high salinity and temperatures.

(b) Distillation-based desalination inhibits the diversification of water and power sources.

(c) RO desalination can be linked to renewable energy sources, while distillation-based desalination relies on heat from thermal sources.

(d) Distillation-based desalination relies on heat that is often generated from combustible resources. As SEWA transitions to renewable resources, distillation-based desalination investments will not be economically sustainable.

(e) The brine from distillation-based desalination is much warmer than that of RO desalination, which can harm marine and contribute to rising seawater temperatures.

2. Focus future power-generation investments on sustainable processes while phasing out existing combustion-based plants

(a) When investing in modern infrastructure to support future energy requirements, neither nuclear or natural gas based power generation are economically viable options.

   i. Nuclear facilities require large initial investments and similar decommissioning costs

   ii. Natural gas is reliant on sensitive non-renewable resources and contributes to greenhouse gas emission.

(b) Modular sustainable energy technologies such as solar and wind power offer many benefits over their non-renewable counterparts that require large facilities.

   i. Modular solutions encourage the steady development of infrastructure compared to the large initial investments required for combustion-based facilities.

   ii. Decentralizing an energy infrastructure ensures network reliability.

   iii. Renewable energy technologies can be implemented to target various attributes of the Arabian Gulf. Solar power can be used to capture energy from the consistent and strong solar insolation experienced in the region, and wind power technologies can be targeted at capturing shamals which is a near continuous source in the spring and summer months.

   iv. Regions with access to fossil fuels are presented with an opportunity to profit off of remaining resources while investing in a power generation infrastructure that can withstand the exhaustion of those resources.

(c) Relying on combustion for power generation and desalination for potable resources, there exists a water and power nexus where both are dependent on exhaustible sources.

(d) The economic benefits from renewable energy sources will outlast future economic investments into depleting fossil fuels. The investment in sustainable and renewable energy resources creates an infrastructure that is reliable and sustainable, even if existing in tandem with combustion power generation. To "secure a sufficient, reliable supply of low-carbon energy and water" (Sharjah Electricity and Water Authority, 2020, p. 13), dependency on fossil fuels needs to be reduced.

3. Establish frequent reporting and monitoring of source water

(a) Water quality guidelines should be set to ensure that source water meets certain standards that promote plant resilience. A regional water board should be established that evaluates the administration of desalination plants. The administration should report data on source water, effluent water, over production of water, and environmental safety. Data collected will provide evidence needed to take action against negative environmental effects. Additionally, fluctuation of source water quality will be detected and recognized to prevent significant damage to the plant.

(b) Additional research should be conducted to determine the impact of ship movement on the desalination process. This research should find specific information on an acceptable distance for shipping vessels to travel near desalination intake ports.

4. Develop policy on brine management with environment and economy in mind

(a) Zero liquid discharge (ZLD) should be included in the policy as the main technology to eliminate brine. Although ZLD discharge is more expensive to install, the costs of brine management will decrease overtime because it decreases the volume of brine and the carbon footprint of desalination plants. In addition, ZLD makes it easier for desalination facilities to follow restrictions on brine regulations and mixing zones.

(b) Brine should be disposed of through submerged disposal. The brine should be dumped into deep ocean areas where the concentration can be diluted. If the desalination facility is not built near deep waters, long pipes should be installed to deliver the brine near the ocean floor.

Suspended Solids	≤ 50 mg/l
Mixing zone radius from outfall	500 m
Temperature	5 °C
Dissolved Oxygen	5 mg/l or 90% saturation
pH	0.2 pH unit change
Total Dissolved Solids (TDS)	≤5% above ambient conditions
Turbitiy	75 NTU or 20% reduction
Oil and Grease	≤10 mg/l

Figure 1: Mixing Zone Limits adapted from the United Arab Emirates Ministry of Environment & Water (2015, p. 6)

(c) The mixing zone limits in Figure 1 are strict enough to create both a positive impact on the environment and the economy overtime. These limits should be adapted into policy and set by SEWA. The Arabian Gulf can be further protected by increasing sampling beyond TDS limits for toxic chemicals, such as boron. Regions in the GCC must consider the Arabian Gulf's health as a critical concern if they intend to continue relying on seawater desalination for freshwater.

(d) The brine in mixing zones should be tested frequently throughout the week, if not continuously.

(e) Organisms that live near mixing zones should be sampled to protect marine ecosystems. The minimum amount of collection should be monthly and the maximum should be weekly.

5. Establish water quality guidelines that promote human health and facility sustainability

(a) Implement remineralization as a post-process of desalination.

i. The combination of highly effective water purification seen in RO/distillation based desalination and internal post-remineralization give desalination plants nearly full jurisdiction over water quality.

ii. Desalinated water is generally slightly acidic due to its purified state. Remineralization offers an internal solution to re-balance water pH before distribution to minimize corrosion.

iii. Remineralization techniques offer other benefits, such as introducing concentrations of minerals that benefit human health or even improving the taste of the water.

(b) Target specific contaminants within water quality standards rather than setting general ranges for total dissolved solids (TDS).

i. Requiring water to have a low TDS generally relates to high clarity, but does not ensure potability.

ii. Regions that specify general TDS ranges rather than monitoring and setting ranges for specific contaminants risk causing chronic health conditions. Certain concentrations of toxic contaminants can remain undetected under TDS ranges alone.

iii. The World Health Organization (WHO) offers an abundant amount of information on these contaminants and their related health concerns.

iv. Desalination plants should conduct a cost and risk analysis of each possible contaminant from the WHO's guidelines (World Health Organization, 2017) to choose which ones to monitor and regulate.

CONCLUSION

SEWA should modify their current desalination policy draft and implement it in Sharjah, UAE. This action will set a good example for other regions in the GCC and will allow Sharjah to lead sustainability in the UAE. A policy is vital for the longevity of desalination that will allow for the continuous and sustainable supply of fresh water. The economic and environmental implications of not having an enforced desalination policy are detrimental and potentially irreversible.

by Robear Mankaryous, Caitlin Kean, Sophie Kurdziel, and Sawyer Wofford

REFERENCES

Sharjah Electricity and Water Authority. (2020, February 5). *SEWA Vision 2025*. https://www.sewa.gov.ae/uploads/pdfs/SEWAVISION2025.pdf

United Arab Emirates Ministry of Environment & Water. (2015, November 2). Tanzim 'iidarat tasrif almiah almurtajieat min mahattat altahliyat 'iilaa albahr [Organizing the management of the discharge of returned water from desalination plants to the sea].

World Health Organization. (2017). *Guidelines for drinking-water quality.* [OCLC: 975491910]. https://apps.who.int/iris/rest/bitstreams/1080656/retrieve

A.2 Starting Interview Questions

- What are the critical aspects of desalination that need regulation?
- What do you think is the most critical aspect of desalination that needs regulation?
- Should drinking water plants have tight regulations?
  - They need it. If plant is shut down, then there is no potable water available
  - What happens if a plant breaks the rules?
- Learn more about difference between RO and thermal
  - Difference in environmental impact
- Learn about input chemicals
  - Are input chemicals necessary?
  - Do they need to be managed when they are disposed into brine?
  - Is there a way of limiting input chemicals?
- Ask about cost of desalination
  - If environmental laws are in place, does the cost of desalination increase?
  - How do you propose regulations if stakeholders are going to lose money?
  - How do you make it appealing (tax cuts)?
- Should drinking water be a public commodity?
- Do you believe wastewater treatment should be prioritized over desalination as a primary source of potable freshwater?
- Other people we can interview?
- What data to capture to create a policy brief? Would surveys be the most beneficial?

A.3 Interview Transcripts

A.3.1 Interview 1

05:28 Sophie Kurdziel: What do you think are critical aspects of regulation that need to go into desalination

05:43 Expert 1: Okay. Well, I'll first just mention that I'm not a Desalination expert but in my opinion the most important thing you've got to be concerned with is what you do with the brine. Okay, so could you repeat the question just make sure I'm on task here.

06:13 Sophie Kurdziel: Yeah, it's the most critical aspect of desalination that you think needs to be regulated.

06:18 Expert 1: Okay. Thank you. I'm very forgetful. But I mean there are many kinds of Desalination there's a couple different ways, but I'm guessing they're doing reverse osmosis. And if they're not they probably will be soon. The biggest problem with ro is the fact that in producing the clean water that the deionized water from seawater is that you've got you've got a water stream a continuous water stream that's higher in ionic strength than the incoming water. Okay, So you're you're you're creating clean water and you're producing water that is more polluted with Whatever may be in that original Source water that you're using. So that has historically been a problem. Since this was started think about the even the little like they have in exchange. I'm sorry. Um, well they have on Exchange as well, but the reverse osmosis units that you can buy for your home. You can buy a RO unit at Home Depot and you can typically put it under your sink and you can use it to make water. Until that's somewhat deionized that's not completely diag. Nosed and you've got a concentrate stream that goes down. I mean they tell you to direct it down the drain, but that water goes somewhere if it's a small stream and it's going to a municipal sewer. The higher salinity is diluted enough. So it's not a problem. but when you have high amounts going to a certain Area that's when you can get an increase in salinity. Of wherever that may be. So if you're dumping in the case of the Emirates and I'm guessing they're dumping it not too far from the intake to their desal plan. I mean you only go so far with it. The farther you go the more money it costs you you want to go far enough so that you're not affecting. Your Source water to a certain amount, but you're still putting it somewhere. so my understanding is that you know really to do a right. You've got to look at what are the life forms where you are discharging and what are the potential impacts? I'll give you an example of Boston's Wastewater. Goes to the Deer Island treatment facility. Which if you're anywhere near that area if you've been out on the water or a plane flight over you see those egg digesters where the biomass is digested to collect methane that's on Deer Island. It's on Deer Island and the treatment facility is located there. Well, they have an outfall. So all of the treated Wastewater isn't just dumped off the island it goes A number of miles and I'm not sure exactly where it does go, but there were extensive studies to make sure that Wastewater. even though it was treated to good standards would not affect any areas of environmental concern as well far enough and it has to be to a certain water quality to be discharged. So those are long studies to do that. So this is where I was trying to own up at the beginning as I don't know desalination very well. I think if you look into what's been done for desalination plants where they're held to high regulations. There was one not long ago that was constructed in Tampa as an example. You might be able to get information on that. I don't maybe 15 years ago 10 years ago. To me, that's not a long time. You may want to see what kind of environmental impact studies did they do for the discharge? what way they required you to know to look into and make sure that they adhere to I would think that would be a good place to start to see and I'm sure there are no regulations. I think you said this but I'm sure there's no regulations in the Emirates. But if you could put forward the appropriate studies and the appropriate sensitivities that have to be taken into account. Maybe that's something they could put into place for policy. So back to your original question, you know, what are the concerns or whatever the words were where you discharge the brine is the big thing. Another concern for desalination is the high energy usage. It takes a lot of electrical power. So there's got to be some concern for where that comes from. And I'm sure in the Emirates that they've got a facility that's up. That's up and operating that they work that out but you can't just put them anywhere. You've got to have the ability to access. Power because they're very energy intensive. So you should you're looking at that as a concern not necessarily. May not necessarily be an environmental concern. Although you could tie back to global warming if you want to go that far.

12:11 Sophie Kurdziel: To clarify in your first part about the brine when you were talking about Boston and how they conducted their own environmental study to see where they needed to dispose of the Wastewater. Do you think that Sharjah would need to do their own study before? Implementing any regulations on that or do you think they could look at other ones like Tampa or Boston to base off? base it off of

12:39 Expert 1: Well firstly Boston is conventional Municipal Wastewater. Not not Brine. I was just using that as an example. But I was I was trying to lead into the fact that I'm pretty sure because again, it's not my area of expertise, but I'm pretty sure. Any desalination facility that is constructed in the US they're gonna be looking at where that brine goes and the potential impacts. I'm guessing this is some sort of environmental impact assessment or study. that's done to determine that's minimal that any alternatives have been considered. So you know, I'm not sure where you could go with recommending regulations for the Emirates, but you could certainly give them background information as to What should be studied which should be done to minimize the impacts? then there are different ways of doing it whether whether See what I wanted to implement that as a policy. An internal policy. I mean they could do that themselves if they wanted to or if if there's a way to get some sort of a regulation like that on the books in the Emirates and I'm I would have no idea how that's done. But but there are policies and and regulations and laws, and I don't know how that works and in Sharjah or the Emirates says as a whole but I think if you give them the information And see if it gets traction as to should it be a law or should it be a policy. Is it would it be something mandatory, but if you found out, you know, what kind of environmental impact studies are done? You know that probably would help them quite a bit.

14:48 Robear Mankaryous: If these like regulations were mandatory. And they were so strict that they forced. you know these plants to shut down for a while, I guess how do you value the ability to gain drinking water over protection of the environment because at some point, you know, like you have to make a decision about which is more feasible or which was more worth it.

15:18 Expert 1: That's the million dollar question. You know that water is in such short supply there. They do have some to my understanding is they have some natural aquifers? But they have a population explosion. I'm not sure exactly what's happening with the population during the pandemic. They have many folks coming in from other countries to work. And I know that there wasn't that was an issue with some of those people trying to go back home because work had dried up. So I don't know where that stands but their population had I I don't remember the exact numbers, but the population had increased. Dramatically and was putting it was a great stressor on the availability of water. So, you know, what are the values certainly, you know people having water such that they can live is a it's a hell of a value but having a clean environment happening is sustainable having sustainable practices is something that we have to we have to think about as well. I mean if if you increase the salinity of the of the intake to as just one example, if you increase the salinity to the intake to the first to the desired plants such that it becomes less efficient. Um, you're entering a spiral that that you know isn't gonna be good for anybody as well as roomy environment as well as draw energy as well as likely affect the production of water. But those are values are what you're talking about is a it's a judgment call. I can tell you that. when you have when you have when Society has everything that it needs this is my opinion, but when Society have has everything it needs. In spite of what may complain about in the United States we've got water our Wastewater for the most part and there's certain local areas where waste waters is treated. We have safe food. We have plenty of food. Yeah. I know there's, you know, we could talk about how maybe not everybody gets that but it's a that is a society here. We're very fortunate. And are the parts of the world oftentimes they'll look into live day to day. And if you ask them about global warming, they're going to say I just want to live till tomorrow. I just want to have enough water or I want to survive a war. I don't know us not not like that, but I'm certain that if you talk to people there that have low water supply. Their prime concern is getting water, not necessarily caring about life forms and you know salinity that was over the brine is discharged. We have that luxury here. That's just my opinion. I don't mean to be on the soapbox. But but your question it's a judgment call that the people of the UAE have to decide the importance of

18:48 Robear Mankaryous: Yeah, Like a judgment call then someone can just like look at numbers and say oh do this instead of this because there's something like values you have to hold.

18:59 Expert 1: One of the things let me just just one more thing. I mean we try to we try oftentimes we'll try to impose our values and I think we've got to make sure that we're looking at their values and your advisor can correct me if you think something is wrong and I'm fine with that.

19:24 Caitlin Kean: Do you know about any of the effects input chemicals could have on the environment?

19:40 Expert 1: Oh. We're talking about reverse osmosis, right? Is it reverse osmosis? Yeah, um I really don't know but I'm but I'm guessing I mean one of the things that you have to do with membranes is that You've got to work on cleaning them and the cleaning chemicals are and I'm not sure if this is what you're getting at, but the cleaning chemicals can be. quite nasty you oftentimes. It's caustic to try to try to remove material that may be on the membrane. And then sometimes it can be an acid to clean things with it in a different way. So yeah, those things are nasty in they you know, you can't discharge those. They've got to be. least to my knowledge that they would have to be captured and treated and then they could potentially be discharged and with a large facility. I'm sure you're talking about large volumes. That you would have to somehow take care of you'd have to make sure that the pH is acceptable, you know, if you would discharge any of these chemicals whether it's acoustic or acid. If you just discharge any of these chemicals to the environment, it's certainly going to affect life until that pH is the life form that may be around it until a pH is neutralized. I contacted a lot of water. You could look I know that. They're there's you could look more at the chemicals that are used. I don't think I have a source that would be helpful. But the membrane manufacturers provide guidance on what needs to be done to the membranes to clean them and you know that that may give you information on what specifically the chemicals are in the quantities that because you may not get that straight answer if you ask the facility, but you could you could get an idea if you if you do a little research into what the membrane manufacturers recommend.

22:11 Caitlin Kean: And then do you see its effect if there is a higher Peak or a lower pH affecting the pipes it's going through?

22:21Expert 1: Absolutely. Yep. Yep corrosion would be an issue. So there are practices that I mean you want you won't use a really low PH solution in pipe and leave it in contact. It would run quickly. Try to try to clean your membranes off. Maybe soak it a little bit but cleaning memories off and then you know move it out. So you reduce the corrosion Part of the issue too. Is that Deionized water itself is very corrosive. in not necessarily because of the pH that it's at so You know pipe selections are important monitoring. Loss of material due to corrosion is important, you know, you might want to see what kind of issues they're having are they having corrosion problems? Ionized Water by myself if they're producing the ionized water and they're not blending in they're running through a pipe for a while. Yeah, that's a you know, that's something that's gonna be a System Engineers concern.

23:37 Caitlin Kean: You think they need to set regulations on how often they check their system?

23:44 Expert 1: Check what on their system?

23:46 Caitlin Kean: The pipes in the water and the pH just making sure to constantly be checking it.

23:51Expert 1: Well, I don't know if they need regulation because if SEWA owns the facility, right, you know, if they have a leak of pure water. You know, I mean if they're leaking a contaminant that's one thing and you know, I don't know if they have the difference, you know acid base or maybe they use other things that help clean it that could be organic in nature. And I believe that you know, there are other chemicals. They would have to handle those chemicals separately and treat them whatever and there should be regulations on that. But as far as checking their pipes if they're producing clean water. And the pipe is corroding away. I mean that's not necessarily a bad thing for the environment, any clean water that leaks. It loses profit. They're losing efficiency. It would go into the environment and probably very readily in so be on them. I don't think you need regulation for that. So regulations for the Hazardous chemicals, we have all those regulations in the states. So anybody producing anything that's considered to be a You know chemical. That needs to be ready. It has its chemical hazardous waste we have regulations that handle that I have no idea what the Emirates regulations on those types of things..

25:30 Sawyer Wofford: Do you see specific regulations? Do you see them raising the cost of desalination or limiting the efficiency of the foundation plants there. Is there one that stands out more?

25:48 Expert 1: hmm Why would see I mean if you if you put I mean it depends on the regulation. And again, I'm not I'm not saying that any regulations are needed. You know, if there are policies, regulations or practices, whatever it may be. So let's say, you know, if there's something that would that you maybe you find something it says that you know, the outfall for your brine has to be 20 miles out. Versus one mile out because it affects the life forms nearby land whether it's maybe more life forms. That's a cost so they would have to extend their outfall a significant distance. That's a cost. But I don't see it as something that would affect the efficiency if it's collecting any hazardous chemicals that may be used In the treatment process and again mainly for cleaning is my knowledge. Bear in mind I'm saying I'm not an expert but if they're if they have hazardous materials that if right now they're just dumping them into the outfall. I mean in my mind there should be a regulation against that and certainly a practice to prevent that but capturing that stuff in a tank. And then treating it that's a cost. That's not efficient. Issue unless your gauge of efficiency is dollars. It's gonna increase the cost of your produced water. Um, so I mean, I think it's a I think it's a money issue. Which often it is with technology we have Technologies to do all kinds of stuff just cost more money.

27:41 Sawyer Wofford: So I think my signal is cutting out a little bit. Let me know if I break up.

27:46 Sawyer Wofford: Let's see. Yeah. Okay. Awesome. Perfect. Um say I guess one of the one of the largest problems where like we've already touched on this a lot more than our previous interviews, but our largest issue with this project is trying to figure out a way to I guess propose the policy on these plants if active right now like they have no policy just because water is deemed as like a valuable source.

28:12 Expert 1: Yeah.

28:12 Sawyer Wofford: So we're just trying to figure out what methods we can use. I guess add weight to our paper in our policy brief in a way that would actually, you know, maybe Inspire some regulation. Is there anything that stands out? That's a tough question. But is there anything that stands out is obvious that you think would add weight to these policies?

28:36 Expert 1: Yeah, you know anytime there's a proposal. to spend money to a company, a government any anything um You got it. You got to somehow. Look at the benefits. Um As an example. Um Just kind of think about cleaning the cobwebs out of my head here. But something I've talked about in some of my classes is the great lakes in the United States United States in Canada, but I think the United States was the culprit in polluting them. What we cleaned up discharged dramatically. into the Great Lakes So the Great Lakes were some of them where I think was Lake Erie was the filthiest just pretty much I think they said it was dead, you know, meaning that you know, just don't have much in the way of life from there. Just not. You know, conducive to fish and other aquatic organisms. but what happened is we passed regulations in the United States that made industry and communities clean up their Wastewater So now if you go to the Great Lakes, pretty much every great lake has a big fishery industry. It has tourism people go to those Lakes to vacation. If they were polluted. Certainly, you wouldn't have the Fisheries maybe a little bit and some of the cleaner areas of the legs, but nobody wants to go to a place for tourism. If it's filthy polluted stinks dead fish, you know. I think the same thing applies here. I mean that's really looking at if you want to convince somebody to spend money. You got to somehow say you can get it back. So you know, one of the things I believe the Emirates wants to do is Is look at it, you know expanding their economy and I and I believe they've really pushed their tourism industry. I think a lot of folks go to Dubai. You know, on vacation there are beaches in the area, certainly good places to eat good places. It means it's a really interesting area. I hope someday you guys you're doing a remote project, but hopefully you'll get there. It's a fascinating part of the world. But I think if you talk to the improvements that can be made to do that. You have to document what degradation is there right now? Can you show that what they're doing now is a bad practice is somehow affecting life in some way. If you can do that. And it potentially affects tourism or expansion of their economy in some way. I think you've got a compelling argument if there's commercial Fisheries in that area. You know, that's another way. I mean if you can show that you know, there's some potential impact to the commercial Fisheries. And by looking at other studies like Campa or somewhere else that may be more recent. Maybe you can get some information on that. How can you help them determine what the impacts are but find the impacts. determine how the impacts for some connection between those impacts and you know livelihood and and goals of the Emirates and I think maybe you'll be able to commission that if they invest the money to do things a little bit differently to protect the environment. They'll be a Payback.

32:34 Sawyer Wofford: Yeah, that's awesome.

32:34 Expert 1: eight dollars

32:35 Sawyer Wofford: That's yeah, yeah. Yeah, we haven't really particularly thought of that much. So thank you. That's yeah, very useful, especially getting you know money back in some way that would be a great argument. um Well, yeah, we also wanted to know if you had any opinion on. you think like these Foundation plants and I guess more broadly drinking water. Do you view that as a public or private commodity? Do you see it as like any benefits? between those two pros and cons

33:18 Expert 1: Um Yeah, you know, that's a tough one. You know you can look to. You know the developed world where there are both. There are private water companies. And there are public water companies. Um Sometimes it's not a lot of not a lot of difference in them. You know somehow the treatment processes have to be paid for. You've got to be able to make water and be able to do it. continuously and produce clean water at adequate quality there are startling cases where that hasn't been done in in our country, but I'm not so sure that That was a fault of of the the water being public or private because there are examples of both public entities being run very well and private entities being run very well. You can just look at Massachusetts and you can find both that are doing a great job and like I say, you can look at other places where both are not doing a good job. I mean, I think you know the bigger question that maybe you're getting to and and you know, is it a right to have clean water? um, I don't know if that's where you're going with it, you know, because that might fall under then something that is a public. You know something that maybe the government should provide. But anyway, I don't I can't go.

35:07 Sawyer Wofford: No, that's good. Yeah, the reason it kind of comes up is particularly due to like regulation. Like it's a lot easier to regulate like it's a all publicly owned and you know, it's very easy to apply regulation to all of them in charge of specifically it is see you which owns all the desalination plants and we are just wanted to triple check our argument to make sure there wasn't a reason that maybe it should be privatized or yeah, if you don't see anything obvious and that's That's totally yeah.

35:38 Expert 1: You know, the thing that I guess is much more familiar with, you know, the regulations in our country, but just because some company is private. They still have to. They still have to abide by regulations and it may be confusing but they're if they can be private. But yet to be called a public system because they provide water to the public so they have to so they can be privatized as an entity. But yet they're providing a public service and they have to abide by the drinking water regulation. So there's no there's no way of getting around it. You can't privatize and then and then think you're gonna adhere to different regulations. The drinking of the bottle drinking water is a whole different industry. but in terms of the water that comes in our Taps and pipelines that's

36:35 Sawyer Wofford: Yeah. I'm so yeah, we wanted to bring up something else. That's really interesting. One of the most interesting parts of our project we found is that there's kind of like this movement that's being led by siwa there. They're like focusing on educating the younger generation about ideas of conservation and you know being able to treat Wastewater to a state that's like You can actually drink it which right now it's viewed as like on pure generally with within like the adult population. So they haven't even tried to pass policy or anything on that. But yes want to see what's main mission statements is let's like try to make a movement towards Wastewater recirculation. Do you personally do see that as a better solution than relying on desalination. Like is that a is that a right direction to be heading?

37:32 Expert 1: Well, I don't think you're gonna have either or I think I think there's gonna be multiple. Facets that we have to utilize and I think desal is something that that we're all going to be doing. It's just gonna be necessary but

37:48 Sawyer Wofford: Yes.

37:49 Expert 1: reuse of Wastewater I think is huge. I think it is something that's needed. Lots of times they're there. If you look at the way you may want to do this, you might look at how water is used in the communities. A lot of water is used for things that May not really require drinking water quality. Okay, I mean think about why we Flushing. Toilets with water that we can drink. I mean nobody's gonna be drinking from the toilet. I hope you know, um, why are we doing some industrial processes? Um, like cooling water? With drinking water when treated Wastewater be completely adequate and we've done that we've looked at that in a lot of places around the world. Do the treatment that's necessary for the next step. Don't just dump the Wastewater. Figure out what you need to do. You've got it in your community. Do the treatment needed to bring it to a new level and then utilize it in an inappropriate fashion. I'll give you another example. Worcester's Wastewater goes to the upper Blackstone. I don't know. I called the upper blacks always water treatment facility. It's in it's right. I'm trying to get a correction. It's right off. Right right outside of Worcester. It's on the Blackstone River. Okay, so right on 146 if you were going down 146 leaving Worcester heading South I guess it's like heading towards Uxbridge. It's on the right and if the winds are right sometimes you can smell it. There is an industrial park up the hill from there and there is a waste of energy. are facilities there they take The solid refuse and they burn it, but they try to capture the energy from it and they need cooling water. So we had an mqp. I don't know how many years ago four or five years ago where they looked at taking Wastewater from the upper Blackstone treatment facility and just doing one step to it. To clean it a little bit more than how it's discharged and then piping it up the hill and it could have made up the water needed by the waste to energy treatment waste of energy facility. That up the hill in the water would even be perfectly adequate for Other industrial processes that maybe others would want to tap into. It hasn't been done and it 's just indicative of how much water we have. And we really are very fortunate in most places of our country. How much is how much water we have? You know, it's not in such short supply yet. So they treat the water and they dump it into the Blackstone River. Okay. Why not use that water one more time? And I think in a place that is as dry as the Middle East. There's so many opportunities to take that Wastewater and do some simple treatment steps and you could use it for a lot of different things particularly Industries or whatever industry. They may have metal cooling if they have something like, you know, power generation where they have cooling towers it can be makeup water. And you can not use drinking water. Until it save the drinking water for the drinking. So I think it's a big way to go.

41:39 Sawyer Wofford: yeah, yeah as currently they have like very little Wastewater recirculation on most rely on groundwater for More like agricultural purposes and then they it's almost all of their potable Source comes directly from desalinated water. But yeah, that's very interesting. I wonder we could talk about like some conversion or conservation in terms of like where that you sounded water goes. I think that could be very interesting.

42:13 Expert 1: but treated Wastewater is great for agriculture if you look Israel. Israel captures, I think in the world the highest amount of Wastewater, and I think it's Almost all goes to agriculture. So they they use it in a beneficial

42:30 Sawyer Wofford: yeah, that's a good point, especially because a lot of the groundwater would be viewed as like You know culturally accepted as as drinkable and potable. Um it could maybe solve lots of those issues by converting some of their groundwater sources to Drinking sources and using starting the recirculation of Wastewater into Agriculture and stuff like that.

42:51 Expert 1: But there's also direct potable reuse Namibia. the system in windhoek.They take their Wastewater. They treated really well. It goes right back into into their drinking water system.

43:03 Sawyer Wofford: Yeah, that's what Japan is doing as well. We found in a research. Yeah, it is just like a even like our project advisor. She has like a bottle of treated Wastewater that she's just been like it's been like sitting on her desk for like 15 years and she's like I still haven't opened it yet.

A.3.2 Interview 2

03:00 Sophie Kurdziel: What are the most critical aspects of desalination that you think need to be regulated?

03:18 Expert 2: Well, I mean, I think. the one of the issues with desalination has always been entered the energy it takes and so That usually comes into play more in terms of choosing between desalination and if there's other options. But it's generally considered. a relatively energy you know large consumer of energy and so You know the big picture and I don't know if this would fit into the policy, but big picture is to what extent are renewable energy sources use to produce desalinated water. Otherwise you're having a significant impact on climate change and climate change gases and from all the energy. It takes to produce the D cell. So energy I think thinking about energy in. There's any considerations that could still be made with respect to energy the energy it takes. The types of energy that's used would be I think one possible thing to think about. as you mentioned of course the brine that's produced is an issue and I don't I don't really know and you know, you can you can help me better understand it, but I don't really know what options are feasible on the table at this point for managing the Bride of my experiences. I grew up in California and about a decade ago, California went through the process of building a lot of desalination facilities and I haven't really I haven't really checked back in on that to see how many were actually built. I know. I just know that at least a few of them were built. There's one a pretty large one was built near where I grew up in Carlsbad, California. and the way those facilities work is they're typically co-located next to power plants. In California, there's a lot of power plants right on the coast. Because they use seawater for for cooling and so so these facilities typically have there's a large intake pipe that goes out into the ocean. The brain seawater in but that's really for. The power plant and then the power plant uses the water. And then the water gets heated up a little bit by the power plant, which is beneficial. If you're using membrane processes because it reduces the mass transfer issue. So you don't have to pump it as you don't have to use as high pumping. To to push the one membrane. And so that that's a real benefit. And and so then you generate your purified water and then you have the reject water and brine. And then again because they're co-located with these power plants. The water gets back mixed in with whatever other cooling water. The power plant is just charging back out in the ocean. And so then you have this. relatively warm brine solution that goes back into the ocean so Leasing California. I know there's there have to be some type of ecological assessment, you know every Every location is different. So there have to be some kind of ecological assessment to. to try to evaluate what impact this warm salty salty water salt to even for the ocean. Is going to have on the ecosystem surrounding the discharge. so that's I guess that would be the second issue and again, I I don't know exactly. You know. What the what the options are. I mean, there's also for Inland I think in Arizona or Nevada they're doing desalination of some Waters, I think they that I don't know the source of this salinity, but they're doing desalination in the brine gets dried in big lagoons. you know, so that's very land intensive but You live in a desert that maybe that's you know, maybe that's what the option that you're considering, But certainly that takes up a lot of a lot of space and other question is what do you do with? With the the solid materials are there uses for those things? So is there some kind of beneficial use you could come up with? to deal with all that and then I guess the third thing and you may have mentioned this as well. And your email is the water the water quality perhaps of the seawater that's kind of less less of an issue. Because a lot of contaminants can't get through. The the membranes, you know conventional contaminants that you might have in. Lake or groundwater that we're worried about for drinking water. Those are relatively large molecules compared to the porosity of these types of desalination memories, but I don't know maybe they're not even using membrane processes. So there's other desalination processes. So so depending on what technology you're using, I guess that you would want to consider if any kind of contaminants in this in the water you're treating there's anypotential for them to To get into the treated water and if they're not they are going to be concentrated, right? So you're the brunt just like the salts are being concentrated. So now you're discharging. Not only salty water, but whatever contaminants might be in the water older concentrated. So So probably some some assessment of that might be might be needed. But yeah, those are those are kind of things I could think of off the top of my head.

10:03 Sophie Kurdziel: yeah, we've definitely seen a lot about All three of those things would you say that energy consumption like out of all three of those things? Which one do you think is I don't know the most. Harmful if it wasn't to be regulated. But it I don't know from what you were saying. I feel like energy consumption was a pretty major consideration.

10:28 Expert 2: Yeah, I think energy is definitely the biggest one. I like I said, I haven't I haven't been involved in desalination in a while or like that. Those kinds of applications haven't really look at them. So the the energy consumption met the Innovations in membrane materials and other or other processes for desalination and probably reduce the energy consumption needed but I'm guessing it's still pretty significant. and you know, it's just from the environmental point of view. I think the the most critical thing I guess you know from as a Critic is that you use, you know the situation where you're using lots of you're using purely fossil fuels to desalinate water. You saltwater. Ecologically climate change perspective that's not sustainable at all.so for many reasons You know fossil fuels of course and then also impact the added burden on the climate. Yeah, I mean the disposal of brine. I'm sure there's can be some serious issues but in general like you. They're pretty localized. You know, they the brine gets. diluted pretty quickly if it's in seawater and then If you're drying it in lagoons and things like that, then you know, those are pretty much I guess you'd have to you'd have to worry about. containment and and not contaminate groundwater. I guess that would probably be the big issue. assuming that there's there's controls in place. So it can't migrate off site. Like if you got a flood or something that it's not going to It's not going to get washed into you know some other Aquatic habitats. That but I think if you've got very permeable soil you'd have to have some kind of liner system. I'm guessing so it doesn't just you know, the water doesn't particularly potentially. Infiltrate into the soil and contaminate the soil with really high salty conditions.

13:05 Sophie Kurdziel: I was gonna say you mentioned that they were attached in California. They were connected to the power plants. Do you think that that system helps the effect that it's having on the energy consumption when they're kind of dual process

13:26 Expert 2: Yeah, that's I mean, that's something. It that way is at least for membrane. systems for desalin membrane desalination It's just it's easier to pump the water through the it takes less energy to pump the water through the membrane if it's warmer. it's less viscous and so it just takes significantly less energy. It's still energy intensive, but it cuts. I don't know. Decent amount of energy down to do it that way. you know, what kind of desalination Technologies kind of typical they probably have other desalination facilities in the region, but is there sort of a one or two that are more common

14:19 Sophie Kurdziel*:* Yeah, I think in Sharjah it's mostly multi-stage Flash.

14:27 Expert 2: Yeah.

14:27 Sophie Kurdziel: Is that right? Yeah, and so Ro is not the main one in charge of specifically.

14:35 Expert 2: I mean if you're distilling in it and you having a little warmer to start with I don't know maybe that's helpful as well.

14:42 Sophie Kurdziel*:* Yeah. That's interesting. I have never heard about the power plant using that as well in tandem with it, but that's cool.

14:52 Expert 2: Yeah, it's also. They it's also they also use their Inlet and Outlet pipes. So in California, at least these pipes got like a mile or two, so They're pretty expensive to put in place. I'd say that's a lot of capital costs right there.

15:18 Robear Mankaryous: Yeah, I was gonna ask because we sort of have like this. I guess larger question of how much regulation do you put on plants producing drinking water? Right? Because if you regular if you have a section of the world that needs these plants like just for you know, drinking water to survive and you start regulating these facilities too heavily. You run the risk of like running out of drinking water. I know when we spoke to siwa. they are suggested that like sometimes variations in the water quality coming in can actually force them to shut down the plants and they're only producing water a few hours ahead of what they need. So that doesn't include storage because obviously you can go and store the water the drinking water instead, but they like rely heavily on these desalination plants. And so do you think there's like a point where maybe we step back and let these plants do their thing because they're critical for drinking water or do you think hey, you know toughen up. you can you can both produce water and be within regulations

16:35 Expert 2: Yeah, well, that's a really interesting question. I mean one thing to consider is What is the water being used for so drinking is a very small fraction? of water use so You know, so I think you from that perspective. Just the amount of water that you need to survive for drinking is, you know, we're talking to a few gallons per day. But if you factor in all the other uses of water, which really don't require. the same level of treatment or have the same. Sort of ethical, you know, that's almost like sort of an ethical opposite is an ethical question. And I think from that point of view you really have to look at. What fraction of the water is it ethically important to provide? And who gets that water and why for what purpose? so to what you know to what extent is that water going to you know provide basic drinking water to? sustain people into what extent is that water using being used for other purposes that are perhaps important but you know. another way to think of that question is Is what are you so what are you potentially what uses of water would you be subsidizing? In a sense by not having the regulations. Beyond what's needed for drinking water That makes sense. So, you know, I mean if you're providing a significant amount of water for industry. And having no regulations or reduced regulations provides a cheaper, you know resource for industry, but at the cost of the health of people that just rely upon it for drinking water. But now what have you done? Is that is that really ethical? So I think that's that would be another way to kind of frame that question or think about that question, but you'd have to dig into. What's the expected what use or consumption of that water Beyond, especially Beyond? Providing kind of the Safe Water for to provide the basic needs for the population. And in many cases that's a pretty small fraction of the water that's being produced. a lot of the water goes for other purposes that again are not are important. but you might think about them differently and with respect to to. That trade-off between providing the water at a lower cost versus not having a regulations on the drinking piece. I don't know. Hopefully that was not too too vague of any answer that gives you something to work on.

20:08 Robear Mankaryous: Yeah, because I know like I mean the UAE. the water usage per person is like astronomical when compared to the rest of the world But that's not all drinking water, right?

20:22 Expert 2: Yeah, yeah.

20:24 Robear Mankaryous: And I know in the UA specifically they tend to use groundwater sources when they do Agriculture and that kind of thing. So at least in Sharjah. desalinated water tends to go directly to potable resources our portable versions of water, but yeah, I guess like perhaps just some trade-offs to make right like people don't need. Obviously don't regulate it so much where you have people dying because of water to drink but regulate it. you know reasonably and taking to consideration that not all of this water is being used for. Legitimate reasons or like critical reasons and you know the environment at some point. You have to start worrying about that being the critical Factor.

21:11 Expert 2: yeah, yeah, and you know, I think and in the United States you were we're there's a lot of chemicals in the water that we don't regulate and there's been very few new regulations and drinking water in the United States are less. decade couple decades and what happens is that the people that pay the price for that? Are generally not the people that benefit from that. so You know, for example. the United States there's a lot of widespread contamination of drinking water by per fluorinated compounds. So these are things that are used to produce like Water resistant clothing Teflon pans and all kinds of products. and the companies that made those products and contaminated the water with these compounds. Got all the benefits of it, you know in terms of they made a lot of money. On it and they really didn't have to pay much for the water. The water was dirt cheap. and now now that the you know, there's a lot of evidence for people getting seriously ill and having all kinds of really serious health problems. from drinking water They're not they're not paying for the the problem to clean it up. They're not paying for the health bills. They're not paying for. You know people that have lost all the equity in their homes because they can't sell their homes anymore because it's contaminated with water. So there's the health health of cost of people losing their jobs because they can't work. Yeah, they they're not paying those cost. But they you know, they paid. that they got the water for you know below what it was actually worth so that I think those are you know, that's you know, I mean you could you could think about a sliding scale for the cost of water perhaps, you know, but don't I guess my this is my opinion is just I'm against you know, subsidizing the cost of water for some people. they could you know for profit reasons while the true cost of the water are being paid by other people in terms of health health effects So that's I mean that's that that to me. That's the ethical question in terms of regulations.

24:43 Caitlin Kean: Yeah, I'll go. So we want to learn more about the input chemicals that are put in because we know there's seawater and it doesn't go straight directly through the desalination. There's chemicals that go in first and we want to know what you knew about it.

25:00 Expert 2: I don't know that much about was a multi-flash distillation. I know more about membrane desalination. membrane desalination, it's mostly It's mostly like acid. It's in bases. That are added. Because you know as you concentrate that brine it wants to precipitate out so you have to and that can that can foul up the pipes and the membranes and things like that. So they typically tend to acidify it. at the beginning just to prevent things from precipitating in the system. which caused a lot of problems and then and then the water that's produced. Is relatively acidic and it's too acidic for distribution because it will eat up the pipes and you'll get corrosion in the pipes which can cause all kinds of other problems. And so then they have to add base. To bring the pH back up. So it doesn't corrode and eat out the distribution system. There may be something similar like that to multiflash distillation, but I don't really know too much about that process.

26:21 Caitlin Kean: And we just had a question when you think those chemicals need to be managed at all or they're causing harm if they're getting dumped back into the seawater.

26:35 Expert 2: Yeah, I mean, I guess that's you definitely would want to look at what the water quality is of whatever is being dumped anywhere. generally Ask the bases. There's there's limits on that in terms of discharges in the US so It's like probably between has to be between five and nine or something. I don't know the exact numbers, but there's there's like a range. and definitely if you if you if it's too low if it's too acidic that can have a lot of causes a lot of problems. Organisms can't survive shellfish start dissolving their shells start dissolving. That kind of thing near the near the discharge area and then high pH can have is can be toxic to organisms as well. So so yeah. I think acids bases are any chemical that might end up in the the reject water the brine. You want you you want to pretty you want to have a pretty good idea what that is and have some limits on. What concentrations there could be in that material? That discharge for sure.

28:00 Caitlin Kean: Is there a consequence of us drinking water? Humans drinking water that's too acidic.

28:16 Expert 2: Oh, is there any impacts on humans? Well, I mean yeah, I mean there's two like a acetic sulfuric acid is basically, you know really concentrated acid in water and that'll burn out here for not sure insides. So yeah, but even I think you know assuming you're not dumping something that's like ph1 but if if it's you know pH five or something like that. It's most the problems are mostly related to corrosion of the distribution system. So that creates. Some non-health problems and that you know, the pipes are getting corroded and they're not going to last as long. but then in the United States, we have a lot of older pipes that have lead and copper in them and so starts corroding away that led a copper and that you get basically you flip, Michigan. You probably know about you know, I've heard at least something about the water issues in Flint, Michigan. And the reason why that happened was that. They switched water sources of water. and and the new source didn't have those same chemistry the same pH and so and they didn't add any corrosion Inhibitors. And so that was more aggressive towards corrosion in the system and released all athletic Copper from from the pipes. That's usually the main health issue for water with low ph with wired high pH a lot of alkalinity you can get a lot of precipitation on the pipes. So and so parts of the United States. There's a lot the water the groundwater is there's Limestone aquifers which are pretty high in PH and a lot of calcium and so when those Waters go if they're not adjusted the pH not lowered you get calcium carbonate precipitating in the pipes and the pipes get can get completely shut filled calcium carbonate if you don't You if you let system run at that high of a pH. But there's probably not I can't think of. Many health issues with a high pH it still has big impact on the infrastructure.

30:57 Caitlin Kean: Thank you. That makes sense. Sorry, you can go.

31:05 Sawyer Wofford: Great. All right. So we next wanted to look into the cost of desalination and specifically do you see any scenarios where environmental laws that are put on a desalination plant can increase the cost of the desalinated water that's coming out? Like putting regulations on a plant, do you see that being able to raise the price of water coming out? Is there any scenario where that happens?

31:43 Expert 2: yeah, my opinion on that is that well first it kind of depends on how you how you define the cost of the water. Yeah, it goes back to Rovers, you know question. So if you're talking about, you know, just the cost to produce it. then there's very little way that a new tech a new regulation is not going to raise a car. The rate cost is going to go up. You know, they're gonna have to monitor for it. If there's a problem. They're gonna have to add some kind of technology or they're gonna have to reduce production or there's something's gonna happen. That will raise the cost of the water. so so, you know if you look at just the cost of production, that's The answer but if you look more broadly about the costs. in terms of the cost on the ecosystem the cost and human health You know, those are those are real. They're more difficult to Define and quantify, but they are real costs. They do have a real impact. a really economic impact on on communities so so in that case, you know, it's it's hard to say if a new regulation. Increases cost or decreases costs total cost to society.

33:26 Expert 2: people are so that's that's you know, that's kind of depends how you look at it I guess is my point.

33:35 Sawyer Wofford: I think what we're going to have to be doing is there's this thing you've probably heard of it's the social carbon cost. It's like a calculation of How much energy you're using that translated into how much carbon you're burning in terms of like an environmental standpoint?

33:52 Expert 2: Yeah. a print

33:55 Sawyer Wofford: Yeah. Yeah. It's basically like saying how much impact will this have on directly on our economy and like the people and like, you know people having to move because of sea levels or temperature rises. So I think that's probably a good way

34:09 Expert 2: exactly

34:10 Sawyer Wofford: to put it especially since you said the energy is definitely something key to consider.

34:18 Expert 2: Yeah, that's a good way to try to capture some of these even if they're not economic costs that it captures a lot of stuff and there's ways to do that with water like water footprints. Which you know can capture some of those costs.

34:35 Sawyer Wofford: Yeah, it's good because it shows direct impact rather than theoretical.

34:39 Expert 2: Yeah, yeah that always helps.

34:42 Sawyer Wofford: Yeah, um, do you see I mean, this is like probably the toughest question we're gonna throw at you but it's worth asking. I guess do you see a lot of this like Sharjah it's you know, completely different government and especially with their prioritizing desalination with no regulation like for us to go and propose regulation. Like we need to have some kind of weight. Do you see any like, I don't know anything that stands out is weight that we could add to this that makes it more appealing to like Government and see what to like, maybe consider these regulations.

35:23 Expert 2: I mean, I think I think yes, that's that's the toughest question. I mean I think of how you know how we function here in the US. and you know, I would go back to What are the professed values of the of the government you know, so? So from the point of view of the United States, you know, we have professed values of Justice equality. These are some things that you know are in the Declaration of Independence and the Constitution and so forth And so if you believe in those things and you want those things to happen, then you know there needs to be equal access to water. You know water probably needs to be a right. You can't live without water. So if you believe in you know. You know life liberty. You Pursuit of Happiness if you live if you believe in that life part. Then you shouldn't have to drink water that's killing you. No matter what it cost right so. so going back to those kinds of things and I guess not knowing anything about their government or what their professed values are. or values that they act on would be I mean, I guess that would be a place to start if you could link it to things that even on paper they're saying they're trying to do. and try to connect those policies to like a little more fundamental level to their society and what they're hoping to accomplish. And the future with their society. That would probably be one way to approach it. Yes, if you can turn some of these. You know carbon carbon. Issues into real dollars to their economy or future trade possibilities and that kind of thing. That would be the other I guess way to try to do it.

37:51 *Sawyer Wofford:* Yeah, yeah that kind of connects to an overarching theme we've continued to run into during this. one of C was main mission statements is talking about they don't really view desalination as like As an organization as the solution to the freshwater shortage that these aired climates are experiencing. They still view the solution as like Wastewater recirculation, but that's like a a cultural. It's culturally unaccepted to drink Wastewater, even if it's recirculated because it's you know, it's not considered pure water. So that's why they've had to resort to desalination. And it's really interesting. See it was like sending out almost like like they're sending out groups of people to schools like a targeting like young people growing up and and Sharjah and they're educating them on how conservation is, you know a key. Thing to understand hoping that in the future. Wastewater will be acceptable to drink. So that's we're going to maybe Loop it in somehow. We're still trying to figure that out. But do you generally believe that Wastewater research circulation is a Better solution or reviews desalination as maybe better because you can pair it with energy plants or whatever other reasons.

39:20 Expert 2: yeah, I mean again like California made a big push towards, you know, Wastewater Reclamation and reuse and I know I think it's the Hyperion wastewater treatment plant and in Los Angeles a couple years ago came out with a zero discharge initiative, you know, so so the technology is there. In various forms and again, I don't know the particular situation where you guys are dealing with. But you know California's. You know dry. You know similar there's some similarities in terms of not enough water and too many people. So yeah, I mean, I think that's that's definitely should be a priority. Fact is that you know Nature has been recycling water for us and so we've been drinking recycled Wastewater already. So in terms of in terms of this idea that you know, we don't we can't do that. I mean we've been letting nature do it so we wouldn't be here. So, I guess maybe that's one that's one point one point. You can make it's like that should sailed already. Even now I mean it's interesting when as as I worked at Ohio State for a number of years and lived in the Midwest and And this is pretty typical where? a lot of the water comes from surface water from rivers and they're really not that big and you know the river and that's why the towns the cities like Columbus and Cincinnati and Pittsburgh, you know, that's why they they are where they are is because there was water there was Rivers there that they could tap into for drinking water and then put their Wastewater in and and hundred years ago, they would just dump the waste water back in there and tell it started causing, you know, noticeable problems, and then they started treating it but even now human today a city of Columbus though it under like low flow conditions when it's been pretty dry. And you know, like say they're in a drought just a typical drought not like a once in a hundred year drop, but let's say once in a two or three year drought they'll take water from the river they'll use it and then go the wastewater treatment plant the wastewater treatment plant treats it and then puts it back in the river. That what fraction of the flow of that River that's made up of that Wastewater treated Wastewater that goes back in is under drought conditions is pretty high. It's EPA looks at situations like regular regulations are for when you know, it's like it could be like 90% of the flow. So and then that water goes Downstream and then is the drinking water for the next town. and in that I mean we've been doing that for for you know decades and that's just again, relying on in nature and natural purification through the ecosystems in the streams to deal with all the stuff that's in there. now I can't deal with some of these chemicals that we're talking about earlier, but you know a lot of it can and that's how that's how you know, a lot of our cities have managed for for a really long time. And California places that don't have a lot of water that they have to be more creative. And so they've kind of been more intentional about taking the Wastewater and turning it into drinking water mostly through groundwater recharge, which is a little more palatable. I guess to the people that if at least goes through you put in the ground and then pump it out of the ground people are more comfortable with it. Check it. I mean I would be too.

43:34 Sawyer Wofford: Yeah, yeah for sure. In California are most of the desalination plants. Are they private or public entities or do you have any opinion on which one you think would be better?

43:58 Expert 2: Yeah, it's another good question. I don't know what What the situation is in, California? so I can't really comment on that but I mean my opinion is that they should be public. you know water is so fundamental to you know to life and communities that to put it in to control by a private entity. Just doesn't make sense to me. you have to in my opinion is a it's so vital to community into human health that there needs to be. Just strong public involvement and public oversight. Of those systems so so that their prioritize that you're not making choices. between you know subsidizing water for industry versus human health and you know, you're not going to get that with a private entity in my opinion.But that's that's not the way things are going, you know.

45:25 Sawyer Wofford: Yeah.

45:27 Expert 2: It's not I understand. That's not the way things have been going and the United States

45:33 Sawyer Wofford: It's mostly I think it's entirely public just because see what controls all the desalination plants so it's definitely easier for us to analyze but yeah.

45:46 Expert 2: Yeah, yeah, we encourage them to keep it that way.

A.3.3 Interview 3

02:39 Sophie Kurdziel: What do you think is the most critical parts of desalination that need regulation?

02:58 Expert 3: well, two things I'll just Certainly, there's a quote or although the quality of the water. That's provided is usually pretty darn good. I guess the things that would be of consideration include my perspective is the associated energy requirements associated with it is a major challenge depending on the locations where you're working. There's one consideration. There is and I guess I don't know if I'd say cost is really a requirement. But that's a consideration I imagine and then I guess the other thing I'd say is there's probably our considerations regarding both the withdrawal of water and and you know potentially the discharges as well. I'd say that there's environmental impacts related to that. You know, the things I can recall are that you know, there might be you know, if you are withdrawing water to you know, or was desalinization. I guess you're installing it from the ocean or whatever you are if you have salt water, so you have supplied it's still Mount that you'd be trying to use is one question. The other question is whether there's a discharge of say brine or something like that that might be related to that would be potentially have environmental impacts as well. and I'm trying to think of other things. I know that. They have some examples. I was trying to think of where I know there's only one desalination plant in Massachusetts. And there was an iqp that was done and related to that and it was a developed and as it is in I think I can't remember the name of the plant itself, but it actually probably had good background because in that case their concern was that they had Then they either they put in this very nice desalination. There were some concerns environmental concerns when they put this thing in because it was open but in a stream and in Massachusetts where they located this thing, but they ended up being a plant where they couldn't really there are a bunch of policy issues that result in Practical issues that just in the fact that they didn't have any people you actually use in that water. And so they out of regulatory things related to that. But those are the verminal issues I would imagine as well. You know, I imagine also that the nature of the water that's provided has to be reviewed as well. You know, I think and I'm not sure if there's considerations regarding the quality of the fact that it's just you're pretty much remove a lot of stuff from associated with your leftover pure water without the some of the other constituents of minerals and things remove with it as well. I believe. Sure, though.

05:48 Sophie Kurdziel: What do you think is the most vital Of all the ones you mentioned which one do you think like needs to be under regulation?

06:26 Expert 3: I was well impacts you to that have any discharges should be under regulation in part. It depends on where you is. And I guess I said energy is a requirement. One of these things is there and there's no consideration for the energy. Yeah, you could end up, you know Bringing Down the the energy grid and having a huge impact and I guess the other energy aspect is, you know, you're providing potable water for people in a community say, you know, you don't have a reliable Energy System unto me water and the thing gets shut down or you have a power outage and what what happens then you know, so there are pretty broad considerations regarding energy. So I'm not going to one or the other I'd say both of those considerations are significant, you know. Probably depends a little bit on the location where you put this facility what sources are available. The size of the population related to you know, who you're providing water for. And you know, I guess I'd probably would consider, you know, the water that you provide for people would be consideration as well. You know, it's usually for Desales pretty much I would think it's read Safe Water for the most part, you know. I would My Views is probably straight pure water. That's your briding. But it does you know, you still need to consider the quality of the water as is developed facility and distributed to the people in the waters system as well. So I would you know I guess if you provide in a detail facility, maybe there's not a concern regarding. You're looking at straight potable water output from the facility itself. But she with that what has been distributed to a population. So, you know, the question might be what is the Water by the time it gets? in equation

08:36 Robear Mankaryous: You sort of hinted at my question a little earlier but if you put regulations on like the sources of drinking water How do you value having drinking water versus protecting the environment? So if these regulations become too tight that these plans have to shut down for a while. And people don't have access to drinking water. I know in siwa. If a plant goes down, they only produce a few hours ahead of what they need. So obviously it doesn't take into consideration the amount of water they have stored. but they're like producing. As much as they're using basically. So, how do you feel about? the balance between regulations and the ability to have drinking water

09:30 Expert 3: I'm well. I guess if you have a population. Public health is usually what? drives the priority I think it's a more complex equation. if you think about the impacts on the environment and the you know long-term implications or The environment and public health as well. So you know, so there's a clearly a trade-off and I think that you know, you you know, usually if we're looking at from civil engineering perspective, usually the Providing public health and providing water is essential people are not going to be drinking safe drinking water as a result of that. That's a obviously a huge concern. So it's hard to put a balance on it. I'd say there's there's going to be some balance though, because I think if you just if you always we want people have safe drinking water obviously, but if it's always at the Judgment of the environment, you know, then you you still have a problem later on anyway, so so I certainly wouldn't say that people shouldn't have safe drinking water. You know, I went hand on the other hand. I think there's a trade-off in there to think about how that's provided. What what resources are provided to develop that otherwise a little bit of small worry about the brine discharge that's got to be considered in their analysis or assessment. It's good question is a tough balance and it depends probably on the circumstances of the location and the implications for you know Safe Drinking Water, you know, I think I'm in part there's Quality drinking water for people there's also a range of uses that may exist out there. So the size of the facility that you design is designed to meet, you know, requirements. Now, you could meet the required, you know Supply now, there'll be people on one hand you talk about Safe Drinking Water for people and that's right, you know, you have these visions that people will not have safe water. That's obviously a concern. There's also industrial uses of these Water Systems, you know, I mean, there's and so and there's broader uses when people use this water the question is, you know, is it used is it specifically for for drinking water for the health or the other uses for it, you know are people actually using this one. under their lots and turn into a completely dry climate into a climbing pets, you know, as a nice green grass and just like, you know, I I don't know the uses I would imagine that industrial uses would be quite important, you know quite often actually in our cases of In Massachusetts, there would be another aspect of safety as a fire safety. So we would design a water system to handle potable water use and included an additional allocation to provide enough product enough water enough of capacity and pressure to handle the cases. Where a fire May develop. Okay you may have and that would be through your water systems as well. Okay, and then you had the recognition that there's actually for your water supply. You may have a peak demand that you have to meet, you know, there might be variations in your water supply that you have to meet. So then the question is, you know well under do you meet those circumstances under all cases or their cases where you might have, you know limited, you know, the energy resources might be limited you have this decided facility. That's probably Limited in terms of the, you know, the capacity of the plant as well as the well and generally the capacitive plant and how it can handle flows under, you know, the supply needs under different circumstances. So when you design your plant and you look at the impact on the environment, are you designing this plan to meet the peak capacity or do you provide additional storage to complement that place? So and again without knowing that specific circumstances, whether you have a plant that's in you know, there's already a treatment plan you want to replace it with the desal facility, you know where you clearly need to you have the salt water or whatever in this applies that you're working on to determine, you know, so so there are a lot of factors involved in that. Of a long-windedness. I don't know if I answered the question but

13:56 Robear Mankaryous: Yeah, no, I think I did. We've also heard concerns over. How different cultures and stuff might value? either side differently and like not to impose our own values in this paper that kind of thing.

14:10 Expert 3: Yeah, it's actually interesting because I know the other example is Namibia window as a water supply, you know that and say do you're right, you know, they're there can be cases where well, I guess they think they have a d self facility. But they actually have reuse of water will it take the Wastewater? And that would be another question the nature of the water that their source is good point.

14:34 Robear Mankaryous: All right, Caitlin. Do you want to connect

14:39 Caitlin Kean: Yeah, so I decided a few questions. Do you like the difference between membrane and thermal in their energy uses? Because the UAE is looking to go from thermal to membrane for desalination.

14:55 Expert 3: You know, I have to admit I have not looked into the details that I don't think I can provide much. I'm sure there are others who can provide more on that for you. I have not looked into the details of those that distinction in the nature of the process itself while anyways so

15:13 Caitlin Kean: Another question on treating the water before going through desalination. And is it important to regulate what you're treating the water with what chemicals go in to make it? better for drinking water

15:28 Expert 3: Yeah, I would think so. I guess the question I kind of wonder about is that well, you know when you say to regulate the chemicals that go in you mean like the additions to complement the The water or you're trying to remove any pollutants related to it. Which are you referring to?

15:48 Caitlin Kean: the additions to complement the water

15:51 Expert 3: Okay. Yeah, I think my answer would be yes. I would think it'd be important to consider that because I think you know, if you look at a regular water supply versus a facility, I would imagine that the nature of the water is different and the actual to some extent the health value in the nutrients associated with that water might be different as well. And I think you should be that is something that I think should be considered. who shouldn't you know both know or have a Know what the water is. Of course, I guess the the you know, what you whatever you're putting stuff in something that has to be made available to the people as well. Yeah. What are you adding to the water? Just going back to actually your other question. So you're looking at so this membrane systems and thermal systems basically is just really it's a completely different approach for the regenerating the systems basically a different basis for the facility, right? And and see your question was just the relative comparison between those. You know, I I don't know the specific answers to that. I would think that there'd be difference in terms of the energy requirements for them. I'd be imagine there's difference in the costs. and and the nature of the water to some extent. I'm not sure if actually the water may not make any difference in terms of the nature of the water that you're getting out of there. But I would Envision that there'd be a pretty significant difference and there could be actually patients. If you're used in some kind of thermal approaches for this thing. Does that lead to a different type of discharge coming out of the system? I guess one of the questions I'd wonder about it involves. If you have a you have a brain that has every salt of associated with it, which you may be discharging but in addition to that if you have a temperature in which you have, you know hot water coming out which I think you do a lot of these facilities. Actually the temperature is a huge thing. Or these things and probably for maybe for the inflow too is but if you're discharging something that a high temperature that will have a huge impact on the environment too has been huge things concerns. I think that might have been one of the concerns they initially had related to was both the Brine and the temperature might have been in cases for this one in Massachusetts. I can't recall the Okay, so I kind of went back and forth and your questions.

18:21 Caitlin Kean: Thank you. Yeah, that makes sense because membrane actually releases the Brian a lower temperature than thermal by a couple degrees Celsius.

18:27 Expert 3: Yeah. okay, so it does I would think that maybe some different side imagine there'd be implications and I guess in all these cases there should be the regulations would be you know, well essential otherwise, there's not going to be a concern, you know to see the regulations are trying to think about the implications of these things. It's hard to incorporate. You know. Other than having regulations to protect the environment. It's hard to incorporate that assessment into assessing the, you know, impacts of the environmental impacts of these things isn't always easy to do. how do you put a value on some of the implications of a discharge of brine going in the environment? What are the other implications? Certainly for protecting the environment in general, you know something that we want to do. Is there a way to put that value in there as a whole field trying to think about how you try to incorporate that into your assessments.

19:33 Robear Mankaryous: We had a conversation with sewa last night. That's the Sharjah of Electricity Water Authority and something interesting that came up was they like to set their regulations based on a percent difference from the existing seawater? Whereas we've seen in other policies around the world, they set their limits like hard values. So let's say you have total dissolved solids and you want to limit it to like a hundred milligrams per liter other foreign policy. They'll say oh, okay. You can't have it go above a hundred milligrams per liter, whereas the regulations they currently have drafted. It'll say you can't have 5% above. The ambience or the existing seawater. Do you think one of those approaches is stronger than the other? Just because it seems like if you always say 5% then the ambience will just slowly rise over time. And so you're 5% will just slowly also rise. over time

20:38 Expert 3: I guess the two considerations it. I would say it depends but you have to come up with a plan in any location or any area that you'd have to think about in some ways either are cases and I can think of examples where they've In a completely different area would be wastewater treatment, you know, they they came up with ideas of saying, you know, depending on the environment to which you're discharging your Wastewater to you have to put that different levels of treatment and I think that's what we use a fair amount in this country. Like for instance in cases. Where a West where there's a that's A sudden drop, you know right near shore of the continental shelf. So you get more circulation in Flushing that have ideas for a case. They well, we don't need this Advanced treatment because it gets flushed out pretty quickly and that you know in some ways that's true, you know, you don't have as big of an impact in the environment. If you get this flushing, you know, whereas in the east coast, you know, you have you know shallower oceans than you discharge so you'd have bigger impacts. So you really had to do a better job treating it. So the other locations where you know, you'll you will Design or you will have requirements to that, you know may vary depending on the nature of your your discharge location in some ways that's reasonable. And you know, even in the percentage of this case, I guess the question is you're right either. There'll be some implications of this but if you had a different areas, you know, I could see that on the other hand the two things I'd probably note is one. You may make a point two, you know that in terms of you know, your you're looking at discharging you're here. Let's say, you know, well, you know, it depends on the area the volume you could change that over that usually doesn't kind of usually once it's designed you have and that's the end, you know, although they might have requirements out of it. You're kind of stuck with it after that. you know, but and and I guess they could do a review of it. They've usually is a big operation to try to manage a change in something as the percentage goes up here to make that. Change what I would say is though that that approach is is a challenging approach in a way in the case of fairness because there'll be some cases where there might be another location where they just don't have that, you know location handy, you know or where they had don't happen to have a location where they have, you know, a already a brine in place. That's you know, maybe it's already Yeah, maybe there's another one Upstream that led to the contaminated. contamination that that gives you a brine there that they can discharge into US. Oh, well, this is already bad. So we'll discharge here. We just kind of what you do in a way but in the other hand, you know, there's a level of fairness between different communities in the case of trying to make regulations. It's not it can be a challenge if you look at the level of fairness and then when you look at how some cases and I guess that would be the case in my areas like maybe like on a river, you know, there'll be stretches River where the water is really slow and where if you discharge your your Wastewater, it'll have a big impact in the water quality River and probably bring it down to the fish can't survive, you know. There were drugs that actually could drop real low. So what do you do? You know you the options are saying well, there might be another location where you know, gee it's not going to have a big impact. See you. You would have a your discharge would be okay, you know, so you can discharge at a more higher level or higher lower content quality level. So, you know to make that decision is not necessarily an easy one and probably kind of depends a little bit on the the number of you know, what anticipated in the future the number of the of facilities under different circumstances and in the just basically what the implications are for environmental implications of what kind of impacts that have so I don't have a specific answer on that a yes or no question answer to what you know, there's there's certainly trade-offs in terms of those different approaches. I can in some ways you can see where they're coming from but you know. In some ways it doesn't make sense to to you know, I guess well, another example would be an close solution Wastewater discharges for dissolved oxygen, you know and seawater as a different dissolved oxygen levels in Inland Waters. So, you know, you you can be trying to put a lot of effort into control the discharges and dissolve oxygen for seawater, but it turns out that it doesn't have that big of an implication because the seat water you know, it is as low as oxygen anyways, it's required for the fish and that circumstance so and there's been lots of debates and discussions about those types of things.

25:29 Sawyer Wofford: Great. Do you do you see any part of the process or any part of any policies that would directly affect like the efficiency. cost of operating desalination plants

25:50 Expert 3: Well, I would say definitely you put regulations on it. That it probably increases the costs in terms of trying to deal with say a brine discharge or something. You have to manage that there be very significant implications. If you're looking at the energy requirements for these things, I would imagine that you know, in terms of how you design it. You might have to to try to look at how you might be able to minimize use probably not only will limit how big of a facility that you can design but will limit the the nature of how you design the facility and some of the implications to try to think about how you might want to minimize energy use Is facility so you're certainly those regulations while then big include locations for this and I'm sure there'll be people who would be innovating people want to put it in the operators or you know, or people were paid for it would be the ones would be most concerned about such a thing, you know, these implications of costs. So in a way, you know, the regulations that you define certainly imply to impact the cost of these facilities, you know, the example I had for secondary wastewater treatment huge costs involved huge space requirements about this another thing that you have to and so so these all have a pretty broad implications in terms of their Your Design so so it can be a sensitive issue, you know, and unfortunately said say you look at the regulations in this country, you know, just think about the politics of what's going on here, you know, so they're a big implications for these regulations and there's lots of debate about them.

27:31 Sawyer Wofford: On that note. Is there anything that stands out as like? adding weight to the project that would like You know. Help help convince charger that they should use. policies

27:52 Expert 3: Um looking at a cost benefit analysis type approach or looking at the broader implications would be a value. Okay. So in terms of thinking about the benefits of these regulations such that there'll be beneficial impacts. Okay, so, you know from their perspective they probably view it as something where these regulations are just you know additional costs. You have to clean the stuff but you know on the other hand there's there's beneficial impacts of of the the regulations you put in whether it's there's a value and environmental health or trying to think about you know, when you put these regulations, is there a economic value that would be a beneficial aspect for them. Yeah think about the trade-offs and think of the broader implications that they might think about. If you look at you know, the implications more broadly in terms of both, you know the cost as well as the benefits the

28:53 Sawyer Wofford: Great. Well, we can probably let you go.

A.4 World Policy Research

A.4.1 Desalination Technology Policies

California, USA	"The most widely used method in California is reverse osmosis (RO), where dissolved constituents are removed by passing the water through a membrane under high pressure. In addition to the potable water, reverse osmosis produces a waste stream (concentrate)... and other dissolved constituents." "The greatest impacts in the field [experiments] have occurred around older multi-stage flash (MSF) plants discharging to water bodies with little flushing, a discharge scenario not relevant in California. Such sites show substantial increases in salinity and temperature, along with accumulation of metals, hydrocarbons, and anti-fouling compounds in receiving waters" (California Water Resources Control Board, 2012, p. 1)
Abu Dhabi	"The production systems used... are primarily tightly coupled co-generation systems with thermal-based multiple stage flash (MSF) or multi-effect distillation (MED) systems which produce water as a by-product of electricity generation. Whilst in many other parts of the world Reverse Osmosis (RO) is the technology of choice for desalination, in the [region] in particular, thermal desalination operations account for over 80% of the production. This is partly a result of the energy efficiencies gained in the linked co-generation, but also because of the proven robustness in the local extreme summer temperatures and humidity conditions as well as extremely high salinity of the seawater which challenge any technology" (United Arab Emirates, 2010, p. 7).

A.4.2 Energy Guideline Policies

Egypt	"Due to major recent discoveries, natural gas is likely to be the primary growth engine for Egypt's energy sector for the foreseeable future. Natural gas production was about 93 million m^3 per day in 2003 and is expected to rise to 140 million m^3 per day in 2007, with much of the increased volume being exported as liquefied natural gas (LNG)" (Arab Republic of Egypt Ministry of Water Resources and Irrigation, 2005, p. 2-28)
UAE	"Evaluation of alternative energies, including solar and wind, suggested that, while these options could be deployed in the UAE, even aggressive development could only supply 6-7% of peak electricity demand by 2020. Stacked against the above options, nuclear-powered generation emerged as a proven, environmentally promising and commercially competitive option which could make a significant base-load contribution to UAE's economy and energy security" (United Arab Emirates, 2010, p. 20).
WHO	"Desalination plants require significant amounts of electricity and heat depending upon the process, temperature and source water quality. For example, it has been estimated that one plant producing about seven million gallons (about 26,500 m3) per day could require about 50 million kWh/yr., which would be similar to the energy demands of an oil refinery or a small steel mill. For this reason, cogeneration facilities provide significant opportunities for efficiency. There is an obvious synergy between desalination and energy plants. Energy production plants require large water intakes for cooling purposes, they produce substantial amounts of waste heat that is usable in the desalination facility, and the spent water disposal system may also be shared" (World Health Organization, 2007, p. 14).
Singapore	"Power Generation is one of the major sources of carbon emissions for any country. With limited alternative energy resources, Singapore relies on imported fuel to power our daily activities. Many of our early policy decisions have helped to reduce emissions from our energy sector. The following are some examples: • Singapore chose not to use coal for electricity generation in our early years of economic development despite its availability and lower price. • Unlike many other countries, Singapore has avoided subsidising energy use. By pricing energy at rates that reflect its market cost, we encourage households and businesses to use energy prudently. • Singapore has switched from fuel oil to natural gas as our main energy source for electricity generation. Natural gas produces the least carbon emissions per unit of electricity generated amongst fossil fuel-fired power plants. By increasing the share of natural gas used in electricity generation, from only 19% in 2000 to about 80% today, we have substantially reduced our emissions growth. Compared with other countries, where coal is still a key component of their fuel mix, Singapore is relatively less carbon intensive" (Republic of Singapore, 2012, p. 34).

A.4.3 Mixing Zone Limit Policies

<table>
<tr>
<td>California, USA</td>
<td>

Suspended Solids	Remove 75% discharge in ocean
Mixing zone radius from outfall	200 m
Temperature	N/A
Dissolved Oxygen	N/A
pH	6.0 to 9.0
Total Dissolved Solids (TDS)	N/A
Turbitiy	75 NTU
Oil and Grease	1.0 mL/l

(California Environmental Protection Agency, 2015, p. 12)

</td>
</tr>
<tr>
<td>Sharjah, UAE</td>
<td>

Suspended Solids	≤ 50 mg/l
Mixing zone radius from outfall	500 m
Temperature	5 °C
Dissolved Oxygen	5 mg/l or 90% saturation
pH	0.2 pH unit change
Total Dissolved Solids (TDS)	≤5% above ambient conditions
Turbitiy	75 NTU or 20% reduction
Oil and Grease	≤10 mg/l

</td>
</tr>
</table>

A.4.4 Potable Quality Policies

<table>
<tr>
<td>Sharjah,
UAE</td>
<td>(Sharjah Electricity and Water Authority, 2015, p. 70)
<table>
<tr><td>pH</td><td>7.0 - 9.2</td></tr>
<tr><td>Residual Chlorine [mg/L]</td><td>0.2 - 0.5</td></tr>
<tr><td>Total Dissolved Solids [mg/L]</td><td>100-1000</td></tr>
<tr><td>Calcium Hardness [mg/L]</td><td>200</td></tr>
<tr><td>Total Alkalinity [mg/L]</td><td>N/A</td></tr>
<tr><td>Uranium [µg/L]</td><td>N/A</td></tr>
</table>
</td>
</tr>
<tr>
<td>Saudia
Arabia</td>
<td>(Electricity & Cogeneration Regulation Authority, 2011, p. 69)
<table>
<tr><th>Parameter</th><th>Symbol</th><th>Unit</th><th>Allowed Range*</th></tr>
<tr><td>Temperature</td><td>T</td><td>˚C</td><td>20 ~ 40</td></tr>
<tr><td>pH</td><td>-</td><td>-</td><td>8.1 ~ 8.6</td></tr>
<tr><td>Calcium Hardness</td><td>CaH</td><td>mg/L as CaCO3</td><td>40 ~ 50</td></tr>
<tr><td>Total Alkalinity</td><td>TA</td><td>mg/L as CaCO3</td><td>40 ~ 50</td></tr>
<tr><td>Sulfate</td><td>SO4</td><td>mg/L</td><td>Max. 2</td></tr>
<tr><td>Iron</td><td>Fe</td><td>mg/L</td><td>Max. 0.05</td></tr>
<tr><td>Copper</td><td>Cu</td><td>mg/L</td><td>Max. 0.05</td></tr>
<tr><td>Residual Chlorine</td><td>RCl</td><td>mg/L</td><td>0.2 ~ 0.5</td></tr>
<tr><td>Turbidity</td><td>-</td><td>NTU</td><td>Max. 1</td></tr>
<tr><td>Total Dissolved Solids</td><td>TDS</td><td>mg/L</td><td>Max. 130</td></tr>
<tr><td>Langelier Saturation Index</td><td>LSI</td><td>-</td><td>0.1 ~ 0.3</td></tr>
</table>
</td>
</tr>
<tr>
<td>Singapore</td>
<td>(Singapore Public Utilities Board, 2019, pp. 1-4)
<table>
<tr><td>pH</td><td>6.5-9.5</td></tr>
<tr><td>Residual Chlorine [mg/L]</td><td>0.194 - 0.284</td></tr>
<tr><td>Total Dissolved Solids [mg/L]</td><td>N/A</td></tr>
<tr><td>Calcium Hardness [mg/L]</td><td>27 - 150</td></tr>
<tr><td>Total Alkalinity [mg/L]</td><td>Aug-46</td></tr>
<tr><td>Uranium [µg/L]</td><td>0.001 - 0.014</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr><td>Kuwait</td><td>(2017, pp. 29-30)
<table>
<tr><td>pH</td><td>6.5 - 8.5</td></tr>
<tr><td>Residual Chlorine [mg/L]</td><td>N/A</td></tr>
<tr><td>Total Dissolved Solids [mg/L]</td><td>max: 1000</td></tr>
<tr><td>Calcium Hardness [mg/L]</td><td>500</td></tr>
<tr><td>Total Alkalinity [mg/L]</td><td>100</td></tr>
<tr><td>Uranium [µg/L]</td><td>N/A</td></tr>
</table></td></tr>
<tr><td>Egypt</td><td>"Poor quality of drinking water is a concern in many parts of Egypt. This is due, in part, to the fact that sources of raw water for many areas have become increasingly polluted, and therefore require more sophisticated treatment to produce drinking water of adequate quality. Furthermore, water treatment units are not always functioning properly as a result of lacking maintenance and proper operation. Even when water treatment is satisfactory, drinking water is sometimes contaminated in leaking distribution networks, which are infiltrated for example by sewage. Rooftop water storage tanks have also been identified as another source of bacterial contamination of drinking water.

Drinking water requirements for major urban towns and rural villages have been estimated to be 4.6 BCM in 99/2000 where approximately 97% of urban population and 70% or rural population of Egypt relies on piped water supply. The major cities in Egypt (217 city) enjoy full potable water coverage (100%). Sanitation services, however, lag behind water supply, where approximately 52% of urban population is covered by collection and treatment sanitation systems while about 11% of rural population in villages is connected to the sewerage system. Municipal water is diverted from two sources: surface water which supplies about 83% of total municipal demand and groundwater, which supplies about 17% of total demands. The total municipal demand (drinking water) is calculated to increase by a factor of 1.4 between 2000 and 2017. The total industrial water utilization is expected to increase by a factor of 2.0 throughout the former period" (Egyptian Environmental Affairs Agency, 2001, p. 58).</td></tr>
</table>

A.4.5 Process Management & Sampling Policies

<table>
<tr>
<td>California, USA</td>
<td>“The owner or operator of a desalination facility must submit a monitoring and reporting plan to the regional water board for approval. The monitoring and reporting plan shall include monitoring of effluent and receiving water characteristics and impacts to all forms of marine life. The Monitoring and Reporting Plan shall, at a minimum, include monitoring for benthic community health, aquatic life toxicity, hypoxia, and receiving water characteristics consistent with Appendix III of this Plan and for compliance with the receiving water limitation in chapter III.M.3. Receiving water monitoring for salinity* shall be conducted at times when the monitoring locations are most likely affected by the discharge” (California Environmental Protection Agency, 2015, p. 50)</td>
</tr>
<tr>
<td>Illinois, USA</td>
<td>
<table>
<tr><th>Parameters</th><th>Time of year</th><th>Daily Max Load Limits lbs/day DAF (DMF)</th><th>Daily Max Concentration Limits (mg/L)</th><th>Sample Frequency</th></tr>
<tr><td>Flow</td><td>All Year</td><td>-</td><td>-</td><td>Continuous</td></tr>
<tr><td>CBOD$_5$</td><td>All Year</td><td>-</td><td>-</td><td>1 Day/Week</td></tr>
<tr><td>Suspended Soilds</td><td>All Year</td><td>-</td><td>-</td><td>1 Day/Week</td></tr>
<tr><td>pH</td><td>All Year</td><td>6 - 9</td><td>-</td><td>1 Day/Week</td></tr>
<tr><td>Fecal Coliform</td><td>May-Oct.</td><td colspan="2"><400 per 100 mL</td><td>3 Days/Week</td></tr>
<tr><td>Chlorine Residual</td><td>All Year</td><td>-</td><td>0.05</td><td></td></tr>
<tr><td rowspan="4">Ammonia Nitrogen</td><td>April-May/Sept.-Oct.</td><td>40 (106)</td><td>2.2</td><td>3 Days/Week</td></tr>
<tr><td>June-August</td><td>39 (102)</td><td>2.1</td><td>3 Days/Week</td></tr>
<tr><td>Nov.-Feb.</td><td>88 (232)</td><td>4.8</td><td>3 Days/Week</td></tr>
<tr><td>March</td><td>68 (179)</td><td>3.7</td><td>3 Days/Week</td></tr>
<tr><td>Total Phosphorus</td><td>All year</td><td>-</td><td>-</td><td>3 Days/Week</td></tr>
<tr><td>Total Nitrogen</td><td>All Year</td><td>-</td><td>-</td><td>1 Day/Month</td></tr>
<tr><td></td><td></td><td></td><td>Daily Minimum</td><td></td></tr>
<tr><td rowspan="2">Dissolved Oxygen</td><td>March - July</td><td>-</td><td>5</td><td>3 Days/Week</td></tr>
<tr><td>August - Feb.</td><td>-</td><td>3.5</td><td>3 Days/Week</td></tr>
</table>
(Illinois Environmental Protection Agency, 2016, p. 2)
</td>
</tr>
<tr>
<td>Sharjah, UAE</td>
<td>
<table>
<tr><th>Parameter</th><th>Units</th><th>Limits</th><th>Sample Frequency</th></tr>
<tr><td>Total Suspended Solids</td><td>mg/L</td><td>≤50</td><td>1 Day/Month</td></tr>
<tr><td>Total Dissolved Solids</td><td>%</td><td>≤ 5% above ambient conditions</td><td>1 Day/Month</td></tr>
<tr><td>pH</td><td>pH unit</td><td>6 - 9 (and not more than 1 pH unit above ambient)</td><td>1 Day/Month</td></tr>
<tr><td>Chlorine residual</td><td>mg/L</td><td>≤ 0.15</td><td>1 Day/Month</td></tr>
<tr><td>Ammonia Nitrogen</td><td>mg/L</td><td>≤ 2.0</td><td>1 Day/Month</td></tr>
<tr><td>Total Phosphorous</td><td>mg/L</td><td>≤ 0.05</td><td>1 Day/Month</td></tr>
<tr><td>Dissolved Oxygen</td><td>mg/L</td><td>Not less than 5 mg/L or 90% saturation</td><td>1 Day/Month</td></tr>
</table>
(United Arab Emirates Ministry of Environment & Water, 2015, pp. 5-8)
</td>
</tr>
</table>

A.4.6 Ship Movement Policies

Singapore	**"in relation to the regulation of activities in and around reservoirs and waterways maintained by the Board** (i) the manner in which reservoirs and waterways may be used, and the designating of areas and granting of permits for such uses; (ii) the types of vessels which may be operated in the reservoirs and waterways, the permits required for such operation, the terms and conditions upon which, and the circumstances in which, those permits may be granted, held, suspended, cancelled, altered, extended, renewed or replaced, and the fees payable in respect thereof; (iia) the requirements relating to the use, stowage, storage, conveyance, loading or unloading of dangerous cargoes on such vessels, including the requirement to obtain the Board's approval and the fees payable for such approval; [Act 11 of 2018 wef 01/04/2018] (iii) the equipment to be carried on such vessels and the insurance and safety requirements for such vessels; (iv) the qualifications for operators of such vessels" (The Statues of the Republic of Singapore, 2020, p. 118).
Egypt	"Ship owners, ship captains, or any other persons in charge of ships and those responsible for oil transport consignments within ports, territorial waters, or the exclusive economic zone of the Arab Republic of Egypt, and the companies operating in oil extraction, shall immediately notify the competent administrative bodies of every oil leakage incident upon its occurrence. Together with the notification they shall indicate the place of the accident, circumstances of the incident, type of leaking materials, quantities, and the procedures taken to stop or limit such leakage, with the provision that the notification shall include the following data: 1. Procedures taken for dealing with the leakage 2. Quantities and types of dispersants used 3. Probable source of leakage, and whether or not a fire has broken out 4. Direction in which the formed oil spill is moving 5. Rate of leakage, if ongoing 6. Dimensions of the oil spill 7. Wind velocity and speed, temperature, and extent of visibility 8. Direction of current speed, and water temperature 9. Condition of the sea 10. Tide status (overflowing, high, medium, weak) 11. Threatened coastal areas 34 12. Nature of the area: coral reefs - marine organisms 13. Reporting source:- name - telephone - address All shipping ports and ports ready to receive oil tankers, and shipping docks shall be provided with the necessary equipment to adequately receive unclean ballast water and residue wastewater from washing the tanks of oil tankers and other ships. Ports shall be provided with lighters and containers necessary to adequately receive waste and oil residues as well as oil mixtures from ships docking in the harbor. The competent administrative body shall receive any ship or tanker and direct it to disposal locations where it can dispose of its waste and unclean ballast water. No ship or tanker shall be authorized to carry out loading and unloading operations except after referring to the competent administrative body to receive and direct it to locations for the disposal of waste and unclean ballast water" (Egypt Environmental Affairs Agency, 1995, pp. 33-34)
WHO	"Source selection and source protection are the best ways to avoid contamination of finished water by certain organics, surface runoff, ship discharges, and chemical and sanitary waste outfalls near the intake to the desalination plant. When contamination occurs, pretreatments may be necessary and these can involve enhanced disinfection, an adsorption process using granular activated carbon or more frequently powdered activated carbon for intermittent contamination. Of course, contaminants in blending waters will be transported to the finished water thus appropriate pretreatment of blending water may also be required" (World Health Organization, 2007, p. 12).

A.4.7 Source Water Policies

WHO

Component	Control Meaures	Operational Parameters	Montioring Frequency	
			Large Plant	Small Plant
Source Water	Detect and prevent contamination by sewage	Enterocci and/or *E.coli*	D or W	W
	Detect and prevent impacts of storm events	Turbidity (used as on-line measurement for process control)	Preferably on-line	Preferably on-line
	Detect and prevent impacts of microalgae/cyanobacteria	Algal species, including cyanobacteria, dinoflagellates, or chlorophyll as a surrogate	W or M	M
	Detect and prevent impacts by industrial discharges	TOC (if concentrations change investigate sources)	W	M
		Petroleum oil hydrocarbons/grease including volatile compounds	W	Y
		Industrial chemcials	W	M
		Radioactivity	Y	Y
	Monitoring associated with downstream control measures	Salinity	D	D
		Chloride	D	D
		Sodium	W	W
		Boron	M	Y
		Bromide	M	Y
		Silica	D	D
		Iron	D	W
		Manganese	M	Y
		Turbidity	On-line	On-line
		Alkalinity	D	D
		pH	On-line	On-line
		Temperature	On-line	On-line
		Heavy metals	W	M
		Low solubility chemicals	W	M
		Hydrogen sulphide & metal sulphides	W	M
		Ammonia	W	M
		Total dissolved soilds	D	D

(World Health Organization, 2007, pp. 129-133)

A.5 Surveys

A.5.1 Desalination Process Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to compare thematically relevant sections of policies and guidelines. Thank you for your participation!

Estimated survey time: ~15 minutes.

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Process management 1

Please review the information below and respond to the questions that follow.

Listed below is one process management guideline from a country/region of the world.

Process Management Guideline 1

"The owner or operator of a desalination facility must submit a monitoring and reporting plan to the regional water board for approval. The monitoring and reporting plan shall include monitoring of effluent and receiving water characteristics and impacts to all forms of marine life. The Monitoring and Reporting Plan shall, at a minimum, include monitoring for benthic community health, aquatic life toxicity, hypoxia, and receiving water characteristics consistent with Appendix III of this Plan and for compliance with the receiving water limitation in chapter III.M.3. Receiving water monitoring for salinity* shall be conducted at times when the monitoring locations are most likely affected by the discharge."

What is the **economic cost** associated with Guideline 1?

Large net loss

Net loss

Net zero

Net gain

Large net gain

Why?

How can the economic cost be improved or mitigated?

What is the **environmental impact** associated with Guideline 1

Large negative impact
Negative impact
Neutral impact
Positive impact
Large positive impact

Why?

How can the economic impact be improved or mitigated?

Large net loss
Net loss
Net zero
Net gain
Large net gain

Why?

How can the economic cost be improved or mitigated?

What is the **environmental impact** associated with Guideline 2?

Large negative impact
Negative impact

Process Management 2

Please review the information below and respond to the questions that follow.

Listed below is another process management guideline from a different country/region of the world.

Process Management Guideline 2

"In order for the Desalinated Water Transmission System Operator (DWTSO) to prepare the one year operational plan and the three year operational each User shall provide the forecast data and maintenance scheduling information as follows: (a) each Water Distribution System Operator (WDSO) shall provide to the DWTSO its Transmitted Water demand forecast data; (b) each Water Producer shall provide to the DWTSO its Desalinated Water or Water, as the case may, production forecast data; and (c) each Water Producer and each WDSO shall provide to the DWTSO its maintenance schedule in relation to its Facility."

What is the **economic costs** associated with Guideline 2?

Neutral impact
Positive impact
Large positive impact

Why?

How can the economic impact be improved or mitigated?

Process Management (1 = Cali, 2 = Saudi Arabia)

Please review the information below and respond to the questions that follow.

The previously presented energy guidelines are presented again below, for convenience.

Process Management Guideline 1

"The owner or operator of a desalination facility must submit a monitoring and reporting plan to the regional water board for approval. The monitoring and reporting plan shall include monitoring of effluent and receiving water characteristics and impacts to all forms of marine life. The Monitoring and Reporting Plan shall, at a minimum, include monitoring for benthic community health, aquatic life toxicity, hypoxia, and receiving water characteristics consistent with Appendix III of this Plan and for compliance with the receiving water limitation in chapter III.M.3. Receiving water monitoring for salinity* shall be conducted at times when the monitoring locations are most likely affected by the discharge."

Process Management Guideline 2

"In order for the Desalinated Water Transmission System Operator (DWTSO) to prepare the one year operational plan and the three year operational each User shall provide the forecast data and maintenance scheduling information as follows: (a) each Water Distribution System Operator (WDSO) shall provide to the DWTSO its Transmitted Water demand forecast data; (b) each Water Producer shall provide to the DWTSO its Desalinated Water or Water, as the case may, production forecast data; and (c) each Water Producer and each WDSO shall provide to the DWTSO its maintenance schedule in relation to its Facility."

What are the pros and cons with having more specific guidelines?

What other factors do you think should be considered for creating regulations of process management?

Please provide additional suggestions for creating and implementing process management guidelines.

Sampling (1 = Illinois)

Please review the information below and respond to the questions that follow.

The following section of the survey deals with different sampling guidelines from around the world.

Below is one sampling guideline from a country/region of the world.

Parameters	Time of year	Daily Max Load Limits lbs/day DAF (DMF)	Daily Max Concentration Limits (mg/L)	Sample Frequency
Flow	All Year	-	-	Continuous
$CBOD_5$	All Year	-	-	1 Day/Week
Suspended Soilds	All Year	-	-	1 Day/Week
pH	All Year	6 - 9	-	1 Day/Week
Fecal Coliform	May-Oct.	<400 per 100 mL		3 Days/Week
Chlorine Residual	All Year	-	0.05	
Ammonia Nitrogen	April-May/Sept.-Oct.	40 (106)	2.2	3 Days/Week
	June-August	39 (102)	2.1	3 Days/Week
	Nov.-Feb.	88 (232)	4.8	3 Days/Week
	March	68 (179)	3.7	3 Days/Week
Total Phosphorus	All year	-	-	3 Days/Week
Total Nitrogen	All Year	-	-	1 Day/Month
			Daily Minimum	
Dissolved Oxygen	March - July	-	5	3 Days/Week
	August - Feb.	-	3.5	3 Days/Week

In your opinion, how strict is this sampling guideline?

- Too lenient
- Lenient
- Neutral
- Strict
- Too Strict

Please explain your answer.

How would you rank this guideline on its rate of sampling?

- Not enough sampling
- Correct amount of sampling
- Too much sampling

Please explain your answer.

Sampling (2 = Sharjah)

Please review the information below and respond to the questions that follow.

The following section of the survey deals with different sampling guidelines from around the world.

Below is a different sampling guideline from a country/region of the world.

Parameter	Units	Limits	Sample Frequency
Total Suspended Solids	mg/L	≤50	1 Day/Month
Total Dissolved Solids	%	≤ 5% above ambient conditions	1 Day/Month
pH	pH unit	6 - 9 (and not more than 1 pH unit above ambient)	1 Day/Month
Chlorine residual	mg/L	≤ 0.15	1 Day/Month
Ammonia Nitrogen	mg/L	≤ 2.0	1 Day/Month
Total Phosphorous	mg/L	≤ 0.05	1 Day/Month
Dissolved Oxygen	mg/L	Not less than 5 mg/L or 90% saturation	1 Day/Month

In your opinion, how strict is this sampling guideline?

Too lenient
Lenient
Neutral
Strict
Too Strict

Please explain your answer.

How would you rank this guideline on its rate of sampling?

Not enough sampling
Correct amount of sampling
Too much sampling

Please explain your answer.

Please provide additional suggestions on sampling regulations for desalination plants.

Block 7

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

Powered by Qualtrics

A.5.2 Desalination Technologies Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to compare thematically relevant sections of policies and guidelines. Thank you for your participation!

Estimated survey time: ~15 minutes.

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Desalination Technology Guideline 1 (California)

Please read through the guideline below and respond to the questions that follow.

Desalination plants have two popular choices when it comes to desalination technologies: thermal based plants and membrane based plants. Presented below is a desalination technology guideline from a country/region of the world.

Desalination Guideline 1

"The most widely used method [in the region] is **reverse osmosis (RO)**, where dissolved constituents are removed by passing the water through a membrane under high pressure. In addition to the potable water, reverse osmosis produces a waste stream (concentrate)... and other dissolved constituents."

"The greatest impacts in the field [experiments] have occurred around older multi-stage flash (MSF) plants discharging to water bodies with little flushing, a discharge scenario not relevant in [the region]. Such sites show substantial increases in salinity and temperature, along with accumulation of metals, hydrocarbons, and anti-fouling compounds in receiving waters."

The energy guideline above promotes reverse osmosis as a main supplier to the region's potable water needs. What is the **environmental impact** associated with reverse osmosis?

- Large Negative Impact
- Negative Impact
- Neutral Impact
- Positive Impact
- Large Positive Impact

You have indicated that reverse osmosis has a positive impact on the environment. Why?

You have indicated that reverse osmosis has a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?

Desalination technologies are often categorized by economic costs, alongside environmental impact. What is the **economic cost** associated with reverse osmosis?

Large Net Loss
Net Loss
Net Zero
Net Gain
Large Net Gain

You have indicated that reverse osmosis has a net gain with regards to economic cost. Why?

You have indicated that reverse osmosis has a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?

Please provide additional comments on **Desalination Guideline 1** below.

Desalination Technology Guideline 2 (Abu Dhabi)

Please read through the guideline below and respond to the questions that follow.

Various regions of the world have relied on thermal based desalination plants, as opposed to membrane based ones. Presented below is a second desalination technology guideline from a different country/region of the world.

Desalination Technology Guideline 2

"The production systems used... are primarily tightly coupled co-generation systems with **thermal-based** multiple stage flash (MSF) or multi-effect distillation (MED) **systems** which produce water as a by-product of electricity generation. Whilst in many other parts of the world Reverse Osmosis (RO) is the technology of choice for desalination, in the [region] in particular, thermal desalination operations account for over 80% of the production. This is partly a result of the energy efficiencies gained in the linked co-generation, but also because of the proven robustness in the local extreme summer temperatures and humidity conditions as well as extremely high salinity of the seawater which challenge any technology."

The energy guideline above promotes thermal-based systems as a main supplier to the region's potable water needs. What is the **environmental impact** associated with thermal-based systems?

Large Negative Impact
Negative Impact
Neutral Impact
Positive Impact

Large Positive Impact

You have indicated that thermal-based systems have a positive impact on the environment. Why?

You have indicated that thermal-based systems have a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?

Desalination technologies are often categorized by economic costs, alongside environmental impact. What is the **economic cost** associated with thermal-based systems?

Large Net Loss
Net Loss

Net Zero
Net Gain
Large Net Gain

You have indicated that thermal-based systems have a net gain with regards to economic cost. Why?

You have indicated that thermal-based systems have a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?

Please provide additional comments on **Desalination Guideline 2** below.

Desalination Technologies (1 = California, 2 = Abu Dhabi)

The previously presented energy guidelines are presented again below, for convenience. Please respond to the questions that follow.

Desalination Technology Guideline 1

"The most widely used method [in the region] is **reverse osmosis (RO)**, where dissolved constituents are removed by passing the water through a membrane under high pressure. In addition to the potable water, reverse osmosis produces a waste stream (concentrate) that contains elevated concentrations of salts (typically double in the case of seawater) and other dissolved constituents."

"The greatest impacts in the field [experiments] have occurred around older multi-stage flash (MSF) plants discharging to water bodies with little flushing, a discharge scenario not relevant in [the region]. Such sites show substantial increases in salinity and temperature, along with accumulation of metals, hydrocarbons, and anti-fouling compounds in receiving waters."

Desalination Technology Guideline 2

"The production systems used... are primarily tightly coupled co-generation systems with thermal-based **multiple stage flash (MSF)** or **multi-effect distillation (MED)** systems which produce water as a by-product of electricity generation. Whilst in many other parts of the world Reverse Osmosis (RO) is the technology of choice for desalination, in the [region] in particular, thermal desalination operations account for over 80% of the production. This is partly a result of the energy efficiencies gained in the linked co-generation, but also because of the proven robustness in the local extreme summer temperatures and humidity conditions as well as extremely high salinity of the seawater which challenge any technology."

In your opinion, which guideline would present a **greater economic cost**?

Desalination Technology Guideline 1 (reverse osmosis) presents a **greater economic cost**.

Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a **greater economic cost**.

In your opinion, which guideline would present a **larger negative environmental impact**?

Desalination Technology Guideline 1 (reverse osmosis) presents a **larger negative environmental impact**.

Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a **larger negative environmental impact**.

Arid regions in the Arabian Gulf have pointed to the robustness of thermal based processes in "extreme summer temperatures". What factors should these regions consider when exploring alternative desalination technologies?

Please provide additional comments on the comparison between **Desalination Guideline 1** and **Desalination Guideline 2** below.

Final Submit

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

Powered by Qualtrics

A.5.3 Discharge Limits Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to compare thematically relevant sections of policies and guidelines. Thank you for your participation!

Estimated survey time: ~15 minutes

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Discharge Limits (Sharjah)

Please review the information below and respond to the questions that follow.

We are looking to create suggestions for brine discharge limits. Some of these limits include salinity units (PSU), total dissolved solids (TDS), suspended solids, and pH. Listed below is discharge parameters for guideline 1

	Guideline 1
Suspended Solids	≤ 50 mg/l
Mixing zone radius from outfall	500 m
Temperature	5 °C
Dissolved Oxygen	5 mg/l or 90% saturation
pH	0.2 pH unit change
Total Dissolved Solids (TDS)	≤5% above ambient conditions
Turbitiy	75 NTU or 20% reduction
Oil and Grease	≤10 mg/l

What is the **economic costs** associated with guideline 1?

Large net loss

Net loss

Net zero

Net gain

Large net gain

Why?

How can the economic impact be improved or mitigated?

What is the **environmental impact** associated with guideline 1?

Large negative impact
Negative impact
Neutral impact
Positive impact
Large positive impact

Why?

How can the economic cost be improved or mitigated?

Discharge Limits (California)

Please review the information below and respond to the quesitons that follow.

Below is a table of brine discharge parameters for guideline 2

	Guideline 2
Suspended Solids	Remove 75% discharge in ocean
Mixing zone radius from outfall	200 m
Temperature	N/A
Dissolved Oxygen	N/A
pH	6.0 to 9.0
Total Dissolved Solids (TDS)	N/A
Turbitiy	75 NTU
Oil and Grease	1.0 mL/l

What is the **economic costs** associated with guideline 2?

Large net loss
Net loss
Net zero
Net gain
Large net gain

Why?

How can the economic cost be improved or mitigated for guideline 2?

What is the **environmental impact** associated with guideline 1?

Large negative impact
Negative impact
Neutral impact
Positive impact
Large positive impact

Why?

How can the economic impact be improved or mitigated?

Comparing

Please review the information below and respond to the quesitons that follow.

Below is the combined table for brine discharge limits

	Guideline 1	Guideline 2
Suspended Solids	≤ 50 mg/l	Remove 75% discharge in ocean
Mixing zone radius from outfall	500 m	200 m
Temperature	5 °C	N/A
Dissolved Oxygen	5 mg/l or 90% saturation	N/A
pH	0.2 pH unit change	6.0 to 9.0
Total Dissolved Solids (TDS)	≤5% above ambient conditions	N/A
Turbitiy	75 NTU or 20% reduction	75 NTU
Oil and Grease	≤10 mg/l	1.0 mL/l

In your opinion, which guideline would present a **greater economic cost**?

Guideline 1 presents a **greater economic cost**.
Guideline 2 presents a **greater economic cost**.

In your opinion, which guideline would present a **larger negative environmental impact**?

Guideline 1 presents a **larger negative environmental impact**.
Guideline 2 presents a **larger negative environmental impact**.

Are there any other factors to consider when selecting discharge parameters?

Please provide additional comments below about discharge limits.

Additional Questions

Please respond to the following questions to the best of your ability.

	Guideline 1	Guideline 2
Suspended Solids	≤ 50 mg/l	Remove 75% discharge in ocean

Should parameters be set as numbers or percent differences from ambient water (referencing the table above)?

percentages
numbers

Why?

Should policies set distances for how close brine can be discharged from desalination facilities?

Yes
No

At what distance should they be set?

Why?

Does increasing the radius of the mixing zone allow for fewer restrictions?

Yes
No

Why?

How often should data be collected about marine life living near brine deposits?

- Daily
- Weekly
- Monthly
- Yearly
- Every 2 years
- Other

How often?

Why?

Please provide additional comments on brine discharge.

Block 6

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

Powered by Qualtrics

A.5.4 Energy Guidelines Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to compare thematically relevant sections of policies and guidelines. Thank you for your participation!

Estimated survey time: ~15 minutes.

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Energy Production Guideline 1 (UAE)

Please read through the guideline below and respond to the questions that follow.

The process of desalination requires large amounts of energy to ensure adequate freshwater production. An energy production guideline from a country/region of the world is presented below.

Energy Guideline 1

"Evaluation of alternative energies, including solar and wind, suggested that, while these options could be deployed in the [region], even aggressive development could only supply 6-7% of peak electricity demand by 2020. Stacked against the above options, **nuclear-powered generation** emerged at a proven, environmentally promising and commercially competitive option which could make a significant base-load contribution to [the region]'s economy and energy security."

The energy guideline above promotes nuclear-powered generation as a main supplier to the region's energy needs. What is the **environmental impact** associated with nuclear-powered generation?

Large Negative Impact

Negative Impact

Neutral Impact

Positive Impact

Large Positive Impact

You have indicated that nuclear-powered generation has a positive impact on the environment. Why?

You have indicated that nuclear-powered generation has a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?

Energy generation sources are often categorized by economic costs, alongside environmental impact. What is the **economic cost** associated with nuclear-powered generation?

Large Net Loss
Net Loss
Net Zero
Net Gain
Large Net Gain

You have indicated that nuclear-powered generation has a net gain with regards to economic cost. Why?

You have indicated that nuclear-powered generation has a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?

Please provide additional comments on **Energy Guideline 1** below.

Energy Production Guideline 2 (Egypt)

Please read through the guideline below and respond to the questions that follow.

A second energy production guideline from a different country/region of the world is presented below.

Energy Guideline 2

"Due to major recent discoveries, **natural gas** is likely to be the primary growth engine for [the region]'s energy sector for the foreseeable future. Natural gas production was about 93 million m³ per day in 2003 and is expected to rise to 140 million m³ per day in 2007..."

"Currently, the petroleum sector [in the region] is promoting and encouraging more applications using **natural gas** in local market for substituting of oil and freeing it for export purposes. The largest applications are the usage of natural gas for electricity generation followed by other applications for industrial processes."

The energy guideline above promotes natural gas as a main supplier to the region's energy needs. What is the **environmental impact** associated with natural gas?

Large Negative Impact
Negative Impact
Neutral Impact
Positive Impact
Large Positive Impact

You have indicated that natural gas has a positive impact on the environment. Why?

You have indicated that natural gas has a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?

Energy generation sources are often categorized by economic costs, alongside environmental impact. What is the **economic cost** associated with natural gas?

Large Net Loss
Net Loss
Net Zero
Net Gain
Large Net Gain

You have indicated that natural gas has a net gain with regards to economic cost. Why?

You have indicated that natural gas has a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?

Please provide additional comments on **Energy Guideline 2** below.

Compare Energy Production Guidelines (1 = UAE, 2 = Egypt)

The previously presented energy guidelines are presented again below, for convenience. Please respond to the questions that follow.

Energy Guideline 1

"Evaluation of alternative energies, including solar and wind, suggested that, while these options could be deployed in the [region], even aggressive development could only supply 6-7% of peak electricity demand by 2020. Stacked against the above options, **nuclear-powered generation** emerged at a proven, environmentally promising and commercially competitive option which could make a significant base-load contribution to [the region]'s economy and energy security."

Energy Guideline 2

"Due to major recent discoveries, **natural gas** is likely to be the primary growth engine for [the region]'s energy sector for the foreseeable future. Natural gas production was about 93 million m^3 per day in 2003 and is expected to rise to 140 million m^3 per day in 2007..."

"Currently, the petroleum sector [in the region] is promoting and encouraging more applications using **natural gas** in local market for substituting of oil and freeing it for export purposes. The largest applications are the usage of natural gas for electricity generation followed by other applications for industrial processes."

In your opinion, which guideline would present a **greater economic cost**?

Energy Guideline 1 (nuclear-powered generation) presents a **greater economic cost**.

Energy Guideline 2 (natural gas) presents a **greater economic cost**.

In your opinion, which guideline would present a **larger negative environmental impact**?

Energy Guideline 1 (nuclear-powered generation) presents a **larger negative environmental impact**.

Energy Guideline 2 (natural gas) presents a **larger negative environmental impact**.

Arid regions in the Arabian Gulf have historically relied on oil as an energy source. What factors should these regions consider when exploring alternative energy sources?

Please provide additional comments on general energy production guidelines.

Final Submit

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

A.5.5 Potable Quality Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to compare thematically relevant sections of policies and guidelines. Thank you for your participation!

Estimated survey time: ~15 minutes

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Potable Water Qual. (1 = Sharjah, 2 = Saudi Arabia, 3 = Kuwait, 4 = Singapore)

Many different regions choose to regulate their water very differently, sometimes directly following suggestions from the World Health Organization while other times establishing entirely new regulations. Below are selections** from regulations imposed on desalination plants' output water quality in four different regions that rely on desalination as a main source of potable freshwater.

**These regulations do not reflect the entire policy regarding water quality for each region.

	Region 1	Region 2	Region 3	Region 4
pH	7.0 - 9.2	8.1 - 8.6	6.5 - 8.5	6.5-9.5
Residual Chlorine [mg/L]	0.2 - 0.5	0.2 - 0.5	N/A	0.194 - 0.284
Total Dissolved Solids [mg/L]	100-1000	max: 130	max: 1000	N/A
Calcium Hardness [mg/L]	200	40-50	500	27 - 150
Total Alkalinity [mg/L]	N/A	40 - 50	100	8 - 46
Uranium [µg/L]	N/A	N/A	N/A	0.001 - 0.014

What factors lead regions to regulate certain water quality parameters with tighter ranges than other regions? (Example: comparing Region 2's and Region 4's pH restrictions)

The remaining questions on this page use data from the table above to make a statement regarding an aspect of water quality. You will then answer if you agree/disagree with the statement, and provide insight into why you answered the way you did.

Region 4 sets ranges for all contaminants deemed as critical to water quality rather than setting a general TDS range, and therefore included many more contaminant regulations when compared to the other regions:

Because Total Dissolved Solids (TDS) are not inherently hazardous to someone's health, it is better to set limits for each contaminant rather than set a general range for TDS.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Why?

Region 4 sets a range for Uranium concentrations in their potable sources:

It is important to regulate all contaminants that may have adverse health effects, even if they have miniscule concentrations.

- Strongly disagree

- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Why?

general questions

The following questions focus on general water quality policy and related health concerns. Please respond to these questions to the best of your ability.

If a region has proportionate access to freshwater from desalinated and groundwater sources, when should desalination be prioritized as the main source for producing potable water?

What are the main health concerns that arise from potable water from desalinated sources?

What are the main health concerns that arise from potable water from groundwater sources?

Please provide additional comments below.

Please answer if you agree/disagree with the statement made below, and provide insight into why you answered the way you did.

Wastewater recirculation should be prioritized over desalination as the main source of potable freshwater.

- Strongly disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Strongly agree

Why?

Ready To Submit Responses?

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

Powered by Qualtrics

A.5.6 Ship Movement Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to answer questions pertaining to ship movement. Thank you for your participation!

Estimated survey time: ~5 minutes.

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Ship Movement

Please respond to the following questions to the best of your ability.

These questions are related to ship movement regulations in desalination intake zones.

Should there be regulations on how close ports are to desalination facilites?

Yes

No

Why?

Should regulations be set on how close large vessels can come to desalination facilities.

Yes

No

What should be the set distance?

Why not?

How would you rank the **economic costs** associated with desalination facilities that set restrictions on ports?

- Large net loss
- Net loss
- Net zero
- Net gain
- Large net gain

How could these costs be mitigated?

Why?

Please provide additional suggestions on regulations surrounding ship movement.

Block 5

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

Powered by Qualtrics

A.5.7 Source Water Survey

WPI

Introduction

This project correlates to desalination policy in Sharjah, UAE. Our goal is to create a policy brief for the Sharjah Electricity and Water Authority (SEWA) by analyzing relevant sections of policies and guidelines from around the world.

Currently, SEWA lacks policy around factors that affect the inflow and outflow of seawater desalination plants on the Arabian Gulf. Our policy brief will present suggestions on how to alleviate negative factors affecting water quality and climate change.

In this survey, you will be asked to compare thematically relevant sections of policies and guidelines. Thank you for your participation!

Estimated survey time: ~10 minutes.

Informed Consent Agreement

Informed Consent Agreement

Investigator(s): Caitlin Kean, Sophie Kurdziel, Robear Mankaryous, Sawyer Wofford, and Joseph Doiron

Contact Information: Doiron, Joseph - jdoiron@wpi.edu

Title of Research Study: A Policy Study considering Desalination in Sharjah, UAE

Sponsor: Sharjah Electricity and Water Authority (SEWA)

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: There are no risks of injury associated with this study. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

- McKeogh, Ruth - 508 831 6699 - irb@wpi.edu - IRB Manager
- Johnson, Gabriel - 508 831 4989 - gjohnson@wpi.edu - Human Protection Administrator

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By selecting "I agree", you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

I agree

I disagree

Get Email

Please provide your email below in the event that we need to contact you for further questions or clarifications. This information will not be publicized, and any publication or presentation of the data will not identify you.

Source Water (1=UN)

Please review the information below and respond to the questions that follow.

The quality of the source water that is used for desalination can have a direct impact on the desalination process. Listed below is one guideline for controlling the quality of source water.

Table Key:
On-line - Continuously
D - Daily
W - Weekly
M - Monthly
Y - Yearly

Component	Control Meaures	Operational Parameters	Montioring Frequency	
			Large Plant	Small Plant
Source Water	Detect and prevent contamination by sewage	Enterocci and/or *E.coli*	D or W	W
	Detect and prevent impacts of storm events	Turbidity (used as on-line measurement for process control)	Preferably on-line	Preferably on-line
	Detect and prevent impacts of microalgae/cyanobacteria	Algal species, including cyanobacteria, dinoflagellates, or chlorophyll as a surrogate	W or M	M
	Detect and prevent impacts by industrial discharges	TOC (if concentrations change investigate sources)	W	M
		Petroleum oil hydrocarbons/grease including volatile compounds	W	Y
		Industrial chemcials	W	M
		Radioactivity	Y	Y
	Monitoring associated with downstream control measures	Salinity	D	D
		Chloride	D	D
		Sodium	W	W
		Boron	M	Y
		Bromide	M	Y
		Silica	D	D
		Iron	D	W
		Manganese	M	Y
		Turbidity	On-line	On-line
		Alkalinity	D	D
		pH	On-line	On-line
		Temperature	On-line	On-line
		Heavy metals	W	M
		Low solubility chemicals	W	M
		Hydrogen sulphide & metal sulphides	W	M
		Ammonia	W	M
		Total dissolved soilds	D	D

What is the **economic cost** associated with these control measures?

Large net loss
Net loss
Net zero
Net gain
Large net gain

Why?

How can the economic cost be improved or mitigated?

In your opinion, what would be the **environmental impact** if this guideline was implemented?

Large negative impact

The UAE and other other countries in the Middle East use the Arabian Gulf as their main source of water. What factors should these countries consider when creating regulations on the quality of source water?

How does monitoring source water vary between thermal and membrane based desalination?

What effects can poor source water quality have on the desalination process?

Negative impact
Neutral impact
Positive impact
Large positive impact

Why?

How can the economic impact be improved or mitigated?

Additional Source Water

Please respond to the following questions to the best of your ability.

Please provide additional suggestions you have on regulations pertaining to source water quality.

Block 5

This is the last section of this survey. By clicking next, you are agreeing to submit your responses. If you would like to change any of your responses, you can go back and edit them now.

Powered by Qualtrics

A.6 Survey Responses

A.6.1 Desalination Process Responses

Q42	Q4 **What is the economic cost associated with Guideline 1?**	Q5 **Why?**	Q6 **How can the economic cost be improved or mitigated?**	Q7 **In your opinion, which guideline would present a larger environmental impact for implement**	Q8 **Why?**	Q9 **How can the economic impact be improved or mitigated?**
Respondent #1	Net zero		This is actually a difficult question to answer. If you are considering cost to the operator, it's a net loss, but if you're considering cost to society, it's a gain, since you're mitigating detrimental effects that could harm other interests.	Positive impact	Presumably, monitoring is connected with environmental protection. Monitoring itself doesn't help, but if there's some sort of environmental mitigation plan, there's a net benefit.	
Respondent #2	Net gain	You need data to make decision.		Positive impact	Action based on data will be targeted against the environmental impact.	
Respondent #3	Net gain	The engagement of regional water board members will be a reasonable way to evaluate the administration of the desalination system. In order to conserve marine life, regular assessment will be strongly needed.		Positive impact	For the control of brines, the Regional Water Board and environment impact agency may provide the latest and standard protocol.It will be good for the biosphere to be protected.	

	Q16 What are the pros and cons with having more specific guidelines?	Q17 What other factors do you think should be considered for creating regulations of process management?	Q18 Please provide additional suggestions for creating and implementing process management guidelines.	Q20 In your opinion, how strict is this sampling guideline?	Q21 Please explain your answer.	Q22 How would you rank this guideline on its rate of sampling?
Respondent #1	Guidelines need to be sufficiently specific that they have meaning and weight, but not so specific that flexibility is not allowed. They also ought to have provisions for adaptive management, in case conditions change.	As mentioned already, it seems to me that the guidelines specify monitoring primarily, and do not specify what would need to be done in response to a certain monitored condition. It would also help if there were some background to explain why the guidelines are worded the way they are. What is the rationale leading to these guidelines?		Neutral	This looks like a "normal" type of sampling for compliance. It does not appear to be onerous, yet it is sufficient to provide a reasonable record of conditions.	Correct amount of sampling
Respondent #2	More specific guidelines are always helpful.	Data on overproduction of water is essential.How are production adjusted against variable demand of water during the day and during the season.Energy consumption data is missing.Source of energy data is missing. Energy consumption is directly linked with carbon footprint.	As above.	Strict	Frequency is sufficient.	Not enough sampling
Respondent #3	The benefits of Guideline 1 are regular reporting and ecological protection. However the process is time-consuming. As per the guidelines 2, the forecast data will deviate from the existing scenario.	Environment safety, human resource, cost and time are important to consider.	The Artificial Intelligence data framework can be introduced for process management.	Strict	The monitoring periods are frequent and adequate.	Correct amount of sampling

Q42	Q80 **What is the economic costs associated with Guideline 2?**	Q81 **Why?**	Q82 **How can the economic cost be improved or mitigated?**	Q83 **In your opinion, which guideline would present a larger environmental impact for implement**	Q84 **Why?**	Q85 **How can the economic impact be improved or mitigated?**
Respondent #1	Net loss		I'm not sure I understand the question. There is undoubtedly a cost associated with these activities, which is why I've answered that this is a loss - it's a loss of net profit, which is what I think you mean. You could improve the bottom line by not doing these actions, but I'm not suggesting that. It's a necessary cost of business.	Positive impact	Knowing the operating conditions can help plan for environmental impacts. Of course, just knowing the information isn't enough (doesn't have an impact) - you need to act on the information in order for it to have impact.	
Respondent #2	Net gain	Evidence based decision always help. Leak in the transmission system can have economic and environmental impact.		Positive impact	as above.	
Respondent #3			Desalination is a continuous method of operation and is subject to change under dynamic conditions. According to the Guideline2 proposal, the fault can be increased over time into desalination plants. Periodic control would be better to work in the sense of environmental conservation and economic considerations.	Neutral impact		The forecast data changes from time to time and it is inconsistent. Artificial intelligence tool management with environmental agency can be adopt to evaluate the project and biosphere effects.

	Q23 Please explain your answer.	Q25 In your opinion, how strict is this sampling guideline?	Q26 Please explain your answer.	Q27 How would you rank this guideline on its rate of sampling?	Q28 Please explain your answer.	Q29 Please provide additional suggestions on sampling regulations for desalination plants.
Respondent #1	see above	Too lenient	Frequency of sampling is not sufficient to capture "events", and also not sufficient to establish good trends. It's also not clear whether enough indicators are being sampled, but that's a hard question to answer without knowing more about the setting.	Not enough sampling	see above	Again, hard to say without knowing the surrounding conditions.
Respondent #2	Boron and other toxic elements are missing.	Too lenient	Too low frequency can miss the peak points.	Not enough sampling	as above	None
Respondent #3	Overall, the rate of sampling is good and excellent.	Lenient	The proposed sampling is restrictive and could impact the desalination process and the discharge system of the ecosystem.	Not enough sampling	Poor.	At regular intervals, sampling should be frequent and routine.

A.6.2 Desalination Technologies Responses

Q26	Q4	Q5	Q6	Q7	Q8
	The energy guideline above promotes reverse osmosis as a main supplier to the region's potable water needs. What is the environmental impact associated with reverse osmosis?	**You have indicated that reverse osmosis has a positive impact on the environment. Why?**	**You have indicated that reverse osmosis has a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?**	**Desalination technologies are often categorized by economic costs, alongside environmental impact. What is the economic cost associated with reverse osmosis?**	**You have indicated that reverse osmosis has a net gain with regards to economic cost. Why?**
Respondent #1	Neutral Impact		By properly designing the concentrate discharge to promote its rapid assimilation in the receiving water.	Net Zero	
Respondent #2	Neutral Impact		Mixing zones; thermal control, deep underground injection disposal in sensitive areas	Large Net Gain	Abundant fresh water for numerous beneficial uses.
Respondent #3	Neutral Impact		The environmental impact is insignificant if the desalination plant concentrate is discharged via properly designed outfall with diffusers which allow salinity of the discharge to be dissipated to less than 10% of the ambient seawater salinity within 300 m from the discharge.	Net Zero	
Respondent #4	Negative Impact		Siting away from sensitive habitat and fish populations, safe containment and disposal of waste.	Net Gain	It is difficult to generalize, as the prices of alternative supplies and the costs of desalinated water (including externalities) vary from place-to-place.
Respondent #5	Positive Impact	The Gulf states are very water scarce and are tempted to use and deplete ancient ground water. By using SWRO they avoid that issue and can also cultivate locally. This all assumes state of the art SWRO, possibly driven by renewables, and careful design of brine discharge.		Net Gain	The reliable supply of desalinated water allows steady economic activity and a known water resource for industry and the community.
Respondent #6	Negative Impact		The high-salt concentrate must be managed appropriately to avoid environmental impacts. It is site-specific, but we use a 5:1 seawater to concentrate "brine" ratio to dilute the brine prior to discharge at our facility. Other techniques are to disperse the brine discharge through diffusers that produces rapid mixing off shore.	Net Loss	
Respondent #7	Neutral Impact		reducing the energy footprint coupling with extensive PV and reducing chemical consumption	Net Loss	
Respondent #8	Negative Impact		Reverse osmosis produces brine which twice the concentration of sea water and that is discharged into the ocean hence impacting the environment. Moreover, the demands for electricity is high depending of the source, if the source of electricity is coal then it has an impact of impacting the atmosphere. Otherwise it will be great for renewable sources of energy linked to reverse osmosis	Large Net Loss	
Respondent #9	Negative Impact		Zero liquid discharge	Net Gain	It is the most energy-efficient desalination technology but still requires a high amount of energy compared to conventional water treatment methods.
Respondent #10	Negative Impact			Large Net Loss	

Q26	Q4 **The energy guideline above promotes reverse osmosis as a main supplier to the region's potable water needs. What is the environmental impact associated with reverse osmosis?**	Q5 **You have indicated that reverse osmosis has a positive impact on the environment. Why?**	Q6 **You have indicated that reverse osmosis has a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?**	Q7 **Desalination technologies are often categorized by economic costs, alongside environmental impact. What is the economic cost associated with reverse osmosis?**	Q8 **You have indicated that reverse osmosis has a net gain with regards to economic cost. Why?**
Respondent #11	Neutral Impact		As RO requires high-grade electrical energy, it would be beneficial to produce this electrical energy efficiently to minimize impacts to economics and environment.	Net Loss	
Respondent #12	Neutral Impact		Reverse osmosis does not necessarily have a negative impact on the environment except for brine disposal. Recovery can be tuned in the RO plant so that the brine concentration has less adverse effects on the environment in which it is discharged. Energy consumption in RO is significantly less than thermal desalination methods, but is still high relative to traditional methods for acquiring potable water; there is still a large carbon footprint associated with RO desalination plants.	Net Gain	The economic cost is very dependent on the region in which the RO desalination plant is. Although the energy consumption for RO is the smallest relative to all other desalination technologies, ranging from 0.5-2 kWh per cubic meter water produced, the net economic cost also depends on the cost of electricity and the price at which the treated water can be sold in that specific region. For the UAE, I would assume the energy costs for operating an RO plant are much smaller than the revenue generated from selling the treated water. I
Respondent #13	Positive Impact	Reverse osmosis remove all the contaminant based on pore size and charge. It would be aid to even smaller molecules such as salts. Brine management is critical in RO process.		Large Net Gain	The potable water production is quite fast and cost effective, when the pre-treatment of feed solution is adequate.
Respondent #14	Negative Impact		Promoting zero liquid discharge (ZLD) technologies that minimize the return of high-salinity concentrate into the sea; by improving the energy efficiency of RO and thereby reducing its carbon footprint; improved membrane cleaning technologies that minimize the use of chemical cleaning agents.	Net Loss	
Respondent #15	Negative Impact		Avoid brine discharge.	Net Gain	Water is essential to an economy.
Respondent #20	Negative Impact			Net Gain	
Respondent #21	Negative Impact			Large Net Gain	
Respondent #22	Positive Impact			Net Gain	
Respondent #23					

Q26	Q9 **You have indicated that reverse osmosis has a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?**	Q10 **Please provide additional comments on Desalination Guideline 1 below.**	Q12 **The energy guideline above promotes thermal-based systems as a main supplier to the region's potable water needs. What is the environmental impact associated with thermal-based systems?**	Q13 **You have indicated that thermal-based systems have a positive impact on the environment. Why?**
Respondent #1	The use of low TDS water has been shown to have a economic benefit to many arid areas due to improved agricultural performance, and reduce corrosion of appliances, which tend to offset the cost of intake and outfall environmental mitigation measures.	The answers to the questions are not simple "yes" or "no" responses. There are degrees of impact, which are dependent on the size and location of a plant, and the environmental mitigation measures it employs.	Negative Impact	
Respondent #2		Can recover some beneficial components from brines	Neutral Impact	
Respondent #3	By using high recovery SWRO system designs and high productivity elements.	All technologies and equipment do cost something - the definition of "net zero" cost is unclear.	Neutral Impact	
Respondent #4			Negative Impact	
Respondent #5		The seawater brine stream also provides a source for future minerals extraction. This is an area of active R&D. Could also increase water recovery if used solar-driven membrane distillation on the brine.	Negative Impact	
Respondent #6	RO requires high energy input to separate the salt. Energy recovery technologies are helpful (~40% savings) but electricity costs still high.			
Respondent #7	Public corporation spend more to procure water that revenue from customers and heavily subsidized water price. Remove redundancies involve private sector and encourage innovation . Remove old and obsolete MSF	The most widely used method [in the region] is MSF owing to a large operational assts installed in 1980 to 2010 and still operating followed by reverse osmosis (RO) wwho is gradually taking over the market share in desalination. In reverse osmosis dissolved constituents are removed by passing the water through a membrane under high pressure. In addition to the potable water, reverse osmosis produces a waste stream (concentrate)... and other dissolved constituents." "The greatest impacts in the field [experiments] have occurred around older multi-stage flash (MSF) plants discharging to water bodies with little flushing, a discharge scenario not relevant in [the region]. Such sites show substantial increases in salinity and temperature, along with accumulation of metals, hydrocarbons, and anti-fouling compounds in receiving waters."	Negative Impact	
Respondent #8	The cost of desalination is expensive due to high electical demand arisning from the high pressure pumps they use to overcome the osmotic pressure of sea water. (About 3 to 4 KWhr/m3).	It's still comes useful however use of reverse omsosis linked to solar or wind or pressure retarded osmosis may be beneficial	Negative Impact	
Respondent #9		n/a	Negative Impact	
Respondent #10			Negative Impact	

Q26	Q9	Q10	Q12	Q13
	You have indicated that reverse osmosis has a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?	**Please provide additional comments on Desalination Guideline 1 below.**	**The energy guideline above promotes thermal-based systems as a main supplier to the region's potable water needs. What is the environmental impact associated with thermal-based systems?**	**You have indicated that thermal-based systems have a positive impact on the environment. Why?**
Respondent #11	The economic cost by reducing the cost associated with high-grade electrical energy to power RO.	Is there any other guidance on other thermal desalination technologies such as membrane distillation or mechanical vapor compression?	Neutral Impact	
Respondent #12		I agree MSF likely has more negative impacts on the environment than does RO, but RO has similar negative impacts, just less severe than they would be with MSF.	Neutral Impact	
Respondent #13		Membrane technology is a renowned sustainable water for the production of fresh water from brackish water. However, membrane fouling is a drawback upon filtration of brackish water. It can be overcome by hydrodynamic condition and superior membrane modules.	Positive Impact	The outcome of thermal desalination is a potable water and the byproducts are minimal.
Respondent #14	Increased energy efficiency that can reduce the pumping costs, as RO requires very high pressures.		Negative Impact	
Respondent #15			Negative Impact	
Respondent #20				
Respondent #21			Neutral Impact	
Respondent #22				
Respondent #23				

Q26	Q14	Q15	Q16	Q17	Q18
	You have indicated that thermal-based systems have a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?	**Desalination technologies are often categorized by economic costs, alongside environmental impact. What is the economic cost associated with thermal-based systems?**	**You have indicated that thermal-based systems have a net gain with regards to economic cost. Why?**	**You have indicated that thermal-based systems have a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?**	**Please provide additional comments on Desalination Guideline 2 below.**
Respondent #1	Guideline 2 may have been true at one time, but it is no longer true. The capital and operating cost of thermal desalination is simply higher, and when the plants currently under construction are operational, most of the region's capacity will no longer be provided by thermal energy. Not only do thermal plants require more energy, they discharge a thermal plume, which usually has a higher concentration of metals, including copper.	Net Loss		Thermal plants are simply more energy intensive than RO plants. There is little that can be done about it, expect to replace the capacity with RO.	
Respondent #2	Co-generation is beneficial and is also applicable to RO facilities. Environmental factors are very similar to RO systems.	Net Zero		Same as RO facilities. Actually there are region specific factors that should be weighed when making the technology selection choices.	Universal decisions are not rational. Region specific and site specific choices should be made to optimize the outcome.
Respondent #3	If designed properly the environmental impact of thermal desalination system can be insignificant. The main discharge load that could cause environmental impact if not dissipated properly is the plant thermal load.	Net Zero		Thermal desalination technology is going to be always more costly that SWRO membrane separation of fresh water from the salt in seawater. Economic costs can be mitigated by replacing thermal desalination with membrane desalination.	Thermal desalination technology has no future outside of the Middle East and even there it is likely to be replaced by membrane desalination - it is not cost competitive.
Respondent #4	Siting away from sensitive habitat and fish populations.	Net Gain	Same answer as to previous question.		
Respondent #5	Need to decarbonise water production. I suggest replace fossil-driven thermal processes with renewables-driven RO.	Net Loss		Need to decarbonise water production. I suggest replace fossil-driven thermal processes with renewables-driven RO.	
Respondent #6					I am not familiar with MSF or MED systems
Respondent #7	replacing the old MSF or coupling the steam generating machine with solar panels instead of steam boiler	Large Net Loss		currently energy footprint is too large to justify the cost. There is no alternative but replacing thermal	the main reason for the MSF success is robustness of operation
Respondent #8	They increase carbon foot print depending on the source of the electricity	Large Net Loss		Thermal based systems are more expensive than the reverse osmosis themselves.. hence not an economical decision to go for thermal based solutions. Also	You need to know what ranges of salinity feed are you looking at and your desired outcome. Do you need drinking water or water for irrigation.there are solar based desalination plants you may have a look at those.
Respondent #9	Zero liquid discharge	Net Loss		Energy consumption for thermal desalination technologies is greater than that for reverse osmosis.	n/a
Respondent #10		Large Net Loss			

Q26	Q14 **You have indicated that thermal-based systems have a neutral or negative impact on the environment. How can the environmental impact be improved or mitigated?**	Q15 **Desalination technologies are often categorized by economic costs, alongside environmental impact. What is the economic cost associated with thermal-based systems?**	Q16 **You have indicated that thermal-based systems have a net gain with regards to economic cost. Why?**	Q17 **You have indicated that thermal-based systems have a net zero or net loss with regards to economic cost. How can the economic cost be improved or mitigated?**	Q18 **Please provide additional comments on Desalination Guideline 2 below.**
Respondent #11	The integration of low-grade waste heat or geothermal to power thermal-based desalination systems would increase the positive impact to the environment.	Net Zero		The economic cost is improved or mitigated with the integration of waste heat or geothermal energy. For thermal-based desalination systems, the gained output ratio (GOR) indicates that they are much less energy-efficient than RO thus economic cost is greater in regards to energy consumption. Using essentially waste energy could offset this cost making it economically viable.	
Respondent #12	The additional negative impact for thermal desalination technologies is related to the temperature and higher salinity of the brine. Improving thermal efficiency as to reduce the temperature of the brine and discharging high salinity brine into deep ocean areas with higher dilution factor may offset these issues.	Net Gain	The economic costs of thermal desalination systems hinges upon the high cost to operate these systems and how those costs can be offset. For regions like the UAE where thermal energy is abundant, especially in power plants, thermal desalination systems are a net economic gain.		Additional methods for handling the negative environmental impacts of discharging thermal desalination brine into the ocean is to operate a zero liquid discharge facility. Mineral crystals also have the potential to serve as an additional revenue stream, depending on the source water and therefore, the composition and specific contaminates in the solids.
Respondent #13		Net Zero		Thermal based system is a higher energy requirement, Hence, the thermal system have lesser gain.	The scale formation is dominant in the thermal desalination. Membrane based thermal desalination also showed promising effect on the production of potable water from brackish water.
Respondent #14	Reducing discharge (high salinity and high temperature) from the plant to the nearby water body; better pretreatment that reduces scalants in the water, and subsequently reduces the amount of anti-scalants used in the thermal-based system	Net Zero		The economic costs are reduced by coupling desalination with power generation, but this is not feasible in the long-term with renewable energy sources. Without co-generation, thermal-based systems are very energy intensive processes.	
Respondent #15	Brine discharge Thermal discharge	Net Gain	Water is essential to an economy		
Respondent #20					
Respondent #21		Net Gain			
Respondent #22					
Respondent #23					

Q26	Q20	Q21	Q22	Q23
	In your opinion, which guideline would present a greater economic cost?	**In your opinion, which guideline would present a larger environmental impact for implement**	**Arid regions in the Arabian Gulf have pointed to the robustness of thermal based processes in "extreme summer temperatures". What factors should these regions consider when exploring alternative desalination technologies?**	**Please provide additional comments on the comparison between Desalination Guideline 1 and Desalination Guideline 2 below.**
Respondent #1	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Thermal plants have significant cooling water requirements, greatly increasing the amount of water withdrawn from the sea, with its attendant impacts on marine life.	Thermal desalination plants are being replaced with RO plants across the Middle East and around the world.
Respondent #2	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	They should optimize. The binary choices in the above questions are not appropriate. Site specific factors should dominate.	It is not a black and white choice. Either approach could be appropriate depending upon economic circumstances. Of greater import is that there should not be government subsidies so that consumers have greater incentive to not waste the product water.
Respondent #3	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Increasing energy costs and the fact that the theoretical energy use for separation of salts from water by thermal evaporation will always be higher than that for membrane separation.	Thermal desalination plants will be phased out as a main desalination technology from the Middle East by year 2030.
Respondent #4	Desalination Technology Guideline 1 (reverse osmosis) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	I do not have the expertise to answer this.	
Respondent #5	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	SWRO also functions well at raised ambient temperatures.	
Respondent #6				
Respondent #7	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	the robustness at high temperature is incorrect MSF are generally sensitive to temperature insofar that they produce less . Alternative technologies are interesting but optimization on SWRO is the mainstream to reduce costs and energy footprint	none
Respondent #8	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Explore feed water propoertiessuch as salitiny, temperature & what product water quality they want to achive.	Nil
Respondent #9	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Technologies exploiting thermal energy	n/a
Respondent #10	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.		

Q26	Q20	Q21	Q22	Q23
	In your opinion, which guideline would present a greater economic cost?	**In your opinion, which guideline would present a larger environmental impact for implement**	**Arid regions in the Arabian Gulf have pointed to the robustness of thermal based processes in "extreme summer temperatures". What factors should these regions consider when exploring alternative desalination technologies?**	**Please provide additional comments on the comparison between Desalination Guideline 1 and Desalination Guideline 2 below.**
Respondent #11	Desalination Technology Guideline 1 (reverse osmosis) presents a greater economic cost.	Desalination Technology Guideline 1 (reverse osmosis) presents a larger negative environmental impact.	I would recommend evaluating a hybrid process to increase water production at possibly a lower cost. Using RO for desalination to its effective salinity limit of 70,000 mg/L would most likely be the most energy efficient (and cost efficient). For the RO brine, a thermal desalination technology could be used to treat water with high salinity (greater than 70,000 mg/L) with the integration of waste heat or another form of low-grade thermal energy to power the technology. This would increase the water production while decreasing the amount of brine to be disposed.	
Respondent #12	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Thermal based systems are also inherently better at handling fouling and scaling issues than membrane based systems. These regions should consider the composition of the source waters and what potential fouling and scaling species are present. Also, RO is the most attractive desalination technology because of it's low energy consumption, but as the salinity of the source water increases, the energy efficiency and applicability of RO decreases altogether, favoring thermal systems.	
Respondent #13	Desalination Technology Guideline 1 (reverse osmosis) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Membrane based thermal desalination can be considered. Membrane process intensification with solar powered desalination can be explored.	Reverse osmosis is energy effective process as compared to thermal desalination. Pre-treatment need to be focused prior to removal of contaminants from brackish water.
Respondent #14	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Higher salinity of the Arabian gulf and the higher water temperatures make it harder for RO to work in this region as RO polyamide membranes struggle at these temperatures. But newer membranes are able to tackle this problem better. Newer membrane technologies such as membrane distillation can be considered in this region as well. This technology is especially useful for targeting high salinity water sources. New technologies must be selected that minimize the concentrate generated and returned to the Arabian gulf after desalination.	With the advent of newer RO polymer membranes that can tolerate high salinity and temperature, RO is growing in the Arabian gulf region as well. As renewable energy grows in the region, it will not be possible to couple power generation with desalination to a large extent anymore. Without the extra energy from the power generators, thermal technologies become extremely poor economically. Hence in the long-term the move towards RO and reduction of thermal desalination in the region is inevitable.
Respondent #15	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a greater economic cost.	Desalination Technology Guideline 2 (multiple stage flash or multi-effect distillation) presents a larger negative environmental impact.	Thermal processes are more robust and less prone to unexpected failure	Vapor compression desalination has the energy efficiency of reverse osmosis and the robustness of thermal processes. Furthermore, it can recover so much water there is zero liquid discharge.
Respondent #20				
Respondent #21				
Respondent #22				
Respondent #23				

A.6.3 Discharge Limits Responses

Q39	Q37 What is the economic costs associated with guideline 1?	Q39 Why?	Q47 How can the economic impact be improved or mitigated?	Q43 In your opinion, which guideline would present a larger environmental impact for implement	Q45 Why?	Q41 How can the economic cost be improved or mitigated?
Respondent #1	Net loss			Positive impact		
Respondent #2	Net loss			Positive impact		
Respondent #3	Net loss			Positive impact		
Respondent #4	Net gain	The guideline 1 would be beneficial for the long term desalination operation.		Positive impact	As per the guidelines, the permissible limit for contaminants and other parameters are low. Hence, it may have lesser effect with ecosystem.	
	Q51 Are there any other factors to consider when selecting discharge parameters?	Q21 Please provide additional comments below about discharge limits.	Q23 Should parameters be set as numbers or percent differences from ambient water (referencing the table above)?	Q24 Why?	Q25 Should policies set distances for how close brine can be discharged from desalination facilities?	Q26 At what distance should they be set?
Respondent #1	Location of discharge; identification of sensitive ecosystems; flow rate; trace contaminants;		numbers	Percent difference less related to ecosystem protection.	Yes	
Respondent #2			percentages	Suspended solids are not important for brine discharges,. Do you mean dissolved solids?	No	
Respondent #3			numbers		Yes	
Respondent #4	The discharge water needs to be characterization for chemical constituents. Then, the required measurement needs to segregate the waste based on the chemical functionality.	The discharge limits needs to par with WHO standards. Data management on discharge limits needs to be maintained.	percentages	Percentage is standard parametric value to asses the water quality and other constituents.	Yes	The set distance should be deep sea ocean.

Q39	Q49 **What is the economic costs associated with guideline 2?**	Q51 **Why?**	Q53 **How can the economic cost be improved or mitigated for guideline 2?**	Q55 **What is the environmental impact associated with guideline 1?**	Q57 **Why?**	Q59 **How can the economic impact be improved or mitigated?**	Q47 **In your opinion, which guideline would present a greater economic cost?**	Q49 **In your opinion, which guideline would present a larger environmental impact for implement**
Respondent #1	Net loss			Positive impact			Guideline 1 presents a greater economic cost.	Guideline 2 presents a larger negative environmental impact.
Respondent #2	Net loss			Positive impact			Guideline 1 presents a greater economic cost.	Guideline 1 presents a larger negative environmental impact.
Respondent #3	Net zero			Positive impact			Guideline 1 presents a greater economic cost.	Guideline 2 presents a larger negative environmental impact.
Respondent #4	Net gain	The guideline 2 have limited regulation in brine management. The maintenance cost would quite low and it would be profitable.		Negative impact		Pre-treatment methodology with novel zero liquid discharge units can be designed to reduce the contaminant removal.	Guideline 1 presents a greater economic cost.	Guideline 2 presents a larger negative environmental impact.

	Q27 Why?	Q28 Does increasing the radius of the mixing zone allow for fewer restrictions?	Q29 Why?	Q30 How often should data be collected about marine life living near brine deposits?	Q33 How often?	Q31 Why?	Q32 Please provide additional comments on brine discharge.
Respondent #1		Yes		Weekly			
Respondent #2		No		Monthly		Initially monthly, then yearly.	
Respondent #3		No		Monthly			
Respondent #4		No	I hope there will be no change with regulation corresponding to mixing zone.	Weekly		The flow dynamics of seawater is unsteady state, thus it is necessary to maintain the data for every week.	Zero liquid discharge and less carbon footprint can be aimed for the brine management. Hybrid membrane processes such as forward osmosis couple reverse osmosis process can be attempted.

A.6.4 Energy Guidelines Responses

Q39	Q5	Q6	Q27	Q7
	What is the economic cost associated with these control measures?	Why?	How can the economic cost be improved or mitigated?	In your opinion, which guideline would present a larger environmental impact for implement
Respondent #1	Net gain	The proposed control measures are standard and adequate. The control measures assist in the elimination of contaminants, thereby enhancing the desalination process under continuous mode.		Positive impact
Respondent #2	Net gain	This allows preventing the production of bad quality water, fouling and clogging the membranes		Neutral impact
Respondent #3	Net gain	It can make the process more efficient		Positive impact
Respondent #4	Net gain	pre-emptive actions taken based on monitoring can save a lot of money from wastage later on. In addition, it improves the reliability and quality of the services provided.		Large positive impact
Respondent #5	Net loss		You need to know that the plant is operating properly and that there is no contamination. Compared with the overall cost of building and operating the plant, these analytical costs seem a rather minor component. They could perhaps be reduced by combining samples from more than one plant at a central laboratory, although this may be difficult depending on how far apart they are..	Neutral impact

Q39	Q8 Why?	Q37 How can the economic impact be improved or mitigated?	Q9 **Please respond to the following questions to the best of your ability.** **The UAE and other other countries in the Middle East use the Arabian Gulf as their main source of water. What factors should these countries consider when creating regulations on the quality of source water?**
Respondent #1	The discharge water should meet the requirement of WHO standards. The brine management is the critical environment issues in desalination process. The mandatory regulations needs to be followed for the disposal of hazardous waste and microbial source.		The main factors for the source water are salinity, microbial contaminants, emerging pollutants and density.
Respondent #2		By keeping good quality feed water	This is a small sea, with extensive oil production. Desalination should be kept away from pollution sources as ae well as fro the discharged concentrate.
Respondent #3			the chemical composition and amount of the brine discharged into the Arabian gulf. The discharge mechanism. The location of desalination plants.
Respondent #4	If the source water is seawater and the source water is improved, it is going to show marked improvement in the ocean ecosystem.		There are many. However, first they need to acknowledge that all these countries share the same water from the Arabian Gulf. So, it should be a collective responsibility to manage the quality of water in the Arabian gulf.
Respondent #5		Again, compared to the amount of salt that has to be disposed of during routine operations, the addition of a small amount of laboratory chemicals is rather minor.	

Q39	Q10	Q11	Q12
	How does monitoring source water vary between thermal and membrane based desalination?	**What effects can poor source water quality have on the desalination process?**	**Please provide additional suggestions you have on regulations pertaining to source water quality.**
Respondent #1	In both process, biofouling is a common problem for deterioration of desalination process. Membrane process is quite sensitive with contaminants such as salts. Moreover, accurate pressure sensor needs to be monitoring on measurement of flux. Back washing and membrane cleaning procedure needs to be optimized. For thermal process, flow dynamics needs to be maintained.	Microbial contamination deteriorate the flux performance and life span.	Emerging pollutant such as microplastics and nanoplastics needs to have standard regulation on disposal. The other contaminants such as boron and heavy metal also have drastic effect on both desalination process. Besides, scaling agents also needs to be treated prior to desalination. Overall, the pre-treatment process needs to be standardized according to water quality. Artificial intelligence and data science can be implemented to quantify the water sources and pollutants corresponding to seasons.
Respondent #2	Thermal production is less sensitive to salts concentration up to the saturation of calcium sulfate, however at high temperature may contain organic matter. RO membranes are sensitive to organics and bacteria fouling as well as scale formation	poor product and higher production cost	Keep away from wastewater. Maintaining good quality control at all stages of the process
Respondent #3	Thermal processes are less susceptible to fouling and scaling than membrane processes, therefore monitoring should take into account these factors depending on the technology.	It can reduce its efficiency.	Regulations should not only consider discharge of brine but also intake and this should be applied to all countries having coastal bounds with the Arabian Gulf.
Respondent #4	The presence of different types of suspended solids play a big role in the performance of membrane based desalination system. These can include the presence of chlorophyll as well. In thermal desalination these are not necessarily as critical.	It reduces the efficiency, increases amount of waste generated and make the process costly.	waste disposal should be considered strictly in the source water and long term sustainability need to be investigated.
Respondent #5			

A.6.5 Potable Quality Responses

Q36	Q21 **What factors lead regions to regulate certain water quality parameters with tighter ranges than other regions? (Example: comparing Region 2's and Region 4's pH restrictions)**	Q24 **The remaining questions on this page use data from the table above to make a statement regarding an aspect of water quality. You will then answer if you agree/disagree with the statement, and provide insight into why you answered the way you did.** **Region 4 sets ranges for all contaminants deemed as critical to water quality rather than setting a general TDS range, and therefore included many more contaminant regulations when compared to the other regions:** **Because Total Dissolved Solids (TDS) are not inherently hazardous to someone's health, it is better to set limits for each contaminant rather than set a general range for TDS.**
Respondent #1	I would have to research this to know the answer. Any other answer would be speculation.	Somewhat agree
Respondent #2	The following factors can cause different regions adopting different limits on the water quality parameters. 1. The variation in the local composition of source water quality 2. Availability/unavailability of appropriate treatment technologies 3. Intended end use However, as you notice the pH is generally within an acceptable neutral to slight alkaline range.	Neither agree nor disagree
Respondent #3	Factors would include: Main source of water, pollution, type of technology used, and how developed the region is. These factors make it harder/easier to alter the water's pH.	Strongly agree
Respondent #4	State of knowledge about the subject matter in the region; How specific quality factors relate to other quality factors in the region - e.g., pH vs. TDS (TDS correlates positively with conductivity and affects pH. The higher the TDS, the higher the conductivity and the lower the pH, towards acidity); The relative presence or absence of certain quality factors - e.g., arsenic, uranium, etc.	Somewhat disagree
Respondent #5	Societal concerns rather than scientific	Somewhat disagree
Respondent #6	When it comes to regulations, the most important thing to understand is the power dynamic. The more powerful, more knowledgeable people set the standards, at least in the United States. Of course, there are phenomenal people working in the USEPA and MADEP, but power and money can overshadow good intentions. Moreover, we have a tendency in this country to approach environmental regulations reactively, prioritizing financial interest and jobs over human and environmental health. Conversely, much of Europe uses the precautionary principle, prioritizing protection of the environment and health. In areas with naturally occurring Uranium, labor organizations and some politicians being supported by those organizations may push for fewer regulations so they can mine for the resource without fear of being penalized for the externalities of their work. Conversely, environmental and environmental justice groups would lobby for stricter regulations on Uranium in drinking water for protection of human health. Lower pH (below 7) can cause metals to leach into drinking water, so pH numbers should be above 7. However, regions with a power plant in the area or large vehicle operation or bus depot resulting in a high volume of C02 may cause acid rain and subsequently lower the pH. Investors in fossil fuels can be large donors to government actors and in turn use their leverage (money) to influence the regulations. So Region 4 may be more industrial and region 2 (with the strict pH allowance) suburban and more residential. Stormwater runoff pollution, salting roads and agricultural runoff can cause higher TDS. This includes most places. I'd guess Regions 1 and 3 are agricultural. Herein you have my pragmatic and cynical reasoning for why I'd guess these restrictions may exist in some areas over others. I hope it is useful...	Somewhat agree
Respondent #7	Region 1 and 3 holds higher TDS and calcium hardness, which have negative effect on the qulityof potable water. The higher concentration of chlorine also has adverse palatable effects to human beings.	Somewhat agree
Respondent #8	The differences in restrictions could be due to varieties of reasons. One such reason could be due to the aquatic ecosystem these waste are disposed. So, if a region have sensitive vegetation or organism who can be affected by fluctuation in pH level, then you can expect tight regulations. Another factor that plays a role is the ocean circulation behaviour of a particular region. If waste is discharged to places where water circulation is minimal, you can expect stricter regulations. In addition cold water ecosystems are going to be treated different to hot water ecosystem.	Somewhat agree
Respondent #9	I guess this depends on the technology used (in terms of the membranes)	Somewhat disagree

Q36	Q27	Q25	Q28
	Why?	**Region 4 sets a range for Uranium concentrations in their potable sources: It is important to regulate all contaminants that may have adverse health effects, even if they have miniscule concentrations.**	**Why?**
Respondent #1	I don't agree with the QUESTION as stated, based on the data provided. In the table provided, there are 5 regulations in Region 4. There are also 5 regulations in Region 2 - thus, I do not know what the basis is for the statement that Region 4 included "many more contaminants". There must be other contaminants for which information is not provided if this statement is accurate. Therefore, I don't have all of the information needed to answer the question that is posed.	Somewhat agree	If a contaminant is not found and never will be found, ,then it does not need to be regulated. This is how it is handled in the US - regulations include data on occurrence, not just health impacts. If something doesn't occur, it is a waste of resources to have to measure it.
Respondent #2	Drinking high TDS water may have an effect on human health, especially when ions such as Ca, Mg, K, bicarbonate, sulfate, etc typically found in very high concentrations in seawater are consumed. However, looking at the data in the table alone I suppose one could say that controlling hardness and alkalinity parameters may bring down the TDS a bit. But more data is needed to be sure if other parameters such as electrical conductivity have limits (which is also another way of providing TDS values)	Somewhat agree	It is possible that Region 4's source water has a relatively higher level of residual uranium concentration, which has resulted them in enforcing specific limits.
Respondent #3	Specifying the limits for each contaminant would be better in my opinion. A general range would be misinterpreted in terms of how ''safe'' a water is. This might lead several researchers to claim that their technology produces safe/potable water by mentioning that TDS is in the nonhazardous range. That range could have an alarming limit of a contaminant that would still fit under the safe guidelines of total dissolved solids.	Somewhat agree	Because we might experience effects on the long term and everything needs to be justified.
Respondent #4	TDS can include material that may not be typically regulated, but which should be restricted	Somewhat agree	It would be ideal to regulate all contaminants, including those at miniscule concentrations. However, in many countries (including some western nations), its a function of technical and financial capacity. They just cannot monitor all of the contaminants that should be regulated. There has to be a cost/benefit analysis - what can be regulated AND monitored in a practical and feasible manner given the availability of resources.
Respondent #5	Most parameters listed are not contaminants of health concern; and a key feature of desalination is the reduction in salts.	Strongly disagree	Biologically available forms of most contaminants is more relevant, but not a good use of resources to monitor all possible contaminants; rather the focus should be on index contaminants that represent broader sets
Respondent #6	You need some limits on TDS because of the potential damage to infrastructure.	Strongly agree	Precautionary principle. We have renewable alternatives to Uranium, we should use them.
Respondent #7	Yes. The permissible limits for the pollutants are varies with respect to one another. The WHO also standardized the regulation for water quality and individual pollutants. It is not necessary to set range for TDS. It is mandatory to set a permissible limit for individual pollutants.	Strongly agree	Yes. The heavy metal are toxic to human beings and bisophere. It is necessary to remove the uranium pollutant for the production of potable water.
Respondent #8	Regulations are much more complicated than it looks. In principle the statement is correct. However, there are many different pollutants (could be 100s) in reject water. It is not always practical to regulate all of them. Regulation comes with regular monitoring. Monitoring can costs a lot of money. If 100 different parameters are regularly monitored, you can anticipate the costs it would take. For practical reasons, aggregate parameters like TDS are regulated and monitored.	Neither agree nor disagree	Uranium is not available everywhere in the world. Why regulate if there aren't much possibility of getting it? Unreasonable regulation can be destructive to the cause of environmental protection.
Respondent #9	Drinking water with high TDS concentrations will expose human bodies to various chemicals, toxins and may cause chronic health conditions. Hazardous chemicals or other health-affecting substances should not be in drinking water, too.	Neither agree nor disagree	It is important to regulate all contaminants that may have adverse health effects, however, it depends on the concentration and period of exposure.

Q36	Q5	Q19	Q33
	The following questions focus on general water quality policy and related health concerns. Please respond to these questions to the best of your ability. **If a region has proportionate access to freshwater from desalinated and groundwater sources, when should desalination be prioritized as the main source for producing potable water?**	**What are the main health concerns that arise from potable water from desalinated sources?**	**What are the main health concerns that arise from potable water from groundwater sources?**
Respondent #1	This question is too broad to be answered with clarity. There are dozens of factors that go into selection of an appropriate water source, and the sustainability of that source. Economics, raw water quality, need for water for uses other than drinking (e.g., agriculture, industry, etc.), availability of options for waste disposal (for products of treatment), land subsidence, cultural/religious factors, etc.	Again, this is a very broad question and depends on the treatment used.	This is very dependent on the geographical location and subsurface conditions.
Respondent #2	1.If the rate of groundwater recharge is poor (not enough rainfall) 2. Urban population growth is rapid and expected to put deplete groundwater unsustainably	Lack of mineral content in the desal water may cause health effects.	Untreated groundwater in some regions may have residual arsenic content resulting in negative health effects
Respondent #3	When the groundwater starts to run out, gets contaminated or requires a large capital for transforming and distributing.	Since desalination removes salt from water, essential minerals are also removed which would lead to many health risks associated with the deficiency of iodine, fluoride, and calcium. Affecting teeth, thyroid glands and bones.	Groundwater can be contaminated with viruses, germs, parasites, and also chemicals. These can cause health problems like salmonella, shigella and hepatitis A
Respondent #4	When groundwater depletion crosses the threshold of long-term sustainability, desalination should be used to supplement potable water supplies.	Proper desalination removes all minerals from the water. Yet, humans needs certain minerals to maintain good health. Hence, desalination must include introduction of those minerals prior to distribution into the potable water supply. In addition, the waste product of the desalination process can often contain toxic levels of various materials. It must be disposed of properly.	Arsenic, fluoride, and other minerals and substance can often be found naturally in groundwater. Hence, the answer to this questions depends on the natural quality of the source groundwater, as well as any unnatural contamination that may affect that quality.
Respondent #5			
Respondent #6	hmm. In periods of drought, desalination may be a better source allowing groundwater sources to replenish.	The sheer amount of contaminants humans discharge into the ocean worries me more than the salt content and the desalination process may remove important minerals. Though not your question, desalination has shown to be harmful to the environment, so not the best solution.	Groundwater is typically much cleaner than surface water that is used for drinking. The main health concerns are naturally occurring metals and other contaminants such as Arsenic (near Worcester). The lack of regulation for agricultural runoff means pesticides can leach into groundwater and be detrimental to human health. Chlorine and other disinfectant byproducts are also a concern.
Respondent #7	Groundwater should be prioritized for the production of freshwater. However, the groundwater quality should be characterized prior to the desalination. Besides, the sustainability should be considered.	The health concerns varies from one place to other, which depends on the source. The main health effects are cause by heavy metal and hardness.In general, longer exposure of heavy metal cause physiological disorders and cancer. The hardness mainly change the palatable of water and kidney damage.	Microbial disease is the main health concern from groundwater.
Respondent #8	I am not sure if I understand the statement clearly. Diversity in selecting the source of the water can be quite important in ensuring resiliency of a water supply system. On that front all the different sources should be used. However, in general producing desalinated water is costlier than groundwater sources (without desalination). So appropriate balance need to be maintained.	A common concern is a lack of enough minerals. Tastes are weird, at times salty. There are also lack of social acceptance towards desalinated water for potable use. There aren't really big health concerns though. Fluoride is one such example.	It depends on what is there in the groundwater. For example in some part of Indian subcontinent groundwater is contaminated with arsenic, which can cause skin cancer. It depends on geological profile (i.e. minerals). There are uranium in the groundwater, but, everywhere though. There are irons, ammonia.
Respondent #9	If a threshold of a chemical or substance of concern is exceeded. Meanwhile the desalinated water should be used to dilute the groundwater in order to reduce the concentrations.	I haven't heard from negative health effects but there might be some existing.	water quality degradation from natural processes (e.g. weathering), pollution intake through leakages (for shallow aquifers), salinity (saltwater intrusion or upconing).

Q36	Q9	Q20	Q26
	Please provide additional comments below.	**Please answer if you agree/disagree with the statement made below, and provide insight into why you answered the way you did. Wastewater recirculation should be prioritized over desalination as the main source of potable freshwater.**	**Why?**
Respondent #1	The questions are too broad, and the team should be researching these answers, not asking them in a survey.	Neither agree nor disagree	
Respondent #2		Somewhat agree	Treated wastewater reuse for potable purposes is a very important step. However, the "prioritixzation" aspect will depend on the population size, ability to treat the wastewater to high quality and the general acceptability by the public.
Respondent #3	.	Neither agree nor disagree	not very sure about this
Respondent #4		Somewhat agree	Recycling of wastewater often requires less resources and energy.
Respondent #5			
Respondent #6		Somewhat agree	It does not cause environmental harm the way desalination does.
Respondent #7	The main contaminants are heavy metal ions, high concentration of salts, emerging pollutants (endocrine disruptors and microplastics) microbes and natural organic matter. The efficient desalination system needs to be designed to eliminate this contaminants.	Somewhat agree	Yes. The wastewater re-circulation may reduce the concentration effect in feed tank and also waste management can be reduced.
Respondent #8	I don't have anything new to add	Strongly agree	The general spirit is correct. I suppose it meant for potable use without drinking.
Respondent #9	none	Neither agree nor disagree	I think there is no yes and no as it depends on the region/location. Wastewater reuse requires strong regulation to avoid the spread of contaminants into the environment. Desalination might be a much better option in terms of water quality, however, the technology is expensive and storage of brine can be a problem.

A.6.6 Ship Movement Responses

Q3	Q5 Should there be regulations on how close ports are to desalination facilites?	Q6 Why?	Q7 Should regulations be set on how close large vessels can come to desalination facilities.	Q8 What should be the set distance?
Respondent #1	Yes	The ports and other supporting processes contaminate the water quality and it can affect the desalination plant.	Yes	The set distance should be 100 km

	Q9 Why not?	Q10 How would you rank the economic costs associated with desalination facilities that set restrictions on ports?	Q11 How could these costs be mitigated?	Q12 Why?	Q13 Please provide additional suggestions on regulations surrounding ship movement.
Respondent #1		Net gain		The economic cost depends on the unit operation, energy and infrastructure The treated water would be beneficial for various port activities.	Transportation and accessibility need to be considered. Environmental impact and brine management needs to be monitored. Zero liquid discharge system can be installed for sustainable development.

A.6.7 Source Water Responses

Q39	Q5	Q6	Q27	Q7
	What is the economic cost associated with these control measures?	**Why?**	**How can the economic cost be improved or mitigated?**	**In your opinion, which guideline would present a larger environmental impact for implement**
Respondent #1	Net gain	The proposed control measures are standard and adequate. The control measures assist in the elimination of contaminants, thereby enhancing the desalination process under continuous mode.		Positive impact
Respondent #2	Net gain	This allows preventing the production of bad quality water, fouling and clogging the membranes		Neutral impact
Respondent #3	Net gain	It can make the process more efficient		Positive impact
Respondent #4	Net gain	pre-emptive actions taken based on monitoring can save a lot of money from wastage later on. In addition, it improves the reliability and quality of the services provided.		Large positive impact
Respondent #5	Net loss		You need to know that the plant is operating properly and that there is no contamination. Compared with the overall cost of building and operating the plant, these analytical costs seem a rather minor component. They could perhaps be reduced by combining samples from more than one plant at a central laboratory, although this may be difficult depending on how far apart they are..	Neutral impact

Q39	Q8 **Why?**	Q37 **How can the economic impact be improved or mitigated?**	Q9 **Please respond to the following questions to the best of your ability.** **The UAE and other other countries in the Middle East use the Arabian Gulf as their main source of water. What factors should these countries consider when creating regulations on the quality of source water?**
Respondent #1	The discharge water should meet the requirement of WHO standards. The brine management is the critical environment issues in desalination process. The mandatory regulations needs to be followed for the disposal of hazardous waste and microbial source.		The main factors for the source water are salinity, microbial contaminants, emerging pollutants and density.
Respondent #2		By keeping good quality feed water	This is a small sea, with extensive oil production. Desalination should be kept away from pollution sources as ae well as fro the discharged concentrate.
Respondent #3			the chemical composition and amount of the brine discharged into the Arabian gulf. The discharge mechanism. The location of desalination plants.
Respondent #4	If the source water is seawater and the source water is improved, it is going to show marked improvement in the ocean ecosystem.		There are many. However, first they need to acknowledge that all these countries share the same water from the Arabian Gulf. So, it should be a collective responsibility to manage the quality of water in the Arabian gulf.
Respondent #5		Again, compared to the amount of salt that has to be disposed of during routine operations, the addition of a small amount of laboratory chemicals is rather minor.	

Q39	Q10	Q11	Q12
	How does monitoring source water vary between thermal and membrane based desalination?	**What effects can poor source water quality have on the desalination process?**	**Please provide additional suggestions you have on regulations pertaining to source water quality.**
Respondent #1	In both process, biofouling is a common problem for deterioration of desalination process. Membrane process is quite sensitive with contaminants such as salts. Moreover, accurate pressure sensor needs to be monitoring on measurement of flux. Back washing and membrane cleaning procedure needs to be optimized. For thermal process, flow dynamics needs to be maintained.	Microbial contamination deteriorate the flux performance and life span.	Emerging pollutant such as microplastics and nanoplastics needs to have standard regulation on disposal. The other contaminants such as boron and heavy metal also have drastic effect on both desalination process. Besides, scaling agents also needs to be treated prior to desalination. Overall, the pre-treatment process needs to be standardized according to water quality. Artificial intelligence and data science can be implemented to quantify the water sources and pollutants corresponding to seasons.
Respondent #2	Thermal production is less sensitive to salts concentration up to the saturation of calcium sulfate, however at high temperature may contain organic matter. RO membranes are sensitive to organics and bacteria fouling as well as scale formation	poor product and higher production cost	Keep away from wastewater. Maintaining good quality control at all stages of the process
Respondent #3	Thermal processes are less susceptible to fouling and scaling than membrane processes, therefore monitoring should take into account these factors depending on the technology.	It can reduce its efficiency.	Regulations should not only consider discharge of brine but also intake and this should be applied to all countries having coastal bounds with the Arabian Gulf.
Respondent #4	The presence of different types of suspended solids play a big role in the performance of membrane based desalination system. These can include the presence of chlorophyll as well. In thermal desalination these are not necessarily as critical.	It reduces the efficiency, increases amount of waste generated and make the process costly.	waste disposal should be considered strictly in the source water and long term sustainability need to be investigated.
Respondent #5			