A Diversified Energy Portfolio for SEWA's Water Processes

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WPI

AUS | الجامعة الأمريكية في الشارقة
American University of Sharjah

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by
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Report Submitted to:

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Abstract

The emirate of Sharjah is a rapidly growing region looking to decrease its carbon footprint in a country known for its fossil fuel supplies. Sharjah Electricity and Water Authority (SEWA), a local public works ministry, is also building new desalination plants to meet the increasing water demand in the emirate. Our project is to create a diversified energy portfolio including renewable energy to power its water processes. Through interviews and a series of three surveys via the Delphi method, we learned about the advantages and disadvantages of different renewable energy sources as well as received feedback on potential energy portfolios. Our team then used the information gathered to build energy portfolios for both 2020 and 2050 that we recommended to SEWA to assist in increasing their renewable energy options in the region. We suggested that SEWA increase efforts in the research and development of solar energy, especially solar PV, and conduct a feasibility study building upon the results of our project.

Acknowledgments

We would like to thank Dr. AlaEldin Idris, Ms. Mayyada Al Bardan, and Mr. Waleed El Damaty for answering our questions, allowing us to conduct this study, and giving us a letter of support. Additionally, we would like to thank Eng. Othman Suroor Al Mas, for providing us with data. We would like to thank the Sharjah Electricity and Water Authority as a whole for sponsoring our project. We would also like to thank the American University of Sharjah (AUS) for allowing us to stay on their campus and work in their buildings. We would also like to thank all of our participants who were willing to be a part of our study. They were an integral part in our studies success, we could not have done this study without them. We would also like to thank the AUS professors, specifically, for participating in the study as well as the interviews after Round 3. Thank you also, to Sarah Tariq and Urooj Ilyas, who helped us with data collection and editing of the paper. Finally, we would like to express our utmost gratitude to Dr. Joseph Doiron and Dr. John Bergendahl for advising us and supporting us throughout our study.

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Executive Summary

Background

Many countries are starting to transition from fossil fuels to renewable energy sources to help combat climate change. Climate change causes many problems worldwide including temperature increases, rising sea levels, and increased concentrations of carbonate in ocean water. For the UAE, rising sea levels are a serious danger. By 2100, it is projected that the UAE will lose 6% of its coastline due to the increasing sea levels and the lack of sediment available in the area. The country's main protection against this threat is the mangrove forests at the coast. However, due to urbanization these groves are decreasing in number. The UAE needs to join the effort to diversify their portfolio in order to help prevent against these changes.

The UAE is a quickly developing country. Due to the arid climate, the country depends heavily on desalination to provide drinking water. As a result, the country has become heavily dependent on fossil fuels to meet its energy demands. As the population continues to increase, the energy demand needed to produce water increases. The UAE is now unable to produce enough natural gas to meet this demand, forcing the country to import natural gas from other places. For economic and environmental reasons, the country has begun transitioning to renewable energy sources. Diversifying the energy portfolio will allow the country to be able to be more self-reliant and environmentally friendly.

Sharjah is one of the emirates that has not begun the process of transitioning to a new energy portfolio. The current energy portfolio is 100% natural gas, with oil as reserve. The emirate is the third largest in the UAE, with a population of 1.4 million people as of 2015. Like UAE, the population of Sharjah is increasing dramatically, and to meet the increased water demand the emirate is building a new desalination plant. Sharjah Electricity and Water Authority

(SEWA) is the governing body that provides water and electricity to the emirate. SEWA is looking to incorporate renewable energy to meet this increased energy demand. Our study aims to help SEWA create a diversified energy portfolio including renewable energy to power its water processes.

Methodology

We used the Delphi method to conduct our project due to this being a policy study focused on a technical subject. The Delphi method uses a set of surveys sent to experts to narrow down an answer that generates consensus and divergence. Round one asks broader questions to get the participants to start thinking about the subject of the study. Using the answers obtained from round one, a second survey is sent out to narrow down the scope of the study. After the data is obtained from round two, the most common answer is sent out in round three asking if the participants agree or disagree and their explanation as to why.

In order to test our surveys before they were sent out, we asked a few experts from Worcester Polytechnic Institute to take the questionnaires to confirm there were no errors and that the questions we had were worded in the best and most accurate way possible. Based on their comments, we attempted to make sure each round was easy to understand and error free before sending them out to the participants.

In Round 1, we asked participants to provide a general idea of the energy sources they would like to include in an ideal diversified energy portfolio and to explain their answers for both a 2020 portfolio and a 2050 portfolio. Then, using thematic coding, we chose explanations that best summarizes the views of the survey pool to present in the report of Round 1. The report was sent out with Round 2 offered the experts a chance to learn from their peers.

Before taking the Round 2 survey, participants were asked to look at the Round 1 report. In the survey, we asked the participants to assign each energy source a number of points based on how much they wanted that source to contribute to energy portfolios for 2020 and 2050. We planned to create an average portfolio from the answers we received. We found the average of the points for each option as well as analyzed the explanations regarding their choices again. Our findings from Round 2 were presented alongside the survey for Round 3.

For Round 3, survey takers were instructed to read through the report before completing the questionnaires again. Then, survey participants were asked to decide if the portfolio presented to them was ideal for Sharjah for both 2020 and 2050. If they did not believe the portfolio was optimal then they were asked to create a new portfolio using the energy sources they were presented in Round 2. It was important that the participants were able to come to a consensus on an energy profile because the goal of this survey was to arrive at a consensus among the experts about an energy portfolio.

Findings

Finding 1: Final Portfolio for 2020

The energy portfolio for 2020 can be found in Figure A below. Natural gas was given an average of 43 out of 100 points. After natural gas comes oil with an average of 21 points. Next, comes solar PV energy with an average of 19 points. Then, waste-to-energy with an average of 6 points and solar CSP with an average of 5 points, followed by solar thermal with an average of 4 points and offshore wind turbines with an average of 1 point. Inland wind turbines comes last with an average of 1 point of the overall portfolio.

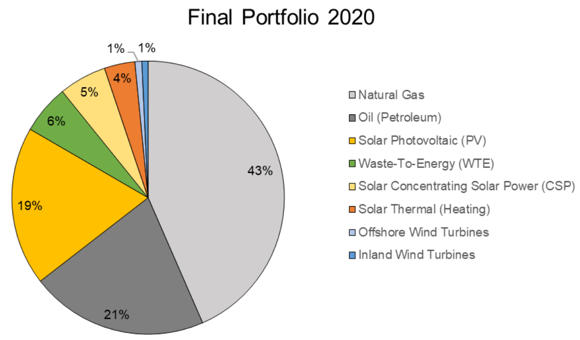


Figure A: Final Portfolio 2020

<u>Finding 2: Final Portfolio for 2050</u>

Figure B shows the final portfolio for 2050. Solar PV was given an average of 40 out of 100 points for the final portfolio for 2050. Next, solar CSP was given an average of 15 points. After solar CSP, natural gas was given an average of 12 points. Then, waste-to-energy with an average of 9 points. After WTE, nuclear was given an average of 8 points. Then, solar thermal energy with an average of 7 points. Following solar thermal energy comes offshore wind turbines with an average of 4 points. Then, oil with an average of 3 points. Finally comes standard inland wind turbines with an average of 2 points of the final portfolio for 2050.

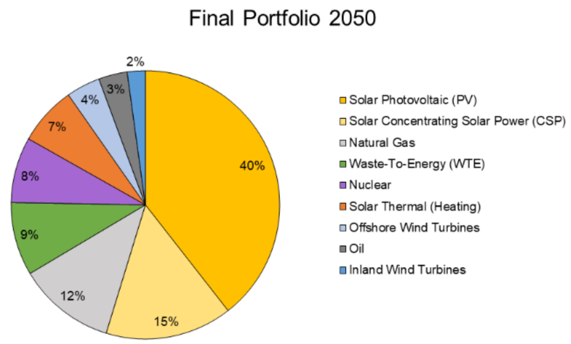


Figure B: Final Portfolio 2050

Recommendations

Recommendation 1: Continuation of Round 3

Round 3 could be repeated with different groups of experts in order to obtain a more thorough portfolio. By adding another diverse group of participants, the response would reflect the opinions of a wider group of experts. This could be repeated as many times as necessary in order to obtain a consensus among a wide group of experts.

Recommendation 2: Feasibility Study

Our ideal study gives SEWA a very optimistic goal to aim for. We advise SEWA to conduct a feasibility study to find what portfolio experts believe would be a plausible goal for SEWA to aim for in the future. This feasibility study could be structured similarly to this study but use the world “feasibility” instead of “ideal” when asking about the portfolios.

Recommendation 3: Potential Research & Development

SEWA may also look at these portfolios as a prioritizing tool. The portfolios can be used to help decide where to invest research and development efforts. For example, because solar PV was predicted to have a high contribution, it may be wise to prioritize efforts in R&D regarding solar PV to further advance the technology and make it more cost-effective in the futures.

Conclusion

In 2020, we recommend that the energy portfolio remain mainly fossil fuels. Solar energy has the greatest potential for being a substantial contributor to SEWA’s energy portfolios. Even in 2020, without many technological advancements, solar PV was found to be the most economically feasible out of all the renewable energy options. WTE should also be considered to also act as a method of waste management.

In 2050, solar PV and solar CSP are the main contributors to the energy portfolio. By 2050, innovations should render these technologies more efficient and lower in costs. Natural gas should remain a small part of the energy portfolio due to its extremely low costs and accessibility. Nuclear, while an efficient means of producing energy, faces several concerns relating to safety and area needed for installation. If wind turbines become cost-efficient in the near future, we recommend placing them offshore in Sharjah's areas on the Gulf of Oman.

Our recommendations and suggestions from this study reflect the opinions of several different experts in the field of renewable energy and energy production. Our analysis has shown that solar energy has the strongest potential out of all the renewable energy options to be a major contributor to SEWA's energy for its water processes. Fossil fuels should still comprise a portion of the 2050 energy portfolio due to its reliability and its accessibility. However, the nature of this study attempted to focus on ideal portfolios for these year.

Chapter 1: Introduction

1.1: Context of the Problem

Countries everywhere face the challenge of generating enough energy for the public while lowering carbon emissions due to the impact of fossil fuel consumption on the environment. One country that has already taken initiative to implement more renewable energy practices is the UAE, a nation known for its abundant fossil fuel supply. With time, there have been several technological improvements in different types of clean energy technology, making alternative options more cost-efficient and accessible. Additionally, due to the climate and environment of the UAE, a large amount of energy is spent on processing the country's water supply in order to be ready for public use. Currently, the country primarily uses fossil fuels, which release greenhouse gases that contribute to climate change throughout the world.

Climate change caused by greenhouse gases provides ongoing problems that threaten the environment of the planet, such rising sea levels. For the UAE and other coastal countries, rising sea levels present a danger to coastal infrastructure as well as native animal and plant species. Unlike many countries, the UAE lacks the type of soil that is carried and deposited by ocean currents along the shore, which helps prevent coastal flooding. Studies have found that along the Arabian Peninsula, the wetlands and mangrove trees are very important for protection against flooding due to sea level rise. Urbanization has resulted in damage and destruction of many of these areas, reducing the protection against coastal flooding (Sandre et.al, 2018). For this reason, countries around the world are starting to implement policies to increase the amount of clean energy generated in order to reduce greenhouse gases and slow the effects of climate change.

The UAE has experienced a large population increase since its founding. In 1971, the population was a little under 300,000. In the present day, the population stands at 9.4 million, 31 times larger than in 1971. This number is expected to increase, according to the World Data Bank. The population is predicted to climb up to 10.6 million for 2030 as seen below in Figure 1 (World Bank Group, 2019).

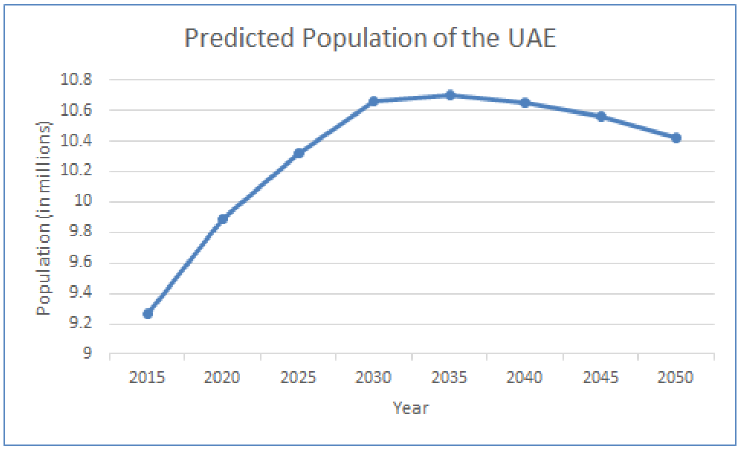


Figure 1: Predicted Population of the UAE through 2050

In a 2015 census conducted by the Department of Statistics and Community Development in Sharjah (DSCD), they found that more than 1.4 million people live in the emirate of Sharjah alone. 90% of the population, almost 1.3 million people, reside in Sharjah city, resulting in a population density of 5143 people per square kilometer. As with any growing population, the electricity and water demand of the emirate will increase as a result (The Editor, 2017).

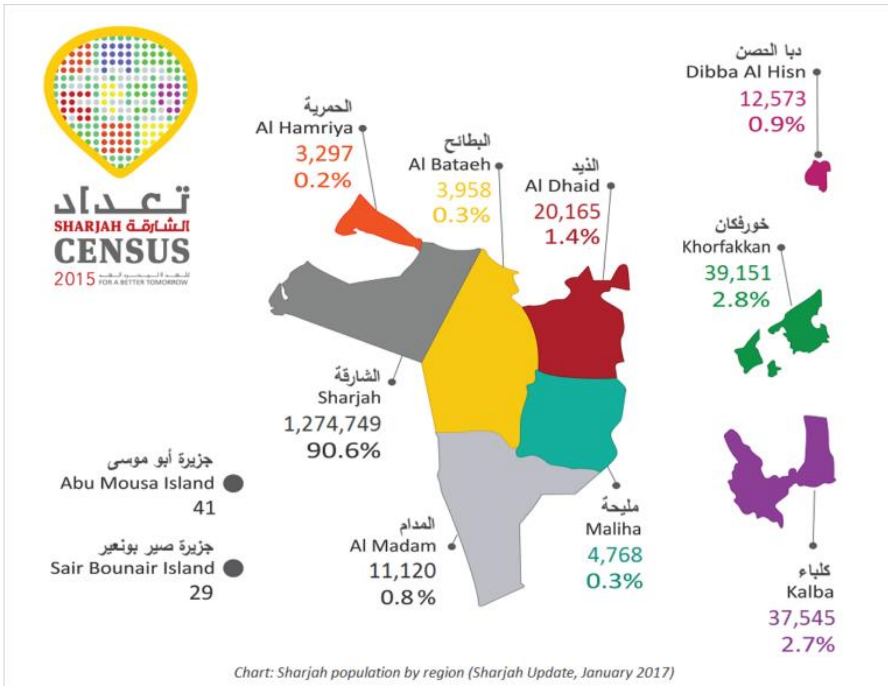


Figure 2: Population of Sharjah Municipalities

Reprinted from *Sharjah Update*, by The Editor, 2017, Retrieved from http://www.sharjahupdate.com/2017/01/sharjah-census-2015-results-announced-sharjah-population-reaches-1-4-million/ Copyright 2017 by Sharjah Update

1.2: This Project

The UAE has become dependent on oil and gas resources due to the location of the country and its availability. However, the increase in energy demands due to the increased population means that the amount of natural gas needed is higher than the amount it produces, making it an importer of the resource. The natural gas produced in the country also needs to be treated due to its high Sulphur content, making it more difficult for the country to produce enough. Along with the potentially increased prices of exports the UAE will potentially face in the future due to increased international tensions, this represents a large cost to the UAE economically. These present both security and economic problems to the country (Masdar Institute of Science and Technology & International Renewable Energy Agency, 2015).

Aside from its plentiful reserves of oil and natural gas and its quickly increasing population size, the UAE is also well known for its rapidly growing and developing economy, especially its growth from the past 30 years. The country's economy ranks high in terms of GDP per capita, human development, and energy consumption per capita (Al-Mulali & Che Sab, 2018). From 2016 to 2017, the UAE's GDP increased by 0.8%. However, oil and natural gas contributed the most to the GDP as presented in Table 1 below. This shows that the UAE is still highly dependent on oil and gas as part of their economy. InIn 2012, the Green Economy Initiative was launched by Sheikh Mohammed with the plan of both further developing the country's economy and becoming a more environmentally friendly nation. This initiative included encouraging investments in renewable energy and the development of other green technologies. In order to maintain the twin goals of economic growth and reduction of fossil fuel consumption, local energy and water authorities like SEWA must consider diversifying their energy portfolio with renewable energy options (The Official Portal of the UAE Government, 2019).

Economic sector	Sector contribution to the GDP for 2017 (%)
(Extractive Industries (including Crude Oil and Natural Gas	29.5
Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles	11.7
Financial and Insurance Activities	8.6
Construction and Building	8.4
Transformative Industries	8.3
Public Administration and Defense; Compulsory Social Security	5.8
Real Estate Activities	5.7
Transport and Storage	5.4
Electricity, Gas and Water	3.2
Information and Communications	2.9
Professional, Scientific and Technical Activities	2.6
Accommodation and Food Services Activities	2.2
Administrative and Support Services Activities	1.9
Other sectors	3.9

Table 1: Contribution of the Economic Sectors in GDP for 2017
Adapted from *The Official Portal of the UAE Government*, by UAE Government, 2018, Retrieved from https://www.government.ae/en/about-the-uae/economy. Copyright 2019 by Government.ae.

As a country, the UAE has plans to obtain its energy from 12% clean coal, 38% gas, 6% nuclear, and 44% renewable energy by the year 2050. Currently, the clean energy efforts in the UAE are primarily centered in Dubai and Abu Dhabi. The largest source of renewable energy in the UAE is solar power. Solar panels are used by residents and businesses alike in Dubai and Abu Dhabi due to the initiatives that allow solar panels to be installed on one's property in exchange for reduced electricity bills, with Dubai having installed solar panels on 1,354 buildings as of October 2019. The UAE also has multiple large solar parks and projects and plans to build more. The electricity is used on site and the surplus is exported to the emirates' electrical network. Along with solar power, the UAE has plans for nuclear power plants. With the help of US financing, four nuclear power plants are intended to be constructed in 2020, 2021, 2022, and 2023 in Abu Dhabi, where it is feasible due to the large land area (International Trade Administration, 2019). While Sharjah doesn't have the resources available for some of these methods, others could be potential energy sources for the emirate.

Research concerning the potential of wind energy has been done for the emirate of Sharjah. A study used 16 different types of wind turbines to find the most efficient models for a wind park in Sharjah when considering several factors such as energy output and the price of power generation. Models with higher hubs performed better, due to the higher speed of wind found at their respective elevations. Despite the increased elevation, the wind speeds were still quite low, with an average speed of around 3.64 m/s at 10 m. Due to these slower wind speeds, models with lower rated wind speeds worked more effectively than those with high wind speeds (Al-Tajer & Poullikkas, 2015). In spite of the low wind speeds in the emirate, this study shows that there is potential for this energy types in Sharjah, making it a candidate for powering SEWA's water processes.

1.3: Problem Statement

SEWA is looking to create a diversified energy portfolio for their water processes that includes renewable energy. WPI-AUS students will work with the appropriate SEWA department to identify which potential renewable energy sources are most appropriate for Sharjah.

1.4: Summary

In this chapter we looked at the context of the problem, our project, and our problem statement. We looked at the climate and population of the UAE and Sharjah specifically. In addition, we examined the available energy technologies for the UAE and introduced our problem statement.

In chapter two we provide more detail concerning the background of our project. We explain who our sponsor is and present some background specifically about renewable energy technologies. We then go over a few case studies to inquire about renewable energy policies. In chapter three, we explain the methodology of our project, our data collection, and how we will analyze our findings. In chapter four, we look at our findings from each round of our project. In chapter five, we analyze our findings from chapter 4 and find common trends among data. Finally, chapter six is our conclusion and we talk about where to go in the future regarding our project.

Chapter 2: Literature Review

2.1: Project Site and Sponsor

2.1.1: Site Description

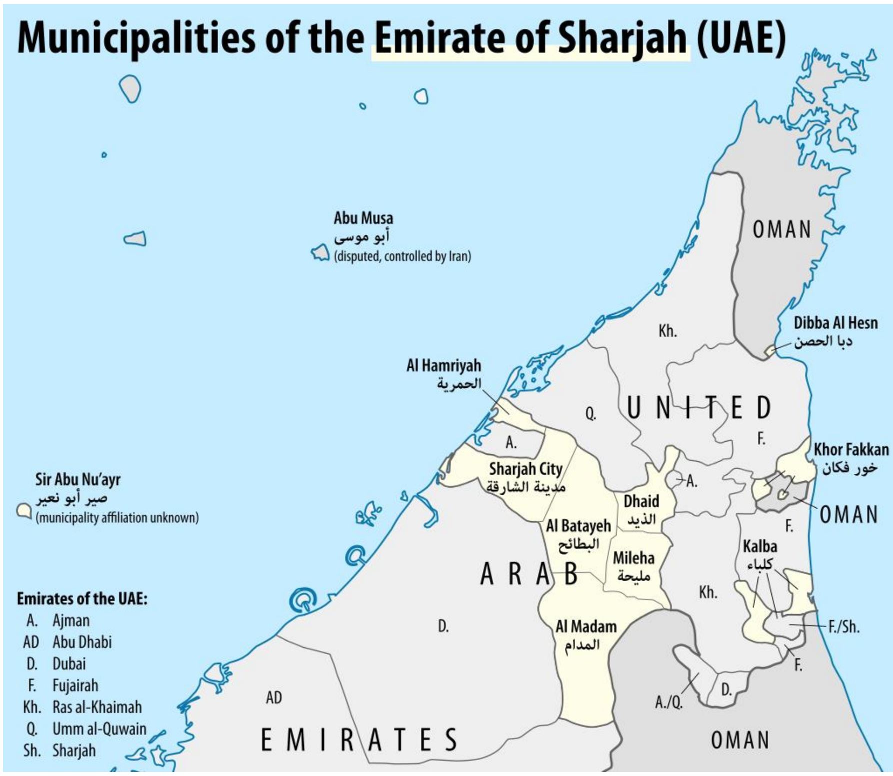


Figure 3: The Emirate of Sharjah (UAE)
Adapted from "Dhaid, " by M. Dörrbecker, 2018, 2018, May 6, *Wikipedia*. Retrieved Sept 12, 2019, from https://en.wikipedia.org/wiki/Dhaid.

Sharjah is the third largest emirate in the UAE with a population of 1.41 million people as of 2015 and an area of 2590 square kilometers (The Editor, 2017). It is located in the northern region of the UAE and has land on both the western coast (Arabian Gulf) and eastern coast (Gulf of Oman). Within Sharjah, there are five major cities: Khorfakkan, a port city, Kalba, a historic hub, Dibba, a set of coastal villages, Al Dhaid, the agricultural center of the UAE, and Al Badayer, a popular desert area. Sharjah is also well-known for being a cultural hub. Because the emirate is only a short drive from Dubai and rich with the arts, tourism is a substantial part of their economy. It is home to almost 25% of all museums in the UAE, including the Sharjah Museum of Islamic Civilization. Sharjah is ruled by His Highness Sheikh Dr. Sultan bin Muhammad Al Qasami, whose family has ruled since 1600AD (The Official Portal of the UAE Government, 2019).

2.1.2: Agency Profile

The UAE government supplies water and electricity to its people through four different authorities: Federal Electricity & Water Authority (FEWA), Abu Dhabi Electricity & Water Authority (ADWEA), Dubai Electricity & Water Authority (DEWA), and our sponsor, Sharjah Electricity & Water Authority (SEWA). SEWA aims to provide the necessary resources to the public while also engaging in sustainable practices to preserve the environment. In order to help preserve the environment and follow in the rest of the UAE's footsteps, SEWA has turned toward generating electricity using renewable energy sources (SEWA, 2019).

2.2: Stakeholders

SEWA is the main stakeholder of our project. The authority is looking to provide drinkable water for Sharjah's residents through more sustainable means. SEWA is invested in the results of this project as they believe the findings from our study will be useful in making decisions concerning what renewable energy options to use in the future. To accommodate for the increase in water needs and the desire to shift away from fossil fuels, SEWA needs a wider variety of energy sources to produce potable water. As a result of their investment in our project, they have given us access to some of their data as well as members of their engineering team, hoping that these resources will help us in our study.

A less direct stakeholder is the UAE government. The UAE government's oversight is larger than SEWA, so they might like to see what other effects our analysis might have. For example, they might be involved because several studies have proven that energy consumption and economic growth are very closely related (Keček, Mikulić, & Lovrinčević, 2019). By 2050, the UAE also hopes to create over 90,000 jobs in the renewable energy field. The goal to experience an increase in renewable energy related jobs for economic growth puts the federal government in a position to be a stakeholder in this project (International Trade Administration, 2019).

2.3: Benefits & Background of Renewable Energy

Modern power distribution systems made energy reliably available and relatively independent from energy plant location. More than two centuries of past industrialization took advantage of non-renewable energy resources, often with undesirable side effects such as pollution and other damages to the environment. Extraction from nuclear energy grew in popularity in the second half of the 20th century, relieving some demands on limited fossil fuel reserves. The most common renewable energy systems worldwide are hydroelectric, solar PV, and wind. In 2007, the world's renewable energy production share was calculated to be 19%. Approximately 16% was due to hydroelectric energy production. Wind and PV energy production, the two most promising renewable energy resources, was still very modest. The wind energy production forecast for 2011 was more than 200 GW and, despite the silicon shortages in years prior, the PV industry is growing at more than 30% per year. Other emerging renewable technologies include wave and tidal energy conversion, biomass energy conversion, and small scale hydroelectric plants (Liserre, Sauter, & Hung, 2010). By the end of 2018, renewable energy production equated to 26% of global energy production. This increase is driven by targets and stable policies (GSR, 2019).

Solar cells directly convert the sun's energy into electricity without any moving parts. This includes solar CSP and solar PV. CSP uses mirrors and/or lenses in order to concentrate solar power, which can then be converted to heat and electricity. PV devices such as solar panels use semiconductor cells in order to convert solar energy into electricity. The ocean is Earth's largest collector of solar energy, and ocean thermal platforms have a large potential for electricity generation. The UAE has a number of viable solar energy options to choose from. In addition to solar energy, the UAE could explore using wind energy technologies. Wind energy represents the most cost-competitive renewable energy source in most countries. Regarding the UAE, solar energy is the most promising energy source due to extremely sunny conditions year-round. Wind as an energy source can be used anywhere in the world and represents a dual-use technology: the land under the wind turbines can still be used for farming, ranching, and forestry. Biomass power ranges from burning wood chips in power plants to burning biogas from waste treatment plants to generate methanol and ethanol, which can be used as fuels (Turner, 1999).

There is a connection between renewable energy and sustainable development. Environmental issues humans face today need long-term solutions for sustainable development. Environmental problems span a continuously growing range of pollutants, hazards, and ecosystem degradation. Renewable energy technologies produce marketable energy by converting natural phenomena into useful energy forms. These technologies use the energy present in sunlight and its direct and indirect impacts on Earth, gravitational forces, and the heat from the Earth's core as the resources from which they produce energy. These renewable energy technologies use resources that are readily available, infinite, and have little to no negative environmental impact. These resources represent a massive energy potential which mimics that of equivalent fossil resources. Renewable energy technologies become important as environmental concerns increase, utility costs climb, and labor costs rise. Renewable energy technologies require a low operating cost whereas fossil-based technologies require a high operating cost. Development of advanced renewable energy technologies can serve as cost-effective and environmentally responsible alternatives to conventional energy generation (Dincer, 2000).

2.4: Power Consumption and the Desalination Process

Because the UAE is a constantly growing country, more power is needed to meet the needs of the people as the population increases. Air conditioning and clean water processing are two of the main factors as to why the UAE has one of the highest electricity consumption per capita (Sgouridis et al., 2016). Presently, Sharjah has a desalination capacity of 115 million Imperial gallons per day (MIGD). As seen in Figure 4, the electricity generated for water production has slowly declined in the past three years. However, there is a drastic rise between 2014 and 2015 due to the installation of the latest desalination plant in Hamriyah. The amount of electricity generated will experience a similar surge in the coming years once the new 60 MIGD capacity desalination plant opens in 2020 (SEWA Research and Studies Department, 2019).

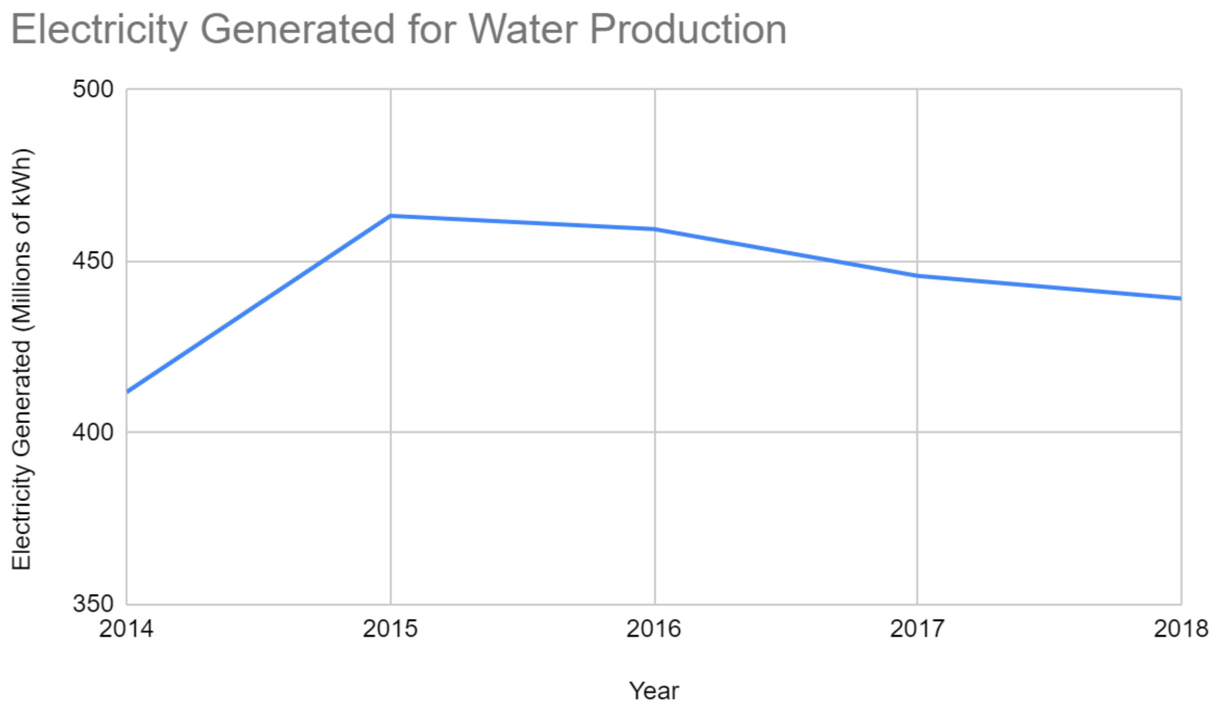


Figure 4: Electricity Generated for Sharjah's Water Production 2014-2018

In 2010, electricity and desalination accounted for around 36% of the UAE's total natural gas consumption (Said, Alshehhi, & Mehmood, 2018). In 2018, because of Sharjah's extremely arid climate, only about 10% of their water supply came from groundwater. The rest of the water that they produced had to be taken from the sea and brackish water and desalinated in one of SEWA's nine processing facilities (SEWA Research and Studies Department, 2019).

Currently, a major concern for incorporating more renewable energy into the current energy portfolio is dealing with the dependence of water processing methods on electricity generation. This is because most of the water is desalinated using heat for thermal cogeneration plants, where excess heat is repurposed. In water processing, the excess heat is used for the heat needed in multi-stage-flash (MSF) desalination (Masdar Institute of Science and Technology & International Renewable Energy Agency, 2015). About 95% of the UAE's desalination plants process water by thermal desalination using MSF technology. Since most renewable energy sources will only directly generate electricity, they must be able to provide enough energy to produce the heat needed for MSF desalination while maintaining both cost efficiency and production capacity of fossil-fuel powered plants.

While MSF has a high installed capacity, it is much less efficient than reverse-osmosis (RO) plants (Sgouridis et al., 2016). There are already six desalination plants using RO that process their water on the Gulf of Oman where salinity is relatively low. If attempts were made to desalinate water in higher salinity areas, a higher amount of waste brine should be expected. This may be a concern as the brine may contain toxic chemicals leftover from previous stages of the desalination process. Despite the fact that RO technology is much harder to maintain, it has great potential to be powered by clean energy sources because RO technology requires less power (Masdar Institute of Science and Technology & International Renewable Energy Agency, 2015).

Sharjah plans to build a new desalination plant due to its anticipated 2022 population boom. SEWA is exploring possible renewable energy sources to use when powering the new desalination plant to reduce the region's reliance on fossil fuels. The plant will function on the basis of reverse osmosis technology, a less energy-intensive method of desalinating seawater (Gnana, 2019). A typical reverse osmosis desalination plant consumes 10-13kWh per every 1000 US gallons. As Sharjah's new desalination plant is expected to have a capacity of 60 million imperial gallons per day, this will amount to an energy consumption of at least 720MWh per day. Implementing some renewable energy sources into its energy portfolio will assist SEWA in offsetting some of the CO_2 emissions that may accompany this increase in energy consumption (Peterson, 2017).

2.5: Summaries of Case Studies

In this section we review three case studies regarding renewable energy technologies to assist in determining possible problems we may encounter as part of this policy study. In the first case study, we discuss Ghana's struggles to move toward an energy portfolio supported by renewable energy. The second case study we review is about the use of renewable energy in Germany. The study examines the implementation of an energy transition policy to switch over to renewable energy sources. In the final case study we review, we explore the renewable energy technologies in Jordan. Jordan has experimented with renewable energy but due to the lack of investment in the entire system, they have not been able to optimize its usage.

2.5.1 Renewable Energy Prospects: Ghana

Ghana has a number of natural resources that can be used to power different types of renewable energy including solar, wind, biomass, and hydroelectric. Despite the abundance of resources, Ghana lacks the policies and regulations that can allow them to truly take advantage of what they have. The country aimed to have renewable energy contributed to at least 10% of the national grid's electricity by 2020. Ghana also plans on increasing access to renewable energy, effectively monitoring the importation and local production of renewable energy technology, as well as developing sustainable markets for renewable energy (Gboney, 2009).

To help achieve its goals, Ghana established the Energy Commission (EC), the Public Utilities Regulatory Commission (PURC), and Energy Federation (EF) in 1997. The EC recommends the development and utilization of Ghana's natural resources develops renewable energy regulatory and legislative framework. It also acts as a principal advisor to Ghana's Ministry of Energy. The EC's work ensures that the more renewable energy will be incorporated into Ghana's energy portfolio. The PURC is responsible for regulating the distribution of renewable energy technologies. That is, it facilitates the renewable energy technologies' connection to the national grid. Additionally, it is also responsible for regulating prices and quality of service. Lastly, the EF promotes the development of energy efficiency and providing consumers with energy solutions. The already-existing Ministry of Energy is responsible for creating policies for the energy sector (Gboney, 2009).

Several obstacles slowed or hindered the effects of the above policies. The majority of the problems encountered were either financial or regulation-based. For example, there is a lack of favorable pricing framework for renewable energy technology. The 2008 pricing approach failed to address the benefits renewable energy could provide for the environment, favoring the conventional fossil fuel based energy production methods. Additionally, there is a severe lack of information for renewable energy technology consumers to make well-informed decisions and many investors are unable to secure the capital to invest in this technology (Gboney, 2009).

There are also many assumptions people make about renewable energy technologies that deter them from becoming supporters of clean energy implementation. Upfront, the cost of renewable energy is typically much higher than that of fossil fuels. People also tend to believe that these technologies are risky and unreliable. As time goes on, innovations in renewable energy make for more reliable equipment, eliminating this belief. Poor access to capital as well as the high costs associated with investing deter people from renewable energy. For example, people of low income in rural areas who may need access to electricity the most typically cannot afford the cost of purchasing and installing renewable energy generators. Additionally, a lack of government incentives and outreach to communities promoting renewable energy hinder the growth of renewable energy access. In order to effectively implement these technologies, the public must also be invested in using renewable energy. Communities must further be educated on these matters and encouraged to develop the systems, regulate the framework for the systems, and manage the system. A combination of financial help combined with outreach to encourage people to be more invested in renewable energy technologies will push Ghana towards incorporating more green energy in the country's energy portfolio (Gboney, 2009).

2.5.2 Renewable Energy Prospects: Germany

Germany is seen as a leader in renewable energy efforts, due to their energy transition policy adopted in 2010, called Energiekonzept. This policy sets long term goals for the country to change its energy sources to renewable and environmentally friendly sources rather than fossil fuels. The goals have changed while the policy has been in place, but the current goals can be seen in the table below (Kuittinen & Velte, 2018).

		Status quo	2020	2025	2030	2035	2040	2050
Green-house gas emissions	Reduction of GHG emis-sions in all sectors compared to 1990 levels	-27 % (2016)*	-40 %		-55 %		-70 %	-80 – 95 %
Nuclear phase-out	Gradual shut down of all nuclear power plants by 2022	11 units shut down (2015)	Gradual shut down of remaining 8 reactors					
Renewable energies	Share in final energy consumption	14.9 % (2015)	18 %		30 %		45 %	min. 60 %
	Share in gross electricity consumption	32.3 % (2016)*		40 – 45 %		55 – 60 %		min. 80 %
Energy efficiency	Reduction of primary energy consumption compared to 2008 levels	-7.6 % (2015)*	-20 %					-50 %
	Reduction of gross electricity consumption compared to 2008 levels	-4 % (2015)*	-10 %					-25 %

Table 2: The main goals of the Energiekonzept policy
Adapted from "Case Study Report:Energiewende," by H.Kuittinen & D. Velte, 2018, 2018, January , European Commision. Retrieved Sept 13, 2019, from *https://ec.europa.eu/info/sites/info/files/mission_oriented_r_and_i_policies_case_study_report_energiewende-de.pdf*

These reforms are backed both by political parties and the public. There are multiple driving forces behind this movement, which include environmental concerns, concerns for safe and sustainable energy sources, and the desire to be less dependent on imports. According to surveys, most of the German population feels strongly about climate change and how it affects the environment, along with their sense of duty to make an effort to protect the planet. Germans have also been against using nuclear power for decades, aiming to shut down all nuclear power plants in the country by 2032. However, the 2011 nuclear accident in Fukushima, Japan in which an earthquake and tsunami caused three nuclear cores to melt down spurred the passing of a law requiring all nuclear power plants to cease operation by 2022 (Kuittinen & Velte, 2018).

All levels of government participate in efforts for this project. At the federal level, the Ministry for Economic Affairs and Energy is the branch in charge of this transition away from nuclear power. The regional presidents in charge meet with the federal government to discuss the efforts and outcomes. Along with these groups, other branches of the government coordinate their own efforts that relate to this initiative. While this works well with communication, some people believe that having a horizontal system can lead to disconnects among the different regions (Kuittinen & Velte, 2018).

The cost of these reforms cannot be calculated very accurately due to the complexity. Some critics say that the costs are primarily paid by the consumers, due to the extra tariff prices that cause higher electric bills. The price of power has increased by 50% in 2018 when compared to 2007. However, this switch offers opportunities for new jobs. Germany is the leader in Europe when it comes to the number of jobs in the renewable energy market sector, causing the transition to produce both financial costs and financial benefits (Kuittinen & Velte, 2018).

German greenhouse gas emissions have decreased by 27% since 1990. However, since 2016 emissions have been on the increase. This is thought to be due to lack of gas emission reductions in the transportation, power, industrial, and heating industries. By reducing nuclear power and simultaneously dealing with increased energy demands, conventional energy sources have not decreased in quantity, making the greenhouse gas emissions the same (Kuittinen & Velte, 2018).

2.5.3 Renewable Energy Prospects: Jordan

Jordan has been at the forefront of renewable energy deployment in the Middle East, with the sector accounting for 7.9% of the country's total electricity generation in 2018 compared to 2% in 2013. Jordan aims for around 20% of the energy mix to come from renewables by 2020. Yet, challenges hindering the upscaling of renewables are multiplying as the sector gains momentum. Being an early adopter of renewables, Jordan's experience should serve as lessons both for economies in the region and developing countries around the world (Obeid, 2019).

RE Site	RE Technology	Installed Capacity (MW)	Financing (Million USD)
Mafraq I and II	Solar PV	133.4	180
Al Safawi	Solar PV	66.7	65
Mafraq	Solar PV	10	23
Qweira	Solar PV	103	128
Al Rajef	Wind	83	186
Tafilah	Wind	117	302
Fujeij	Wind	90	187
Ma'an	Wind	80	149

*Table 3: Relationship between investments made & capacity installe*d at RE sites (Jordan)
Adapted from: "Jordan: A case study in expanding renewable energy" by Jessica Obied

Jordan is a highly indebted economy and heavily reliant on fossil fuels. Violent conflicts have disrupted the fuel supply over different periods in the past 16 years, revealing the fragility of the kingdom's energy security. To improve energy security and lessen the economic burden, in 2012 Jordan put in place a phased removal of fuel and electricity subsidies, and adopted aggressive renewable energy targets to mitigate its dependency on fossil fuels. Since 2007 renewable energy had been a central energy policy, with the authorities pledging to increase the sector's share in the energy mix to 10% by 2020, a goal which was modified in 2018 to 20%. In 2012, the kingdom became the first country in the region to develop a regulatory framework for the sector, through issuance of the Renewable Energy and Energy Efficiency Law (REEEL) No. 13. It has adopted net-metering and power wheeling policies to facilitate the deployment of small scale wind and solar projects and invested heavily in utility scale projects. In 2018, the country was ranked as having the third most attractive environment for renewable energy investment among developing countries by the Bloomberg Climatescope Index (Obeid, 2019).

The cost of developing many of the thermal projects and early renewable energy plants is higher than in other countries in the region, which hinders the government's ability to decrease electricity tariffs. While the government has been focusing on attracting renewable energy projects, it has neglected the status of the grid, the balance and flexibility of the system, control and demand side management, and energy storage. The lack of investment in the grid is a key barrier to increase renewable energy generation. The kingdom has focused on two types of renewable energy technologies: solar photovoltaic and wind farms. While focusing on these energy technologies, the kingdom has failed to focus on energy storage. Without having storage, the excess energy created will go to waste (Obeid, 2019).

Jordan is not a success story yet, but the challenges it has faced are a learning case for other developing countries. The intermittency of renewables will become an increasingly significant challenge for the electrical grid as renewables cross the 10% threshold of the primary energy mix. This will require costly system balancing, storage, and control. Development of the sector cannot take place without accounting for the broader power sector in terms of the energy mix, implementation of thermal generation regulations, and investment in the grid and other components (Obeid, 2019).

2.5.4: Cross-Case Analysis

We analyzed the three case studies presented above using the cross-case analysis technique in order to find common trends in the policies of the country, as well as the differences and how effective they were. We will look at the similarities and differences in investment, policies, and public opinion of transitioning to renewable energy.

Increasing Renewable Energy Contribution to Energy Portfolio

The case studies from above all aimed to increase the contribution of renewable energy to the national energy portfolio by 2020. All countries were originally fossil fuel-based, and hoped to use more solar power and wind energy achieve their respective goals. While Germany did not face many financial obstacles, developing countries like Ghana and Jordan struggled mainly due to lack of capital. The absence of financial support and regulation in the market also led to the slow spread of renewable energy technology. Due to the lack of policies supporting renewable energy technology in these countries, access to clean energy is difficult for those who may need it the most, including people in areas already lacking electricity. Both Ghana and Jordan lack investment in an energy storage system and therefore let excess energy go to waste.

Increase Public Involvement

One commonality that Germany and Ghana shared was their attempt to encourage the public and private businesses to install renewable energy devices on their land to contribute to the energy production. This was far more effective in Germany. The German public supports expansion into renewable energy, with 95% of the public considering the transition to renewable energies very important. Ghana's biggest difficulty with convincing the public is the financial cost of these technologies. These devices are more expensive than fossil fuels, and people in low income areas can't afford to install them. The public also trusts conventional methods more due to their reliability. Due to outdated pricing framework, fossil fuels are typically more favored as the pricing approach fails to account for the many health and environmental benefits that come with renewable energy. This distancing from renewable energy translates into a public disinterested in renewable energy technology. Without people in communities involved and interested in implementing renewable energy, systems are less likely to be maintained and managed.

Financial Resources to Invest

While Jordan and Ghana are considered developing countries, the UAE is not. However, it is not at the same level of development as Germany. The UAE has the financial resources required to invest in renewable energy as well as other energy storage systems like more developed countries. It is easier to incorporate renewable energy technologies in areas of the world that can afford to invest heavily into the system as a whole. This is evident when looking at the three case studies we reviewed. Jordan and Ghana are not as capable as Germany when it comes to investing in renewable energy technologies.

2.6: Summary

With a growing population and higher demand for water, SEWA needs more energy options to continue to provide the public with drinkable water. SEWA already has several desalination plants, with more to come in the near future. Because the power consumption of desalination plants is so large, SEWA needs to determine how it can meet its future energy demands. As part of its search for more energy production methods, SEWA hopes to power its water processes with more renewable energy in order to step away from using finite fossil fuels and reduce their carbon footprint. By incorporating more clean energy into their energy portfolio, Sharjah is helping the UAE achieve its goal of having renewable energy contribute to 44% of the country's total energy mix by 2050. Doing so will also help in mitigating the effects of climate change.

It has become apparent, however that SEWA's goal is something that cannot be accomplished by a single expert. Rather, we need the knowledge of several experts with backgrounds in clean energy and powering SEWA's water processes to create an optimal energy portfolio. Moving forward, we will be looking into methods to gather information from these experts to build the energy portfolio.

Chapter 3: Methodology

As part of the UAE's plan to become a greener and more environmentally friendly nation, a public works authority for Sharjah, SEWA has decided to reconsider how its water processes are powered. Currently, these processes are powered almost exclusively through fossil fuels, but SEWA's goal was that this project would assist in building an energy profile that will both supply enough water to its customers while also decreasing its greenhouse gas emissions. This included providing recommendations of green energy sources and projected relative generation capacities of each source. The following section will review how and when we accomplished this task, including what we accomplished each step, goals for data collection, and any problems encountered. The objectives of this project were the following:

- Understand the advantages and disadvantages of using certain types of renewable energy
- Create a diversified energy portfolio for SEWA's water processes that includes renewable energy for both 2020 and 2050

3.1: Delphi Method

We used the Delphi method to conduct our project due to this being a policy study focused on a technical subject. The Delphi method uses a set of surveys or questionnaires sent to experts to narrow down an answer that generates consensus and divergence. For the Delphi method to work, round one should ask broader questions that participants answer to the best of their abilities. Using the answers obtained from round one, a second survey is sent out with more specific questions being asked. After the data is obtained from round two, the most common answer is sent out in round three asking if the participants agree or disagree and their explanation as to why they agree or disagree. This step can be used as many times as needed to come to a consensus from the participants (Twin, 2019).

3.2: Participant Criteria

To conduct a Delphi study, participants in the study must be experts in the field. Our team defined experts as people who have been studying renewable energy or energy production or working in the industry for several years. We intended to use a variety of experts local to the area as part of our participant pool. Professors at local universities were invited to participate in the survey. Understanding our need for a variety of local experts, SEWA also provided a letter supporting our study and encouraging people to take our survey. Using this letter as support, we reached out to contacts who did not work in academia provided by SEWA and our American University of Sharjah (AUS) partners asking them to either take the survey or distribute it to people with the appropriate background.

Our final participants pool include professors from AUS and WPI in the chemical, civil, electrical, environmental, and mechanical engineering departments also well as various engineers who work in consulting firms and environmental waste management companies.

3.3 Data Collection Methods

Our goal in performing a decision-making Delphi study was to understand expert opinions on different energy sources to propose an ideal energy portfolio and policy recommendations for SEWA's water processes. Because this is such a complex and technical problem, this cannot be achieved without the knowledge and expertise of several people in the field of energy production. The desired result from the study is a list of renewable energy options, each with a value describing its proposed contribution to powering water processes, that the survey-takers could generally agree upon. Not only did we need to determine which energy sources would work best, we also needed to understand why they worked best to recommend informed policy decisions. For example, responses may include why using solar PV to power 10% of the energy needed for a facility is better than using wind energy to power the same amount.

Questionnaires and surveys were used to collect our data. The way in which we structured the surveys meant that the answers would not be biased by the other experts opinions, allowing any consensus to be natural agreement rather than influenced by response bias. To collect data from the participants in this study, we used the survey software from Qualtrics. Qualtrics offered a simple interface that also allowed for sophisticated data collection, analysis, and reporting. The information we gathered could also be exported as a spreadsheet and formatted for easy reporting. Qualtrics was also considered to look more professional than other available survey software such as Google Forms. When distributing the surveys, it was critical that we captured the attention of the participant and that they regarded our study seriously so that they would continue to participate in all three rounds of our survey.

To obtain more detailed answers, we conducted 3 follow up interviews with AUS professors. In these interviews, we asked for clarification for some of their answers as well as questions aimed to obtain more detailed reasonings as to their answers. We looked for trends among their answers in order to get a better idea of their reasonings for their responses. We also asked for why they changed their answers and about whether the structure of the Delphi study changed their opinions in the subsequent rounds or not.

<u>3.3.1: Pilot Test</u>

Pilot testing is a key component of a research study used to catch errors and give researchers a chance to reflect on and change their procedures. In order to ensure that the surveys for each round were designed properly and that the questions asked were structured in a manner that facilitated responses from experts, we ran a pilot study with a small number of participants before each round. Doing so would help ensure that questions were properly understood by the experts and that we were prepared to conduct analysis on each round for the actual Delphi study.

Participants

Due to the time constraints and nature of our methodology, we enrolled WPI students and faculty to participate in our pilot test. We believed that because members of the WPI community were familiar with IQPs, they better understood our urgency and would be more willing to provide prompt and meaningful responses. Because we also wanted to confirm that experts understood our project, we reached out to members of WPI's Renewable Energy Innovation Lab as well as faculty members with a background in renewable energy to pilot test each round.

Procedure

Before we sent the surveys for each round in the Delphi study, we asked various people to take the questionnaires in order to confirm there were no errors and that the questions we had were worded in the best and most accurate way possible. The pilot test for Round 1 was sent out after the pilot tester agreed to participate. This meant anywhere from a couple of weeks to a few days before the official distribution of Round 1. The pilot tests for Rounds 2 and 3 were sent out a few days after we received responses from Rounds 1 and 2, respectively, so that we had a mock report of the previous round to present to the pilot testers, allowing the pilot test to resemble the actual Delphi study as closely as possible. As with the actual study, links to each of the surveys were sent to the pilot testers. They were asked to complete the questionnaire and inform us if they encountered anything that may cause confusion. If major changes were made to the survey, we would reach out to pilot testers again and see if their answer would have changed.

Anticipated Outcome

We expected the pilot testers to find some parts of the survey that were worded poorly or difficult to understand. Based on their comments, we planned to edit the survey in order to make sure that when the final survey was sent out the participants were able to understand what was being asked of them.

<u>3.3.2: Round 1</u>

Participant Recruitment, Selection, and Enrollment

Prior to arriving to Sharjah, we compiled a list of professors from AUS and University of Sharjah who have a background in the field of renewable energy. We also compiled a list of companies in the area who had sections that worked with energy generation or water processes. When arriving to Sharjah, we visited the professors in AUS to explain our project and ask for their participation. We were also given a list of businesses that SEWA recommended we contact, along with a letter from SEWA endorsing our project. Those who we deemed to have an appropriate background were sent the Round One link through email, and those who responded were sent the subsequent surveys.

Data Collection

We created all our surveys using Qualtrics. The survey was sent out through email to the experts we wanted to participate in our study. After two days we sent a follow up email to the experts who had not answered the survey. The final day the survey was open we sent one last reminder email to the experts that had not answered the survey. We left the survey open for a few days after for those who may have wanted to answer but didn't have time, and after a few days we closed the survey.

Please choose the types of energy sources you would like to include in an **ideal** energy profile for 2020. If you would like to suggest an energy source that is not included on this list, please select "OTHER" and specify in the next question.

Wood & Agricultural Products	Oil (Petroleum)
Biomass	Coal
Standard Inland Wind Turbines	Natural Gas
Offshore Wind Turbines	Nuclear Energy
Solar Thermal (Heating)	Maritime Energy
Solar Photovoltaic (PV)	Geothermal
Solar Concentrating Solar Power (CSP)	OTHER

Figure 5: Round 1 Survey Question

Analysis & Round One Report

In the first round we looked at the results and selected the most common energy options. Analyzing the data we received in the first round was key in creating the questionnaire for the following round. Using thematic coding, we chose explanations that best summarizes the views of the survey pool to present in the report of Round 1 accompanying the second round. Google Sheets was also utilized to further analyze the data and as a thematic coding assistant through its conditional formatting tools.

3.3.3: Round 2

Data Collection

A link to Round 2 and PDF of the Round 1 report were emailed to the participants that completed Round 1. Before participants filled out Round 2, people were asked to read through the report of Round 1. Using a constant sum survey, survey takers were asked to allocate exactly

100 points to different renewable energy sources based on how much they expected each energy source to contribute to the portfolio. Additionally, participants were asked to explain the reasoning behind their choices.

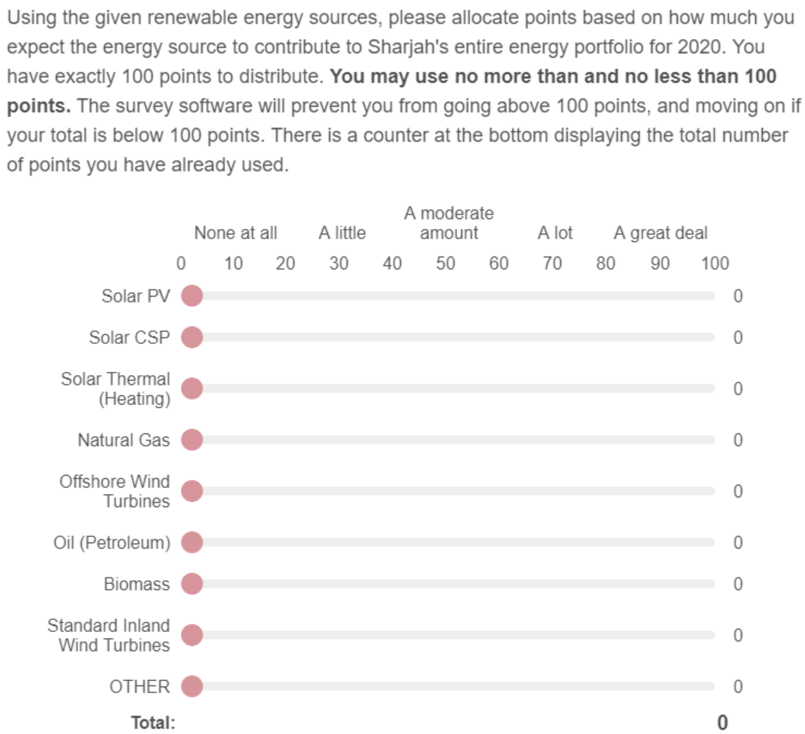


Figure 6: Round 2 Survey Question (2020)

Data Analysis & Round Two Report

We created a mean portfolio from the answers we received. We found the average and standard deviation of the points for each option as well as analyzed the explanations regarding their choices again. We used Google Sheets and Microsoft Excel to create a table with the averages of each energy source. We then created a pie chart showing the mean portfolio using the table we created. Selection of explanations to be presented in the report of Round 2 were dependent on the argument presented and how strongly the argument was defended.

3.3.4: Round 3

Data Collection

Our findings from Round 2 were presented alongside the survey for Round 3. The link to Round 3 and a PDF of the Round 2 report were emailed to people who completed the Round 2 survey. Survey takers were again instructed to read through the report before completing the questionnaires. Then, survey participants were asked to decide if the portfolio presented to them was optimal for Sharjah for both 2020 and 2050. If they did not believe the portfolio was ideal, then they were asked to create a new portfolio with the same energy sources from Round 2, without an OTHER category, and explain the reasoning behind their new portfolio. If they did believe the portfolio was optimal, they were asked to explain why.

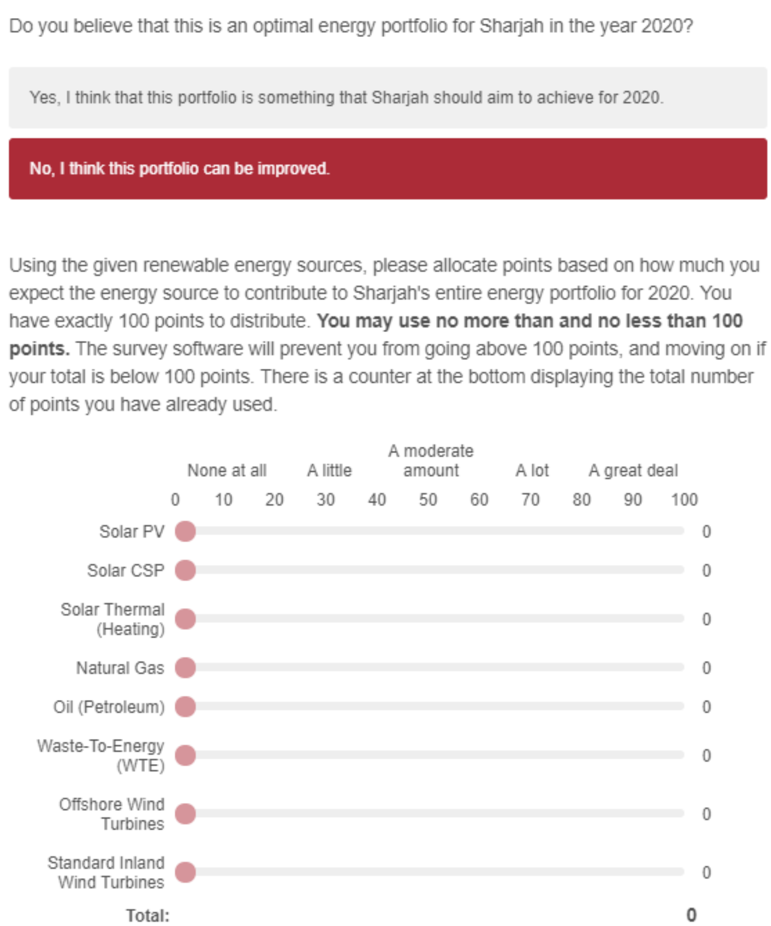


Figure 7: Round 3 Survey Question - "No"

Data Analysis

Because the goal of this survey was to create a portfolio, it was important that the participants were able to come to a consensus on an energy profile. However, we needed to also see that opinions of the minority were heard to encourage survey participants to consider all options. The goal of this round was to take people's opinions on the portfolio created from Round 2 and adjust it based on the responses. However, because people who agreed with the portfolio did not input any new point values for the contributions of each energy source, we substituted the point values for each energy source with those found in that year's portfolio. For example, consider the scenario in which a survey taker agreed with an energy portfolio. If the contribution from energy sources A, B, and C in the Round 2 portfolio were 20, 30, and 50%, then in our calculations for the final portfolio, we treated this response as if the participant answered "No" to the main question and allocated 20, 30, and 50 points to energy options A, B, and C. This final portfolio was then presented as a final deliverable.

3.4: Ethical Considerations and IRB Documentation

This project did not present any risks to the participant. Their data was kept confidential by using an anonymous feature of Qualtrics which allowed the responses to be anonymous and unable to be traced back to the participant that had filled the form out. The questions that we asked were questions one may expect as an engineer, professor, or manufacturing position level executive to receive in their daily life.

Chapter 4: Findings

In the following sections, we will discuss the results from each of the rounds. Each round will be divided into a breakdown of the participants, and the reporting of findings from both the 2020 questions and the 2050 questions. We will report the most popular and least popular energy sources as well as energy sources with the largest contributions and smallest contributions for each energy portfolio. Additionally, we will highlight a few explanations that best summarizes trends in people's reasoning.

4.1: Pilot Test

In the section below, we reflect on our survey design and what steps we took to ensure proper understanding of questions. We will discuss changes made to the original surveys after conducting the pilot tests for each round. This is an important process in our study to ensure utmost understanding of our questions for each round.

4.1.1: Round 1

When pilot testing Round 1, we learned that our original idea of including a large amount of specific energy types made it difficult for the experts to select choices. Our first pilot tester let us know that they were not familiar with some of the very specific energy sources, such as Orimulsion, despite having many years of experience in the field. We realized that this may occur with other experts and condensed the list of energy types into general categories, which we implemented in the round prior to sending it to the experts. Figure 8, below, shows the original copy of the Round 1 survey prior to condensing it into general categories to show how detailed the energy types originally were.

Figure 8: Original Question and Options for Round 1

4.1.2: Round 2

Figure 9 below shows a version of Round 2 sent to pilot testers before changes were made for the Delphi study. Round 2 of the pilot test produced two findings related to user experience and survey design. First, in the main constant sum question, one pilot tester did not realize he had reached 100 points and was unaware that the sliders would stop moving once the point total reached the threshold. Additionally, participants were not explicitly told that they were required to distribute exactly 100 points. To fix this, we added a few sentences clarifying how the program for the constant sum question functioned so that participants would understand why sliders would not move, or why they were instructed to fix their answers when their portfolio did not add up to 100 points.

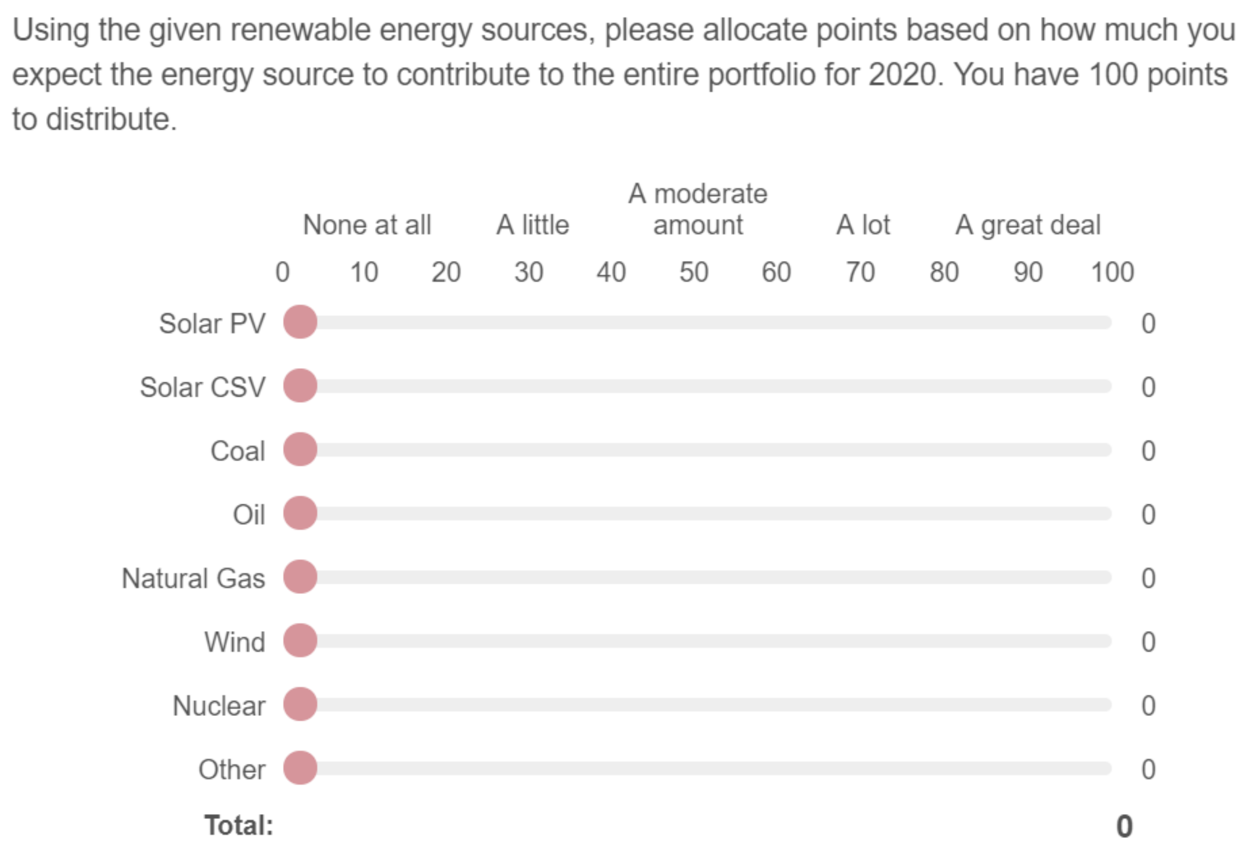


Figure 9: Original Question for Round 2

Second, we realized from an early response that people may want to put more than one energy source under the OTHER category. Participants were not provided with instructions on how to specify multiple energy sources or how to inform us of how many points each option was given. As a result, we quickly adjusted the question asking for the energy sources put under OTHER to specify the number of points for each energy source if there was more than one. Energy sources would be split with commas and points allocated towards an option would be put in parentheses next to the energy source.

4.1.3: Round 3

Pilot testing Round 3 revealed that there was an issue with question phrasing. Some pilot testers didn’t understand what we were asking them to agree or disagree with or the original question found in Figure 10 below. We changed the question to ask if they believe the portfolio shown to them is optimal or not optimal for the future of Sharjah. Additionally, we clearly defined what it is meant when we ask them whether they believe or do not believe it is an optimal portfolio in the answer choices presented to them.

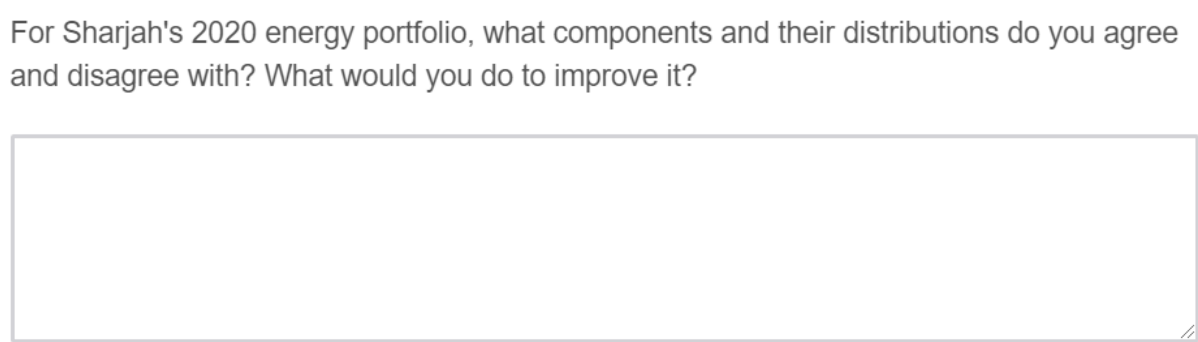


Figure 10: Original Question for Round 3

4.2: Delphi Study

4.2.1: Round 1

Participants

To recruit participants for our survey, we reached out to several AUS professors who had a background in renewable energy or energy production and emailed them about our project. After agreeing to participate, they were sent a link to Round 1 and asked to complete it. Additionally, using personal connections and contacts provided to us by SEWA, we emailed potential survey participants at non-academic companies a link to Round 1 asking them to participate. Table 4 provides a breakdown of participants’ employers. Also, professors were divided into institutional affiliation and departments. The majority of the survey-takers were from an academic background, stretching across the different departments specified below.

Company/Department	Number of Participants
AUS Civil Engineering	2
AUS Electrical Engineering	6
AUS Mechanical Engineering	2
WPI Environmental Engineering	2
WPI Chemical Engineering	1
Al Mostajed Technologies Co. L.L.C.	1
Bee'ah	2
Etihad ESCO	1
Griffin Consultants	2
Honeywell UOP	1
IDOM Consulting	1
Total	21

Table 4: Breakdown of Participants for Round 1

Round 1: 2020

In Round 1, we asked the participants to create a diversified energy portfolio for 2020 to power SEWA's water processes which includes renewable energy. We know that 2020 is only a month away. Because of this we expected to see many portfolios with minimal amounts of renewable energy due to the feasibility of putting them in place in such a short period of time.

The graph below shows how frequently each energy source was chosen. Solar PV was the most common answer with 17 people choosing to include this in their energy portfolio. This was followed closely by solar CSP with 14 people, then solar thermal heating with 12 people. Next was natural gas with 10 people, followed by offshore wind turbines with eight people, then oil with seven people. Biomass with six people followed, then standard inland wind turbines with four people, then nuclear and maritime with three people. Geothermal was chosen by two people, which is followed by wood & agricultural products which was chosen by one person. Finally, coal was chosen by zero people.

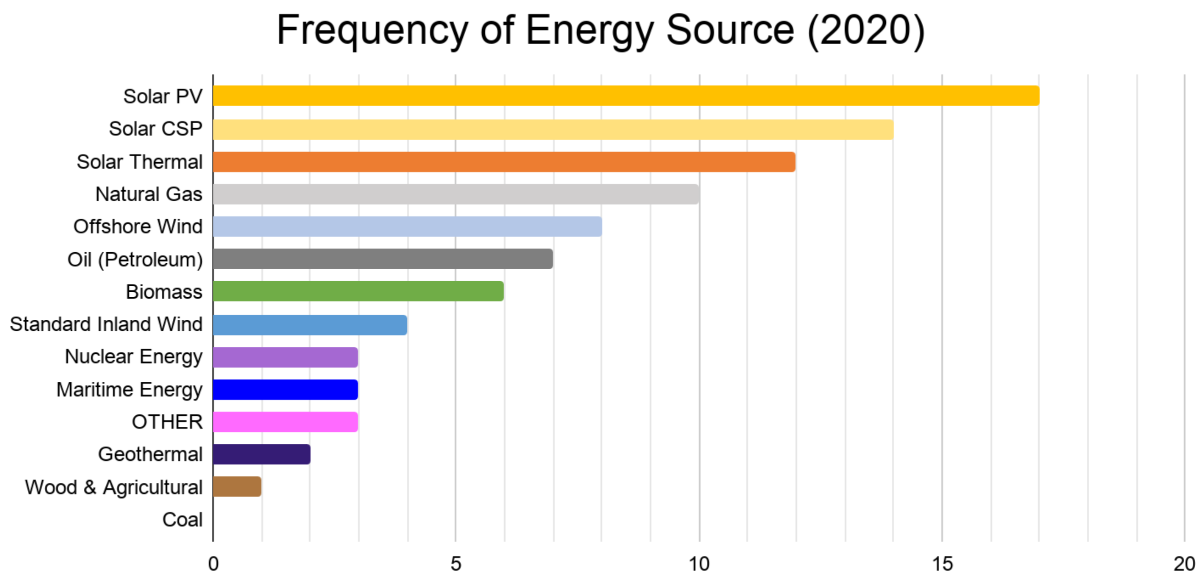


Figure 11: Number of Times each Energy Source was Picked (2020)

Round 1: 2050

In the second part of Round 1 we asked the participants to select energy types for their 2050 portfolio. The graph below shows how frequently each energy source was chosen. Solar PV was picked the most often, with 19 out of 21 picking it as an option. Solar PV was followed by solar CSP with 18 people and solar thermal heating with 14 people. Both types of wind energy were the next most frequently picked, with 12 people picking offshore wind turbines and eight people picking standard inland wind turbines. The rest of the results included six people picking maritime, five picking biomass, four picking natural gas, nuclear energy, and geothermal, two picking wood and agricultural products, and one picking other and oil. Coal was the least chosen with zero of the participants picking it as an energy source.

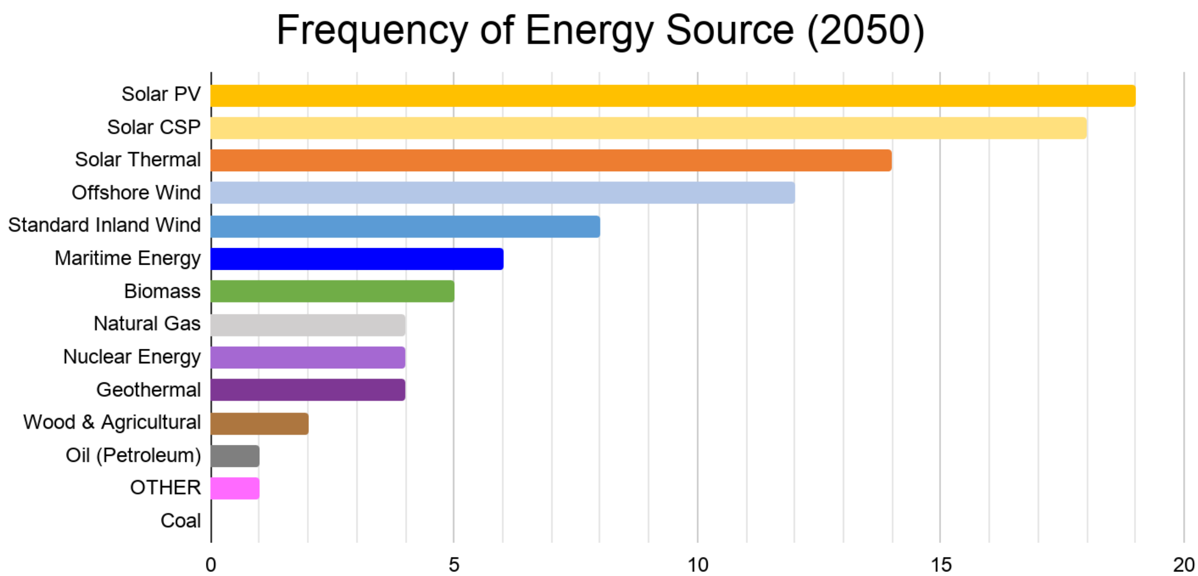


Figure 12: Number of Times each Energy Source was Picked (2050)

Round 1: 2020 vs. 2050

In order to compare the portfolios from 2020 and 2050, the number of times each energy source was chosen should be looked at more closely. Figure 13 shows the change in the number of times each energy source was chosen from the 2020 portfolio to the 2050 portfolio.

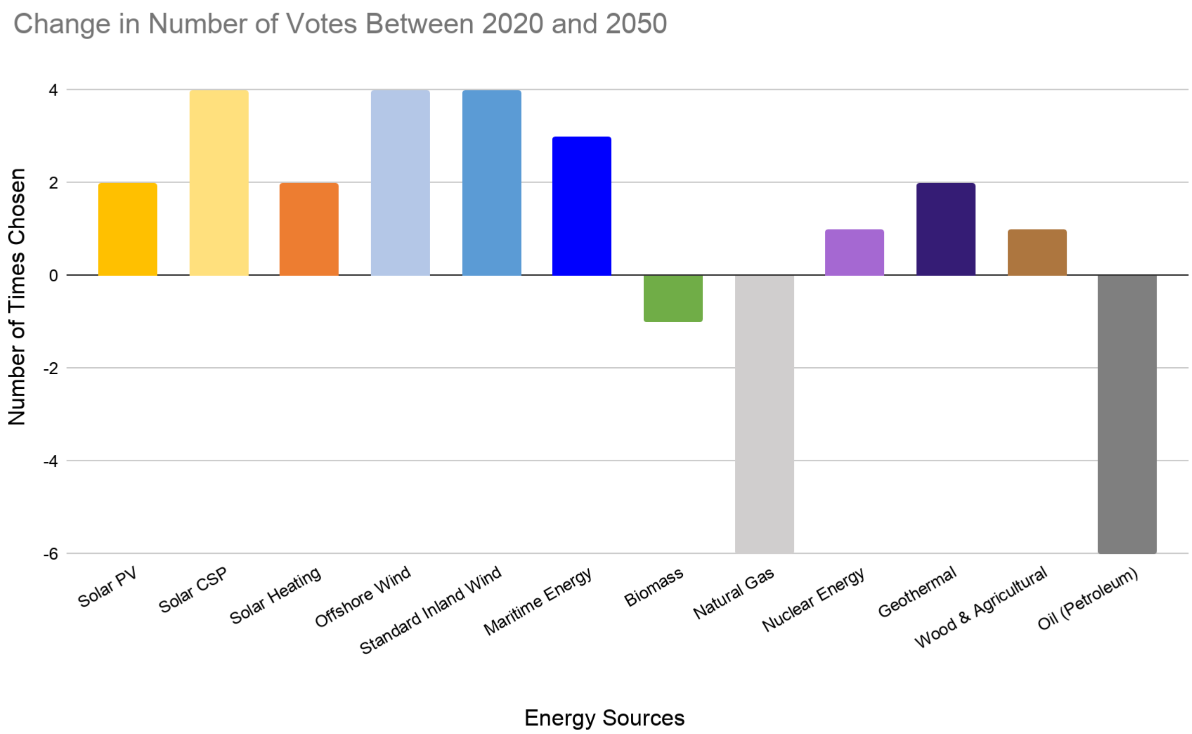


Figure 13: Change in Number of Votes between 2020 and 2050

Figure 13 shows that natural gas and oil have decreased between the portfolio for 2020 and 2050. Natural gas and oil both were chosen six less times for the 2050 portfolio than the 2020 portfolio. Natural gas, in particular, went from 10 people choosing the energy source for 2020 to four people choosing the energy source for 2050. This was expected due to the increased efficiencies of renewable energy technologies in the future, there being only a finite amount of natural resources, and the environmental impacts of natural resources. On average across all renewable energy technologies, 2.2 more people chose them for the 2050 portfolio than the 2020 portfolio. As expected, all forms of solar energy have increased on average by 2.67 people. In addition to solar energy, we expected to see a jump in wind energy as well. When taking a closer look at wind energy, both offshore wind turbines and standard inland wind turbines increased by four people between the 2020 portfolio and the 2050 portfolio. Maritime was chosen by three more people for 2050 than 2020. Geothermal was chosen two more times for 2050 than 2020.

Nuclear energy and wood & agricultural products were both chosen by one more person for 2050 than 2020. Biomass was chosen by one less person for 2050 than 2020.

4.2.2: Round 2

Participants

Table 5 shows the number of participants from each company or university who filled out the survey for Round 2. In Round 1, 21 people took the survey. In Round 2, 17 people completed the survey, resulting in an 81% retention rate from Round 1. Two professors from WPI, one engineer from Griffin Consultants, and one engineer from Etihad ESCO did not complete the questionnaire for Round 2.

Company/Department	Number of Participants
AUS Civil Engineering	2
AUS Electrical Engineering	6
AUS Mechanical Engineering	2
WPI Chemical Engineering	1
Al Mostajed Technologies Co. L.L.C.	1
Bee'ah	2
Griffin Consultants	1
Honeywell UOP	1
IDOM Consulting	1
TOTAL	17

Table 5: Breakdown of Participants from Round 2

Round 2: 2020

In Round 2 we asked the participants to assign a number of points representing the contribution they wanted each energy type to contribute to the portfolio. These energy sources were the eight most common choices from Round 1. In addition, participants were given an

OTHER option so they could add any energy sources they deemed fit for their portfolio. Below is a pie chart with the mean energy portfolio. Natural gas had the highest contribution, with an average of 31 points of the portfolio. This is followed by oil and solar PV both with an average of 24 points. Next came waste-to-energy with an average of 8 points. We grouped biomass into WTE, as biomass is a portion of WTE. Following WTE comes solar CSP with an average of 7 points, then solar thermal with an average of 4 points. Both offshore wind turbines and standard inland wind turbines were the least chosen with an average of 1 point of the final portfolio.

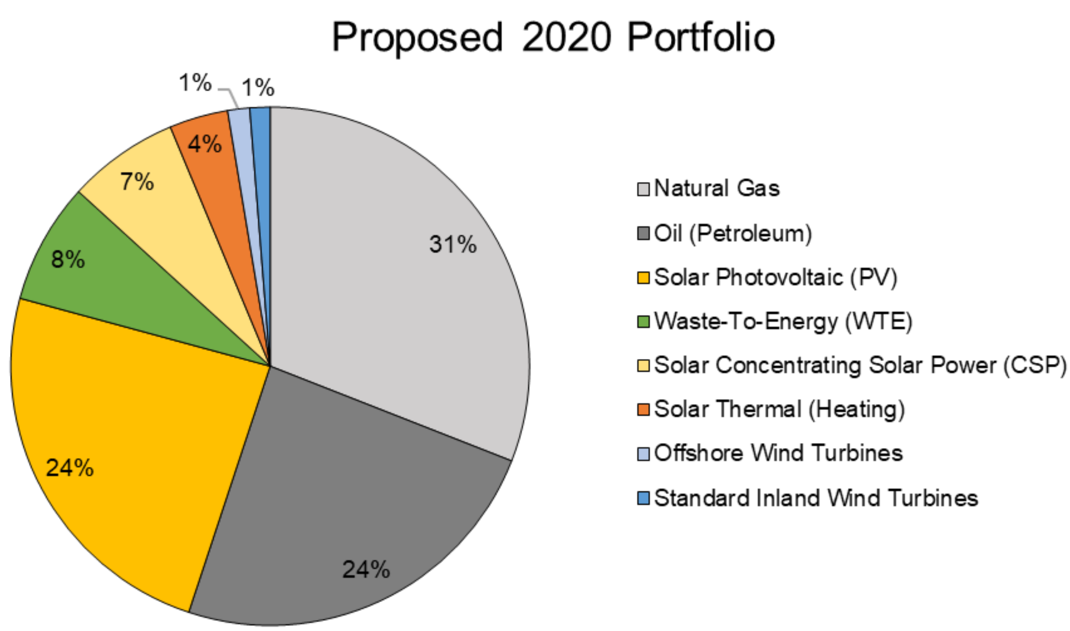


Figure 14: Mean Energy Portfolio (2020)

To look for trends based on the background of the experts we compared those from companies and those from academia. We looked at the differences between how experts from academia assigned points compared employees from companies. We chose these two groups due to the low numbers of experts from different academic disciplines and the low number of experts who responded from each company, so to retrieve meaningful data we combined them into these two general groups. In terms of fossil fuels, experts from academia overall allotted more points to natural gas and oil than those from companies, with professors assigning an average of 34.3 points to natural gas and 33.3 points to oil, while those from companies assigned an average of 23.3 points to natural gas and 6.2 points to oil.

Experts from companies on average allocated more points to solar PV and WTE than professors, with experts from companies assigning solar PV an average of 34.0 points and WTE an average of 18.5 points, while professors assigned solar PV an average of 18.1 points and WTE an average of 1.4 points.

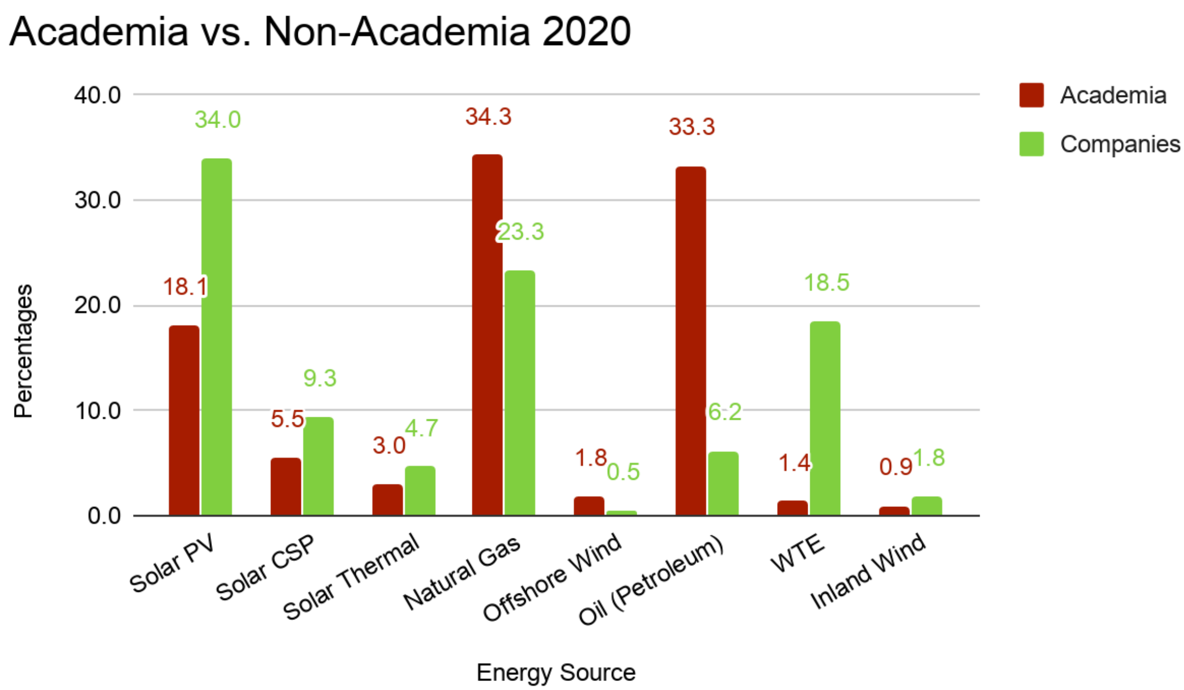


Figure 15: Academia vs Non-Academia (R2: 2020)

We then looked at how often the experts picked these energy types. Based on the number of points the expert assigned each energy source the choices were given a ranking of high importance (35+ points), medium importance (10-35), low importance (1-10), or no importance (0). We decided that assigning an energy source more than one third of the portfolio meant they considered it a highly important energy source, which is why we ranked 35+ as high. We chose the medium as being between one tenth and one third. Our reasoning was that one tenth of the portfolio was still a considerable portion, but it was not at the same level of importance than the high valued ones were. Then, we separated those who added a few points and those who added no points at all.

As can be seen in Figure 17, 33% percent of those from companies did not allocate any points to natural gas and 50.0% of company employees did not assign any points to oil, as compared to 9.1% of professors who did not assign any points to natural gas and 0% who did not choose oil. Similarly, 83.3% of professors considered natural gas highly important and 54.6% of professors considered oil highly important, compared to 33.3% of those from companies who considered natural gas highly important and 0.0% who considered oil highly important.

All experts allocated points to solar PV. 81.8% of professors did not allocate any points to WTE, while 50.0% of experts from companies allocated no points to WTE. No professors considered WTE as highly important, while 33.3% of experts from companies considered WTE highly important.

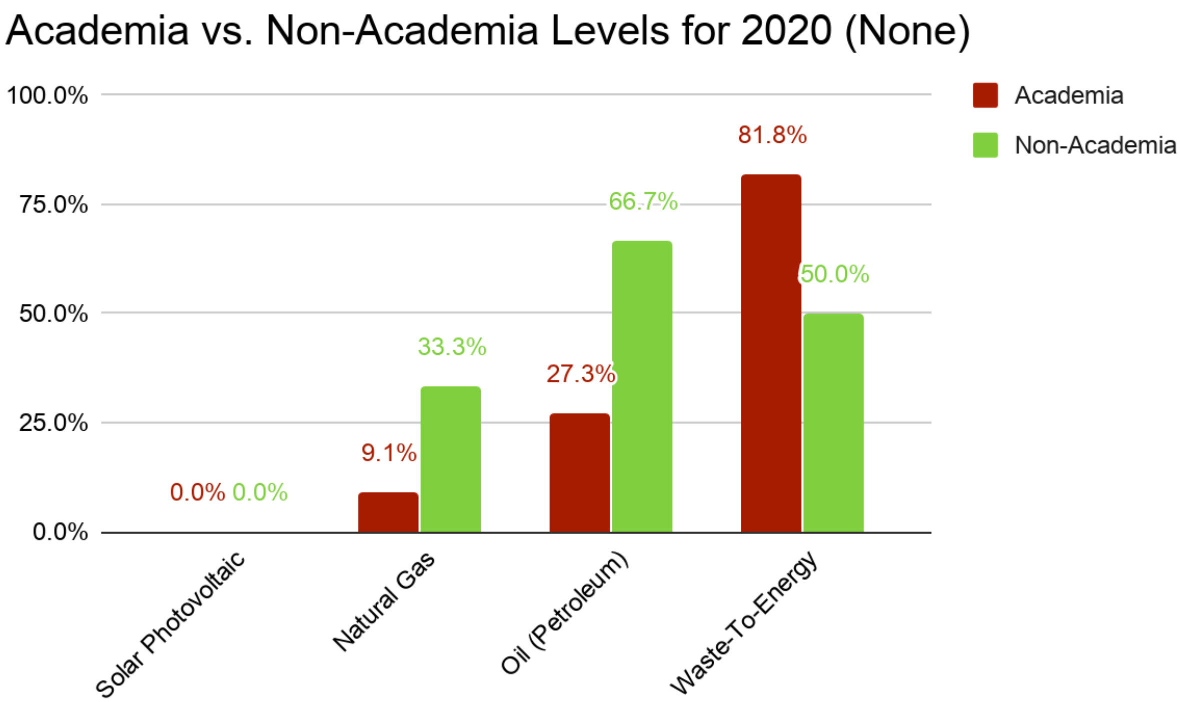


Figure 16: Academia vs Non-Academia No Importance (R2: 2020)

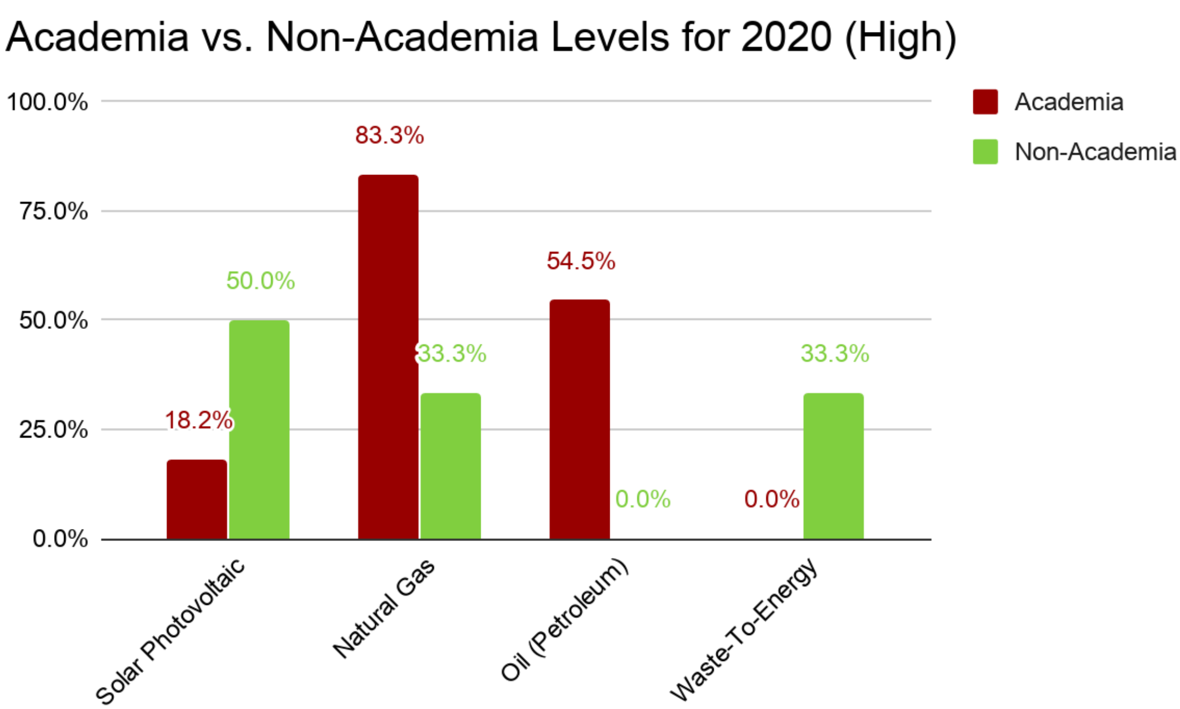


Figure 17: Academia vs Non-Academia High Importance (R2: 2020)

Round 2: 2050

For 2050, the seven most commonly picked energy sources in Round 1, in addition to an OTHER option for additional energy sources, were provided as options to allocate points to. Figure 18 below is a graph showing the average points allocated to each energy type. Solar PV was given the most points, with an average of 43 out of 100 points. Solar CSP was given the next highest point value, with people giving it an average of 16 points. Solar CSP was followed by waste-to-energy and solar thermal, each with an average of nine points. Natural gas was picked as an OTHER option and received an average of eight points. Offshore wind turbines was next with five points. Nuclear was also picked as an OTHER option and received four points. Standard inland wind turbines and oil were the least picked with three points.

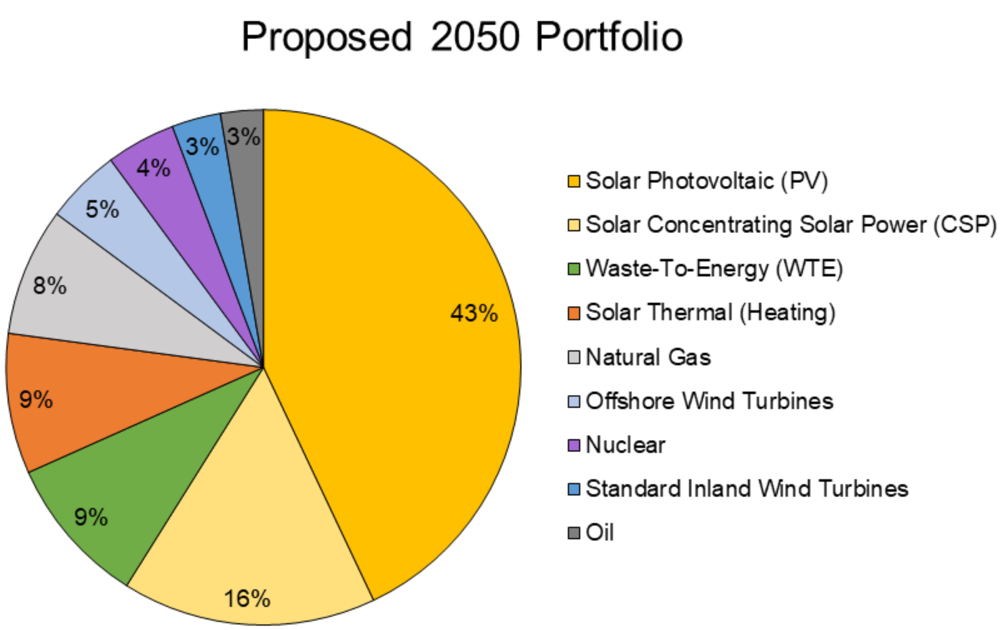


Figure 18: Mean Energy Portfolio (2050)

Figure 19 below shows the average points allotted to each energy source in the year 2050 by people in academia, and people working outside of academia. On average, professors designated more points to several renewable energy sources than everyone else.

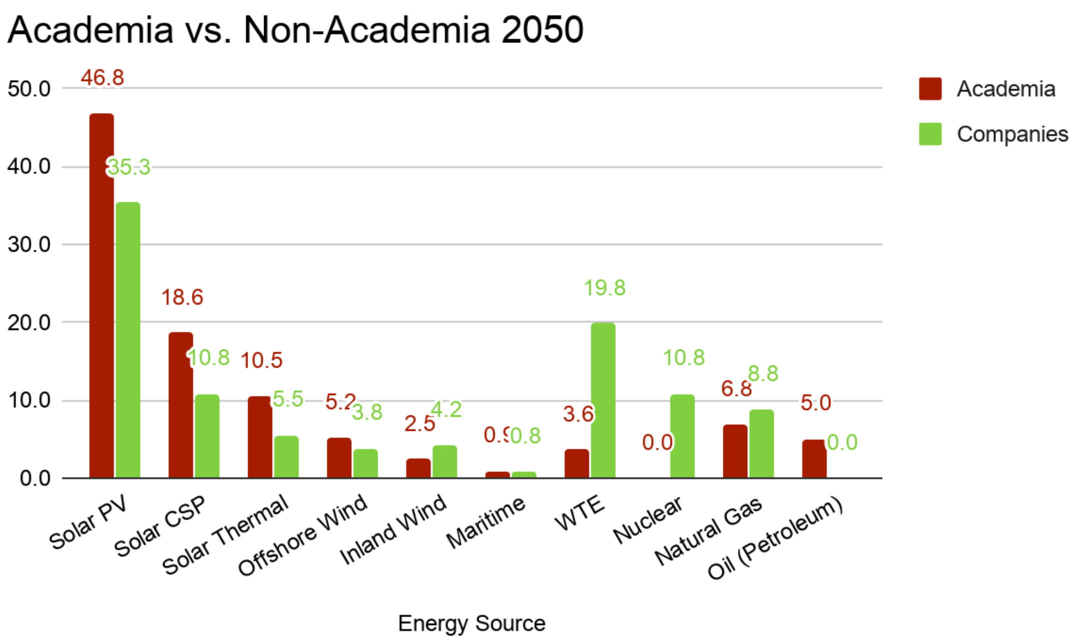


Figure 19: Academia vs Non-Academia (R2: 2050)

Figure 20 shows the distribution of people from academia vs. non-academia who included WTE in their portfolios. For example, 50.0% of people from businesses allotted more than 35 points to WTE. We can see that only 9.1% of professors included WTE in their portfolios while all non-academic participants opted to include WTE in their portfolios.

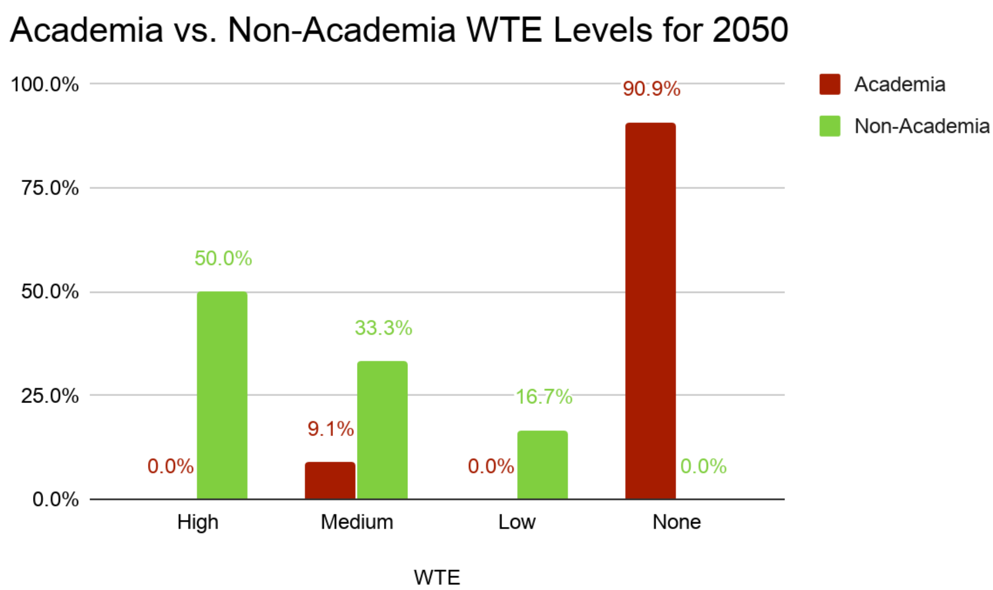


Figure 20: Academia vs. Non-Academia WTE Levels (R2: 2050)

Round 2: 2020 vs 2050

In order to examine the differences between the 2020 portfolio and the 2050 portfolio, we should take a closer look at the percentage change of the energy sources. Figure 15 below shows the change in percentage of each energy source.

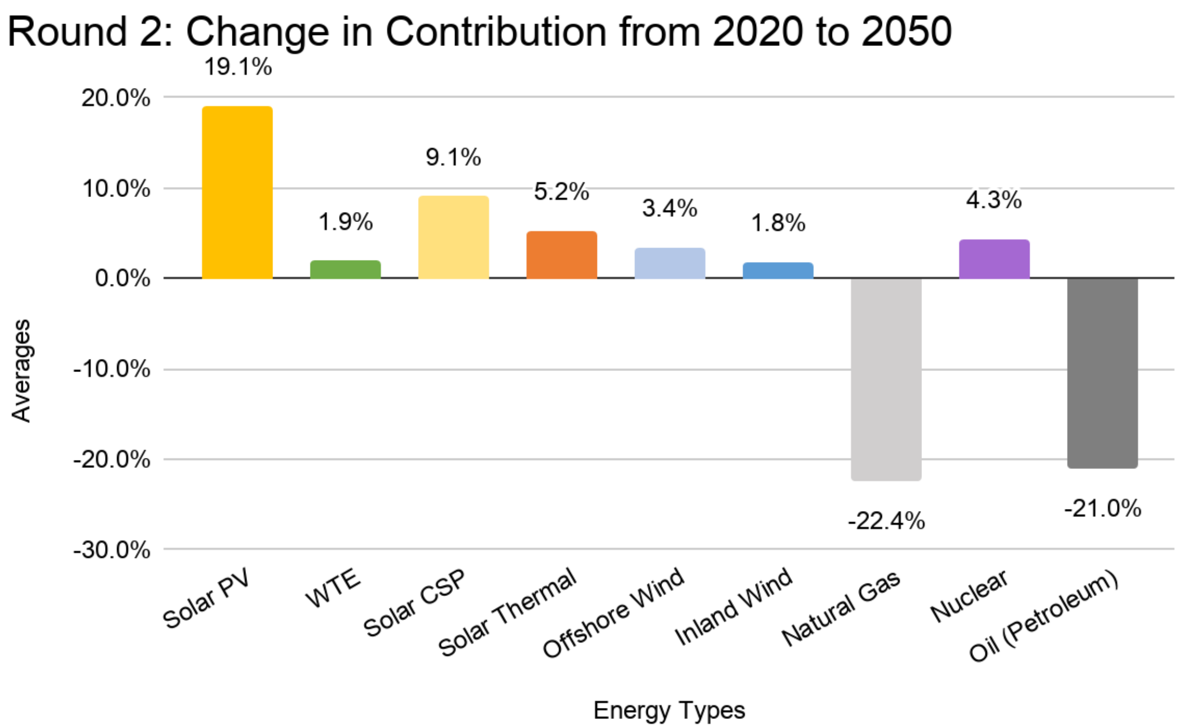


Figure 21: Change in the Contribution of Energy Sources from 2020 to 2050

When we look closer at the difference between 2020 and 2050 of fossil fuels, a substantial decrease in the percentage it makes up of the portfolio is shown. Looking specifically at oil, we see a decrease of 21.0%. For the 2020 portfolio, oil was assigned 24% of the entire portfolio, while oil was assigned only 3% of the portfolio for 2050. When looking at natural gas, the decrease between the 2020 portfolio and the 2050 portfolio is 22.4%. For the 2020 portfolio, natural gas was assigned 31% of the entire portfolio. In contrast, natural gas was assigned 8% of the portfolio for 2050. This massive decrease for fossil fuels is due to the harmful environmental effects of using oil to generate electricity as well as the development of renewable energy. The most substantial increase is for solar PV with 19.1%. Solar PV was assigned 24% for 2020 and 43% for 2050. This increase is due to the increasing efficiency and decreasing cost of solar PV. After solar PV, solar CSP had the second largest increase with 9.1%. Solar CSP was given 7% of the 2020 portfolio and 16% of the 2050 portfolio. After solar CSP comes solar thermal with a positive change in percentage of 5.2%. Solar thermal energy increased from 4% of the 2020 portfolio to 9% of the 2050 portfolio. After all the solar energy types comes nuclear energy with a positive change in percentage of 4.3%. Nuclear was assigned 0% for 2020 and 4.33% for 2050. Next, offshore wind turbines was assigned 1.4% for the 2020 portfolio and 4.7% for the 2050 portfolio giving it an overall change in percentage of 3.4%. After offshore wind turbines comes waste-To-Energy with 7.6% for 2020 and 9.4% for 2050, creating an overall change of percentage of 1.9%. Finally, after WTE, standard inland wind turbines were assigned 1.3% of the 2020 portfolio and 3.1% of the 2050 portfolio giving it an overall positive change in percentage of 1.8%.

4.2.3: Round 3

Participants

Table 6 shows the employers of the participants in our Round 3 survey. Between Rounds 2 and 3, we experienced a retention rate of 65%, significantly less than our retention rate between rounds 1 and 2. The majority of the electrical engineering professors from AUS, as well as one participant from Bee’ah and Griffin Consultants did not take the survey from Round 3.

Company/Department	Number of Participants
AUS Civil Engineering	2
AUS Electrical Engineering	2
AUS Mechanical Engineering	2
WPI Chemical Engineering	1
Al Mostajed Technologies Co. L.L.C.	1
Bee'ah	1
Honeywell UOP	1
IDOM Consulting	1
TOTAL	11

Table 6: Breakdown of Participants from Round 2

Round 3: 2020

In Round 3, we asked the participants to decide if the portfolio collected from Round 2 was a goal that SEWA should aim for in 2020. If the participant said no then they rebuilt the portfolio and a new average portfolio was created. Figure 16 is a pie chart showing this new portfolio. Natural gas was given an average of 43 out of 100 points. After natural gas comes oil with an average of 21 points. Next, comes solar PV energy with an average of 19 points. Then, waste-to-energy with an average of 6 points and solar CSP with an average of 5 points. Then, solar thermal with an average of 4 points and offshore wind turbines with an average of 1 point. Inland wind turbines come last with an average of 1 point of the overall portfolio.

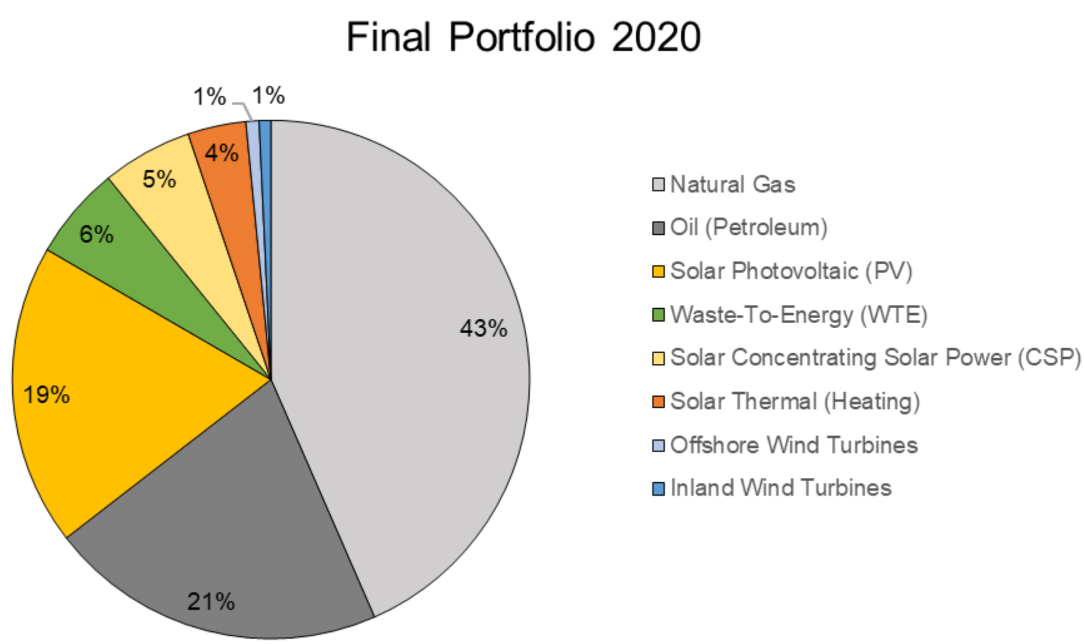


Figure 22: Final Portfolio 2020

Round 3: 2050

The same question, "do you believe that this is an optimal energy portfolio for Sharjah," was posed to participants to solicit their responses regarding a portfolio for 2050. Figure 23 shows the final portfolio for 2050. Solar PV was given an average of 40 out of 100 points for the final portfolio for 2050. Next, solar CSP was given an average of 15 points. After solar CSP, natural gas was given an average of 12 points. Then, waste-to-energy with an average of 9 points. After WTE, nuclear was given an average of 8 points. Then, solar thermal energy with an average of 7 points. Following solar thermal energy comes offshore wind turbines with an average of 4 points. Then, oil with an average of 3 points. Finally comes standard inland wind turbines with an average of 2 points of the final portfolio for 2050.

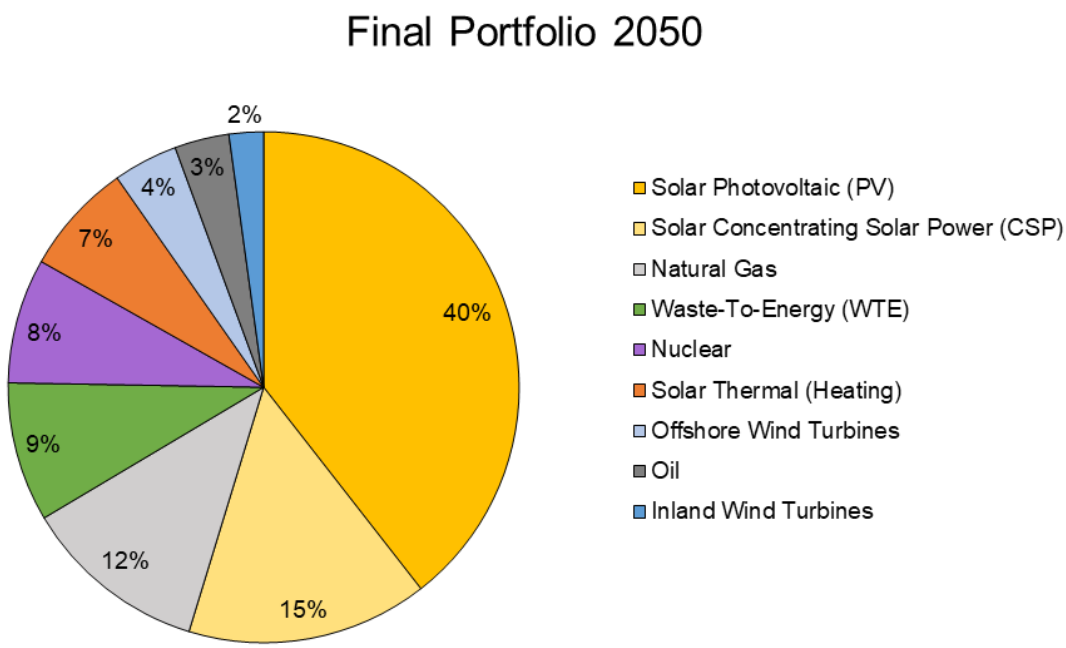


Figure 23: Final Portfolio 2050

Round 3: 2020 vs. 2050

As in Round 2, the largest positive change in contribution from 2020 to 2050 was by solar PV. Similarly, the two largest drops in contribution from 2020 to 2050 were natural gas and petroleum again as several participants wish to move away from complete dependency on fossil fuels. All other energy options, besides solar CSP experienced a less than 4% increase in contribution. Survey takers cited technological innovations in the coming years for the differences in solar energy contribution from 2020 to 2050.

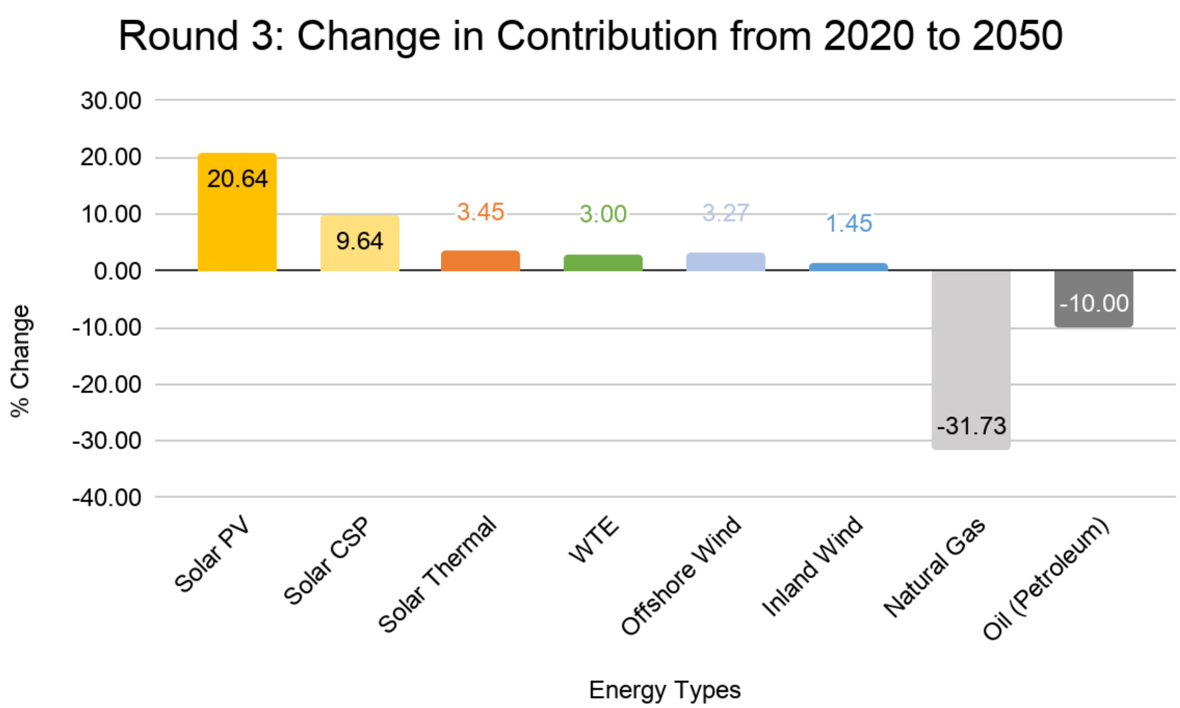


Figure 24: Change in Contribution from 2020 to 2050 from Round 3 Results

Round 3: Interviews

We interviewed 3 AUS professors to gain a deeper understanding of their thought processes and why they changed their opinion on some of their answers. Prior to the interview, we looked at the professors' survey responses for all three rounds. We took note of responses that needed clarification as well as looked at how their responses changed between rounds and compiled a list of questions to ask based on these observations. We also asked about their opinions as to the final portfolio in order to get more detailed responses. The questions we asked as well as their responses can be found below.

Professor 1:

Our first question was about their difference of energy sources between Round 1 and Round 2. In the 2020 Round 1, the professor included both nuclear and geothermal as energy options he would like to see in a portfolio. Neither of the options were included in the 2020 portfolio for Round 2 due to the low number of people picking it, although we left in the OTHER option in case they wanted to add some points to it. We asked whether the professor would have assigned points to the two sources if they were given as slider choices. The professor responded that he would have assigned points to the two sources if they were options in the 2020 Round 2 choices, but said that in his opinion they could be replaced with other choices.

For our next question, we asked about the discrepancy between one of their comments in Round 1 for 2050 and their response for Round 2. In Round 1, the professor said that we should be able to eliminate fossil fuels by 2050, and therefore did not add natural gas or oil as options he would have liked to see in the portfolio. However, in Round 2, the professor selected the OTHER option and added natural gas and oil as energy sources he would like to see. When asked, the professor said that in the first round he was very optimistic and in the second round he was more realistic and decided that it would be unreasonable to eliminate all fossil fuels by 2050. For this reason, he added fossil fuels for the 2050 portfolio that he expected to see, despite his earlier beliefs.

To obtain a better understanding of how the overall responses influenced his opinions, we asked the professor if reading the results of the rounds affected how they answered for the subsequent rounds. He replied that it did to an extent, but his answers didn’t change dramatically based on the answers of the other professors. As for results, he was surprised, he said that he was not expecting such a high percentage of WTE as an energy source. However, he did agree that with Bee’ah’s new waste management plant, WTE may become a feasible option. He also mentioned that in Abu Dhabi they were looking into WTE as an option as well.

Lastly, we asked if while answering he focused more on an idealized answer or a practical one. He replied that it was a mixture of both. He believed that the portfolios were very optimistic and mentioned that without knowing the constraints and limitations of SEWA, it was difficult to know exactly what portfolio would be a realistic one.

Professor 2:

Our first question was to clarify some of the professor’s choices for the Round 1 portfolio between 2020 and 2050. In the Round 1 portfolio, the professor included biomass as a choice in their biomass portfolio but did not include it in the 2050 portfolio. When asked, he responded that he changed his mind due to the lack of available waste in the area, as Sharjah in specific does not have a lot of waste. He considered waste conversion as recycling acceptable, but he did not think it would provide a substantial part of an energy portfolio for 2050.

Next, we asked about the differences between his answers in Round 1 and Round 2. For Round 1, he included both nuclear and maritime energy as possible sources for 2020, However, in Round 2, he did not assign any points to either. His response was that in Round 1 he likely did not notice the timing and therefore decided to not include them in his next portfolio. He was also less sure about adding nuclear into 2050 due to the nature of a nuclear power plant. He said that a nuclear power plant would need to be built on a large scale. However, nuclear energy would be covering the baseload of the energy source, which for Sharjah is quite small, resulting in a small nuclear power plant. Along with this, he said that the load varied very significantly in the different seasons. The issue was that the load for winter is significantly smaller than in the summer. Nuclear power plants are intended to be run at full capacity all the time, which would force the nuclear power plant to have an output that would be enough for the winter, but not enough for the summer.

We then asked about the professor's choice to include fossil fuels in the Round 3 portfolio, despite not including it in his Round 2 portfolio. When asked about the reasoning he said that he changed their mind due to the fast response rate of natural gas and the need for a fast-acting energy source. He agreed that natural gas could be eliminated if the other emirates were able to provide fast response energy by using natural gas. However, it would be working off the assumption that the other emirates would be providing this source, which would not be a guarantee. Even by increasing the efficiency of natural gas and making a combined cycle, the cycle would slow down dramatically. In Round 2, he said that he was very optimistic, but then later looked back and realized the technical problems with eliminating natural gas.

In Round 2, the professor recommended large scale storage devices as an OTHER option. However, this is not considered an energy generation source, which he agreed with, so it would not belong in a portfolio. He did say that it would be a good option, albeit an expensive one, and it would solve some of the issues with requiring a fast response, as storage has the fastest response speed.

The final question was about the reasoning he gave in Round 3 for offshore wind turbines. In his response he was giving a reasoning for the energy sources inclusion, but he did not finish his argument. He explained that offshore wind turbines could be effective in the section of Sharjah on the Gulf of Oman, due to the higher wind speeds of the area.

Lastly, we asked about how he believed that the reports influenced his responses for subsequent rounds. The professor believed that the reports changed his responses and that as he learned from the other experts' thoughts he changed his responses.

Professor 3:

To begin with the third professor, we asked about one of his Round 1 answers that changed throughout the subsequent rounds. The third professor picked nuclear energy as an option for an energy source in the first round for 2050. However, he did not assign any points to nuclear energy in the second round. He stated that he did not believe nuclear energy was a good option due to the safety problems with nuclear energy. However, he did accept that a baseload was needed and that without oil, nuclear energy would be the best environmentally friendly option for a reliable energy source. However, he did not wish to see it implemented due to the scale of the accidents that would occur if the plant broke down. As a result, he preferred using fossil fuels as a baseload rather than nuclear energy, but he believed that nuclear would be the best option if fossil fuels were completely eliminated.

We asked about the professor's choice to remove offshore and inland wind turbines in his portfolios between Round 2 and Round 3 for both years. When asked about the reasons, he responded that after thinking about it he decided that there is not sufficient wind speeds inland for turbines to be affected. He stated that he was not familiar enough with the offshore wind speeds to make judgments as to whether they would be effective offshore, but he did not think there was enough of a coastal area for them to be a good option. Therefore, he decided they weren't suitable energy sources for SEWA.

When asked about his reasoning for adding waste to energy in 2050 in Round 3, he replied that he thought that it would make sense to use as an energy source because the waste was being burned anyway. Because of this, it would make sense to use it as an energy source as a result, although only when oil was gone from the portfolio. He did not see WTE as the most effective source due to the need to import bio waste due to the lack of agricultural and animal waste in the area.

When we inquired about his opinions on the reports and whether they changed his answers in the subsequent rounds he said that he did take into account the reports. However, he found some of the responses too idealistic. He did not believe that the emirate would be able to get rid of oil completely due to its high availability in the area and the ease with which it could be obtained. He also believed that WTE would not be able to contribute such a large amount of the portfolio due to the lack of biofuels in the area.

Overall:

All three professors said that they believed that they were too optimistic in the earlier rounds, and as a result changed their answers in either Round 2 or Round 3 in order to account for that. Despite this change in their responses, they still believed that the overall portfolio was too optimistic. They did not necessarily think it was a major problem however, expressing that having an optimistic goal has its benefits.

Two of the three professors believed that nuclear energy could cover the baseload in the future, as they considered it a more environmentally friendly energy source than fossil fuels while being able to reliably provide energy. However, both professors were concerned about safety, and for that reason it was not their first choice for an energy type. One of the professors said he would rather have fossil fuels as a baseload rather than nuclear energy despite their negative environmental impact. The last professor did not think nuclear energy was economically feasible due to a combination of factors including fluctuating energy demands and the size of a power plant.

All three professors were surprised by the high average WTE had in the portfolio. Two out of the three did not think it was the most economically feasible due to the lack of waste in the UAE, however, all three still supported the use due to the fact that waste will always be available and Bee’ah’s current waste plant. Although they all supported the use, whether for energy generation or recycling, one professor did not believe that it would provide a significant contribution to an energy portfolio.

Round 2 vs Round 3 Distributions:

We looked at the distribution of points for each energy type in Round 2 and the minimum, maximum, and mean for Round 3 for both 2020 and 2050. We looked at the overall distributions and trends, as well as comparing the two rounds to see how the overall numbers changed between the two rounds.

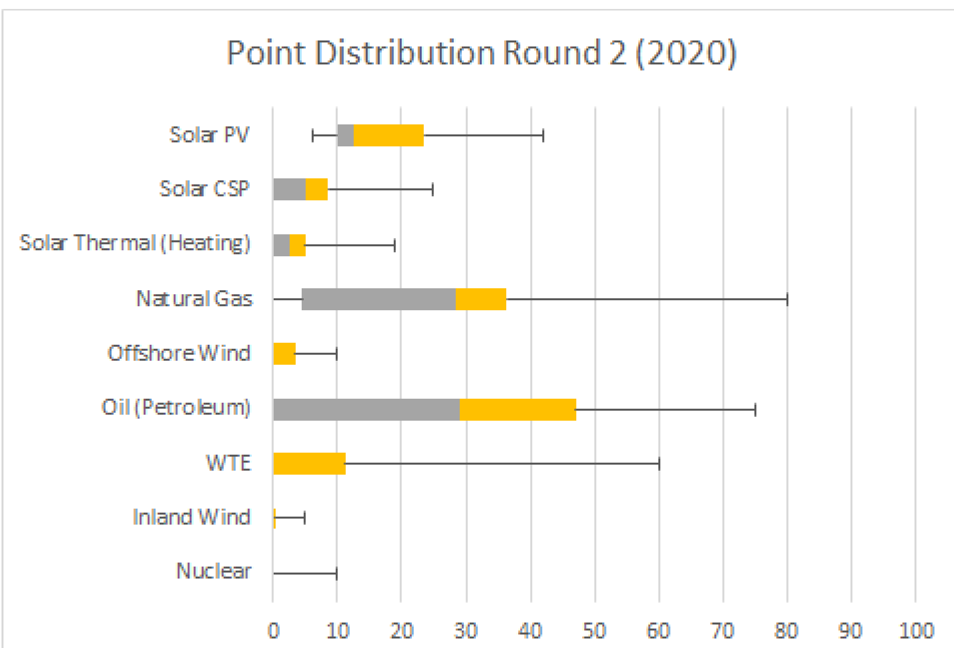


Figure 25: Distribution of points in Round 2 (2020)

Round 2-2020	Solar PV	Solar CSP	Solar Thermal	Natural Gas	Offshore Wind	Oil	WTE	Inland Wind	Nuclear
Minimum	6	0	0	0	0	0	0	0	0
1st Quartile	10	0	0	4.5	0	0	0	0	0
Median	12.5	5	2.5	28.5	0	29	0	0	0
3rd Quartile	23.5	8.5	5	36.25	3.5	47	11.25	0.25	0
Maximum	42	25	19	80	10	75	60	5	10
Mean	24	7	4	30	1	24	7	1	1

Table 7: Statistics of distribution of points in Round 2 (2020)

For 2020, all three types of solar energy had similar distributions, as can be seen in Figure 25 above. Solar PV was the most popular, with three out of four people assigning it at least 10 points and all participants assigning it some number of points. The majority of people assigned solar PV between six and 23.5 points. There were a few outliers with the maximum allocation being 42 points. There was only one other energy source in which at least 75% of people assigned some points.

The top quartile of natural gas and WTE were significantly larger than the rest of the quartiles, with the top 25% having over two times wider of a point distribution than the bottom 75%. WTE especially had a very large distribution, as the bottom 50% did not assign any points to WTE and the third quartile assigned between zero and 11.25 points, while the top percentile assigned between 11.25 and 60 points. For both energy types, it is likely that outliers affected the mean dramatically.

Round 3-2020	Solar PV	Solar CSP	Solar Thermal	Natural Gas	Offshore Wind	Oil	WTE	Inland Wind
Minimum	3	0	0	0	0	0	0	0
Maximum	42	25	19	95	5	75	60	5
Mean	22	6	4	35	0	23	7	1

Table 8: Statistics of distribution of points in Round 3 (2020)

Between Round 2 and Round 3 the most notable changes were in natural gas and nuclear energy. Both the maximum and average increased between the two rounds, with a 15 point increase in the maximum and a 5 point increase in the average. Nuclear energy was not a popular choice in Round 2, with only a 10 point maximum from one expert. In Round 3 nuclear energy was completely eliminated. The other energy types were very similar between both rounds.

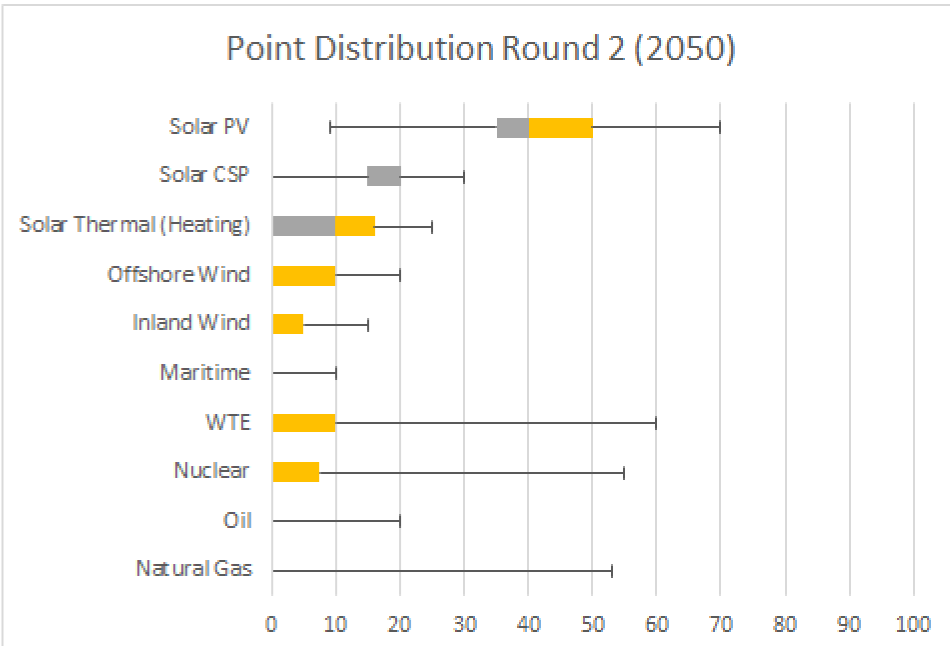


Figure 26: Distribution of points in Round 2 (2050)

Round 2-2050	Solar PV	Solar CSP	Solar Thermal	Offshore Wind	Inland Wind	Maritime	WTE	Nuclear	Oil	Natural Gas
Minimum	9	0	0	0	0	0	0	0	0	0
1st Quartile	35	15	0	0	0	0	0	0	0	0
Median	40	20	10	0	0	0	0	0	0	0
3rd Quartile	50	20	16	10	5	0	10	7.5	0	0
Maximum	70	30	25	20	15	10	60	55	20	53
Mean	43	16	9	5	3	1	9	8	3	7

Table 9: Statistics of distribution of points in Round 2 (2050)

In Round 2, solar PV was again the only energy source to have a minimum value above zero. The distribution was overall wide, but the middle 50% all allocated between 35 and 50 points. Solar CSP was the only other energy source where more than 25% of participants allocated more than zero points, with over 25% assigning more than 15 points. Maritime, oil, and natural gas were the three energy sources where the bottom 75% assigned no points to the energy sources. However, the maximum for natural gas was still 53 points, showing that the those who considered it a contributor considered it important enough to assign over half the points to.

Round 3-2050	Solar PV	Solar CSP	Solar Thermal	Offshore Wind	Inland Wind	Maritime	WTE	Nuclear	Oil	Natural Gas
Minimum	10	0	0	0	0	0	0	0	0	0
Maximum	70	30	25	15	15	10	60	50	15	53
Mean	43	15	8	3	3	1	9	7	3	11

Table 10: Statistics of distribution of points in Round 3 (2050)

Between Round 2 and Round 3 there were very few changes in the 2050 distributions. Offshore wind became slightly less popular with offshore wind equal to inland wind. Natural gas experienced the most noticeable increase with the average increasing 4 points, while the other energy types were all very similar between the two rounds.

Chapter 5: Discussion

The following section will analyze the findings from our series of surveys. We will discuss our observations, such as advantages and disadvantages of different types of energy sources, for both 2020 and 2050. The explanations behind people's responses will also be explored in more depth. We will also look at any outliers we discovered, in addition to common trends in arguments for several energy options.

5.1: 2020 Discussion

The portfolio created for 2020 includes primarily natural gas and oil as predicted. Because the energy portfolio of Sharjah is currently 100% natural gas with small reserves of oil in the case of emergency, it would realistically be extremely difficult to change the energy portfolio in such a short period of time. However, we asked for an ideal portfolio, implying that time and other resources were not an issue. In the 2020 portfolio, fossil fuels make up 60% of the energy profile. This indicates that while natural gas and oil should still be the main energy source in 2020's energy portfolio, there is plenty of room for improvement to include renewable energy options.

After reviewing our findings, seeing that all three types of solar energy (PV, CSP, and thermal) were selected as some of the most popular renewable energy choices was not a surprise. From prior research and knowledge, we predicted that solar power would be a favorite due to the area's sunny climate. Experts reaffirmed this by explaining that the high irradiance levels (~2000-2200 kWh/m^2) made the area ideal for solar power. There is also already a precedent for solar energy in the UAE as there are several solar-energy-based projects, both completed and under development, around the country. A couple of well-known ones mentioned by participants include solar parks in Abu Dhabi and Dubai. Additionally, all types of solar energy were chosen due to the financial advantages they had when compared to other renewable energy options. For example, as seen in the report for Round 1 found in Appendix D, survey participants believed that solar energy had a great cost/benefit ratio and a high return on investment over time. Out of all the renewable energy options, solar energy, particularly PV, would have the best economic feasibility in 2020. If SEWA is looking to transition to renewable energy immediately, solar PV would be the best place to start due to its low price and great potential in the area. Additionally, SEWA should begin planning for the future by beginning implementation of the solar CSP and thermal to take advantage of the region's resources.

A notable energy source that participants wanted to include in their energy portfolio was waste-to-energy (WTE). WTE involves the incineration of all types of waste, not just biomass, to produce energy. The method also doubles as a waste management process to reduce the amount of trash that ends up in landfills. Upon further research and analyzing the understanding of participants' interpretations of biomass and WTE, we decided to combine the two categories into WTE as it was more general and inclusive. A pattern observed was that people who chose WTE and biomass often cited the growing population as a reason to turn towards these technologies. As long as people live in the area, the community will always generate waste to burn and produce energy with. Also, like solar energy, there is already a precedent for WTE technology in the area as Bee'ah plans to open a WTE plant in Sharjah within the next couple of years. Directing the waste to incineration plants will also move waste out of landfills, working toward the UAE's goal of diverting 75% of its solid waste away from landfill sites by 2021 (Bee'ah, 2017).

Despite the fact that almost 40% of participants included wind energy in their portfolio, many believed that low wind speed, availability of land, and inability to supply as much energy as other resources made it unfavorable. The number of people showing support for wind energy demonstrates the country's desire to move toward sustainable energy sources. Wind energy, while not widely supported, can still also be considered, especially offshore wind options on Sharjah's regions bordering the Gulf of Oman. However, the area's lack of ideal conditions for wind turbines may render wind energy unfit for the 2020 portfolio. Without time for innovations in wind energy technology, wind-energy-based projects should be the last option considered, behind solar energy and WTE.

5.2: 2050 Discussion

As with 2020, the three types of solar energy were the most commonly chosen. As expected, many people cited the need to reduce carbon emissions in the environment as a major factor for their choice. Along with that, the decreasing price of solar energy was also mentioned, and how in the future it would become cost effective enough to warrant using over fossil fuels. One expert stated that they believed solar PV technology would advance far enough in the future that solar PV alone could provide enough energy for residential purposes. However, one participant stated that they did not think that solar energy alone would be able to provide enough energy for the emirate. Solar heating was picked the least, but of the people who selected it, one stated that the heating would be useful for the process of desalination. Those in academia showed more support for Solar CSP than those from outside companies, which may have to do with current research into the technology.

The greatest change seen in allocations for the energy portfolio in 2050 was for solar PV systems. Multiple experts believed solar energy development is on the rise, with predictions of heavy reliance on the energy source by 2050. Two experts also highlighted the potential for impact that 30 years of development will have on the efficiency of the PV and concentrated solar power (CSP) systems. As the technology for capture and storage of sunlight improves, cost of solar energy development projects will also see a decline. A combination of rising demand and an affordable renewable energy alternative may allow for the exponential increase in solar energy use in the future. The biggest source of agreement was when it came to the use of photovoltaic cells. Many of the experts believed that the potential of solar was very high, although one expert did point out the problems the cells may face due to temperature and sandy conditions. Between Round 2 and Round 3 the percentage did decrease slightly, but the reasonings given continued to support their use. One experts suggested that solar CSP may be more effective than PV. While the technology is less advanced, their belief was that with technological improvements solar CSP would be more effective than solar PV in the future.

Wind energy was picked by many experts, making up the next largest selections of the portfolio. Offshore wind turbines were more popular than inland wind turbines, which was expected due to the low inland wind speeds, although one expert believes that with technological advancements inland wind turbines could still be effective by this time. Not all the experts believed that wind is a good option, with one expert stating that they did not think wind energy would be very effective due to the distance the energy needed to be moved. However, they stated that if technology advances as rapidly as it has been, they may change their mind.

Geothermal was not selected often as a whole. However, about one quarter of professors selected it of the time, while those in industry did not select it at all. One of the reasons against the usage included the fact that the UAE does not lie in a position where geothermal is an economically efficient option, due to the temperature variations and thickness of the earth's crust in the area. There were no experts that gave reasonings for the use of geothermal.

We were surprised to see oil and natural gas appear several times each in the OTHER category as natural gas was only selected four times, and oil was only selected once in Round 1. Oil and natural gas were picked because they are so readily available in the UAE. Because the rest of the world will also likely steer away from fossil fuels, there will be cheap and abundant fossil fuel supplies for the UAE. Sharjah will also have limitations in implementing solar expansion due to its smaller land area in comparison with other emirates. Therefore, the process of phasing out natural gas might be slower for the emirate to implement. Additionally, people are still unsure if renewable energy sources will be as reliable as conventional energy sources by 2050. Leaving some fossil fuels in the mix for 2050 will help create a portfolio that even people who are wary of complete dependence on renewable energy can trust.

Nuclear was also selected multiple times in the OTHER category. One expert believed that nuclear energy plants have the potential to be the primary source for energy generation, as it was believed to be a source of clean energy requiring little maintenance. It can produce enough energy to compete with conventional power plants, making it a great energy source to include. However, like some forms of solar energy, nuclear energy requires a lot of space that the emirate does not have due to its small size, making it a less than ideal energy source to include. Participants also strongly expressed safety fears in installing nuclear plants, referencing disasters like Chernobyl and Fukushima. Their argument for the use of nuclear energy was that it would take only trained staff in order to run the plant, making it effective as a primary energy source due to the limited resource use. This differed dramatically with professors who were interviewed. Two out of three professors who were interviewed saw potential in the use of nuclear energy. However, due to the dangers of nuclear power plants, they were unwilling to make it a large source of contribution and wary of the potential dangers. The third professor did not believe that it would be economically feasible due to load variances throughout the year and how it would affect the output and usage of the plant. While nuclear plants would be able to generate clean energy, it may be difficult to convince officials due to these types of concerns.

5.3: Things to Consider

Feasibility

The energy portfolio for 2020 is made up of 60% fossil fuels and 40% renewable energy. Despite the fact that experts believe implementing this particular portfolio for 2020 is unrealistic, the percent contribution of each energy source can still serve as a guide for prioritizing the implementation of different energy options. It would be difficult to turn away from natural gas because it is so cheap and plentiful. As a result, SEWA may be reluctant to shy away from gas due to its cost-effectiveness. Additionally, many participants noted that installing solar energy systems of any kind will take time and lots of land to accomplish. Solar PV, specifically, as it is one of the cheapest options, has the greatest potential to become a major contributor to the energy portfolio.

Among those who agreed with the 2050 portfolio in Round 3, there were some that stated that although they wanted SEWA to aim for this portfolio, they saw it as very optimistic and did not think it was an attainable goal. One expert said that reaching 80% renewables would be easy to achieve but the rest would take decades to complete the transition based on the 80-20 principle, which would assume that 20% of the effort would be needed to reach the 80% mark, while reaching the 100% mark would take the rest of the effort.

One problem that some of the experts and the professors who were interviewed believed would make a big impact was the desire to change to a renewable energy source. They believed that while it was possible, it would be difficult to do so due to a perceived lack of need to change to these energy sources, which are less reliable and oftentimes more expensive.

Interpretation of "Ideal"

Between rounds 2 and 3, renewable energy sources contributed less to the 2020 portfolio. Overall, in Round 2, renewable energy sources accounted for 45% of the entire portfolio, but in Round 3, they only accounted for 37% of the portfolio. This difference suggests that people's definition of "ideal" between rounds 2 and 3 changed. After interviewing a few participants, and following people's responses throughout the rounds, we learned that many people started out answering "optimistically" in Round 1, but by Round 3, they had begun to look at the portfolio more realistically and assigned more points to fossil fuels, resulting in a 12% increase in natural gas alone for our final portfolio. Even people who agreed with the portfolios for both 2020 and 2050 believed that these portfolios were too optimistic or ambitious. People who disagreed with the portfolio tended to have a preference for fossil fuels 2020. We observed that people from academia assigned more points to fossil fuels in 2020, while experts from non-academic backgrounds assigned more points to renewable energy sources for 2020. This may be because the professors looked at the portfolio from a more realistic perspective than those from non-academia.

Because 2020 was only a month away when the surveys were sent out, people began to argue that little to no change could be accomplished between when they took the survey and 2020. Even people who agreed with the portfolio believed it was too optimistic and were wondering why fossil fuels did not account for more of the portfolio. These differences among participants' definitions of "ideal" may have skewed the results. For example, one person may have approached building the portfolio being 25% realistic whereas another participant may have been 100% realistic.

Biases

Professors typically had renewable energy sources contribute a higher percentage than those in the non-academic fields. One energy source where this trend did not exist was WTE. This particularly high contribution from WTE was likely due to the engineers we included from Bee'ah, a waste management company planning on finishing construction on a WTE facility in Sharjah by 2021. As a result, Bee'ah, the only company to have more than one participant in Round 2, may have had a strong impact concerning WTE contributions. One AUS professor also cited Bee'ah's projects as reasoning for allocating points to WTE.

Additionally, because a large portion of renewable energy research done at AUS focuses on solar energy, all types of solar energy were allotted more points by professors than other engineers. For example, as seen in Figure 19, there was a big difference between the percentage of professors picking solar PV in 2050 rather than companies. This highlights that there may have also been a bias towards solar energy in this study.

We attempted to avoid these biases by including as many people from non-academic backgrounds and include a wide variety of companies. However, we were unable to receive responses from many businesses in the area, making it biased toward the companies who had more people participate in the study. All biases should be kept in mind when looking at the final portfolio.

5.4: Limitations

Throughout our study we encountered a few limitations that might have hindered our results. In our study, we had a high academic expert to non-academic expert ratio which may have its benefits, but we believe including more experts from different companies in the field of energy generation, power systems, renewable energy, or water processing would improve the quality of our study. We would like to have seen more participants from oil and natural gas companies to incorporate the positives of those energy generation technologies. In addition to not having a diversified pool of participants, we only had a maximum total of 21 participants. While 21 participants is well within the guidelines for a successful Delphi Study, we believe that the findings could be more robust with a higher number of participants.

5.5: Recommendations for Future Research

Recommendation 1: Continuation of Round 3

Round 3 could be repeated with different groups of experts in order to obtain a more thorough portfolio. By adding another diverse group of participants, the response would reflect the opinions of a wider group of experts. This could be repeated as many times as necessary in order to obtain a consensus among a wide group of experts.

Recommendation 2: Feasibility Study

In the future, we advise SEWA to conduct a feasibility study to find what experts believe would be possible for the future of Sharjah's energy portfolio. Due to a large number of factors, including economic reasons, the unique government structure, and the lack of public awareness about the topic, it may be difficult to show a need to change to renewable energy sources, especially when current energy sources are so cheap. These aspects were not considered in this study, but in the future would be important in order to find a feasible energy portfolio from an economic, social, and political standpoint. Our ideal study gives SEWA a very optimistic goal to aim for. On the contrary, we believe a feasibility study would provide SEWA with a plausible goal to aim for in the future. This feasibility study could be structured the same way as this study but use the world "feasibility" instead of "ideal" when asking about the portfolios.

Recommendation 3: Potential Research & Development

SEWA may also look at this portfolios as a prioritizing tool. The portfolios can be used to help in deciding where to invest research and development efforts. For example, because solar PV was predicted to have a high contribution, it may be wise to prioritize efforts in R&D regarding solar PV to further advance the technology and make them more cost-effective in the future.

Chapter 6: Conclusion

In this chapter, we will summarize the findings of our study and review recommendations we have for SEWA in building its future energy portfolio. Through our project, we gained a better understanding of what renewable energy sources experts think should be in the future of Sharjah's energy mix. By analyzing the experts' opinions, we developed two energy portfolios, one for 2020, and one for 2050, that SEWA should ideally aim to achieve by the respective years. We also briefly suggest how to build upon this study in the future.

In the 2020 portfolio, it was determined that the energy portfolio mix should remain mainly fossil-fuel-dependent. Different renewable energy options made up the remaining 40% of the energy portfolio. Solar based energy sources comprised the majority of the renewable energy contribution, followed by WTE and wind energy. Solar energy was commonly picked and given a higher contribution to the portfolio due to the area's ideal climate for these types of technologies. Solar PV was mainly chosen due to its low cost and great efficiency when compared with other clean energy options. It was the only renewable energy source where the majority of the participants agreed that immediate installation was economically feasible. Solar CSP should also be implemented to take advantage of the area's resources. The addition of solar thermal to help in heating during the desalination process would also decrease the amount of energy needed to power the desalination plant. Wind energies would also constitute a very small portion of the energy portfolio. The lack of ideal conditions in Sharjah do not make them a priority in Sharjah's energy portfolio for its water processes in 2020. Rather, they are simply an option SEWA should keep an eye while they wait for innovations to make wind energy more cost-efficient.

Based on the results we received, we recommend that the 2050 portfolio is comprised of 40% solar PV and 15% solar CSP. By this point in time, experts predict that there will be several technological advancements in both solar PV and solar CSP making them more economical. Solar thermal will constitute a small portion of this portfolio to continue to assist in the heating stages in the desalination process. Natural gas should still make up a significant portion of the portfolio due to its fast response time, low costs, and reliability. Additionally, WTE should still make up about 10% of the energy portfolio to not only generate electricity for its desalination plants, but to also assist in the waste management of Sharjah's population by 2050. We recommend that SEWA also consider looking into incorporating nuclear into the energy portfolio. Due to the nature of nuclear plants and their ability to produce large amounts of energy, nuclear energy could also be used to generate electricity for other needs in addition to powering desalination plants. However, there are strong feelings against nuclear energy based on safety fears. As mentioned before, wind energy technologies over time will become more efficient. By 2050, we suggest that offshore wind turbines be installed in Sharjah's regions bordering the Gulf of Oman. Offshore winds are typically stronger than inland winds, making offshore wind turbines a more ideal electricity generator.

Our recommendations and suggestions from this study reflect the opinions of several different experts in the field of renewable energy and energy production. Our analysis has shown that solar energy has the strongest potential out of all the renewable energy options to be a major contributor to SEWA's energy for its water processes. Fossil fuels should still comprise a portion of both the 2020 and 2050 energy portfolios due to its reliability and its accessibility. However, the nature of this study attempted to focus on ideal portfolios for these years. Our team observed that there were several interpretations of the word "ideal," resulting in responses varying in levels of practicality. We recommend that there be future studies follow up on this study discussing and determining the feasibility of these portfolios.

Appendices

*Note: Text in brackets [] indicate the type of response requested in the survey question.

Appendix A: IRB Consent Form

Informed Consent Agreement for Participation in a Research Study

Investigators: Isabelle Chan, Brendan Train, Veronika Enis

Contact Information:
gr-sharjah-re@wpi.edu

Sponsor: Sharjah Electricity and Water Authority

Title of Research Study: A Diversified Energy Portfolio for Powering Water Processes

Introduction

You are being asked to participate in a research study. This study will take approximately twenty minutes to complete, spread over the span of six weeks. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: This study is investigating renewable energy sources and how they can be used to create a diversified energy portfolio in the emirate of Sharjah in the UAE.

Procedures to be followed: A preliminary form will ask for your participation in the study. You will be asked to fill out a series of three surveys. The first will ask the participant to build an energy portfolio and explain their choices. One week later, we will send out another survey based on the results of the first survey requesting participants to predict the energy source's contribution to the portfolio and explain. Then, we will send out a common portfolio from the last round and ask the participants to agree or disagree with an explanation of their answers.

Risks to study participants: There are minimal risks associated with this participating in this study. You may wish to give an answer that others would want to hear rather than what you truly believe. There is also a very small chance that others will find out how you have answered, which may make an impact on your personal or professional life.

Benefits to research participants and others: There are minimal benefits associated with participating in this study. Participant may benefit from this study by being given the opportunity to learn from their peers. Findings from this study will potentially benefit governments pursuing renewable energy policies.

Record keeping and confidentiality: Responses will be stored in the Qualtrics survey system. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators 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.

Cost/Payment: There is no direct cost or payment for participation.

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

Professor Kent Rissmiller WPI IRB Chair 508-831-5019 kjr@wpi.edu	Gabriel Johnson Human Subjects Administrator 508-831-4989 gjohnson@wpi.edu

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 signing below, 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.

_____________________________ Date: ____________________

Study Participant Signature

____

Study Participant Name (Please print)

______________________________________ Date: ____________________

Appendix B: Letter of Support from SEWA

إدارة البحوث و الدراسات
RESEARCH & STUDIES DEPT.

هيئة كهرباء ومياه الشارقة
Sharjah Electricity & Water Authority

07 November 2019

To Whom it May Concern

Subject: SEWA-AUS-WPI Interactive Qualifying Project Program

Sharjah Electricity and Water Authority (SEWA) and American University of Sharjah (AUS) are working with Worcester Polytechnic Institute (WPI), Massachusetts, USA, jointly on Interactive Qualifying Project (IQP).

During the course of IQP, students based at AUS are conducting **research on Water & Renewable Energy.** At the end of the projects, students will deliver findings and recommendations through formal reports and oral presentations to projects sponsor.

These projects will provide critical inputs to SEWA. The research findings in water-related areas will help SEWA draw a planning roadmap aligned with SEWA's goals and objectives.

Your support and help are highly appreciated.

Best Regards,

Eng. Mayada Al Bardan,
Manager, Research & Studies Dept.

Appendix C: Round 1 Survey Questions

1. First Name [Text Entry]
2. Last Name [Text Entry]
3. Employer [Text Entry]
4. Position [Text Entry]
5. Email [Text Entry]
6. IRB Consent Form [Yes/No]
7. Please choose the types of energy sources you would like to include in an energy profile for 2020. If you would like to suggest an energy source that is not included on this list, please select "OTHER" and specify in the next question. If you would like to specify more than one unlisted energy source, please separate your choices with commas in the following question. [Multiple Choice, Can Select Multiple Choices]

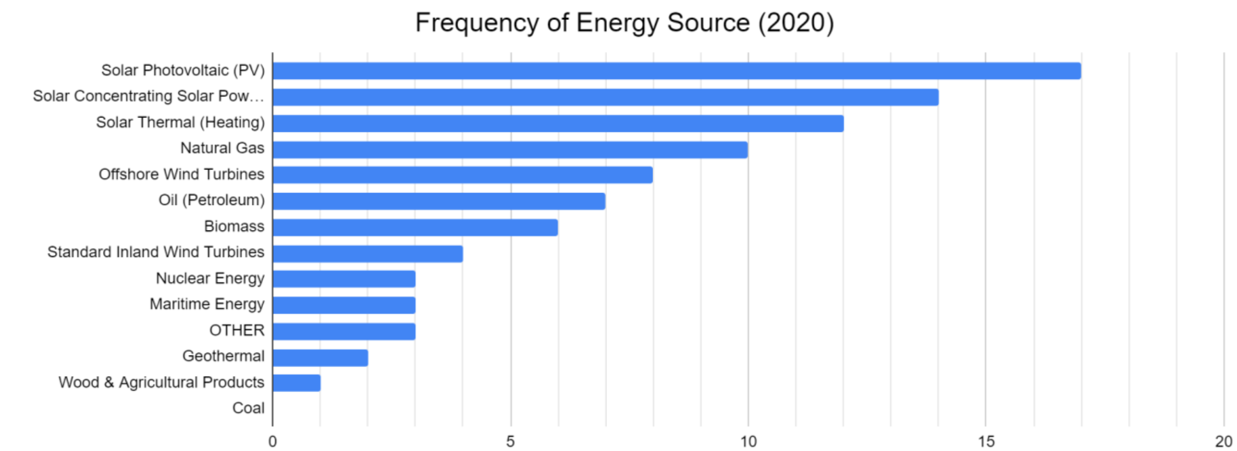
Wood & Agricultural Products	Oil (Petroleum)
Biomass	Coal
Standard Wind Turbines	Natural Gas
Offshore Wind Turbines	Nuclear Energy
Solar Thermal (Heating)	Maritime Energy
Solar Photovoltaic (PV)	Geothermal
Solar Concentrating Solar Power (CSP)	OTHER

8. If you selected "OTHER" in the previous question, please name the energy source(s). [Text Entry, Minimum 100 Characters]
9. Using the energy sources you selected above for 2020, please describe why you chose these options. [Text Entry, Minimum 100 Characters]

Appendix D: Round 1 Report

<u>Findings for 2020 Portfolio:</u>

Summary of Responses



This graph shows the number of times each energy source was selected to be included in a survey taker's energy portfolio for the year 2020.

Arguments for Energy Sources

Below are reasons survey takers decided to include, or not include, a certain energy source in his or her 2020 energy portfolio. Unless noted, all responses below are "Pros" or benefits of the listed energy sources.

*Note: Responses may have been edited for clarity and grammatical errors.

Key: Energy Source (Number of Votes)

General Solar Energy - PV(17), CSP(14), Heating(12):

"The renewable resources in the form of solar (PV and CSP) have great potential in UAE and their projects are economically feasible."

"However, apart from the obvious benefits to the climate, solar power also has an extremely high Return On Investment over the long term."

Solar PV (17):

"Photovoltaic cells is being more and more attractive with the increase in its efficiency and reduction in its costs."

Solar Heating (12):

"For water desalination, solar thermal heating and concentrating solar power can be used for partial heating of water as part of the desalination process."

Natural Gas (10):

"Since the target is 2020, I would like to keep the more common source of energy, such as natural gas and oil."

"Natural gas generation power plants is a must as it is characterized by a fast response to meet load variations. Natural gas is the lowest emission fossil fuel resource."

“A gas powered plant is over 40% efficient in terms of power production, and combined cycle plants are over 60% efficient.”

Offshore Wind Turbines (8) & Standard Inland Wind Turbines (4):

“For 2020, renewable energy should have an important presence in the [energy] mix, especially wind and solar photovoltaic, which has a very good benefit/cost ratios.”

Oil (7):

“Conventional energy generation from oil (petroleum) is still needed until full dependence on renewable energy sources is achieved.”
“Oil and Natural gas because of availability and economical values.”
“Maximize the usage of natural energy sources at a low cost.”

Biomass (6):

“Lot of waste available that can be used as an energy source.”

Nuclear Energy (3):

“Nuclear energy is a clean source and is a perfect option for baseload as renewable resources can not be dispatched.”

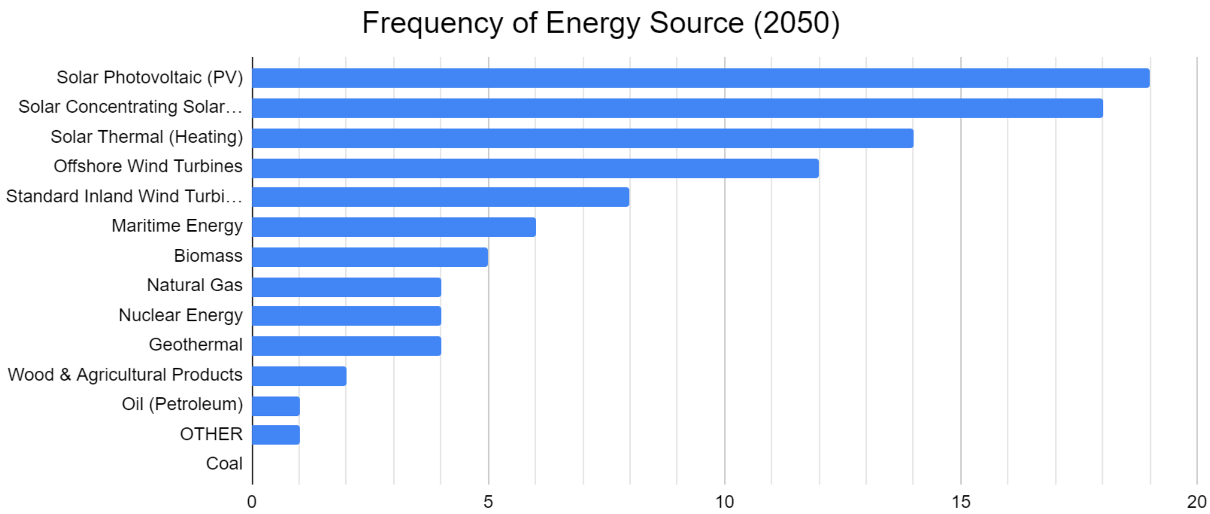
Maritime Energy (3):

“I wish to see Maritime energy as UAE is surrounded by the Arabian Gulf and the Gulf of Oman or the Indian ocean. However, I am not sure how mature is this technology.”

OTHER: Waste-To-Energy (1)

“Waste-to-Energy plant is a sustainable source of energy and does not require a huge area like a solar farm. Waste remains a part of our daily lives, from organic matter to petroleum-based plastic, waste comes in many forms. So as long as the community continue producing waste, the WTE plants continue to generate energy.”

Findings for 2050 Portfolio:
Summary of Responses



This graph demonstrates the number of times each energy source was selected to be included in a survey taker's energy portfolio for the year 2050.

Arguments for Energy Sources

Below are reasons survey takers decided to include, or not include, a certain energy source in his or her 2050 energy portfolio. Unless noted, all responses below are "Pros" or benefits of the listed energy sources.

*Note: Responses may have been edited for clarity and grammatical errors.

Key: Energy Source (Number of Votes)

General Solar Energy - PV(19), CSP(18), Heating(14):

"The penetration of solar can be much higher in 2050 because of decreasing solar cost."

"The Gulf region is one of the world's richest areas in sunshine. Average annual sun irradiation: ~ 2000 – 2200 kWh/m2."

Cons:

"Considering the high demand of energy I am not too optimistic on just solar energy."

Solar PV (19):

"I think in 2050, efficiency of solar photovoltaic cells will have increased to enable full dependence on solar power to generate electricity for residential purposes."

Solar CSP (18):

"Within this time frame, other sources can be completed, such as solar thermal or CSP."

Solar Heating (14):

"Solar thermal will continue to [contribute a] large part in water desalination."

Offshore Wind Turbines (12):

"I will go with the same options but added off-shore wind turbines as Wind energy has no potential in UAE due to low average wind speeds; however, off-shore wind could be feasible."

“ I do believe that by 2050 these are essentially inevitable, especially offshore wind (again, depends on the wind resource and where the turbines would be) and photovoltaics.”
Cons:
“ Wind turbines are not there yet in my view due to the distance the energy has to be moved. However, with the rapid pace at which technology is moving, my views may change in the next decade.”

Standard Inland Wind Turbines (8):
“Hopefully, wind turbines technology will also have evolved to enable energy generation from low wind speeds inland and can be used for residential power generation.”

Maritime Energy (6):
“Maritime energy should be explored since Sharjah has a long coastline.”

Biomass (5):
Cons:
“I would think that biomass and wood products would have source limitations”

Natural Gas (4):
“Conventional and less pollutant sources, such as natural gas, might be still in use, just to regulate renewable ones.”
“Oil and gas may become expensive commodity or vanish in that case the other reliable option will be nuclear.”

Nuclear Energy (4):
“Nuclear Energy is a clean form of energy that is also very efficient.”

Geothermal (4):
Cons:
“I excluded geothermal because of harmful gases besides, due to the thickness of the earth's crust and the variation of temperature with depth, UAE does not lie in economically feasible areas for geothermal energy.”

Oil (1):
Cons:
“By 2050, we should have enough reasons to switch completely away from the traditional fossil fuel and towards more environment friendly and renewable solutions.”

OTHER: Waste-To-Energy (1)
“The volume of waste is proportional to the growth of the population and the GDP of the country. By [the] year 2050, I believe that the waste generated in Sharjah will also increase due to the development of area and population growth. The more waste generated, the more energy will be produced and delivered to the grid of Sharjah by the year 2050.”

Appendix E: Round 2 Survey Questions

1. First Name [Text Entry]
2. Last Name [Text Entry]
3. Using the given renewable energy sources, please allocate points based on how much you expect the energy source to contribute to the entire portfolio for 2020. You have exactly 100 points to distribute. **You may use no more than and no less than 100 points.** The survey software will prevent you from going above 100 points and moving on if your total is below 100 points. There is a counter at the bottom displaying the total number of points you have already used. [Constant Sum via Sliders]

Solar PV	Oil (Petroleum)
Solar CSP	Biomass
Solar Thermal (Heating)	Standard Inland Wind Turbines
Natural Gas	OTHER
Offshore Wind Turbines	

4. Using the energy sources you selected above for 2020, please describe the reasoning behind your distribution of points. [Text Entry, Minimum 150 Characters]
5. Using the given renewable energy sources, please allocate points based on how much you expect the energy source to contribute to the entire portfolio for 2050. You have exactly 100 points to distribute. **You may use no more than and no less than 100 points.** The survey software will prevent you from going above 100 points and moving on if your total is below 100 points. There is a counter at the bottom displaying the total number of points you have already used. [Constant Sum via Sliders]

Solar PV	Standard Inland Wind Turbines
Solar CSP	Maritime
Solar Thermal (Heating)	Biomass
Offshore Wind Turbines	OTHER

6. Using the energy sources you selected above for 2020, please describe the reasoning behind your distribution of points. [Text Entry, Minimum 150 Characters]

Appendix F: Round 2 Report

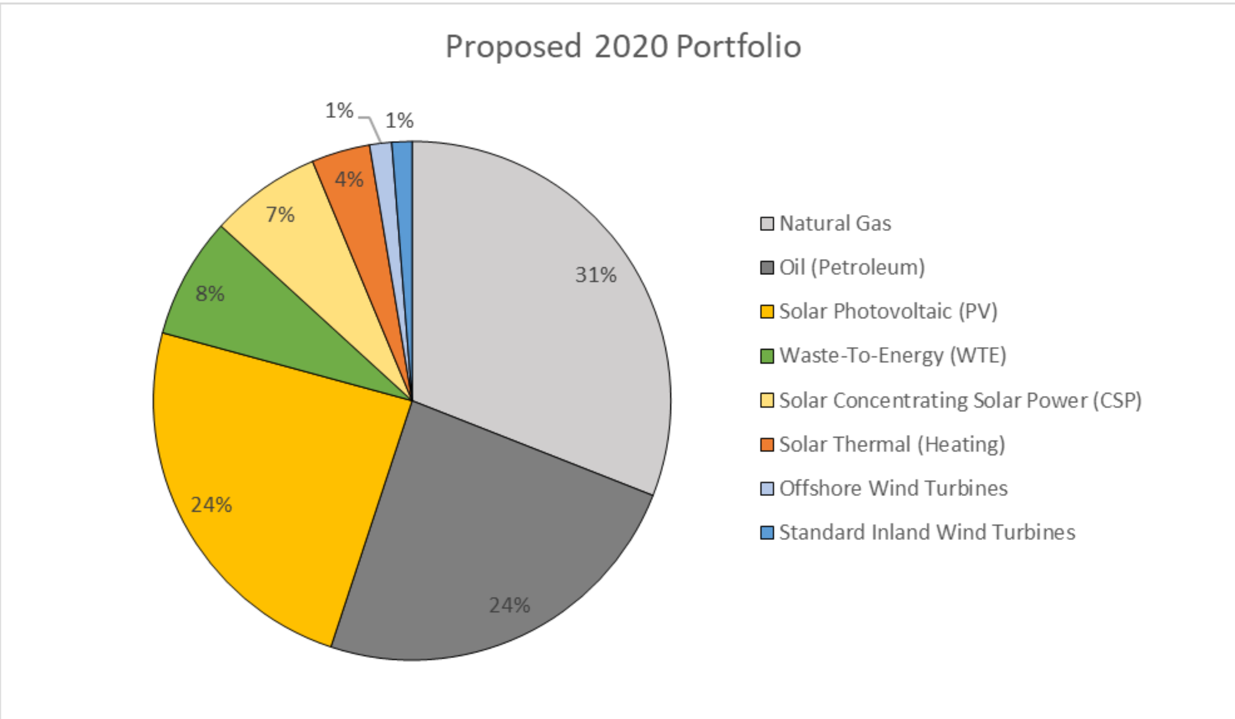
Reasons survey takers decided to assign a certain energy source points in his or her 2020 energy portfolio are in quotes below. Responses may have been edited for clarity and grammatical errors.

Key:

Energy Source (% Avg. Contribution): [Respondent's Points Allotted]: Explanation	Note: If multiple energy sources are listed, points given are separated by commas for each source.

<u>Findings for 2020:</u>

Proposed Energy Portfolio for 2020



Arguments for Energy Sources

Solar Energy (PV (24%), CSP (7%), Heating (4%)):

[15, 5, 5]: "[I]t will take some time before solar power is considered an efficient source of energy. Solar PV and Solar CSP farms require a considerable area to provide the quantity of power that would be relevant to compensate for gas and petroleum based turbines currently used in conventional power plants."

Natural Gas (31%) & Oil (24%):

[35, 5]: "Natural Gas and Oil (petroleum) have been included for obvious reasons, that is the current dependence on these fuels mandates that conventional turbines are always available in energy portfolios of the immediate future, at least on a standby basis."

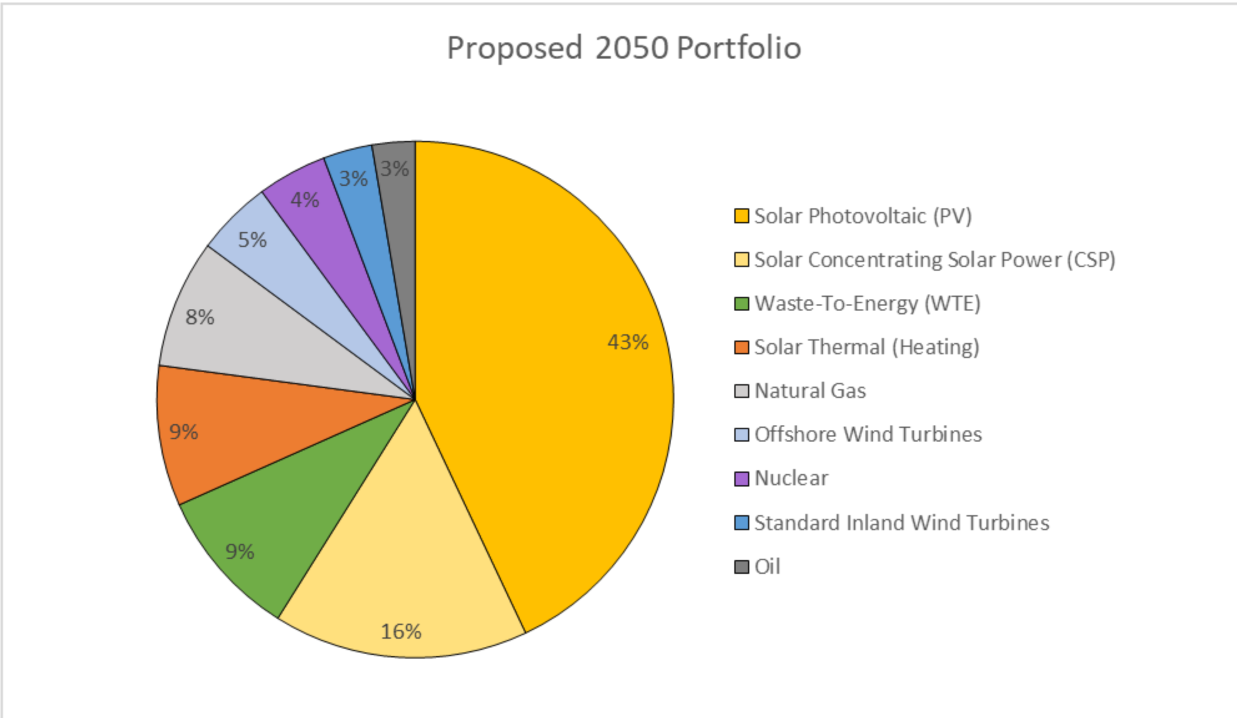
[30 ,45]: "Oil … due to its availability will keep dominating the market."

Waste-to-Energy & Biomass (8%):

[?, 15]: “Biomass power plants are not efficient in terms of power generation. However, a reason for its inclusion is the ample amount of [biomass available] as fuel for these power plants. Municipal Solid Waste (MSW) is the general waste that is produced by humans all over the world. An efficient way of reducing this waste [and it's disposing space] is to convert it to fuel for power plants. It won't increase [overall] efficiency but will greatly impact the efficiency with respect to environment[al] conservation.”

<u>Findings for 2050:</u>

Proposed Energy Portfolio for 2050



Arguments for Energy Sources

Solar Energy (PV (43%), CSP (16%), Heating (9%)):

[9,15,1]: “Both [solar and biomass] are plentiful in this region and a good form of ensuring a clean environment and atmosphere, without the emissions that are expended from conventional power plants.”

[50, 20, 0]: “Double sided panels, partly translucent panels will aid the spread of solar panels. But Sharjah does not have a lot of land compared to other Emirates. So PV is capped at 50, CSP will thus need to be developed. But time and cost may impede CSP, so capped at 20”

[35, 15, 10]: “SEWA can't completely rely on solar power because its not reliable and will require very large energy storage batteries which is just not feasible”

Offshore Wind Turbines (5%) & Standard Inland Wind Turbines (3%):

[0, 15]: “Further inland in Sharjah near the mountains the wind speeds may be favourable because of low population and no man made obstructions to wind. But wind is not very reliable, and UAE doesn't have very high wind speeds as needed for very large power generation.”

Waste-to-Energy & Biomass(9%):

[60]: “Also, Waste to energy power plant[s] produce clean and renewable energy through thermochemical process. The energy generated from WTE plants, reduces the dependency on the production of power plants based [on] fossil fuels”

OTHER:

Hydroelectric (0.33%):

[5]: “[There is a] lack of information online regarding the availability of areas in the country for development of hydroelectric power plants. [However] if the area is available, hydroelectric plants are very easily a highly efficient and clean form of energy.”

Nuclear (4%):

[55]: The only resource needed to make nuclear energy a primary fuel is fully trained and dedicated staff to run nuclear power plants. Nuclear energy can fully compensate for power generation, keep the environment clean and necessitate the overall technological development of a country.

Natural Gas (8%):

[63]: “Gas is a local resource and will become more difficult to sell as the rest of the world moves to renewables. Therefore, the producing countries will use [gas] to supply their own needs.”

Oil (3%):

[15]: “One reason being the characteristically unreliable nature of renewable resources. So to meet base load demands, but to have a practical goal of weaning of oil I think a 15 percent generating capacity based on oil is ok for 2050.”

Appendix G: Round 3 Survey Questions

1. First Name [Text Entry]
2. Last Name [Text Entry]
3. Do you believe that this is an optimal energy portfolio for Sharjah in the year 2020? [Yes/No]

Yes, I think that this portfolio is something that Sharjah should aim to achieve for 2020.
No, I think this portfolio can be improved.

4. If answer to Q3 is "Yes", complete 4a. If answer to Q3 is "No", complete 4b and 4c.
   a. Please explain why you agree with Sharjah's 2020 energy portfolio. [Text Entry, Minimum 200 Characters]
   b. Using the given renewable energy sources, please allocate points based on how much you expect the energy source to contribute to the entire portfolio for 2020. You have exactly 100 points to distribute. **You may use no more than and no less than 100 points.** The survey software will prevent you from going above 100 points and moving on if your total is below 100 points. There is a counter at the bottom displaying the total number of points you have already used. [Constant Sum via Sliders]

Solar PV	Oil (Petroleum)
Solar CSP	Waste-To-Energy (WTE)
Solar Thermal (Heating)	Offshore Wind Turbines
Natural Gas	Standard Inland Wind Turbines

   c. Using the energy sources you selected above for 2020, please fully describe the reasoning behind your distribution of points. [Text Entry, Minimum 150 Characters]
5. Do you believe that this is an optimal energy portfolio for Sharjah in the year 2050? [Yes/No]

Yes, I think that this portfolio is something that Sharjah should aim to achieve for 2050.
No, I think this portfolio can be improved.

6. If answer to Q5 is "Yes", complete 6a. If answer to Q3 is "No", complete 6b and 6c.
   a. Please explain why you agree with Sharjah's 2050 energy portfolio. [Text Entry, Minimum 200 Characters]
   b. Using the given renewable energy sources, please allocate points based on how much you expect the energy source to contribute to the entire portfolio for 2050. You have exactly 100 points to distribute. **You may use no more than and no less than 100 points.** The survey software will prevent you from going above 100 points and moving on if your total is below 100 points. There is a counter at the bottom displaying the total number of points you have already used. [Constant Sum via Sliders]

Solar PV	Offshore Wind Turbines
Solar CSP	Natural Gas

Solar Thermal (Heating)	Nuclear
Waste-To-Energy (WTE)	Oil (Petroleum)
Standard Inland Wind Turbines	

c. Using the energy sources you selected above for 2050, please fully describe the reasoning behind your distribution of points. [Text Entry, Minimum 150 Characters]

Appendix H: Transcript for Interview with Professor 1

Note: Transcripts may have been edited for conciseness or clarity. Text in italics indicate a member of our team speaking. All other text is the survey participant speaking.

So we just have a few questions concerning some of your answers. Between round one and round two, in round one, you included nuclear and geothermal, you said you wanted it in your portfolio. But then in round two we removed geothermal because it was one of the least popular options. But we did leave the other in case people wanted to add it back in there. So we were wondering why you didn't include nuclear and geothermal.

I mean, I'm not a big fan of nuclear and geothermal as a whole. But we do have a lot of nuclear plants throughout the world, and there's no sign that it is going to go away anytime soon. So there are also a lot of places nuclear energy plants are getting built, UAE including. I mean, it has his own plus and minus, of course, because nuclear compared to other fossil fuel based energy technologies, definitely many people view it as environmental friendly, because it doesn't produce carbon dioxide to some degree. But definitely it has its own bottleneck of what to do with the waste. So that is one of the reasons, especially after what happened to Japan. Everybody started being a bit conservative on not going full blown on nuclear, but many people were advocates of nuclear in the past and their big argument was that it's much more environmentally friendly. And also cost wise I think is much lower cost compared to many other many other options. So if you asked me, if it is not a choice definitely I could replace it with some other choices. But this is this is probably the reason you saw me. I'm not a big advocate on that on this. Geothermal on the other hand, yes, I do like this, not that I don't have positive feelings for geothermal. But the problem with geothermal, whether the contribution of geothermal could be very significant or not in the years to come is not something I'm as certain as some of the other choices. For example, we know that solar cost wise we can compete, which is not necessarily the case for many other emerging technologies where, theoretically, this sounds nice, they look nice, but no guarantee that in the long term you're going to see that happening.

If we did keep geothermal in round two and three, if we kept that as a slider choice, do you think you would have given it points?

Yeah, given choice I definitely would.

As a follow up to those two questions, were your answers usually like a balance of practical and an idealistic view. What were you thinking when you when you were thinking about a possible portfolio?

Of course, there's a balance. Sometimes it is easy to get too idealistic and say we're going to change the world. I mean, obviously reality is if you don't find it realistic enough, which is still ambitious, by the way. I saw that the plan that you put, I still find it ambitious because shooting a target of more than 60% based on solar energy, even by 2050 is a very ambitious target to begin with. Which is fine. We do need to have some ambitious target as well. They need a push, if they have the push that will be able to at least come closer, which itself would be a become a big accomplishment on itself. But we still want to see that the other side of the constraint we understand and appreciate that we don't understand their limitations. So that's something that's definitely the biggest trend not only for this. Everywhere the biggest bottleneck is that the technologies that we use, we are comfortable. So the question is, why do we want to change? Right? So the motivation has to be strong enough, big enough to put it away from the fossil fuel. Especially, we're talking in a place where we do have natural resources in terms of oil and gas. If it's something they already have, they know the plus and minus of these technologies, the question is not an easy sale for them, even to their management. Why they need an abrupt shift to something that we actually don't know. A lot of things about them. There's positive and negative in both sides.

In round one, you said that by 2050 we should have enough reasons to completely step away from fossil fuel and towards more environmentally friendly and renewable solutions. Why did you add natural gas and oil in 2050?
Yeah, I think it's more of a realistic side of me, which more or less accepts the fact that we probably would not be able to completely eliminate it, knowing the fact that Sharjah do have some of the natural resources. So I doubt they're going to go completely away from it. If they didn't have it, if they had to bring it from somewhere else, then things would have been a bit different. But that's not the case.

And in for rounds two and three, we had a report from the previous rounds before the survey. Do you think that affected how you answered?
I'm not sure. Yes, it does to some degree, but I wouldn't say dramatically.

Was it surprising to see some of the results or was there anything that caught your eye from what the other experts mentioned?
A little bit more reliance on biomass. I probably wasn't expecting that. But it kind of makes sense to me, because SEWA is building a waste to energy power plant. Following SEWA Abu Dhabi also started discussing that possibility. So there could be a scenario where we might be seeing more and more. UAE in general, I would say it's a more of a consumer country. So more of consumption, meaning more of waste that is getting generated. So managing those waste has always been a will always be a problem. So for that reason, biomass and waste-to-energy based facilities are probably going to be more popular than we think. And this is worldwide. This is not a new technology, by the way. I mean, lots of places already have it. So they have enough reason to believe that this is going to work.

Great. Thank you. I think that's all the questions that we had for today. Thank you.

Appendix I: Transcript for Interview with Professor 2

Note: Transcripts may have been edited for conciseness or clarity. Text in italics indicate a member of our team speaking. All other text is the survey participant speaking.

In round one: You had biomass in the portfolio for 2020, but you excluded it from 2050. Can you explain why you did so?

Specific reason, no. I just changed my mind about this. I wrote a reason for the biomass on the 2050. It's not a clean source. Besides, Sharjah in specific, they don't have these kind of industries that provide these kind of wastes. Meaning, it's like the waste that are useful biomass, and biomass generation are not just the ordinary user's residential wastes, so it's too costly to do it from residential waste. Recycling is okay, but producing electricity is another thing.

In round one in 2020, you pick both nuclear and maritime as energy sources, but then in round two, you didn't assign any points to either of them. Was there a reason for this?

For 2020, maybe I didn't take much notice much of the timeline, the year is less than a year away. When I noticed that, when I talked about 2050, nuclear had a lot of problems especially for SEWA as UAE as a whole. But for SEWA, in specific, it's going to be problematic. More of technical points. And there are other, like emissions, emissions production are not priorities now. It is not how clean the sources is. It is technically how the source could meet the requirements. Nuclear. First, it cannot be built in small scale, it has to be built in a massive scale. So, building nuclear power plants, would possibly cover all SEWA requirements, which is not possible because the nuclear power plants you cannot trap it. So don't go for it if this is going to cover all the requirements. It usually covers what is called the base load, the part of your load that is almost fixed. For SEWA, maybe you are talking about one giga or 1.5, which is a quarter power plant, very small.

In round three: You added natural gas in the portfolio for 2050 after you excluded it from round two. Can you explain why you did so?

At SEWA, there is currently 100% natural gas. Usually other countries or other utilities always have natural gas, as an element. It cannot be decreased. Because natural gas, among other resources, the only one that turns a micro-gas turbine, where it's just gas, not steam, just exhaust gases. So it responds much faster than the other through steam. So this is maybe the fastest option they have. So they cannot get rid of it. But here comes some politics. I mean, if you can rely on another emirate with providing you with this fast response, you can have your system without natural gas. But it's all like this part is have to go to the interlinks between SEWA, Dubai, Fujairah, and all the other emirates. And if everyone realized that other Emirates will be providing the fast response units, then it's a big problem. No one will have it, you get the problem. So, like, as optimistic point of view and emissions. Let's get rid of natural gas, but we can't. Even if you want to increase the efficiency of natural gas and provide a combined cycle of the natural gas, you take the exhaust and use it to produce steam. It will slow down your response. Because now if you have steam and gas in the same cycle you have to follow the speed of the steam. So the whole system efficiency will increase the response will decrease, meaning as if you converted, just from natural gas, using a gas turbine to any resources that can use steam, like nuclear like fuel, oil, so on. So, yeah, some of the responses for the beginning, I was optimistic about and looking at the emissions. And then I start looking at some technical aspects.

For round two, you picked an "OTHER" option saying you wanted large scale storage devices. Can you please explain?
Yeah, this is not a generation option, but this could replace the natural gas. I mean, storage has a very fast response, faster than any generation unit we have. The idea that, if you have, for example, nuclear, which you cannot control it, and you have storage, both together will be a fast responding generation system. But the problem with the storage system is that it's too expensive. And the portfolio I don't know if you're talking about an energy generation portfolio. I'm not sure if you want include storage or not, but possibly it's a technical part of it.

This is back to nuclear. So, you said that loads vary significantly from summer 100%, to winter, 30%. What were you referring to?
So it's the demand of the SEWA network that goes from 100% in summer to 30% in winter. If you have a nuclear power plant rated at 100% of your load, then you will not utilize it fully meaning in the winter. You have to reduce it up to 30%. The main idea for nuclear power plants to be economically feasible is that you utilize it almost 100% all the time, you just turn it off for maintenance, you don't reduce the output. In this case, the only way to have a nuclear power plant is to have it at 30%, which covers the winter, and also would run in the summer continuously. This is too small for a nuclear project. You see where the problem lies?

In your response for round three 2050, in the very last in the very last sentence, you just said offshore wind turbines, and then nothing else. We were just wondering if you wanted to explain anything in that section?
The speed inland is not sufficient economically compared to other wind turbines. With offshore there is a chance. SEWA, and I think even Abu Dhabi and Masdar in specific, they're investing in wind turbines in the UK. They are not investing in wind turbines in the region, because of the average wind speeds, even if you go offshore. Yes, it's economically feasible, but not that much. If you are going to invest, at that point you will invest in another country. SEWA, if they want the best, it's going to be offshore, they cannot put it inland. There are two ways, SEWA only have a shore on the Arabian Gulf. On the other side, on the Indian Ocean, which is called the Gulf of Oman. There are small spots actually related to Sharjah, related to the same Emirate SEWA covering, but they are like they are separated. These spots will be the perfect location if you want to put offshore wind turbines, because the speeds over there, are much more than the Arabian Gulf.

Do you think that reading through the reports changed how you answered in the next round?

Yes, yes, of course. I did read some of these responses and I changed my mind about some things.

Appendix J: Transcript for Interview with Professor 3

Note: Transcripts may have been edited for conciseness or clarity. Text in italics indicate a member of our team speaking. All other text is the survey participant speaking.

Alright so then from round one to round two. For at least in round one for 2050, you had nuclear energy is one of the options. We were wondering why you didn't assign nuclear any points in the Round 2 portfolio.

I don't have preferences for nuclear I even wrote it for the first of it. Like, I'm not a fan of nuclear, even with all the safety because one incident could happen and it can damage, really big area. But, again, since baseload is needed. And let's say 50 years from now, there is no oil, then we have to have a base load and the only stable one would be nuclear. So, we can, or were forced to use it but bare minimum. That's what we will use whatever like I think 25% will be the base load. At that time, with huge capacity of batteries available with customers.

Okay, all right, and then so for round three. Well for rounds one and two you added offshore wind for both of them, and then in round three you removed it for both 2020 and 2050. Why'd you decide to remove it?

Well, again because I just really thought about it. If you're thinking only short term, I understand that they're gonna have really wide coastal region that they can put this wind turbine, but wind turbine will not work actually in all UAE, because the speed. The average or what they call it the rule of thumb, speed has to be above three meter per second, to have feasible wind turbine. Here it's always below that value inland. Offshore I don't know the statistics for the offshore I think they can use it but it came to me that this is for Sharjah and they don't have really big coastal area to have an offshore wind turbine.

In round three, you said, "A baseload is still needed for a stable electric network with either, which either will come from fossil fuel or nuclear." We're just wondering, why do you prefer fossil fuels over nuclear.

Because if an accident happened at the fossil fuel plant, I think long term that small area gonna get damaged, if it happened in power plant, it will go across borders to other countries. I cannot understand people going to nuclear, and they will sit next to them, even if they agree then will the people next, next to them, like their neighbors agree? I will not accept it will be disaster such a small scale disaster and disaster will happen. All engineering projects, whatever, anything you think about can explode. It's really scary thing to do fossil fuel cannot stay just longer period until enough good capacity of batteries will be available within the customer base even houses, then baseload will not be a problem, which means every house has to have batteries. And this needs enough time to get penetrated in the market because we cannot even, even on centralized batteries.

In round three you added waste-to-energy for 2050. And so what are your thoughts on the waste-to-energy system?

We are burning the waste. So, this will contribute to pollution anyhow so I thought on it. And then we need to have electricity we need to have this energy. I thought about it once more I said well biofuel will be feasible, when only oil is not there, especially in this region because still producing oil for even what they call it shell oil in this area. It's on the surface so it's not difficult to produce and it will be cheaper than treating waste, so I added this just because you say 2050, if there will be regulation banning people from using oil, let's say for pollution and it will be enforced by other countries, then we have to use any other source of energy.

All right, and then just one last question. Do you think that reading through the report after each round, do you think affected your answers for the next round.
I think the second round for sure. Firstly I was surprised on the first report, it just made me think, or see how other people think about energy resources. But some of that for me was not feasible like I mean, especially people for enforcing or liking to have nuclear or seeing the value of biofuels. I'm not saying biofuel is of no use. Putting without produce enough bio material to accept our regular voice we're not an agriculture country that produces lots of agriculture waste or like animal waste, so you need to import this to make it feasible to produce power. Even UAE is one of the highest in producing waste per capita or per person, but still it's not enough to produce sustainable energy and make it as cheap of oil. Again, oil costs three to $4 a barrel to produce other countries it take them, 20 from regular oil. And if you're going to go to with Shell Oil, it goes $40 per barrel, so there isn't. As I said, if everyone's switch to renewable that's fine. People still gonna use oil because it used to come out to the ground so people without the need to produce oil. They used to see oil coming out of the ground. Now maybe it's not the case. But it doesn't cost that much to get it out. Like in the UK or what they call it, north of UK, they need to drill, really deep sea to get there, the UAE doesn't have to go thousand meters down to get oil so production is not that difficult.

One other question actually you're saying the main issue with nuclear for you personally is the safety Yeah, yeah, there's actually, I mean I don't know the name of it but there's statistics to tell that per like deaths per terawatt of power produced. Coal has the highest number of deaths
Because the nuclear for this amount of energy you can tell much energy we use from nuclear to call it was still a small portion. So, when you tell me like nuclear use now let's say we have 5%. So 5% percentage of accident in the 5% compared to percentage of accident in to the whole oil I mean coal use, I think it is much lower and I don't think that statistic is correct, in Ukraine, Power plant that Chernobyl. Chernobyl 200,000 people were affected. They brought 20,000 workers just to fix the structure. It was saying that the 20,000 will die within two to four years. And these guys are not in an accident they're coming to fix the accident. And they said, it was a dilemma for the project engineer, he will recruit workers, and he knows these guys will not die between two to four years. Tell them or not this is an ethical or professional dilemma. So, one small accident, it's a disaster.

It's not about the amount produced, it's sorry it's not about the amount that we're using its terawatt that's produced. So the capacity compared to the deaths, even though those individual cases of Fukushima Ukraine, whatever. Even in total, it's not like the number of deaths actually more for traditional fossil fuels and they are for nuclear, but if that's the case, would it change your mind you think.

I don't think so. One thing just happened like this in one of these factories. We're going to keep suffering for the next 50 years until this gets cleaned up, and bad enough, it won't get cleaned up. I think this is a really big mess. To use nuclear said I'm not saying I'm against nuclear, there is a way, they can build plant in very rural area with the really dramatic safety because who want this to be next to his house even like when disaster happen it will go to the neighboring countries.

Thank you again for your participation.

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