Renewable Energy Feasibility Study for the City of Jeddah in the Kingdom of Saudi Arabia

I. Introduction

The notion of developing sustainable communities is generally accepted as a way to reduce the negative environmental impacts associated with human activities, increase the health of citizens, and increase the economic vitality of communities within a country. In order to develop sustainable communities within the Middle East, significant attention is being placed on designing alternative and renewable energy technologies, such as photovoltaic (solar) and grey water recycling system to reduce (1) fossil fuel based energy consumption, (2) water consumption, and (3) climate changing greenhouse gas (GHG) emissions associated anthropogenic activities [1,2, 3]. Most notably, the United Arab Emirates's capital city of Adu Dhabi has created a framework known as "Estimada", Arabic for sustainability, as part of its overall urban development plan to address transportation, power, and water consumption needs. [4,5] However, the solutions and roadmaps being created by other countries within the Middle East are not designed for the unique cultural, political, industrial, environmental, and economic characteristics of the Kingdom of Saudi Arabia; therefore, these solutions and roadmaps are not appropriate for the Kingdom of Saudi Arabia. This paper seeks to understand the Kingdom of Saudi Arabia's (KSA) definition of sustainability in both cultural and environmental terms and identify what sustainability and renewable energy technology trajectories are relevant and appropriate for the Kingdom of Saudi Arabia and the city of Jeddah in particular.

II. Background

The Kingdom of Saudi Arabia (KSA) is an Arab country located in the Middle East's Arabian Peninsula. The country has a total area of ~2,150,000 sq. km which makes it the largest country in the Middle East on a per area basis. The government of the Kingdom of Saudi Arabia is a monarchy and its current ruler is the Custodian of the Two Holy Mosques King Abdullah bin Abdulaziz. The constitution of the Kingdom of Saudi Arabia is based upon the principals found within the holy book of the Qur'an and principals of Shari'ah (Islamic law). [6] The city of Riyadh is the capital and largest city of the Kingdom of Saudi Arabia. Its metropolitan area is 600 sq mi and its urban area is 386.1 sq miles. The Red Sea coastal city of Jeddah is the second largest city in the Kingdom of Saudi Arabia. The city of Jeddah's metropolitan area is 1,158.3 sq mi and its urban area is 509.7 sq miles. The population of the city of Riyadh is ~4.6 million people, and the population of the city of Jeddah is ~ 3.4 million people. [7, 9] The country's total population is estimated to be ~28.7 million people. Of the ~28.7 million people living in the country, ~23.1 million are nationals and ~5.6 million are non-nationals. [10] Approximately, 82% of the country's total population lives within the city limits.

Geography and Climate

In comparison to the United States of America, the Kingdom of Saudi Arabia occupies an area that is slightly more than 1/5 the size of the continental United States of America. The terrain of the Kingdom of Saudi Arabia consists of mostly desert regions with mountains in the country's southwest. As a result, less than 2% of the country's total area is arable and much of the country's population lives along the eastern and western coasts.[10] Much of the desert regions are largely uninhabited expect for a dwindling collection of Bedouin communities.

The climate of the Kingdom of Saudi Arabia is arid with extreme temperatures over 110 degree Fahrenheit midday in the desert from the month of June through the month of August. Along the coastal regions, humidity values have been recorded as reaching 100 percent. [6] The capital city of Riyadh experiences its coldest month (31 degrees Fahrenheit) during January and experiences its hottest month (118 degrees Fahrenheit) during July. Riyadh has its rainy season during the spring months of March, April, and May and during the winter months of December, January, and February. During the time period of 1964-1992, the city of Riyadh received an average of 82.2 mm of rain. [8] The city of Jeddah experiences its coldest month (37 degrees Fahrenheit) during January and experiences its hottest month (117 degrees Fahrenheit) during June. The average annual rainfall of the city of Jeddah is 67 mm. [12]

Economy

The economy of the Kingdom of Saudi Arabia is currently geared towards the production and exportation of petroleum products. The Kingdom of Saudi Arabia is the world's largest producer and exporter of petroleum liquids and is the world's second largest crude oil producer. [13] The country's GDP is estimate at $USD 576.8 billion and its GDP per capita is $USD 20,500. The Kingdom of Saudi Arabia possesses more than 20% of the world's known petroleum reserves, and the petroleum sector of its economy accounts for roughly 80% of budget revenues, 45% of GDP, and 90% of export earnings. [10]

Electricity Resources

The Kingdom of Saudi Arabia (KSA) produced 179.1 billion kWh of electricity in 2007 and it consumed 156.8 billion kWh of electricity in 2006. [10] The country's electricity consumption per capita was 5,215 kWh/capita in 2006. In comparison, the United States of America produced 4.167 trillion kWh of electricity in 2007 and it consumed 3.892 trillion kWh of electricity in 2007. The electricity consumption per capita of the United States of America was 12,669 kWh/capita in 2007. [11]. Figures 1 and 2 show the growth in the Kingdom of Saudi Arabia electricity consumption and electricity consumption per capita from 2000 to 2006.

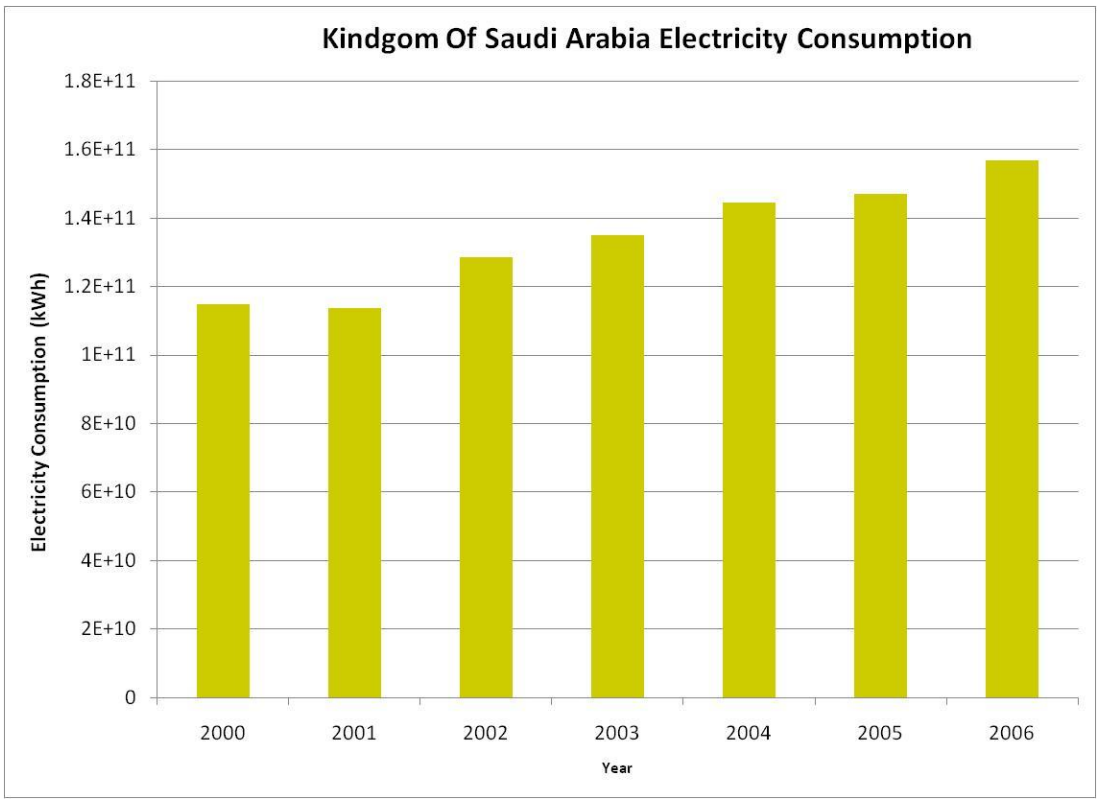

Figure 1: Kingdom of Saudi Arabia Electricity Consumption

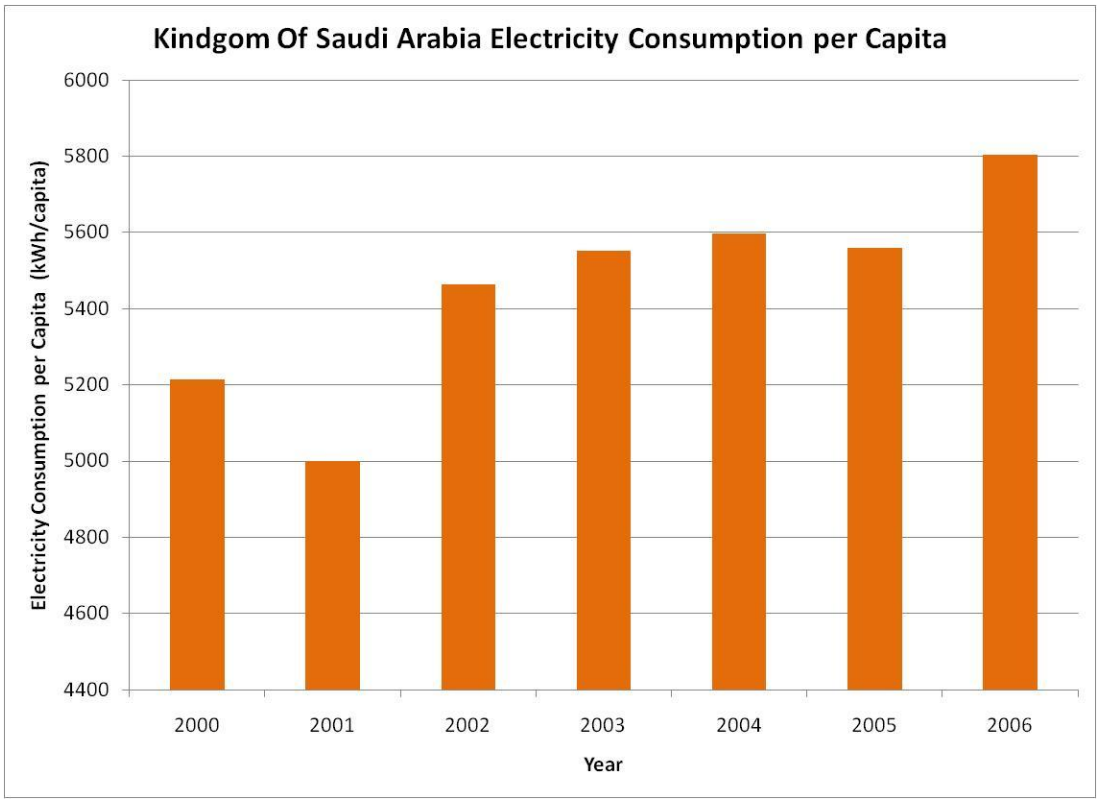

Figure 2: Kingdom of Saudi Arabia Electricity Consumption per Capita

Water Resources

The Kingdom of Saudi Arabia's annual water production was estimated to 2.59 cubic meters of drinking water and the water consumption per capita was estimated to be 102,000 liters annually or 286 liters daily by the National Water Company. According to the cities of Riyadh and Jeddah business unit's quarterly report, the average daily water supply in the two cities is 1,453,748 cubic meter/day and 657,000 cubic meters/day respectively. [14] In 2008, the Jeddah City Council of estimated its resident used ~200 liters of water per capita per day or ~73,000 liters/cap. [15]

III. Methodology

In order to determine which technology sustainability and renewable energy technology are appropriate for the city of Jeddah, members from the University of California, Berkeley and the Dar Al-Hekma College designed a survey to gather the viewpoints of the students at universities about sustainability. There 82 students from Dar Al-Hekma College and 42 students from University of California, Berkeley that participated in the survey. The students were asked to respond to questions about how much they were concerned about environmental pollution in their community using a Likert scale of 1 (very little) to 10 (very much). In addition to the survey, the Black Cloud air quality sensor was installed at both universities to measure CO_2, volatile organic compounds, lights, noise, temperature, and humidity.

To determine the technological feasibility of implementing renewable energy technology in the city of Jeddah, the RETScreen Clean Energy analysis software was used to estimate power production, cost, and GHG emissions of photovoltaic (PV) and wind turbine technologies for central grid electricity generation in the Jeddah area of Saudi Arabia.

Photovoltaic (PV) System

For the photovoltaic (PV) system analysis, the BP Solar mono-Si- BP 4175 unit was selected. This unit has a 175 W capacity, 13.9% efficiency and a frame area of 1.26 square meter.

In order to determine the energy production of the PV system, RETScreen calculates:

I. The solar radiation in plane of the PV array as a function of its orientation and monthly mean daily solar radiation on a horizontal surface

II. The energy production of the PV array given ambient temperature and available solar radiation

III. The inverter losses incurred when converting from DC to AC power

IV. The absorption rate by the electricity grid

Wind Turbine System

For the wind turbine analysis, the Vergnet GEV HP 62/70 unit was selected. This unit has a 1000 kW capacity, a 70 m hub height, a 62 m rotor diameter, and a swept area of 3,019 square meter.

In order to determine the energy production of the wind turbine system, RETScreen calculates:

I. The wind turbine's energy curve as function of wind speeds over a range of 3 m/s to 15 m/s

II. The gross energy production of the wind turbine before any losses as a function of wind speed, atmospheric pressure and temperature conditions

III. The energy production given losses to airfoil soiling, icing, etc.

IV. The absorption rate by the electricity grid

Financial Analysis

For both renewable energy systems, a 25 year project life was assumed and the inflation rate was 2.0%, the discount rate was 12.0%, and the electricity export escalation rate was 2.0%. It is also assumed that 100% of the electricity generated will be sold to the grid. For the PV system, 177,585 MWh will be exported at a rate of $USD 420.00/MWh. For the wind turbine system, 430 MWh will be exported at a rate of $USD 100/MWh.

The initial project cost for 333 Vergnet GEV HP 62/70 wind turbine units was estimated to be USD$ 672, 549,240. Total annual costs: USD$ 55,189,604. Total annual savings: 14,316,562. The payback period is greater than 25 years, but it is estimated to be ~63 years. The initial project cost for 603135 BP Solar mono-Si- BP 4175 PV units was estimated to be USD$ 841,518,061. Total annual costs: USD$ 83,869,268. Total annual savings: USD$ 74,585,505. The payback period is ~13 years.

IV. Results

The survey results for the Dar Al-Hekma students are shown in Figures 3 and 4, while the results for the University of California, Berkeley students are shown in Figures 5 and 6.

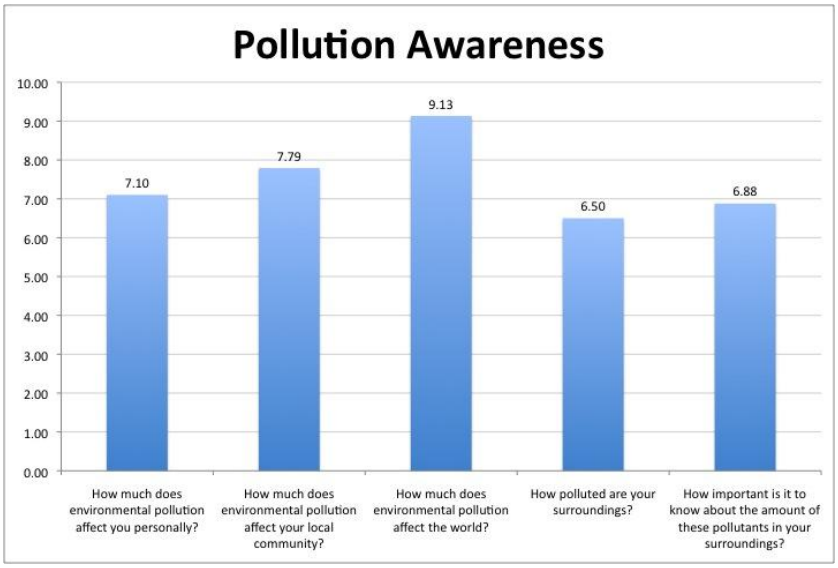

Figure 3: Pollution Awareness at Dar Al-Hekma College

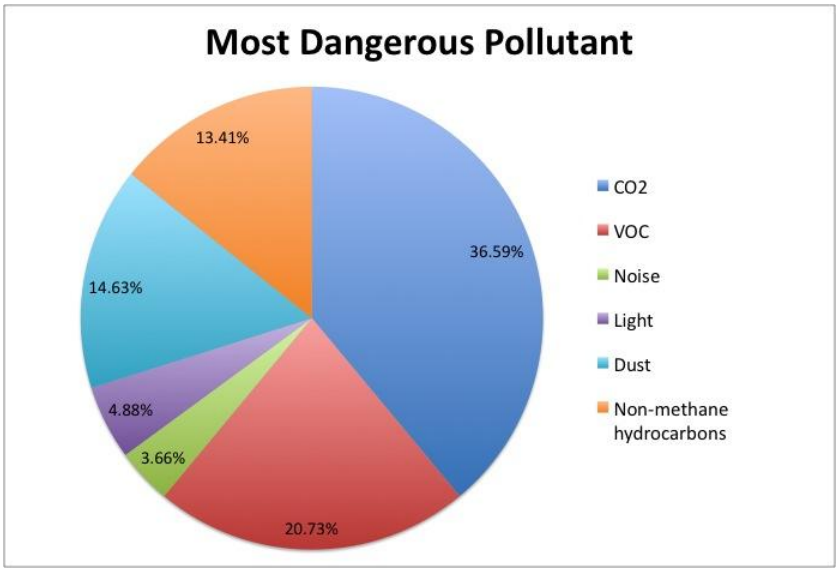

Figure 4: Most Dangerous Pollutant at Dar Al-Hekma College

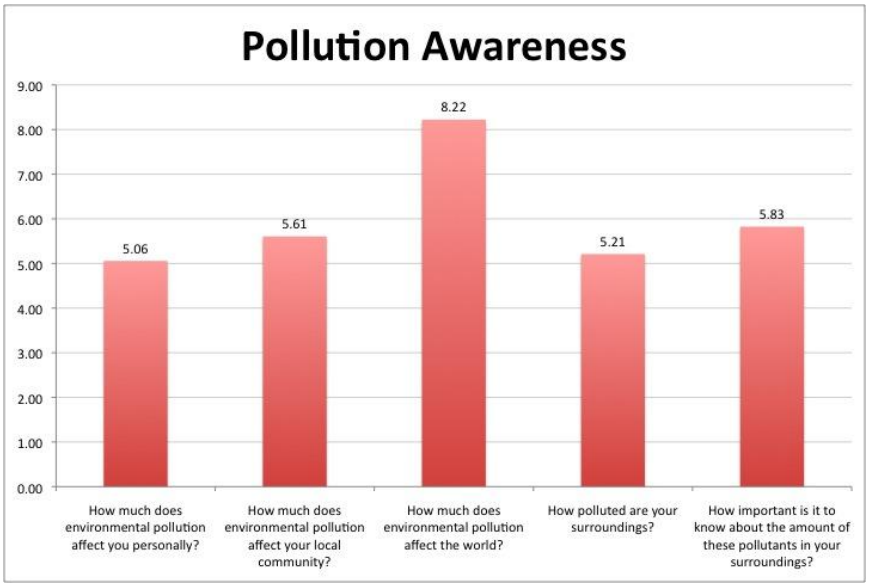

Figure 3: Pollution Awareness at University of California, Berkeley

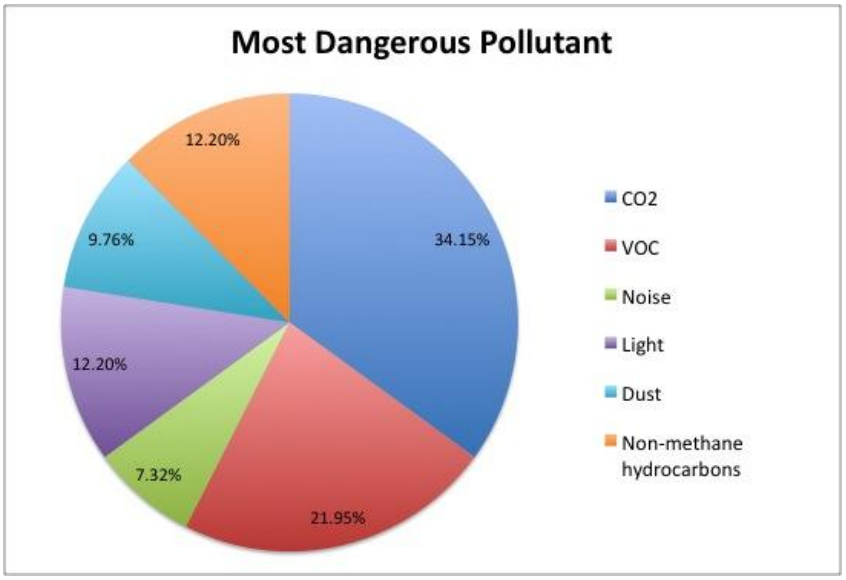

Figure 6: Most Dangerous Pollutant at University of California, Berkeley

The first charts, Figure 3 for Dar Al-Hekma students and Figure 5 for UC Berkeley students, display the Although both groups showed a high level of sensitivity to sustainability issues, it is interesting to note that the Dar Al-Hekma students showed higher levels of sensitivity to sustainability issues than the UC Berkeley students. This may reflect a gender difference as all of the Dar Al-Hekma students were women and 90% of the UC Berkeley students were men. Or it might reflect disciplinary (most of the UC Berkeley students were studying engineering, whereas Dar Al-Hekma students covered many disciplines), regional or cultural differences. These results do raise interesting questions for further research.

The second charts, Figure 4 for Dar Al-Hekma students and Figure 6 for UC Berkeley students, present the data on which pollutant the students consider most dangerous to their community, from this list: carbon dioxide, VOC, noise, light, dust, and non-methane hydrocarbons. The results from both groups were very similar.

The results of the energy production and cost analysis for the wind turbines are shown in Figure 7 – 8, while the results for the photovoltaic system are shown in Figures 9-10.

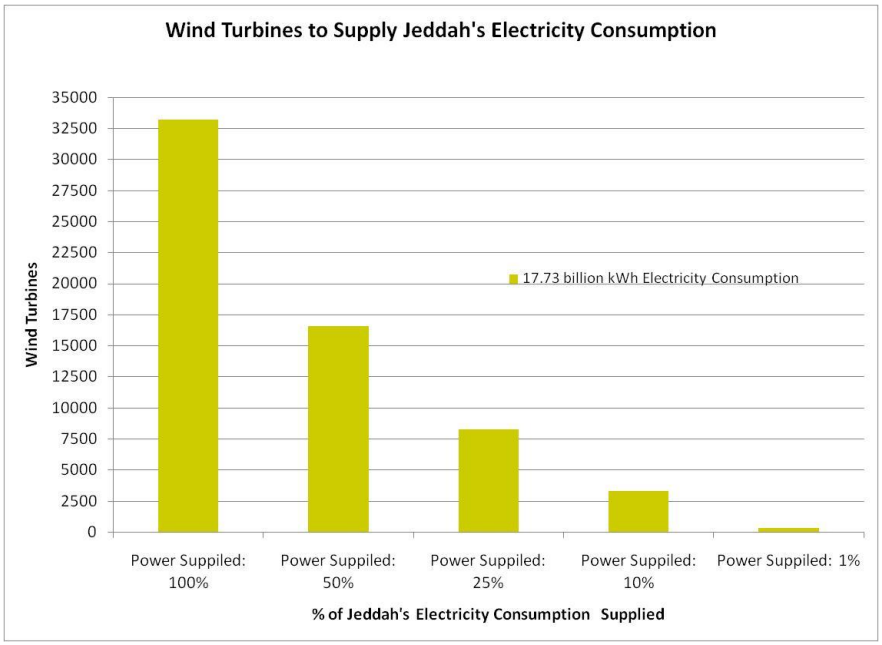

Figure 7: Wind Turbines to Supply Jeddah's Electricity Consumption

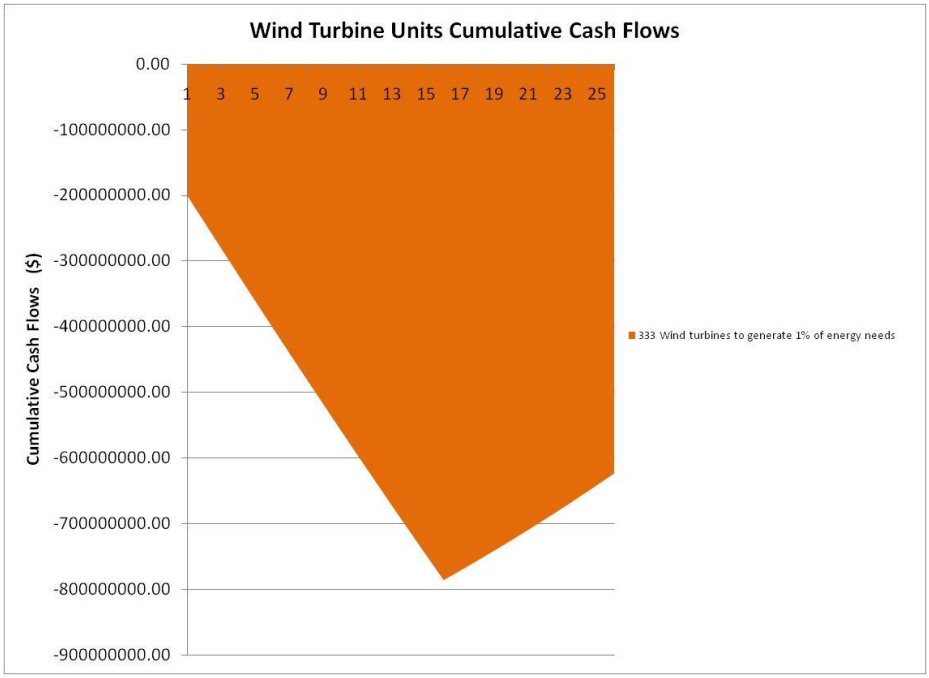

Figure 8: Wind Turbine Units Cumulative Cash Flows

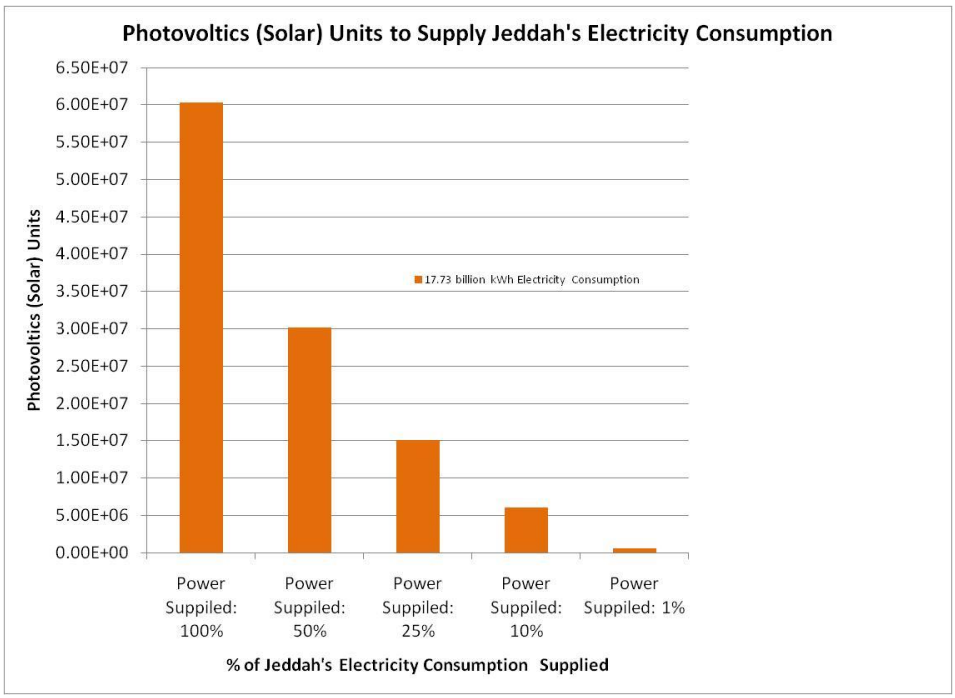

Figure 9: Photovoltics (Solar) Units to Supply Jeddah's Electricity Consumption

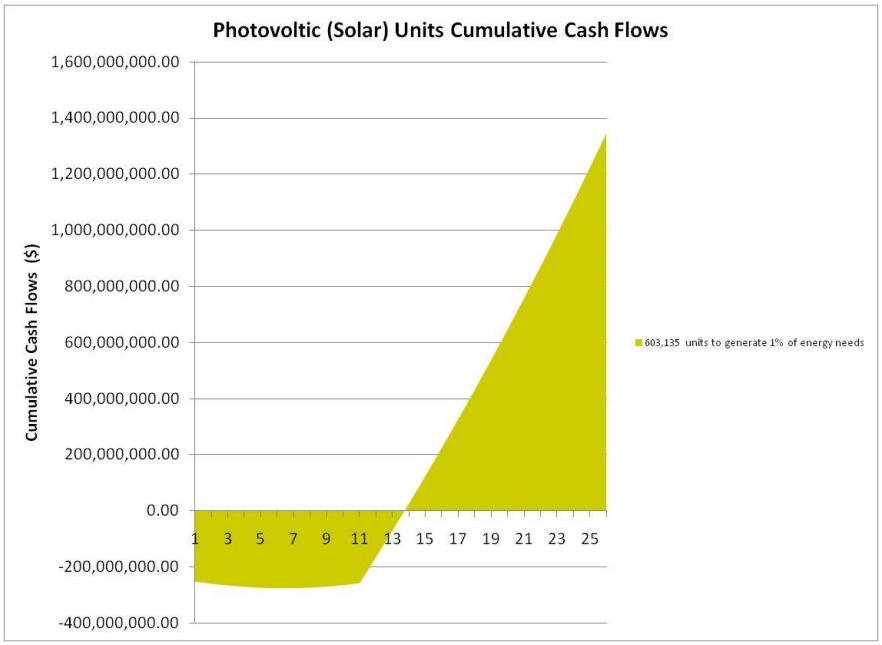

Figure 10: Photovoltic (Solar) Units Cumulative Cash Flows

Given that the annual wind speed of Jeddah is 3.6 m/s, the power generation capaiblites of most wind turbines are limited given that wind turbine's energy curve is a function of wind speed. Futermore, the Red Sea's geography limits the capabilities of tidal and wave power systems. On ther other hand, Jeddah annual daily solar radiation of 5.94 kWh/m^2/day allows PV and solar water heater systems to become ideal candidates for power generation and heating.

V. Discussion and Future Research

Although it is technically feasible and financially viable to install photovoltaic systems in the city of Jeddah for power generation, it is still unknown whether or not the technology would be adopted by a majority of the residents in Jeddah. At Dar Al-Hekma, over half of the students responded that there is little community awareness of sustainability. Some explained that they live in a very consumer-oriented society where people constantly purchase new items with little regard for the waste produced, and thus are not "living in harmony with nature". About one-third of the students responded that sustainability is well-addressed in society. Among the UC Berkeley students, many feel that sustainability is an extremely important issue, but agree that not enough action is currently being taken -- people are still too reliant on what is convenient over what is efficient.

It is recommended that a user needs assessment of residents in Jeddah be conducted through collaboration with Dar Al-Hekma and KAUST understand the water and electricity usage. In particular, focus should be given to understand local views on the reuse of water, such as grey water, and the water and energy conservation projects in Jeddah. Furthermore, metrics for evaluating the sustainability of individuals, communities, and universities within the Kingdom of Saudi Arabia should be created.

Currently, Saudi Aramco, the government owned national oil company of the Kingdom of Saudi Arabia, has taken the lead in the area of environment management and has developed the following metrics: Water Quality, Water Consumption, Water Conservation, Solid Waste Production, Energy Consumption, Energy Conservation, Air Quality, Biological Pollutants, Greenhouse Gas Emissions, and Eutrophication. These metrics should be further refined utilizing the expertise of UCB, Dar Al Hekma, KAUST faculty members in the areas of architecture, urban designs, graphic designs, energy modeling, decision systems.

VI. References

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