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The National Energy Strategy for Saudi Arabia

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Abstract**—**In this paper, we present a technical and an economic assessment of several sources of renewable energy in Saudi Arabia; mainly solar, wind, hydro and biomass. We analyze the environmental and climatic conditions in relation to these sources and give an overview of some of the existing clean energy technologies. Using standardized cost and efficiency data, we carry out a cost benefit analysis to understand the economic factors influencing the sustainability of energy production from renewable sources in light of the energy cost and demand in the Saudi market. Finally, we take a look at the Saudi petroleum industry and the existing sources of conventional energy and assess the potential of building a successful market for renewable energy under the constraints imposed by the flow of subsidized cheap oil. We show that while some renewable energy resources are well suited for distributed or grid connected generation in the kingdom, their viability is greatly undercut by the well developed and well capitalized oil industry.

Keywords**—**Energy strategy, energy policy, renewable energy, Saudi Arabia, oil.

I. INTRODUCTION

WITH a total area of 2,149,690 km^2, Saudi Arabia is roughly about half the size of the European Union or six times the size of Germany. According to the 2004 census, the total population of the kingdom is around 22.97 million, 85% of which live in urban areas [1]. Although the kingdom is one of the least densely populated countries, it has a fast growing population with a birth rate of 28.85 per 1,000 persons [2]. Saudi Arabia is also the world's 20th largest economy with a GDP of $528.3 billion, largely accounted for by the country's exports of petroleum based products. The country possesses the world's largest oil reserves estimated at 267 billion barrels, roughly one-fifth of the world's total proven conventional oil reserves [3]. It is also the largest oil producer, pumping out more than 9.2 million barrels a day, enough to fuel a car to make 20,125 round trips to the moon or generate 15.112 TWh of electricity. Less than a tenth of the daily oil production is used for domestic consumption. Currently, the Saudi energy supply is exclusively sustained by fossil fuel with no input from any source of renewable energy [4].

This paper attempts to explore the potential of utilizing several sources of renewable energy to supply a portion of the kingdom's energy need. In particular, we analyze solar, wind, hydro and biomass and give an overview of some of the existing clean energy technologies. In this paper, we first offer a purely technical and environmental assessment of these sources and their potential, today and in the near future. We then discuss the economic limitations of non-conventional sources of energy in countries like Saudi Arabia with large oil reserves and heavily subsidized energy markets.

II. SOLAR ENERGY

A. Technical Assessment

The Arabian Peninsula, mostly occupied by Saudi Arabia, is one of the world's most productive solar regions and home to some of the highest summer temperatures ever recorded on earth. Every day, massive quantities of sunshine fall on the vast swath of the Arabian Peninsula, enough to produce 12,425 TWh of electricity that can power the kingdom for 72 years. The country's large area covering about 1.4% of the total land and its close proximity to the equator qualifies it as a good candidate for solar energy utilization. In this section, we model key factors that govern the utilization of solar energy such as insolation and air temperature based on the data reported by the Atmospheric Science Data Center at NASA for the region bounded by 15° 25′ N 33° 29′ E and 35° 25′ N 53° 29′ E latitude and longitude lines. This region covers Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates and parts of Oman, Yemen, Iran, Iraq, Sudan, Egypt and the Asian Mediterranean countries. First we explore the amount of the solar energy incident on the Arabian Peninsula's surface and then we evaluate the viability of using several solar energy technologies for electricity generation and water/air heating. Subsequent analysis focuses on the three largest cities in the kingdom with a cumulative electricity consumption of 131 GWh/day, which accounts for over 30% of the total kingdom's electricity consumption.

Fig. 1 shows the annual insolation incident on a horizontal surface averaged over all 12 months for Saudi Arabia with the effect of the number of clear sky days per month. As seen from the map above, all three cities enjoy high insolation due to their proximity to the equatorial region. On the regional scale (5.78 KWh/m2/day average insolation), all three cities rank about average; however, on the global scale (1.36 KWh/m2/day average insolation), they rank much higher [5]. Although the three locations are separated by few latitudinal degrees, the amount of incidental solar energy in Jeddah is slightly higher than Riyadh and Dammam mainly because of the higher solar radiation intensity due to variations in altitude. Other factors contribute to this distribution such as air temperature at ground level and the zenith angle (see Fig. 2 A-C). Moreover, up to 15% of solar radiation is depleted by the terrestrial atmosphere due to scattering by molecules

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(Rayleigh scattering) and aerosols, selective absorption by gases gasses like O2, O3, H2O and CO2 or absorption by cloud masses [6]. Assuming a relatively high efficiency Photovoltaic solar system of 23.4%, we can estimate the technical viability of harnessing solar energy from the three locations as shown in Table I. It is important to notice that all calculations here are performed on the annual monthly averaged insolation incident on a horizontal surface. Typically, solar panels are mounted at an angle to gain more exposure to sunshine resulting in more incident solar energy. However, the relatively high efficiency factor for the photovoltaic solar system assumed here compensates for the zero tilt angle. Calculations in Table I show that the entire kingdom's energy need can be met by dedicating less than one hundredth of one percent of the country's area to capturing solar energy.

TABLE I
AREA REQUIRED TO MEET THE FULL ENERGY DEMAND OF THE LARGEST 3 CITIES USING A PHOTOVOLTAIC SOLAR SYSTEM WITH AN EFFICIENCY OF 23.4%

	Consumption (GWh/day)	Area required (km²)	% of area req'd
Riyadh	69.221	51.24	3.29
Jeddah	50.915	36.64	1.22
Dammam	11.146	8.5	1.06
Saudi	429.589	317.6	0.01

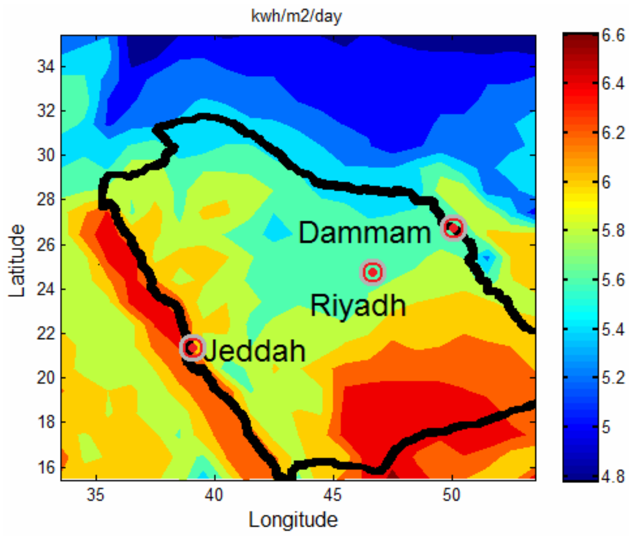

Fig. 1 Annual monthly averaged insolation incident on a horizontal surface

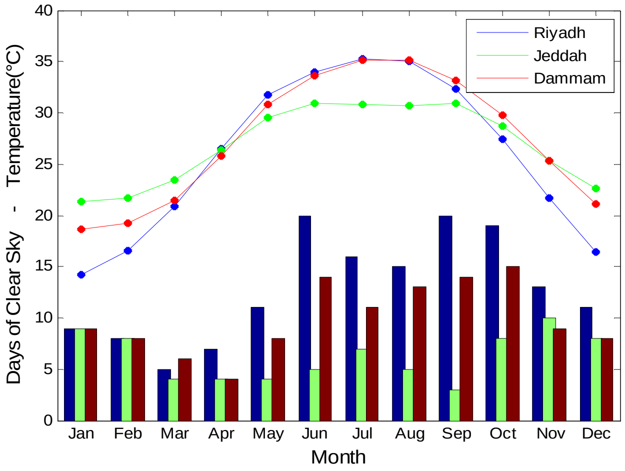

Fig. 2 (a) Monthly average number of clear sky days and average temperature at 10 m above the surface of earth

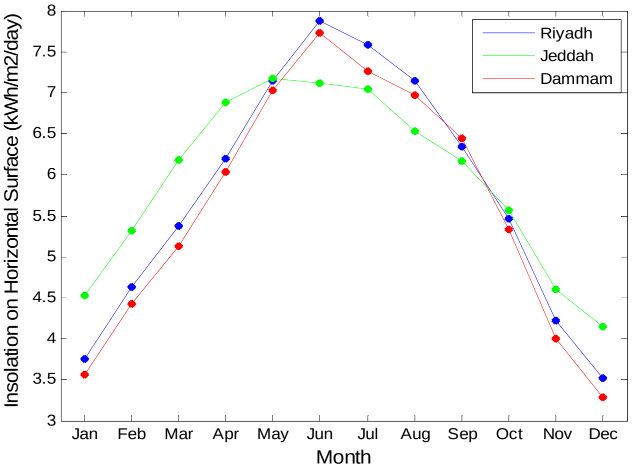

Fig. 2 (b) Monthly average insolation incident on a horizontal surface

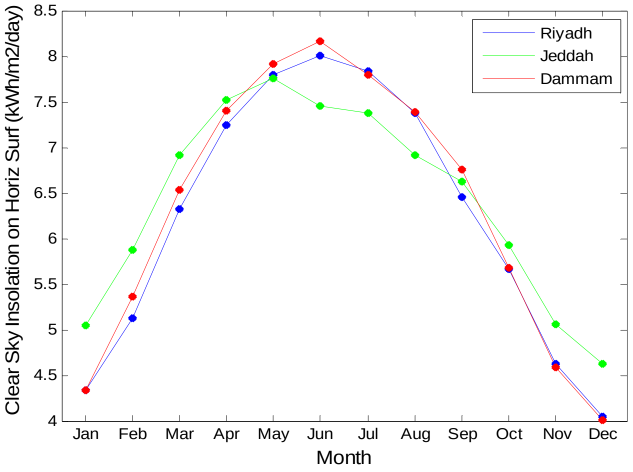

Fig. 2 (c) Monthly average clear sky insolation incident on a horizontal surface

B. Economic Viability of Solar Energy Capture and Conversion

As discussed above, the high amount of solar radiation facilitates a hospitable environment for harnessing solar energy in the kingdom using Photovoltaic technology; however, the economic analysis tells another story. The subsequent economic analysis follows the guidelines of the National Renewable Energy Laboratory. For this analysis, we make the following assumptions:

- Horizontal surface collector
- PV Solar system cost = \$10,000/kw
- Present worth factor of a system = 17.41 years
- National Saudi energy cost = \$0.032/Kwh [7]

The national Saudi energy cost assumed here is the country's industrial pricing. Residential pricing is not used for simplicity since residential and commercial energy pricing, while nationalized, vary depending on load. Mainly, for the economic analysis, we will consider SIR (Savings to Investment Ratio) and the current payback period. Fig. 3A shows the savings to investment ratio for the kingdom where:

$$SIR = (I \times 365 \text{ days} \times CE \times PW) / CS \qquad (1)$$

In this equation:

l: Annual average solar radiation (h/day)

CE: Energy cost

PW: Present worth

CS: PV system cost

The annual average solar radiation, number of hours per day when the system is at peak output, is computed from the annual monthly averaged insolation. As seen from the map, all regions of the kingdom have very poor saving to investment ratios with highest of 0.13. To put numbers in perspective, parts of California and Texas have near unity SIR based on the same system cost and the present worth assumptions [8]. The reason for this disparity is the low energy price in Saudi of \$0.032/kwh compared to \$0.1/kwh in California and \$0.078/kwh in Texas. Photovoltaic systems yield good savings when conventional energy cost is high. Fig. 3B shows the current payback period computed as follows:

$$\text{Payback} = CS / (I \times 365 \text{ days} \times CE) \qquad (2)$$

Obviously, the payback period is impracticable. Jeddah's payback period is the shortest at 130 years. In comparison, most of California and parts of Texas have payback periods ranging between 20-50 years for the same system assumed here. Clearly, the current Photovoltaic technology is not a good option for Saudi Arabia based on today's energy price, PV system cost and PV system efficiency. The only way such a system would be viable with today's technology is if the energy price ramps up. For example, assuming a national energy price, the cost of energy in Saudi Arabia would have to increase by 756% to \$0.2739/Kwh in order to have a close to unity saving to investment ratio. Similarly, the price of energy would have to increase by 396% to \$0.159/kwh in order to have a payback of less than 30 years. Assuming that energy cost in Saudi Arabia remains constant for the foreseeable future, PV solar energy technology will only be feasible if the total system cost drops drastically. To be exact, the system cost would have to drop by 88% to \$1175/kw to have an SIR of one. Similarly, the system cost would have to drop by 79.74% to \$2025/kw have a payback of less than 30 years.

Due to the kingdom's current low energy cost, other cheaper solar energy technologies might look more attractive at this time. We will consider Solar Water Heating (SWH) and Ventilation-Air Preheating (SVP) systems where solar energy is used to heat water or air for residential or industrial uses instead of generating electricity as in Photovoltaic systems. For such systems, solar thermal collectors are used to capture solar energy and transfer it to a fluid medium. Using a similar economic analysis, we assess the economical feasibility of utilizing solar energy to heat water or air in Fig. 4 and 5. Following the guidelines of the National Renewable Energy Lab, the cost of the Solar Water Heating and the Ventilation-Air Preheating Systems are set at \$900/m^2 and \$151/m^2 respectively with a present worth of 17.41 years for both. Also, 40% efficiency is assumed for the Solar Water Heating. Clearly, the maps show that both technologies have great potential for application in Saudi Arabia right now and in the near future. Solar Ventilation-Air Preheating technology's economic analysis shows a high saving to investment ratio of more than 7.5 for all the three cities with a payback period of less than 2.5 years. Solar Water Heating is slightly behind with a saving to investment ratio of close to 0.5 and a payback period of less than 35 years. Table II summarizes the findings.

TABLE II
SUMMARY OF THE ECONOMICAL ANALYSIS OF THE THREE SOLAR ENERGY TECHNOLOGIES BASED ON THE NATIONAL AVERAGE INSOLATION

Technology	PV	SWH	SVP
SIR	0.1175	0.52	7.78
Payback (years)	149	33.5	2.25
\$/Kwh required for SIR>1	0.274 (+756%)	0.0616 (+93%)	---
\$/Kwh for payback<30yrs	0.159 (+397%)	0.0358 (+12%)	---
System cost required for SIR>1	11754 (-88%)	470 (-48%)	---
System cost for payback<30yrs	20253 (-80%)	810 (-10%)	---

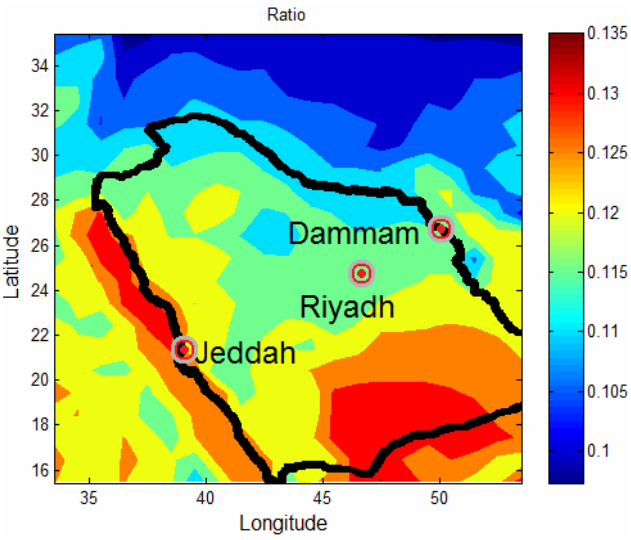

Fig. 3 (a) Savings to Investment Ratio for PV system

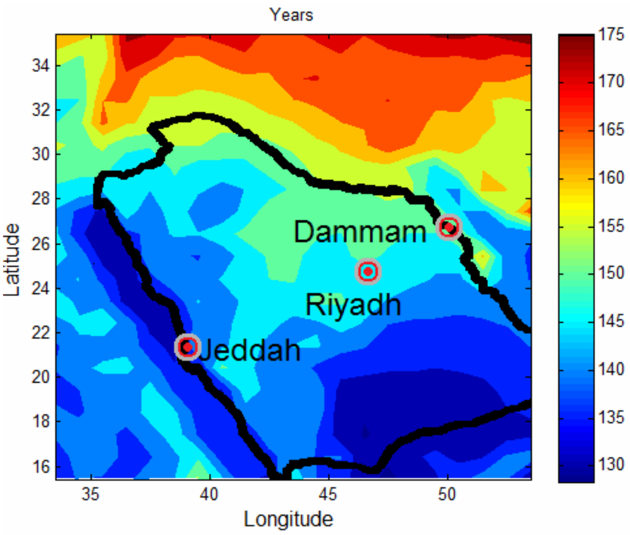

Fig. 3 (b) Payback period (in years) for PV system

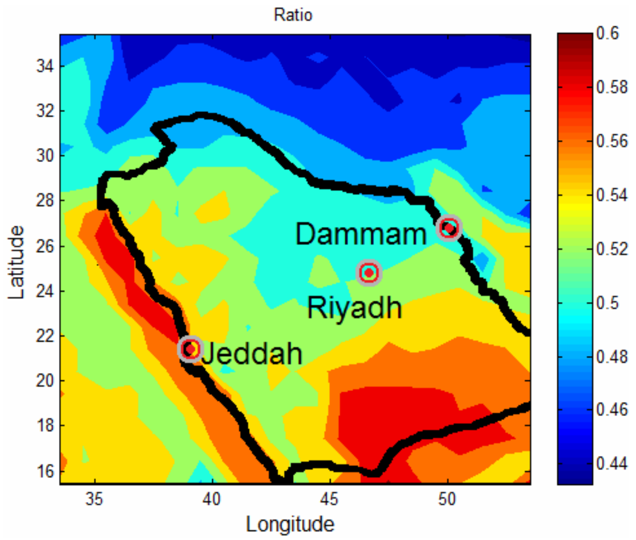

Fig. 4 (a) Savings to Investment Ratio for SWH system

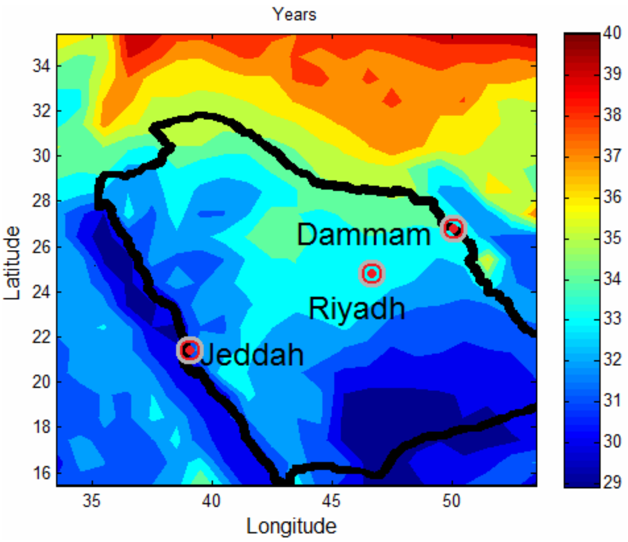

Fig. 4 (b) Payback period (in years) for SWH system

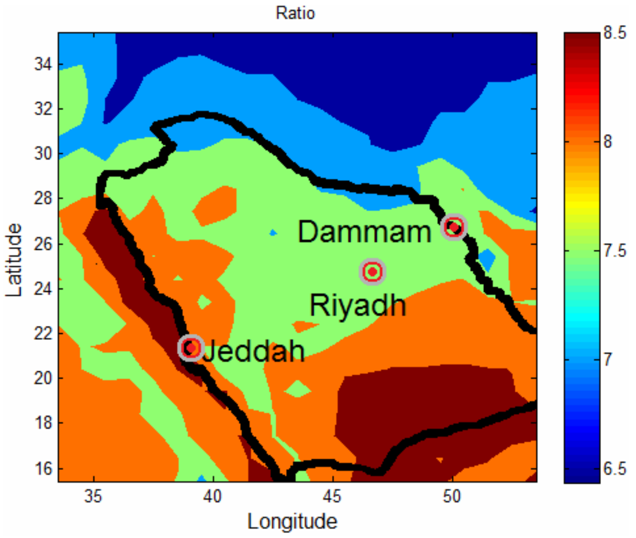

Fig. 5 (a) Savings to Investment Ratio for SVP system

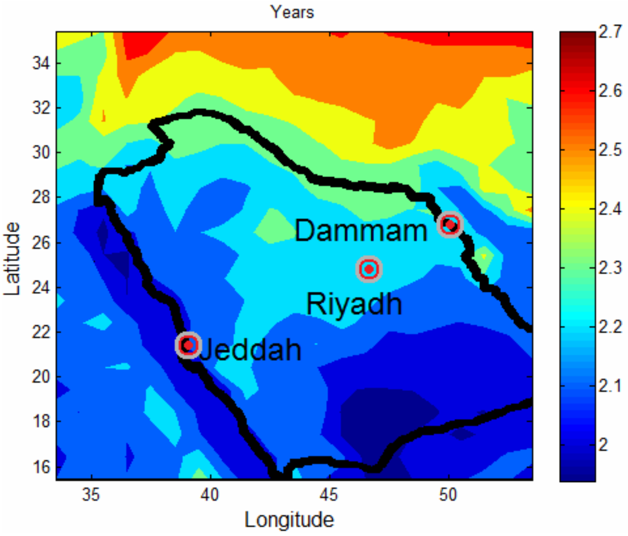

Fig. 5 (b) Payback period (in years) for SVP system

III. WIND ENERGY

A recent study of five sites in Saudi Arabia based on data collected between 1995 and 2002 concluded the viability of using wind energy to power off and on-grid locations [9]. It showed that the two cities of Dhulum and Arar, with average wind speeds of 5.7 and 5.4 m/s respectively, are good candidates for off-grid wind turbines. The same study also concluded the viability of using grid connected wind turbines to partially power the two coastal cities of Yanbo and Dhahran with below average annual wind speed. It estimates that as much as 1080, 990, 730, 883 MWh could be produced using Nordex N43 wind turbine for Dhulum, Arar, Yanbu and Dhahran respectively.

Here, we take a broader look at the potential of using wind energy to meet part of the kingdom's energy need. All subsequent analysis and maps are based on the data reported by the Atmospheric Science Data Center at NASA for the same region defined above. Translation from wind speed to wind power class and wind power density is performed using NREL's definition depicted in table III. Wind power density is computed using linear extrapolation of wind speed and power density relation. Figs. 6 and 7 show the annual monthly averaged wind speed, wind power class and wind power density at 10m and 50m above the surface of the earth respectively. As seen from the maps, for the most part, Saudi Arabia is designated as class 2 wind area. NERL classifies class 3 or greater as suitable for most utility-scale wind turbine applications and class 2 areas as marginally suitable for utility-scale applications and better fit for rural applications. Next we present an economic analysis of the cost of wind energy in Saudi Arabia based on NREL's Wind Turbine Design Cost and Scaling Model [10]. In this model, we calculate the levelized cost of energy (COE) generated by one land-based 1.5 MW baseline turbine with a rotor diameter of 70 m. The levelized COE is based on the average wind power density of the area bounded by the latitude and longitude lines mentioned above of 192.4 W/m^2. In this model,

$$\mathrm{COE} = (\mathrm{FCR} \times \mathrm{ICC} / \mathrm{AEP}_{\mathrm{net}}) + \mathrm{AOE} \tag{3}$$

And

$$\mathrm{AOE} = \mathrm{LLC} + \mathrm{O\&M} + (\mathrm{LRC} \times \mathrm{mr} / \mathrm{AEP}_{\mathrm{net}}) \tag{4}$$

Where: Fixed Charge Rate(*FCR*): the annual amount per dollar of initial capital cost to cover construction financing, financing fees, return on debt and equity, depreciation, insurance, income and property tax; Initial Capital Cost(*ICC*): the turbine system and balance of station cost; Net Annual Energy Production (AEP_{net}): projected energy output based on the annual average wind speed adjusted for factors such as rotor coefficient of power, machine rating (*mr*) and losses; Land Lease Cost (*LLC*): the cost to lease the land for on-land wind turbine or ocean bottom lease cost for off-shore turbine; Levelized Operations and Maintenance Cost (*O&M*): includes cost of labor, parts, supplies, administration and support; Levelized Replacement/Overhaul Cost(*LRC*): includes the cost of major replacement and overhauls throughout the life of the wind turbine; Annual Operating Expenses (*AOE*): the total cost of operating the turbine. Due to the lack of information on the wind turbine installation cost in Saudi Arabia, this model uses the costs reported by NREL for the same turbine. NREL's data are based on year 2002 component costs constituting the initial capital[1]. For this model, we use the following costs:

FCR=11.58%, *ICC*= \$1,403,000, *LLC*= \$0.00108 /KWh, *O&M*= \$0.007 /KWh and *LRC*= \$10.7 /KW.

The computation of the annual energy production is a very involved process. However, for simplicity, we only account for the major factors; capacity coefficient, annual average wind power density and area of rotor. Under these assumptions,

$$AEP_{net} = 0.1924\ KW \times 3{,}848\ m^2 \times 0.3282 \times 8760\ hrs$$
$$= 2{,}129\ MWh$$

Finally, the levelized cost of energy is found to be 0.0919 \$/KWh, almost 287% the cost of conventional electricity in the kingdom. Note that the levelized cost of energy here is a mere approximation of the actual value and it is only intended as a reference for comparison with the cost of conventional energy.

TABLE III
NREL'S CLASSIFICATION OF WIND POWER CLASSES BASED ON WIND POWER DENSITY AND SPEED AT 10 M AND 50 M HEIGHT

Wind power class	**10m Height**		**50m Height**	
	Power Density (W/m²)	Speed (m/s)	Power Density (W/m²)	Speed (m/s)
1	0-100	0-4.4	0-200	0–5.6
2	100-150	4.4-5.1	200-300	5.6-6.4
3	150-200	5.1-5.6	300-400	6.4–7.0
4	200-250	5.6-6.0	400-500	7.0–7.5
5	250-300	6.0-6.4	500-600	7.5-8.0
6	300-400	6.4-7.0	600-800	8.0-8.8
7	400-1000	7.0-9.4	800-2000	8.8–11.9

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[1] See [10] for cost break down by component.

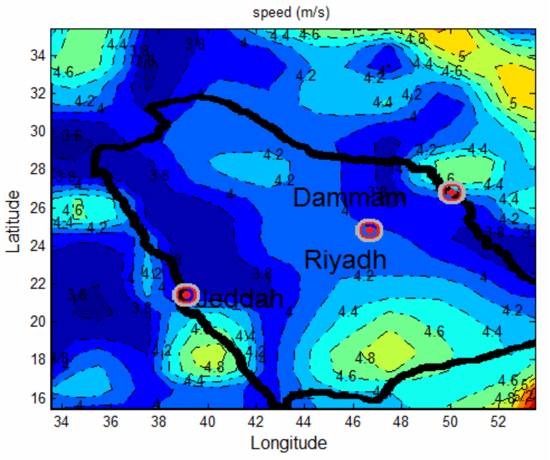

Fig. 6 (a) Wind speed in m/s 10 m above ground

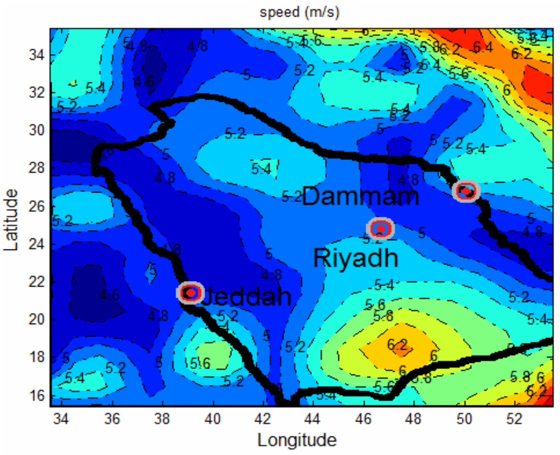

Fig. 7 (a) Wind speed in m/s 50 m above ground

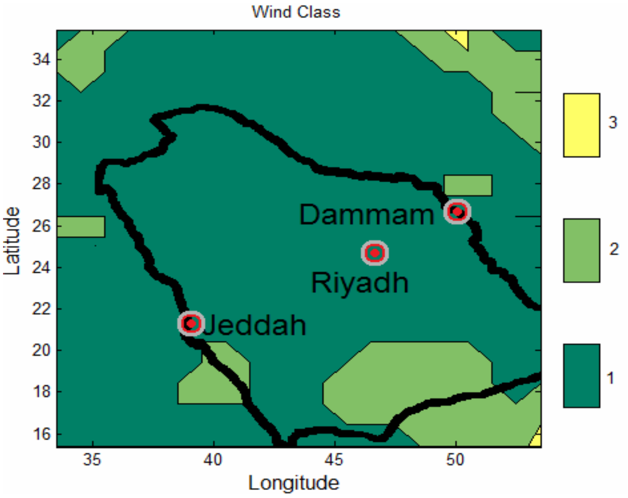

Fig. 6 (b) Wind class 10 m above ground

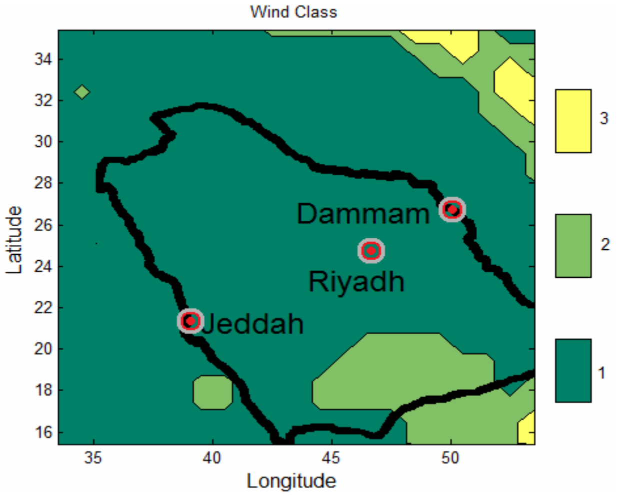

Fig. 7 (b) Wind class 50 m above ground

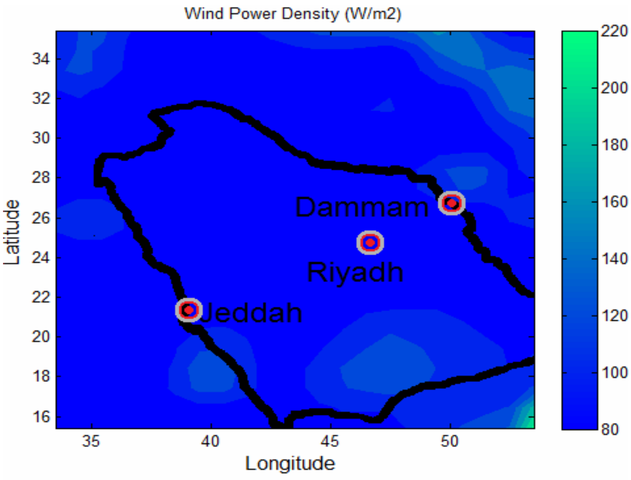

Fig. 6 (c) Power density in W/m2 at 10 m above ground

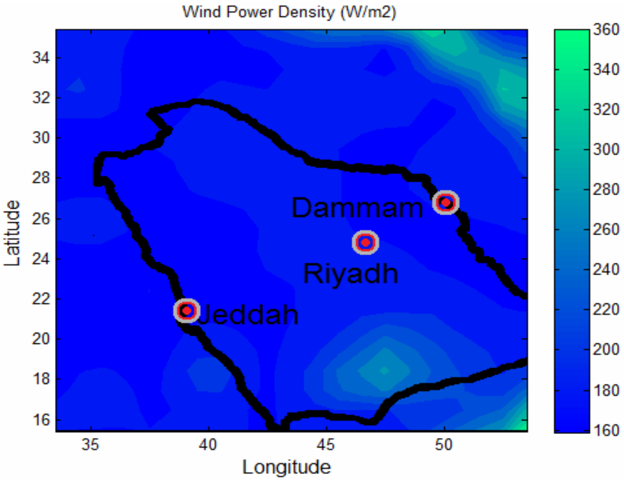

Fig. 7 (c) Power density in W/m2 at 50 m above ground

IV. HYDRO POWER

Saudi Arabia is the largest country in the world without a natural river running to the sea [12]. Water bodies in the kingdom constitute 0% of its area with total renewable water resources estimated at 2.4 cubic km and nearly depleted underground water resources. The scarcity of water has triggered the installation of massive seawater desalination facilities making the kingdom the world's largest producer of desalinated water. In 2002, Saudi Arabia's water desalination output surpassed one billion cubic meters, nearly 70% of the kingdom's freshwater needs. Some of the desalination facilities are dual-purpose plants producing more than 20% of the kingdom's total electricity needs [13]. Due to the county's dry and harsh climate, rainfall is sparse with an annual average of about 100 mm per year compared to 1123 mm annual average global precipitation [14]. Fig. 8 shows the annual average precipitation distribution map based on NASA's Atmospheric Science Data Center survey. In spite of the low rainfall, dams have been constructed to make use of the little rainfall to recharge subterranean water and control flooding. Today, there are more than 200 dams in the kingdom with a cumulative reservoir capacity of 774 million cubic meters [15]. King Fahd Dam is the largest in the country and the second largest in the Middle East with a storage capacity of 325 million m^3, surface area of 18 km^2 and 103 m head [16]. King Fahd Dam has a theoretical potential energy of about 328,055 GJ or 91.2 MWh. However, the effectiveness of dams in Saudi Arabia in containing rainfall water is greatly undermined by the excessive evaporation and sedimentation. A study aimed at modeling the annual and monthly evaporation for King Fahd Dam using auto-regressive first order model and fragments method based on data collected over 22 years found that the average evaporation is 10.1 mm/day with highest evaporation rate in July of 14.31 mm/day and lowest in December of 5.89 mm/day compared to 0.27 mm/day of rainfall [17]. This is not a surprise knowing that nearly a quarter of the solar power incident on the earth's surface is consumed in the evaporation of water [18]. All this leads to the predictable conclusion that the environmental and climatic conditions necessary for a successful utilization of hydro power are missing in Saudi Arabia.

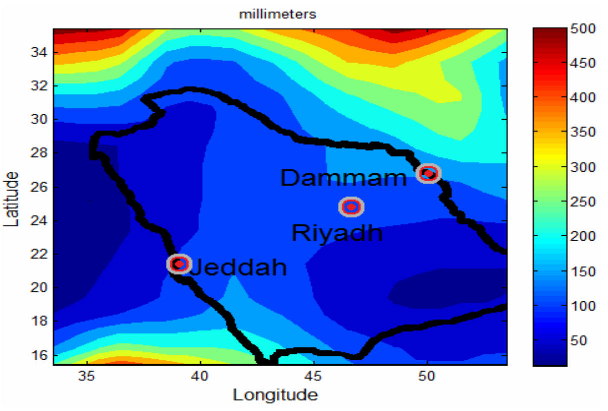

Fig. 8 Annual average precipitation distribution

V. BIOMASS

The Arabian Peninsula's climate is characterized by extreme heat and aridity. With the exception of parts of the coastal and mountainous southwest regions which constitute less than 2% of the total land, the rugged terrain of the Peninsula is largely unsuited for agriculture and soil is generally infertile. No woodlands or forests exist in the kingdom except for the little desert-adapted wildlife that is often put under government protection. In those regions, vegetation is characterized by a small number of species that have successfully adapted to the special demands of the harsh environment. Conditions are even worsened by the extreme temperatures and the scarcity of water. Regions like the Empty Quarter, the largest uninterrupted stretch of sand desert in the word with a total area of 640,000 km2, often receive no rain for as long as 10 years [19]. As a result, most land under cultivation relies on irrigation. The Food and Agriculture Organization of the United Nations estimates that 80% of the 2% of the country that is under cultivation is entirely under irrigation [20].

Nearly three decades ago, the Saudi government embarked on a massive agricultural experiment that can help in the assessment of the potential of the utilization of biomass as a source of energy in the kingdom. In the wake of the 1973 oil crisis, the government announced an ambitious project aimed at wheat self-sufficiency. With large subsidies from the government, the project's goal was reached in 1984 and Saudi Arabia became self-sufficient in wheat. In 1992 wheat production reached a peak of 4.2 million tons making the country a major exporter of wheat with more than 30 destinations including China, the former Soviet Union, and many European and neighboring countries [21]. However, in 2008, the Saudi government announced a gradual phase out of the program citing depletion of water resources as the primary reason [22]. As an alternative, they have decided to invest in large-scale agricultural projects overseas in counties like Turkey, Egypt and Ukraine [23]. This is a realization on the government's part that the development of large scale agricultural projects is unsustainable even for food security, let alone alternative sources of energy.

It should comes as no surprise that the environmental and climatic conditions of the Arabian Peninsula greatly limit the kingdom's ability to exploit the vast swath of land and create working biomass markets to produce energy.

VI. PETROLEUM & MINERALS

Since the discovery of the vast oil reserves in Saudi Arabia, the country's name has become a synonym for oil. With reserves estimated at more than 267 billion barrels, Saudi Arabia is often seen as the central bank of oil. It is home to the two largest on and off shore oil fields, Saffaniyah and Ghawar, with estimated reserves of 19 and 70 billion respectively. On top of being the world's largest producer, the country maintains an additional significant swing capacity capable of accommodating sudden changes in market demand or supply distributions [24]. Also, the kingdom has the world's fourth largest natural gas reserves estimated at 7,300 billion m3. Fig. 9 shows the amount of proven oil and natural gas reserves between 1987 and 2007 [25]. Although this figure shows that rate of oil discovery drastically slowed down after 1988, some speculate that this trend is unrepresentative of the actual amount of the Saudi Arabian proven oil reserves that might have been kept secret for political or economic reasons especially given that the shift takes place around the time of the Second Gulf War that was fueled by disputes on OPEC oil quotas. Needless to say, those figures tell us nothing about the unproven and undiscovered oil and gas reserves in the country "that could dwarf other prolific areas" as Vera de Ladoucetta, a senior vice president at Cambridge Energy Research Associates, puts it [26]. Moreover, the kingdom has the largest Middle Eastern mineral deposits of gold ore, copper and phosphates with estimated quantities of 20 million, 60 million and 10 billion tons respectively which make up the backbone of the mining and minerals sector, the second biller of the Saudi economy [27]. Oil plays a vital role in the Saudi economy. It is estimated that over 75% of the government's revenue and 45% of GDP comes from the sale of petroleum based products [28]. With the assumption that the world economy will remain reliant on oil for the forcible future, the government has heavily invested in the petroleum sector. Rightfully so, the government does not seem concerned with the Peak Oil debate given that the Saudi oil reserves will be the last to face depletion in all scenarios possible. Investments in the petroleum sector reflect the government's national energy strategy as well as its economic growth plan. Fig. 10 shows the refining capacity between 1987 and 2007. It shows that the kingdom has constantly increased its refining capacity to sustain the domestic economic expansion and the population growth. In those 20 years, the population grew by 85% and the refining capacity by 49%. Simultaneously, oil and natural gas production steadily rose in the same period reaching a peak for oil of 9.3 million barrels a day in 2005 and 74.4 billion cubic meters of natural gas a year in 2007, all of which is consumed domestically (see Fig. 11). This massive capability is enabled by an ever growing impressive infrastructure of refineries, processing and treatment plants, pipelines and a fleet of shipping tankers. Saudi Aramco, the world's largest oil corporation, currently operates seven domestic refineries, 85 fields, 320 reservoirs, 48 rigs and more than 9000 miles of crude oil and natural gas pipelines [29]. Vela, a Saudi Aramco's shipping subsidiary, operates the world's sixth largest fleet of supertankers that consist of 19 VLCCs (very large crude carriers) and 5 product tankers. On top of all of that, the government has embarked on a new expansion phase to increase its oil production capacity to 12 million barrels a day through the rehabilitation and the creation of 5 domestic refineries [30]. Moreover, it has committed more than $90 billion over the next five years to invest in upstream and downstream projects locally and globally.

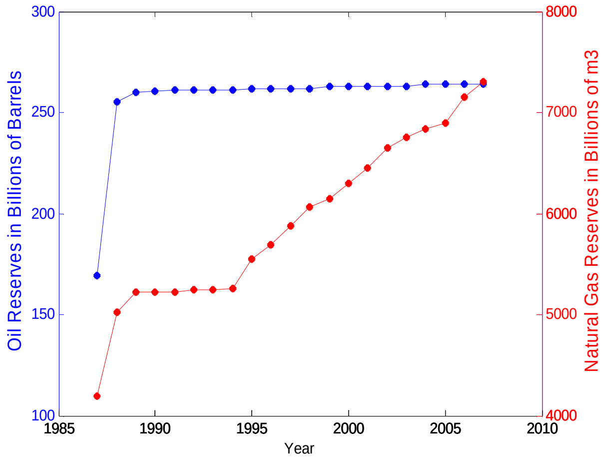

Fig. 9 Saudi proven oil and natural gas reserves between 1987 and 2007

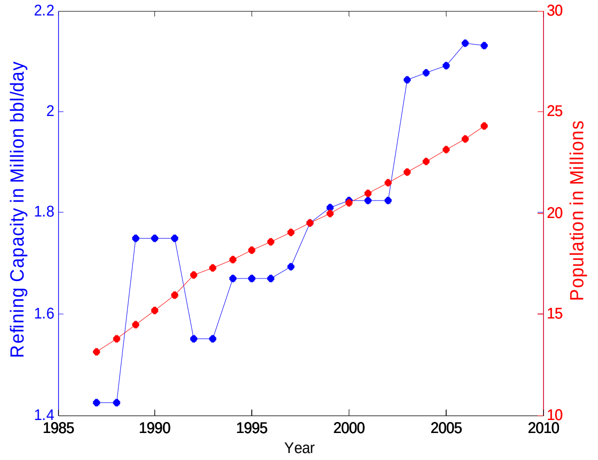

Fig. 10 Saudi refining capacity and population between 1987 and 2007

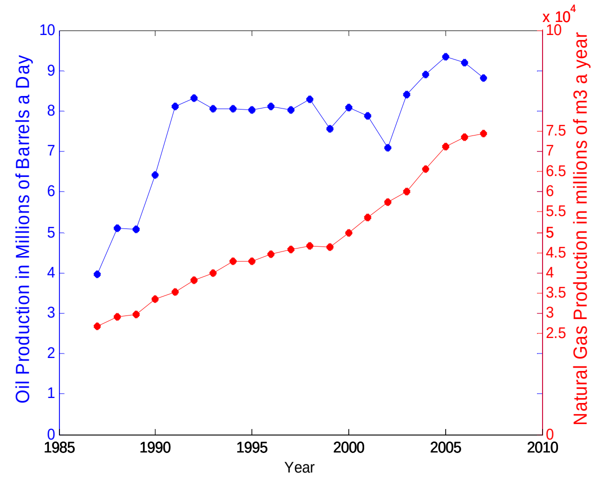

Fig. 11 Saudi oil and natural gas production between 1987 and 2007

VII. DISCUSSION

Clearly, the technological and environmental assessment above of some of the renewable energy sources in Saudi Arabia shows a tremendous potential. Specifically, solar energy appears a promising candidate with a wide range of applications from electricity generation to water and air heating. In fact, Solar Water Heating and Ventilation-Air Preheating would yield economic benefits if deployed today. Wind energy ranks second amongst the sources of renewable energy discussed in this paper in terms of economic return. Although not as abundant as solar energy, it is a viable source that can make an impact if deployed in consortium with other sources of renewable energy. Other sources like biomass and hydro are less promising as someone would expect from an environment like Saudi Arabia's. However, in a purely economic interpretation of the results, the benefit of all sources of renewable energy is dwarfed when compared to the kingdom's massive oil reserves. With today's energy cost, solar and wind energy stand no chance in competing in the Saudi market. Energy cost would have to increase many folds before any of them started to have a sensible effect. This factor is even more pronounced in the kingdom due to its well developed oil infrastructure. Expecting solar energy technology, for example, to compete with oil seems unfair knowing the large investments over many decades that went into developing the oil industry.

On the other hand, energy and services, of all kinds, are heavily subsidized in the kingdom and some argue that a comprehensive change in the approach to the energy policy aimed at reducing cost disparities through less subsidization of conventional energy would quickly change the equation in favor of renewable energy [30]. Many point out the hike in energy cost during the 2nd Gulf War when the declining oil prices and the $94 billion cost of war left the government facing a yawning budget deficit. In one year, gasoline price shot up by 200% and remained at that level until 2008. So a planned increase in energy cost over several years combined with a more balanced investment strategy can bridge the gap between conventional and nonconventional energy and make sources like solar and wind viable economically. This approach is further strengthened by the need for environmental responsibility in face of the imminent threat of global warming. However, the question remains whether this rationale applies to a petroleum sector-driven economy like Saudi Arabia's where oil constitutes 90% of export earnings. Would a country that possesses 21% of the world's oil reserves be eager to shift to renewable energy? And is any other reason besides energy security enough to change a country's energy policy including environmental concerns?

VIII. CONCLUSION

The case against renewable energy in Saudi Arabia seems strong, at least for the foreseeable future. The same set of conditions, if it exists elsewhere, might justify substantial investment in the renewable energy sector. However, for a country like Saudi Arabia with a seemingly endless supply of oil, energy security is not a concern. According to Ali al-Naimi, the Saudi Arabian Oil Minister, Saudi oil reserves will last for about 80 years at the current production rates [32]. Even if the market for conventional energy falls to zero due to a world-wide shift to renewable sources of energy, the Saudi oil reserves will sustain the kingdom's energy needs for hundreds of years based on the current domestic consumption of 1 million barrels a day. This, of course, will have disastrous consequences on the country's oil-dependent economy.

Saudi Arabia is well positioned to economically shift to renewable energy when time is right. Unlike most other countries, it is under no pressure to seek and secure alternative sources of energy. Any move by the government to invest in non-conventional sources of energy now is premature given the low efficiency and high cost of existing technologies. After all, in China, the world's top renewable energy producer, only 7.5% of energy needs comes from renewable energy sources [33].

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