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Energy Trends in Gcc Countries

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ABSTRACT

Over the next decade, as the GCC population soars by 30% to over 50m people, the Gulf region will see an increasing strain on its supplies of electricity, food and water. The ways in which the region faces up to these challenges will have a major impact on its prosperity and quality of life, not only in 2020 but in the decades to come. This study addresses the outlook for these key resources in the next decade, and explores policy options to ensure that supply keeps up with demand. The report also addresses the challenges in carrying out such policies, including funding massive new infrastructure and shaping public attitudes to encourage conservation. Many of these challenges are well known to the region's governments, which have already started to take the needed steps. While much remains to be done, the young populations and significant capital resources of the GCC states are key advantages. The findings are based on two strands of research: (a) Analysis of resource requirements and supplies, drawing on various data sources. (b) A programme of in-depth interviews with economists, academics and other leading experts in the region's resource

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1. INTRODUCTION

Given the huge oil and gas deposits of the Gulf Cooperation Countries, GCC, (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates (UAE)), energy conservation by them may look to be unnecessary. After all, global demand for oil and gas will continue to grow, as rising demand in emerging markets will offset stagnant demand in the OECD. At the same time, non-OPEC supply growth is likely to slow down, and the development of Iraqi and Iranian capacity is likely to be held back by political factors. The GCC countries, meanwhile, control 40% of the world's known oil reserves and 23% of proven natural gas reserves. World dependency on GCC energy exports will grow by 2020. In the circumstances, why should the GCC worry about conserving energy resources?

Yet conservation is a must—not only because hydrocarbon resources are finite, but because conservation makes financial sense. Demand for electricity, which is typically generated by domestic gas, is already outstripping supply in the GCC. Fast population growth threatens to create acute shortages unless something is done. Moreover, using fossil fuels to generate electricity means having less available for export, which in turn means high opportunity costs.

With these factors in mind, the GCC governments are starting to overhaul the way they manage their oil and gas. In particular, most are trying to rein in wasteful domestic consumption

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of electricity and gas. They plan to continue exporting oil as crude, but to reserve a greater proportion of the crude to manufacture value-added refined products, such as petrochemicals and plastics, for export. With the exception of Qatar's plans to export liquefied natural gas (LNG), the region's governments will use natural gas mainly to fuel domestic power plants. They will also invest more in developing cleaner fuels, both in response to global concerns about carbon emissions and as a way to supplement fuel supplies for domestic markets.

All of this represents a forward-thinking approach to solving a problem that is only beginning to emerge. The GCC has substantial fossil fuel reserves, but it cannot be complacent about its long-term supply advantage. Other regions are investing heavily in alternative fuels and in fuel efficiency, as well as in developing previously untapped oil and gas reserves, thus creating potential competitors for GCC supplies.

For example, the Gorgon gas-field found in Australia in 2009, with an estimated 40 trn cu ft in reserves, added some 0.6% to the world's known natural gas reserves, and it is much closer to key Asian markets than the GCC. Another example is the discovery of shale gas in the US in the past two years. *"Before this discovery, the Gulf states had assumed that their cheap gas would not only give their national industries a push, but it would help to attract foreign direct investment from international companies and help them to obtain technology transfer,"* notes Justin Dargin, research fellow at Harvard University's Dubai Programme. *"Three years ago, the cost of buying gas in the US was about US$13 per million Btu compared with US$1 per million Btu in the Gulf. But the shale gas that's been found may stop the Gulf from being so competitive."*

GCC governments are aware that they must prepare for a world of increased competition in energy markets. This is blunting some of the traditional resistance in the region to developing alternative energy sources. Rather than perceiving such fuels as threats to their markets—measures that either reduce demand or offer substitutes for fossil fuel exports—many in the region are starting to see these technologies as part of an unstoppable global trend, and one from which they could actually benefit if they develop competitive technologies themselves.

2. GCC AND THE WIND ENERGY

The power in the earth's wind and in the solar radiation, which reaches the earth, is sufficient to make significant as well as strategic contributions to the GCC countries energy supply. Applications of solar energy in GCC, strating with Saudi Arabia have been growing since 1960. However, effective utilization of solar energy has not yet made reasonable progress mainly due to several obstacles. But, valuable lessons have been learned and a wealth of experience has been gained from the experience. The technical and economic feasibility of wind energy utilization has not yet fully explored. Several studies were conducted to assess the potential of wind energy in the Arabian Gulf and Red sea coast of Saudi Arabia.

According to the wind map of GCC countries, they are characterized by the existence of two vast windy regions along the Arabian Gulf and the Red Sea coastal areas. The mean annual wind speed in these two windy regions exceeds 9 knots (16.7 kmph) and ranges from about 14 to 22 kmph and 16 to 19 kmph over the Arabian Gulf and Red Sea coastal areas, respectively. Even though GCC countries are leading oil producers, they are keenly interested in taking an active part in the development of new technologies for exploiting and utilizing renewable sources of energy, for reasons already explained in this paper. The most natural renewable energy sources which are freely available are wind and solar. The power in the earth's wind and in the solar radiation, which reaches the earth, is sufficient to make significant as well as strategic contributions to the GCC countries energy supply.

Wind energy conversion is recognized as one of the most promising option of the renewable energy. The major challenge to using wind as a source of power is that it is intermittent, cannot be stored (unless batteries are used); and not all winds can be harnessed to meet the timing of energy demands. Further, good wind sites are often located in remote locations far from areas of electric power demand such as cities.

The interest and motivation for harnessing wind power have grown tremendously during the nineteen-eighties in many developed countries as a result of frequent energy crises and persistent issues of environmental pollution (Habali *et al.* 2001). Recently wind energy has attracted a great deal of attention as one of the possible alternative renewable energy sources. By the end of 1998 the global installed capacity of modern grid-connected wind turbines was some 10,000 MW and the growth rates of installation worldwide were 30% - 40% annually. The cost of wind energy was reduced by 30% between 1991 and 1997. Andersen and Jensen (2000) reviewed the reasons behind the success of wind turbines and outlined the future potentials for wind energy technology. Also, according to the American Wind Energy Association (AWEA) and European Wind Energy Association (EWEA),[1] the total worldwide wind electric generating capacity has surged past 10,000 megawatts (MW).

Worldwide, wind energy capacity has expanded at an annual rate of 25.7% during the 1990s, with the total doubling every three years and the cost of production declining steadily. The cost of electricity from wind generation is about one-sixth what it was in the early 1980s and further reductions is expected over the next decade. Industry analysts see the cost dropping by an additional 20 percent to 40 percent by 2005. The French Ministry of Industry, Electricity de France and ADEME (Agency for Environment and Energy Management) have launched French wind generation program EOLE 2005 in July 1996 to develop 250-500 MW of wind power by the year 2007 (Laali and Benard 1998). Wind energy activities in Japan have been summarized by Ushiyama (1998). The activities include development of a 500 KW wind machine, which has been in operation since 1996.

The total installed capacity for power supply reached 8800 KW in 1997. Wind energy activities in China have been summarized by Junfeng and Zhuli (1998). There are 19 wind farms in China, the largest of which is located in Xinjiang with 10 MW total capacities. The total installed capacity of wind power reached 16 MW by the end of 1997. Presently, wind energy continues to be the fastest growing renewable energy source with worldwide wind power installed capacity reaching 14,000 MW. Five nations – Germany, USA, Denmark, Spain and India – account for 80% of the world's installed wind energy capacity.

Realizing the growing importance of wind energy, manufacturers have steadily been developing new techniques to assess wind resources for techno-economical viability. Wind speed data is available from different sources in the Gulf. Among these are the Meteorology and Environment Protection administration (MEPA)[2], Saudi Aramco[3] and others. In 1995 the Energy

Research Institute (ERI) at King Abdel-Aziz City for Science and Technology (KACST) initiated a project in order to record reliable data and to assess the wind potential in Arabian Gulf and Red Sea. Five locations, namely, Abha, Arar, Dhahran, Solar Village and Yanbu, were selected for this purpose (namely Abha, Arar, Dhahran, Solar Village and Yanbu) as a first developmental stage of the project. The installation of monitoring and assessment equipment at those sites has been completed and data collection is still in progress.

Several studies were conducted to assess the potential of wind energy in the Arabian Gulf. Wind data for seven stations in the Eastern Province of Saudi Arabia, UAE, Kuwait, Bahrain, Muscat (Oman) and others, have been analyzed. The derived monthly and annual average wind speeds range from 2.4 to 6.1 m s-1 and from 3.2 to 5.3 m s-1, respectively. Maximum extractable monthly and annual average wind powers were found to vary between 14.2° and 162.5° W m-2, 31.7° and 94.6° W m-2, respectively (Martin and Bakhsh 1985). Wind data for 20 locations in Arabian Gulf and Red Sea have been analyzed. Monthly and annual mean wind speeds and wind powers have been determined. The latter range from 2·5 to 4·4 m s-1, and from 21·8° to 77·7° W m-2, respectively. Results suggest that wind power would be more profitably used for local and small-scale applications. The characteristics of wind regimes and the availability of wind energy resources in GCC countries, in selected sites on the eastern and western coasts of the Red Sea and in the Arabian side of the Gulf and Gulf of Oman, have been studied.

Statistical analysis of the wind speeds involving fitting of observed cumulative distribution to Weibull distribution function by least square technique, determination of the Weibull[4] parameters and evaluation of wind power density by two methods, was carried out. The mean annual wind energy density at 10 m A.G.L[5] lies between 250 and 500 kWh/m^2 on the Red Sea and Gulf coast sites and drops to about 50 kWh/m^2 in inland areas. Yanbu on the east coast has the highest resource while Makkah, affected by the Sarawat Mountains, has the lowest wind energy density. The solar energy in all these areas is abundant. In Makkah and Port Sudan the mean annual solar energy density exceeds 2.0 MWh/m^2. Hourly wind -speed data recorded at automatic solar radiation and meteorological monitoring station, Dhahran (26° 32' N, 50° 13' E), Saudi Arabia has been analyzed to determine monthly wind power (Shaahid and Elhadidy 1994). The wind power is then compared with the monthly mean solar radiation energies for the period 1987–1990.

The monthly average wind speeds for Dhahran range from 4.46 to 6.89 m/s while the solar radiation varies from 3.46 to 7.43 kWh/m^2/day. The annual maximum attainable wind power potential per unit area of the wind stream is 543 kWh/m^2/year and the annual solar potential per unit area of the earth surface is 2.03 MWhr/m^2/year. Hourly mean wind - speed data for the period 1986–2003 [except the years 1989 (some data is missing) and 1991 (Gulf War)] was recorded at the solar radiation and meteorological monitoring station, Dhahran (26° 32' N, 50° 13' E), Saudi Arabia (Elhadidy and Shaahid 1999). The monthly average wind speeds for Dhahran ranged from 4.21 to 6.97 m/s.

The wind power on the south coast of the Gulf has been assessed. A comparison between the wind and solar power showed that the mean attainable wind power is 70.6 W/m^2, while the mean attainable solar power is 500 W/m^2. However, the mean producible wind power is about 50 W/m^2–using Cp = 0.42, while the mean producible solar power through photovoltaic cells is 90 W/m^2 (using 18% efficiency). The availability of wind power in this area is 55% while the availability of solar power is 39%. The use of shrouded walls to improve the performance of WEC (Wind Energy Conversion) is feasible due to the narrow band wind direction, (280° to 30°).

The wind map of Arabian Gulf, Red Sea and the Gulf of Oman, indicates that the area is characterized by the existence of two vast windy regions along the Arabian Gulf and the Red Sea coastal areas (Shaahid and Elhadidy 1994). The mean annual wind speed in these two windy regions exceeds 9 knots (16.7 kmph) and ranges from about 14 to 22 kmph and 16 to 19 kmph over the Arabian Gulf and Red Sea coastal areas, respectively. The application of wind energy in Saudi Arabia is nil except the recent installations by KACST as part of a feasibility study of wind energy utilization in GCC countries. Four sample sites are selected for possible installation of both small and large wind energy conversion systems. These sites are: Yenbo and Al-Wajh on the Red Sea coast, Dhahran on the Arabian Gulf coast and Quaisumah in the north east of the KSA, Kuwait, Bahrain, Dubai, Muscat etc. Using the manufacturers pre-mass production unit capital costs ($/kW) to estimate the cost of electricity produced, in cents/kWh, it is concluded that further reduction in the manufacturers unit capital cost is still required to enable wind energy to compete with other conventional energy sources.

3. SOLAR ENERGY

Recognizing the sun as a major natural resource with which GCC countries are blessed in abundant measure (2200 thermal kilowatt hours (kWh) per square meter) it is believed that solar energy is a valuable and renewable energy source that should be fully exploited for the benefit of these countries. Solar radiation data is available from different sources in GCC countries. Among these are the Meteorology and Environment Protection administration (MEPA), Saudi Aramco, and King Fahd University of Petroleum and Minerals (KFUPM), Kuwait Meteorological Center, Dubai, Bahrain Meteorological Service, National Center of Meteorology and Seismology in Abu Dhabi, Oman's Directorate General of Civil Aviation & Meteorology, etc. Reliable quantitative data on the daily and annual distribution pattern of solar energy at given locations are essential not only for assessing the economic feasibility of solar energy utilization, but also for the thermal design and environmental control of buildings and greenhouses.

It has been found that the existing Arabian Gulf Solar Radiation Atlas does not cover all the parts of the Gulf, Red Sea and Gulf of Oman. Additionally, it does not contain the reliable information that is required for solar-energy applications, as it is based on the data collected by old and uncalibrated instruments; and the magnitude of global solar radiation has changed due to global weather variations and the environmental impacts of the Green House effect. In view of the importance of the need for exact measurements of solar radiation, Saudi Arabia in 1994 initiated the so called Atlas Project, as a joint R&D project between the ERI and the NREL. Twelve locations in the following cities throughout the country were carefully selected: Riyadh, Gassim, Al-Ahsa, Al-Jouf, Tabuk, Madinah, Jeddah, Qaisumah, Wadi Al Dawasir, Sharurah, Abha, and Gizan. All of these stations are connected to a central unit for data collection and all the instruments are calibrated on a regular basis (at 6 month periods) in order to derive reliable and accurate data. To promote further dissemination, the analyzed data is made available on an Internet site.

Applications of solar energy in GCC countries, to a various degree, and in Saudi Arabia especially, the leading country in solar energy projects and applications, have been growing since 1960 (Huraib *et al.* 1996). Research activities commenced with small-scale university projects during 1969, and systematized major R&D work for the development of solar energy technologies was started by the King Abdulaziz City for Science and Technology (KACST) in 1977. For the last two decades the Energy Research Institute (ERI) at KACST has conducted major research, development and demonstration (RD&D) work in this field. The ERI has a number of international joint programs in the field of solar energy including SOLERAS[6] with the United States of America, and HYSOLAR[7] with the Federal Republic of Germany. These joint programs were directed towards projects that were of mutual interest to the committed countries involved and concentrated on large demonstration projects such as electricity generation, water desalination, agricultural applications, and cooling systems.

A brief description of these projects and their associated technical accomplishments are reported by Huraib *et al.* (1996). The solar-energy RD&D activities throughout Saudi Arabia have confirmed that it has a multitude of practical uses. These include lighting, cooling, water heating, crop/fruit drying, water desalination, the operation of irrigation pumps, and the operation of meteorological stations, and in providing road and tunnel lighting, traffic lights, road instruction signals and for small applications at remote sites (Alawaji 2001). However, effective utilization of solar energy in Saudi Arabia and the rest of the GCC countries have not yet made reasonable progress mainly due to several obstacles, some of which are listed as follows (Alawaji 2001, p. 21):

(1) The wide availability of oil, its superiority to solar energy as a source of energy and its relatively low cost

(2) The dust effect, which in some parts can reduce solar energy by 10–20%.

(3) The availability of governmental subsidies for oil and electricity generation and non-availability of similar subsidies for solar energy programs. If such subsidies must continue then solar energy will require incentive programs.

4. HYBRID SYSTEM

The variations in resource availability and end-use suitability tend to limit any particular single renewable technology to specific locations and uses. The solution that is increasingly being favoured as the best means of providing decentralized power with high reliability is the hybrid system. Hybrid systems do not rely on a single energy source, but two, three or even four potential sources. For economical reasons there is typically only two, but all hybrid systems will normally include a diesel generator set. The required electrical energy for rural electrification can be met using one or a combination of options that include wind, solar or hybrid (solar & wind) conversion systems beside the diesel and grid extension.

The selection of one or more of these options depends mainly on the available energy, the performance of conversion system and the characteristics of the electrical load. It also depends on the capital and operational costs of each option. The maintenance requirement and the availability of the required support are also important parameters to be considered in the selection of the suitable options. Very few studies (see e.g. Elhadidy and Shaahid 1999) are conducted on the feasibility of utilizing hybrid systems in meeting power demand in GCC and Saudi Arabia. This is a potential area that needs to be explored more.

As we have mentioned before, the other GCC countries and others too, may benefit from the experience gained in the field of renewable energy R&D in the Kingdom of Saudi Arabia during the last two decades, and which, mainly, has been in the field of solar energy and has been very valuable. The international joint programs have assisted in the establishment of a series of independent RD&D projects on solar energy by the ERI, and several other users throughout the country. The following can be concluded in this regard:

(1) Valuable lessons have been learned from the Kingdom experience in the field of solar energy, which are believed to be very useful to other countries with similar climatic conditions, as well as to the scientific community in general.

(2) A wealth of experience has been gained in the assessment, instrumentation, calibration, data collection, monitoring and analysis of solar energy projects.

(3) Low and medium solar thermal energy applications in the Kingdom of Saudi Arabia are technically and economically feasible and should be encouraged and supported by the government.

(4) The feasibility of wind energy utilization in the Kingdom has not yet fully explored. Experience in this regard will be gained from the installations by KACST.

(5) More feasibility studies have to be conducted in the field of hybrid systems.

(6) In developing countries efforts should be directed to finding applications of those renewable systems that have already been developed in industrialized nations.

(7) Effective utilization of renewable energy systems requires government subsides.

(8) Interaction between regional renewable research centers and local research centers and industries must be promoted.

(9) Awareness among the public about the use and importance of utilization of renewable energy has to be increased.

(10) Renewable energy education and training programs must be incorporated as part of educational programs.

5. THE GULF'S EVOLVING ENERGY POLICY

Industrial diversification boosts demand for oil and gas as feedstock. Despite their fossil fuel riches—or perhaps because of it—GCC states are trying to diversify away from dependence on oil and gas. The aims of diversification are to reduce the region's long-term vulnerability to shifts in international demand, to create jobs for GCC nationals in more knowledge-intensive industries, and to prepare for the eventual transition to a post-hydrocarbons economy.

Although oil and gas will remain the mainstay of the Gulf economies over the next decade, the region's long-term development depends on investing in alternatives as well. The GCC is hardly new to developing energy-intensive industries, such as aluminium and chemicals, but this process will gather pace over the next decade as part of efforts to diversify Gulf economies and create jobs. Owing to its abundant fossil fuel supplies, the GCC has a natural advantage in developing these industries. Nonetheless, some Gulf states face constraints in gas production capacity, in some cases even importing gas to meet current industrial demand, and will need to invest in new capacity.

Over the next decade, the GCC will…

(a) Invest in Adding Value to Exported Fossil Fuels

An increasing proportion of oil and gas will be processed into refined fuels, petrochemicals and plastics. In addition, more gas will be channelled for use in energy-intensive local industries such as plastics, aluminium and copper production. More such projects will emerge in the coming years.

(b) Invest in Power Production to Meet Soaring Demand

Electricity demand will rise by 7-8% per year on average; in the smallest and fastest-growing economies, demand will grow even faster. In the face of seasonal electricity shortages, GCC states will invest heavily in gas-fired generating capacity, and will try to rein in demand for electricity. Tighter energy-efficiency regulations are more likely to be enforced than changes to the subsidy system.

(c) Invest in Renewable Fuels

To diversify their economies and benefit from increased global demand for renewable fuels, GCC states will invest in alternatives such as solar and nuclear power. These sources will help them to meet the shortfall in electricity supplies, and will free up oil and gas for processing and export.

(d) Devote More Resources to Developing "Cleaner" Energy Technologies

There will be growing recognition that global climate change concerns are not merely a fad, and that they in fact present opportunities. To maintain their markets in countries that have set emission limits, GCC states will invest in technologies such as carbon capture and sequestration.

Jean-François Seznec, Visiting Associate Professor at Georgetown University's Center for Contemporary Arab Studies, argues that the most attractive sectors for foreign investment in the GCC in the next decade will be "chemicals, metals and all the industries where low-cost feedstock matters, and all the related services industries." Mr Seznec believes that, in the long term, the GCC will increasingly leave Iran and Iraq to focus on crude oil exports and will concentrate on higher value-added exports. Mr Dargin of Harvard comments: "The development of petrochemicals is seen as important for the national interest. There will be significant new demand in this sector, particularly in India and China." Increasingly, the GCC will find itself in competition for these markets with established petrochemicals exporters such as Germany and the UK.

Clearly, the availability of low-cost feedstock energy is an important attraction for foreign investors. Energy feedstock for industry is typically sold at a break-even price or a small profit, owing to low production and transport costs. *"Supplying gas at the wellhead price rather than the international market price has a significant opportunity cost, but is an important part of*

Gulf industrialisation strategy," says Mr Dargin. That said, the cost of gas in the GCC is likely to rise in the medium to long term. One reason is that some producing countries will shift from their traditional use of associated gas—produced as a byproduct of oil extraction—to greater production of non-associated gas. The non-associated gas likely to be brought on stream in the next decade will tend to be more expensive than the non-associated gas used in the past. Some GCC states (Kuwait, Bahrain and the UAE) will start or increase gas imports, while they try to boost their own production.

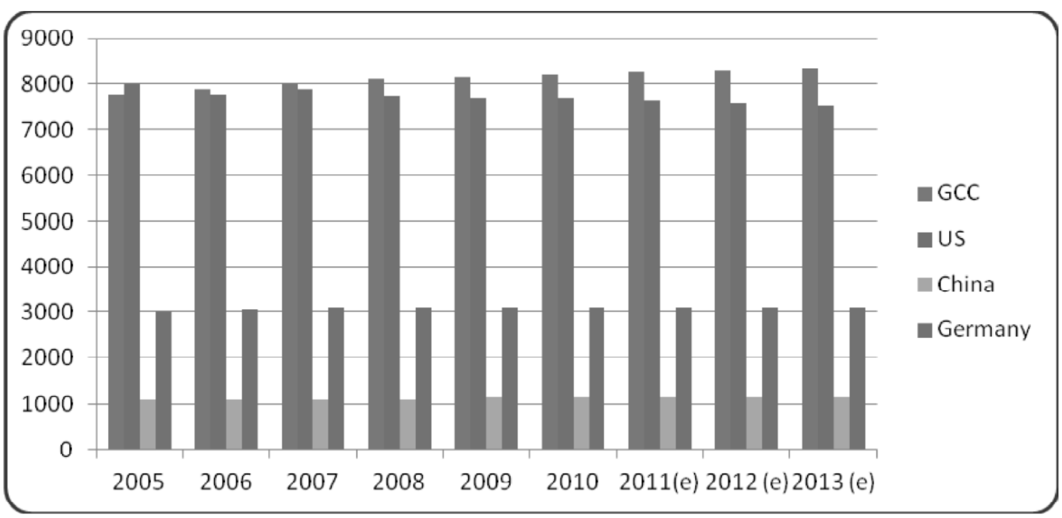
Table 1: Growing Fast

Total energy use in GCC and other economies, millions of tonnes of oil equivalent, 2005-13

	2005	*2006*	*2007*	*2008 actual*	*2009*	*2010*	*2011*	*2012*	*2013 estimated*
Region/Country									
GCC	275.8	289.6	307.6	329.6	343.9	365.8	389.3	412.0	435.4
% change		8.0	6.3	8.4	2.8	5.4	5.9	5.4	5.9
China	1,567.0	1,718.0	1853.0	1988.0	2,096.0	2,265.0	2,394.0	2,531.0	2,671.0
% change		9.6	7.9	7.3	5.4	8.1	5.7	5.7	5.5
US	2,357.0	2,342.0	2,381.0	2,329.0	2,267.0	2,270.0	2,272.0	2,299.0	2,326.0
% change		-0.6	1.7	-2.2	-2.7	0.2	-0.1	0.1	1.2
Japan	531.0	532.0	526.0	514.0	482.0	488.0	491.0	494.0	498.0
% change		0.2	-1.1	-2.3	-6.2	1.2	0.6	0.6	0.8
India	378.0	409.0	434.0	460.0	488.0	519.0	551.0	586.0	625.0
% change		8.2	6.1	6.0	6.1	6.4	6.2	6.4	6.7
Germany	343.0	349.0	355.0	359.0	337.0	336.0	339.0	343.0	347.0
% change		1.7	1.7	1.1	-6.1	-0.3	0.9	1.2	1.2

Figure 1: Energy-guzzlers

Energy consumption per head in GCC and other economies; kg of oil equivalent



(e) Forecasts. Source: Economist Intelligence Unit.

6. MANAGING DOMESTIC DEMAND REMAINS A KEY CHALLENGE

All of this strengthens the argument in favour of domestic conservation of fossil fuel resources. Consumption per head of fuel and electricity is high in the GCC relative to some other energy-intensive economies, such as Germany. Blackouts and brownouts are already common during peak demand times, and it is increasingly difficult for supply to keep pace with demand as the population grows and the economy expands. Energy subsidies represent an increasing cost for GCC governments as populations grow, and governments realise that current consumption patterns are not sustainable. *"To prove you are serious about energy efficiency, you have to start in your own country,"* comments Najib Saab, secretary-general of the Arab Fund for Environmental Development (AFED), and editor of *Al-Bia Wal-Tanmia*, a Lebanon-based environment and development magazine. *"This is still in its infancy in the GCC."*

Yet managing domestic demand for both fossil fuels and electricity remains a key challenge in a region accustomed to plentiful and cheap supplies. An energy-wasteful culture has grown up around subsidised fuel and electricity prices. For example, it is common for people to leave air-conditioning, lighting and music running when they leave their homes. Foreign firms send their least energy-efficient air-conditioners and cars to the Gulf. Many consumers see energy subsidies as part of an implicit social contract with GCC rulers, an essential part of wealth redistribution.

"Subsidies are politically very difficult to change. Energy is the national wealth and people feel they have a right to consume part of those resources. If there were alternative sources of energy, it would be politically easier," comment Kostas Nikolopoulos, Head of Middle East and North Africa for Climate Change Capital, an investment management and advisory firm.

Professor Giacomo Luciani of the Gulf Research Centre in Switzerland says that subsidies should be reduced, but that other measures—such as tightening the regulations on fuel efficiency—are likely to come first. As Mr Saab of the AFED says, *"GCC nationals could save around 40% on their energy bills by adopting energy-efficient products. Regulations are needed because producers won't change by themselves. Car firms still export models to the Gulf that were discontinued everywhere else years ago."* Glada Lahn, Research Fellow in Energy and Development at the UK's Chatham House (Royal Institute of International Affairs) think-tank, acknowledges that cheap energy is considered a right of citizenship in the GCC.

But she notes that subsidies tend to be "regressive": the wealthiest people benefit most, as they have larger houses and bigger cars and engage in more energy intensive activities. *"The issue has to be addressed on several levels,"* she says. *"Governments can generate public understanding of how much is being wasted and how people could benefit from conservation. There should also be a thorough assessment of which groups would lose out when energy prices go up and how they could be compensated in the most efficient way. Meanwhile, the private sector can add pressure for change by demonstrating a commitment to invest in efficiency and alternative energy projects given the right policy incentives"*.

Aside from cutting subsidies, the GCC states could foster more energy-efficient practices in building design and transport infrastructure. Mr Saab notes that there is a pressing need to reduce emissions from transport and industry because of worsening air pollution in many Gulf cities. *"Regardless of climate change, these sectors need to become more energy efficient over the next decade because the air pollution affects people directly,"* he says.

Some of these changes are already under way, according to Ronald McCaffer, professor of construction management at Loughborough University in the UK. He says officials are recognising the need for green buildings, and are addressing environmental issues through engineering as well as architecture. The design of buildings in the Middle East has been predicated on the availability of cheap oil. The result has been heavily air-conditioned buildings absorbing vast amounts of energy. Slowly, however, opinion leaders are realising that the value of oil to the source country is much more important than the cost of buying it at subsidised prices. This is causing a radical examination of the ways that buildings are designed.

7. IMPACT ON HUMAN RESOURCES DEVELOPMENT AND MOBILITY IN GCC

Human resources must be developed to meet these changes and to affect the move to an expanding market driven economy for sustainable energy products and services. Mobility from and to countries that have the wealth to invest in the emerging green market will increase the need for skilled energy experts, scholars, academics and economists. Energy focused education in engineering and economics majors will be in high demand, and universities will have to develop programs that prepare the students to meet these needs in a more integrated multi- and inter-disciplinary way than ever. Academic programs must address local problems and provide more hands-on experience through open ended projects that involve teams of students. Programs should be based on developing students' critical thinking skills and be more innovative if they are to enhance the expansion of the green energy market.

More funding should be available for those types of programs that can partner with the industry to work on energy problems and allow students to think ahead about the future. Governments need to grasp the urgency of upgrading their educational perspective and direct resources towards building these programs in the public and private sector. Governments and universities' resources must go towards creating an atmosphere geared to releasing the employment generating capacity of the private sector to small-sized enterprises.

The GCC is expanding beyond its local labor capacity and it is already attracting skilled labor from the MENA region and from Asia. GCC investors may find an opportunity to expand their investments for private power generation in MENA countries. They could operate in a structure similar to the EU where projects are developed outside its borders. The benefits of

Table 2
Growth Over Time (GCC Electricity Consumption, 2008-20)

	Actual				*Forecast*			
	2006	*2008*	*2010*	*2012*	*2014*	*2016*	*2018*	*2020*
Electricity Consumption								
Total Gwh	307133,7	353647,6	383181,8	427419,2	478047,7	529102,5	589732,7	661859,4
% change year on year	8,0	8,4	5,4	5,4	5,5	5,3	5,7	6,0
Electricity Consumption per head, Kwh	8424,8	8967,9	9307,2	9771,2	10242,1	10771,7	11418,2	12201,4
% change year on year	3,9	4,5	2,5	2,2	2,1	2,6	3,1	3,4

Source: Economist Intelligent unit[8]

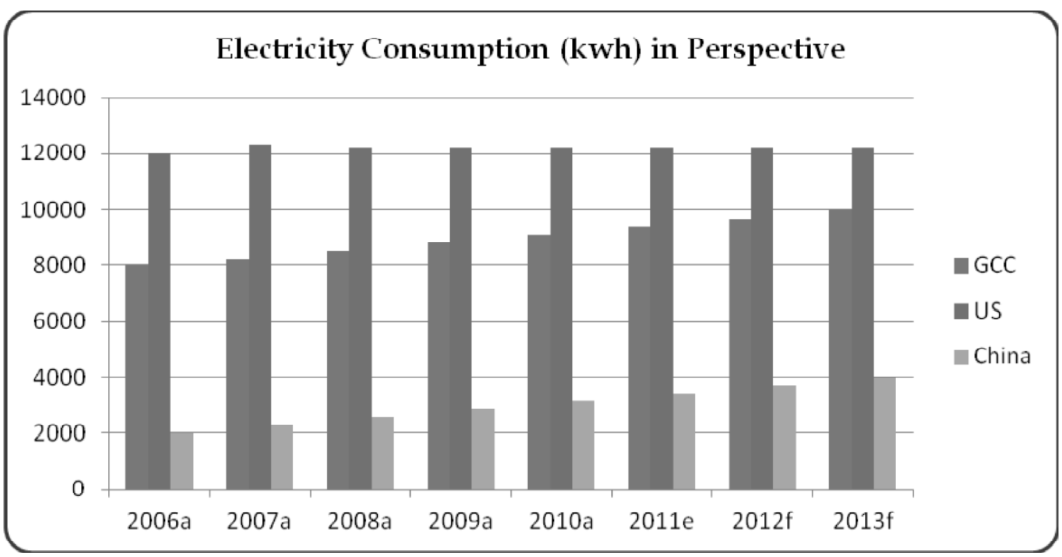
bringing human resources together from across the region has resulted in an accelerated research agenda for Europe and the Arab countries thus reducing the brain drain in critical areas like sustainable energy. As a result, there will be a major impact on climate change and benefits to the global community.

To some extent, this represents a return to the region's architectural roots. In the era before discovery of oil, Gulf Arab countries developed architecture that naturally protected buildings from excess heat. For example, wind towers, which disperse heat by moving air around a building, were used as an early form of air conditioning. In addition, some states are using *"smart demand"* technology in their electricity grids. There are also smaller-scale changes, such as hotels that supply a key card to switch on lighting. The GCC states will follow global best practices to increase the energy efficiency of buildings, including introducing (voluntary) sustainable building codes, predicts Mari Luomi, a researcher specialising in the GCC and climate change at the Finnish Institute of International Affairs. *"Nonetheless there are questions about how well these would be implemented,"* she adds.

8. FUTURE PLANNED INVESTMENT IN SOLAR AND NUCLEAR TECHNOLOGY

The main drivers of growth in oil demand are likely to be in Asia, especially China and India, particularly if these countries continue to subsidise fuel. Yet efforts to reduce carbon emissions and improve energy efficiency are no longer the preserve of the West. Significant changes in regulation are under way in China, as well as in Brazil, South Africa and India, among others, in response to the worldwide drive to curb greenhouse gas emissions.

Figure 2
Electricity Consumption (kwh) – in Perspective



(a): Actual, (e): Estimated, (f): Forecast

Source: Economist Intelligent unit

These shifts are encouraging GCC governments to develop renewable energy sources alongside their traditional fossil fuel exports. Although GCC states will remain concerned about the impact of the global climate change agenda on oil and gas, they will also seek more pro-active approaches to address climate change by adapting the energy mix that they offer. This strategy is similar to that taken by some oil majors, which are seeking to reposition themselves as providers of clean fuels even if their core business is still in hydrocarbons. There will also be a marketing push to emphasise to Western customers in particular that the GCC is responding to their concerns, and some commentators are concerned that more attention could be paid to perceptions than to realities.

According to Mr Saab, Gulf oil producers should invest hundreds of millions of dollars in cleaner fuels. *"If they can make oil cleaner, there will be more demand for it,"* he says, noting that China and the US both invest heavily in clean coal technology. There is significant potential for new investment in cleaner fuel technologies in the GCC, including investments in desulphurisation. Professor Luciani of the Gulf Research Center believes that GCC producers are in a good position to develop carbon capture and sequestration (CCS) technology, as they have the land and the capital resources required for this type of investment. Such investments would be likely to pick up significantly if the UN were to put more incentives for CCS in place after the Kyoto Protocol expires in 2012.

However, the main focus of investment in alternative fuels is likely to be solar and nuclear energy. Mr Nikolopoulos of Climate Change Capital believes that the Gulf is ideally suited to developing solar power. *"With hydrocarbons prices still very high, it makes more sense to finance solar power; using solar power for domestic economies frees up oil and gas for export,"* he explains. He predicts that clean technology will attract increasing investment in the coming years, mainly from North American and European sources. *"Quite a few funds have been set up in the region to invest in clean technologies and renewable fuels. Arab money will increasingly be chasing these opportunities."*

A GCC-wide nuclear project has been proposed, but recent developments suggest that it is more likely to be pursued individually in one or two countries. Given the significant initial capital cost and the different pre-existing energy endowments, nuclear is not equally attractive to all GCC states. However, individual nuclear projects could eventually contribute electricity to a pan-GCC power grid. Beyond that, there is a nascent effort to develop biofuel sources, particularly for the aviation industry. The International Air Transport Association says that 10% of airline fuel should come from alternative energy sources, chiefly biofuels, by 2017; as the GCC seeks to develop its aviation industry and its role as a tourist hub, its airlines may find it worthwhile to be seen addressing these concerns.

So, for example, the UAE-based Etihad Airlines is working with Boeing (UK) to research whether plants that can be grown in seawater mangroves around Abu Dhabi could be used as biofuel feedstock. Similarly, Qatar Airways has announced plans to partner with Airbus (owned by Netherlands-based EADS), the Qatar Science and Technology Park and Qatar Petroleum to develop biofuels.

Despite such intriguing experiments, the long lead times and high start-up costs of renewable energy projects suggest that these fuels are unlikely to make more than a marginal contribution to the GCC's energy mix by 2020. Investments will pick up speed during this period, depending largely on the outcome of negotiations over the post-Kyoto emissions framework. The aviation experience indicates that international regulations and norms will be important drivers of innovation and investment.

Such investment will also contribute to economic diversification and job creation. Given their desire to diversify economies and create jobs, GCC governments will also be keen to develop local production of the equipment and, eventually, the technology for renewable energy production. Several research institutes, including the Masdar Institute of Science and Technology[9] and the King Abdullah University of Science and Technology[10], have launched research and development (R&D) projects on clean energy and alternative energy.

The GCC countries have significant funds for such projects, saved from the recent oil boom. "Overall, these plans rely on government and sovereign wealth fund investments, and on intervention to change the price structure, which will be politically sensitive," notes Ms Lahn of the Royal Institute of International Affairs. *"They don't seem to be self-generating at this time."* Nonetheless, she sees a political will to promote such projects: *"The new generation of GCC policymakers is coming up with very different ideas about how the economy should be oriented. There is a combination of a booming young population being educated in a different way and more experienced leaders who are now looking to leave a clear legacy."*

9. MINERALS: THE NEW FRONTIER

Alongside investments in energy, there will be more investment in exploiting non-oil minerals in the coming years—a potentially lucrative, albeit water-intensive, industry. Minerals found in the GCC include gold, silver, iron ore, copper and bauxite. Some of the mineral deposits left after desalinating seawater, such as magnesium, are also recycled. Historically, the region's mineral wealth has been under-exploited, as the region focused more on developing oil and gas resources. But this is changing as a result of the drive to diversify economically and create jobs. Investment in minerals development is rising, with foreign companies also playing a role.

"*The GCC has huge untapped mineral deposits of all types, and with investment these could grow to be a substantial industry,"* says Nick Carter, president and CEO of American Arabian Development Company, a mineral and petrochemicals firm with projects in the US and Saudi Arabia. According to Ines Scotland, CEO of Citadel Resources, a mining firm based in Australia, growth would be faster if governments were to build on new laws allowing foreign investment in mining by actively granting exploration and mining licences. *"The major risks are around the ability to attract foreign investment,"* says Ms Scotland. *"Investment in exploration is risky, and you need companies that are prepared to take those risks and manage them with technical abilities."* Ms Scotland also notes that the legal framework for investing in mining is largely untested, which makes foreign firms cautious about committing resources. At least initially, most minerals will be exported in raw form.

However, the GCC will continue to develop existing metallurgical industries such as aluminium and copper smelting. It is also investing in other mineral-based industries as part of diversification efforts. For example, a *"mineral railway"* will be built in Saudi Arabia to link mineral mines to processing facilities. *"Most minerals will be used for export and there is not a* *great deal of infrastructure allowing the processing of minerals within the region,"* explains Mr Carter. He adds that over time, new industries will undertake more mineral production locally, *"similar to the development of the petrochemicals industry"*. Smelters will be developed first, he believes, followed by finishing mills and, later, manufacturing plants that use the finished materials.

Like the hydrocarbons sector, the mining sector is vulnerable to shifts in international prices. On the plus side, however, is the sector's relative labour intensity compared to oil and gas extraction. *"For every job created in mining, another seven are created indirectly,"* confirms Ms Scotland of Citadel Resources. Mr Carter of American Arabian agrees: Mr Carter agrees that *"Modern mining processes have the capability to provide very good long term employment opportunities for the local population,"* both in production and in management.

He notes that the availability of local management for mining firms is limited because the industry is new and most of the experienced staff are employed by governments. *"[Government experience] doesn't necessarily lend itself very well to private sector operations, where capital and support might be limited and there are defined time constraints,"* he says. *"On the other hand, local management is important to navigate the political and cultural landscape."* It will take some years to build up local expertise and attract international experts to the GCC's underdeveloped minerals sector, but the rewards are likely to be substantial.

10. POTENTIAL OF RENEWABLE ENERGY SOURCES IN GCC COUNTRIES

As we have observed in the case of Kuwait, the economics of wind power depend strongly on wind speed. Long- and short-term wind speed measurements will normally be needed to ascertain the wind regime. Only when these figures are available can the economics of the projects be determined with any accuracy. In general, studies proved that the global potential of wind energy is large, with the technical potential of generating electricity onshore estimated at 20,000-50,000 terawatt-hours per year and when investigating the potential, special attention should be paid to possibilities offshore.

Recent wind turbines are equipped with cooling systems enabling operation under extreme environmental conditions such as the humidity, temperature, and high air temperatures which occur in Oman. Further investigations need to be done for utilization of the wind energy resources in the southern part of Oman. Study carried by the authority of electricity regulation in Oman found that the potential for off grid wind turbine applications to be limited. These types of applications may be applicable for electricity supply to consumers in the rural areas where there is potential of wind speeds e.g. along the coast in the southern part of Oman and where no grid connection is possible.

The economic analyses show that wind power in hybrid with diesel engines electricity generators can be financially viable in remote locations even in those countries with abundant resources of fossil fuels like Oman [8]. Also, in the mountains north of Salalah - coastal areas in the southern part of Oman - there is significant wind energy.

Various studies forecast that there is potential wind energy in most of the GCC member countries, which increases in summer period. There are no obstacles on the water to block the wind so that the wind blows stronger and steadier over water than land, especially in Oman.

There is a potential of wind energy available offshore. If we take in consideration that Oman, for example, has a coastline of almost 1,700 km, from the Strait of Hormuz in the north to the borders of the Republic of Yemen in the south-west, overlook three seas: the Gulf of Oman, Arab Gulf and the Arabian Sea, then there is a huge amount of wind energy offshore in Oman.

(a) Wind Technologies Development

As a result of intensive basic and applied researches over the last 20 years, development and demonstration efforts are exceptional in several industrialized countries, with leading research centres and industries in Denmark, the Netherlands, the United States of America, Germany and others. The technologies of wind turbines for electricity generation are now in full progress. Meanwhile, wind power has enjoyed fast-paced development in recent years, mostly in the industrialized world, with Germany, the United States, Spain and Denmark emerging as the fastest-growing wind markets worldwide in 1999. The main development features include:

- Turbine sizes increased steadily and, since 1998, most new wind employed turbines have capacities of between 600 kW and 750 kW, and increasing.
- The development of the wind farm concept, which resulted in the promotion of the use of wind electricity generation to large-scale grid-connected applications. However, the permissible wind penetration rate is usually between 10-15 per cent of the grid capacity.
- The total installed capacity in January 2001 reached 16,461 MW, including 65 MW in Egypt compared with 4,779 MW in 1995. In addition, the projected wind power estimated 40,000 MW for 2009 with a 10 per cent growth up to 2016 to reach saturation in between 2030-2035 at about 1.9 terawatts/year. Under these assumptions the cost can come down to US$ 0.027/kWh on average.
- The main technology development features expected in the coming decade, based on the achieved development trends since the 1970s, are wind turbines becoming larger, wind turbines becoming more controllable and grid-compatible, wind turbines will have fewer components, and time to market will become shorter than project preparation time.

Our study survey shows that system future aspects would include:

- Wind turbines becoming larger, with the average size installed in 1998 at 600 kilowatts, up from about 30 kW in the mid-1970s. Turbines of megawatt size are being developed and should soon be commercially available;
- Costs have to come down further, requiring development of advanced flexible concepts and dedicated offshore wind energy systems. Cost reductions up to 45 per cent are feasible within 15 years.

Ultimately, wind electricity costs might come down to about US$ 0.03 per kilowatt hour;

(a) The environmental impact of wind turbines are limited, with noise and environmental aesthetics causing the most problems, which in turn increases public resistance to the installation of new turbines in densely populated areas.

(b) Potentials of Wind Electricity in the GCC Region

(a) Wind resources status: Wind resource measurements are regularly taken by most of the meteorological organizations in the GCC member countries. However, they are not as precise as to satisfy the requirements for wind statistics for energy assessment and electricity potentials in the GCC member countries. Based on the currently available wind data, the wind resources in the GCC member countries can be classified into two groups:

- GCC member countries with limited or no potential for wind electricity generation: Saudi Arabia and the United Arab Emirates;
- GCC member countries with moderate potential for wind electricity generation: Bahrain, Kuwait, Oman, and Qatar;

It should be noted that appropriate and accurate assessments may identify a specific site that could be classified differently than shown above.

(c) Criteria for Evaluating wind Electricity Potentials

The potential for wind energy utilization for electricity generation depends on several factors but with a basic need for good wind resource sites. The following set criteria for evaluation of such potential in a specific GCC member country includes: (a) the available wind resources, (b) energy strategies and policies, (c) the possible wind penetration, (d) prospective site conditions, (e) available local capabilities, and (f) financial availability.

(d) Prospects for Wind Electricity Development in the Region

With the exceptions of Bahrain, Kuwait, Oman, and Qatar, the preliminary resources data do not show very promising potentials for wind electricity generation in the rest of GCC member countries (Saudi Arabia and the United Arab Emirates).

11. OTHER FORMS OF RENEWABLE ENERGY

Hydropower is the energy that comes from potential energy of water. Typically, the power is harnessed by taking advantage of gravity when fall of water occurred from one level to another. The potential energy of falling water is converted into mechanical energy. This form of energy can be developed, and utilized, mainly in Oman. The coast of Oman is formed by the Gulf of Oman on the northeast and the Arabian Sea on the south and east. There are three different forms of energy obtained from hydro ocean energy, wave, tide and OTEC.

(a) Tide Energy (the Oman case): The cause of tides is occurred through a combination of forces created by the rotation of the earth and the gravitational pull of the sun and the moon. Naturally energy is present in water bodies or in their movement can be used for generation of electricity. The idea simply is using the height difference (head) between low and high tides to create a fall similar to that in a conventional hydropower project. This uses the potential energy of the water body. The method of tidal energy broadly works as follows. A tide is trapped in reservoirs constructed behind barrages when it comes onto the shore. When the tide drops later, the water collected is released and is then used like in a regular hydropower project. This method to work effectively it should have the tidal difference - difference in the height of the high and low tides - at least 4m.

A flood tide, entering from the Gulf of Oman through the channel of Hormuz, rides high on the surface of the more salty Arabian Gulf waters. It movements at a speed of up to 0.7 m/s and so does not get very far before the tide reverses direction. However, because of the continuous flow into the Gulf, the mixing effect tends to be extended. Further investigations are required to enable the full extent of this mixing effect to be established.

During an outgoing tide the water, being slightly more salty than that still in the channel of Hormuz, tends to travel deep. Topographical features force the outgoing tide to travel close to the Iranian coast where water depth is at its maximum. The bottle-neck effect of the channel of Hormuz causes two things to happen. First, it restricts and channels water flow. Second, the particular profile of the channel, plus its islands, tends to turn aside a flood tide towards the Omani coast. An outgoing tide does not react in the same way because it is already moving mainly in deeper water close to the Iranian coast.

When considering water movement inside the Arabian Gulf, the effects of flood and outgoing tide can be thought of as energy pulses of approximately 12 hours duration each: pushing and pulling the water already inside the Gulf. This mass of water is also subject to the gravitational effect of the moon and sun. Finally, the oscillatory effect which is maintained by the tidal energy pulses leads to the establishment of a Gulf tidal pattern.

(b) Wave Energy: Wave energy uses the dynamic energy of the waves to generate electricity by rotate an underwater power turbine. This can be insecurely described as an underwater wind farm. Wave height is determined by wind has been blowing, wind speed, the duration of time, the distance over which the wind excites the waves and by the depth and topography of the seafloor.

There has been some scientific study of internal waves in the Arabian Sea and Gulf of Oman through the use of satellite imagery. The imagery shows evidence of fine scale internal wave signatures along the continental shelf around the entire region.

Wave power is proportional to the square of the wave height and wave period. If the significant wave height is given in meters, and the wave period in seconds, the result is the wave power in kilowatts (kW) per meter of wave front length. From table 1 it is clear that wave with 1.4 m height is good to generate electrical power taken in consideration 1,700 km coast length and most of Oman cities are near to the coast.

(c) Ocean Thermal Energy: Ocean Thermal Energy Converter (OTEC) is describing the use of the thermal energy of oceans to generate electricity. This is similar to geothermal power generation where heat attentive in the earth surface is converted into electrical energy. Figure 2 shows a tropical ocean typical temperature profile. For the first 50 m or so close to the surface, commotion maintains the temperature uniform at some 25^{o} C. It then falls rapidly reaching 4^{o} or 5^{o} C in deep places. Actual profiles vary from place to place and also with the seasons.

The Arabian Sea's surface area is about 3,862,000 km2. The maximum width of the Arabian Sea is approximately 2,400 km (1,490 mi), and its maximum depth is 4,652 meters (15,262 ft). Sea or Gulf of Oman is the northwest arm of the Arabian Sea, between the eastern part (Oman) of the Arabian Peninsula to the southwest and Iran to the north. The gulf is 320 km wide between Cape al-Hadd in Oman and Gwadar Bay on the Pakistan–Iran border. It is 560 km long and connects with the Arabian Gulf to the northwest through the Strait of Hormuz. Because of the depth of Arab Sea and Gulf of Oman we expect that there is possibility to find feasible OTEC energy in Oman. Anyway little studies in the last twenty years have been carried in this field OTEC near the coast of Oman.

(d) Geothermal Energy: Geothermal heat originates from weak radioactive activity of volcanic activity in the underground. The temperature in the ground normally raise with 30° C per kilometers depth meaning that a borehole normally need to be more than 3 km in order to be able produce steam or superheated water, that can be used to drive a low pressure steam turbine or other equipment.

Energy usually in the form of hot water or steam is available as heat emitted from within the earth's crust. It is exploited for electricity generation using dry steam or high enthalpy salt water after flashing, or directly as heat for district heating, agriculture, etc. There are more than 55 bore holes in Oman, where the water temperature in the range of 68° C – 137° C.

There are four types of geothermal power plants: (a) dry steam power plants, (b) flash power plants, (c) binary power plants, and (d) flash/binary combined power plants. Decent technology has made possible the economic production of electricity from geothermal resources lesser than 150°C, which is the case in GCC member countries. This plant known as binary geothermal, the facilities that make this possible reduce geothermal energy's already low emission rate to zero. Binary geothermal plants typically use an Organic Rankine Cycle system.

The geothermal water heats another liquid, such as isobutane or other organic fluids such as pentafluoropropane, which boils at a lower temperature than water. The two liquids are kept completely separate through the use of a heat exchanger, which transfers the heat energy from the geothermal water to the working fluid. The secondary fluid expands into gaseous vapor. The force of the expanding vapor turns the turbines that power the generators. The produced geothermal water is injected back into the reservoir.

(e) Hydro Energy: Hydrogen is, at best, an excellent vector of energy. It holds great promise as: (a) Fuel for land and sea vehicles especially when used in high efficiency fuel cells, (b) Fuel for large air- and spacecraft owing to its high energy-to-weight ratio when in cryogenic form, (c) Industrial and domestic fuel for generation of heat and electricity, and (d) A means for transporting large quantities of energy over long distances.

There are several suggestions for the use of hydrogen as a solution for energy shortage: a long-term, clean and a stable production and supply of hydrogen energy to GCC member countries and could be export to EU countries. Also, we should mention that little studies in the last twenty years carried in this field.

(f) Biomass Energy: The biomass sector of GCC member countries has the potential to expand without harmful effects on food supplies and the environment if done in a sustainable manner. Greater recovery of wood from unmanaged and managed woodland, increasing the planting of energy crops (in leased lands), and better exploitation of the existing supply of organic waste materials, could make an important contribution to GCC energy targets, particularly for electricity generation.

Material from waste water and agricultural waste is available in GCC member countries. Biogas material is available from waste water, agricultural waste and animal dung. However, a large amount of waste material is presently used as fertilizer. Animal waste is spread over large areas making collection of sufficient quantities of animal waste difficult and expensive. For these reasons the investigations find only limited potential for biogas electricity production; there is no industry of biofuels in GCC countries. However, there is good potential for expansion of sustainable biofuel production in the future, although it is good to put a plan for importing a significant amount of biofuel from overseas. It is feasible that given the development of more advanced technologies for producing biodiesel and bioethanol GCC countries could use a great range of biomass feedstock's (trees, grasses and waste), supplying domestic loads with biofuel in the further.

12. SUGGESTIONS AND RECOMMENDATIONS

(1) As the cost of fossil fuel based electricity generation in the long term may increase and the production costs of renewable energy technologies decrease due to construction optimization and increased efficiency. The important issue is finding an appropriate starting point and development scenario for the use of renewable energy in GCC countries that may lead to the zero carbon scenarios. The forecast of electricity generation capacity is 35,691 MW in 2014.

(2) Crude oil is still the major source of GCC countries' economies. Also, GCC countries have a wide and of various types of renewable energy, so the growth need for energy could be provided by investing in Renewable energy.

Our study found significant potential sources of RES GCC countries. The findings for each type of RES are as follows:

(1) Solar Energy: GCC countries have one of the highest solar energy concentrations in the world and would be able to produce enough power for all their domestic needs and have power left to export.

(2) Wind Energy: significant wind energy potential in Kuwait, Bahrain and the southern part of Oman and in the mountains north of Salalah. Also, it is found that there is an enormous amount of wind energy offshore in Oman.

(3) Hydro Energy: The wave, tide and OTEC energy are available along the Arabian Sea and Gulf of Oman coast but the energy density is relatively low compared to other locations worldwide. To specify the potential use of hydro energy compared to solar and wind energy resources more studies need to be carry.

(4) Geothermal: The potential for utilizing geothermal energy for electricity production is found to be limited in comparison with Solar and Wind energy but still feasible. More studies need to be done in this field.

(5) Hydrogen: many experts suggest hydrogen as a solution for energy shortage: a long-term, clean and a stable production and supply of hydrogen energy to GCC countries and could be export to EU countries. The problem is that little studies in the last twenty years carried in this field.

(6) Biomass Energy: there is good potential for the GCC countries to expand the production of sustainable biofuel in the future, although it is good to put a plan for importing a significant amount of biofuel from overseas.

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Notes

1. "*World Wind Capacity Tops 10,000-Megawatt Mark",* Press release by the American Wind Energy Association (AWEA) and European Wind Energy Association (EWEA) on April 22, 199.
2. The Meteorology and Environmental Protection Administration (MEPA) Weather Tapes, Jeddah, Saudi Arabia.
3. Saudi Aramco Weather Stations, Dhahran, Saudi Arabia.
4. In probability theory and statistics, the Weibull distribution is a continuous probability distribution used *inter alia* in weather forecasting and related applications, (see e.g. Johnson *et al.* 1994).
5. In weather and climate studies, measurements or simulations often need to refer to a specific height or altitude, which is naturally AGL. However, the values of geophysical variables measured in various places on the natural (ground) surface may not be easily compared in hilly or mountainous terrain, because part of the observed variability is due to changes in the altitude of the surface.
6. Solar Energy Research American Saudi.
7. HYSOLAR, Research Institute For The University Of Stuttgart, Stuttgart, Germany.
8. The Economist Intelligence Unit (EIU) is an independent business within The Economist Group. Through research and analysis, EIU offers forecasting and advisory services to its clients. It provides country, industry and management analysis worldwide and incorporates the former Business International Corporation, a U.K. company acquired by the parent organization in 1986. It is particularly well known for its monthly country reports, five-year country economic forecasts, country risk service reports, and industry reports. The company also specialises in tailored research for companies that require analysis for particular markets or business sectors. 2006 marked the 60th anniversary of the Economist Intelligence Unit's inception. The Economist also produces regular reports on the "liveability" of the world's major cities, which receive wide coverage in international news sources. The Economist Intelligence Unit's Quality-of-Life Index is another noted report. Its current Editorial Director & Chief Economist is Robin Bew.
9. Masdar Institute of Science and Technology (Masdar Institute) is a graduate level, research-oriented university which is focused on alternative energy, sustainability, and the environment. It is located in Masdar City in Abu Dhabi, United Arab Emirates. Masdar Institute is an integral part of the non-profit side of the Masdar Initiative[3] and will be the first institution to occupy Masdar City. The Technology and Development Program [4] at the Massachusetts Institute of Technology is providing scholarly assessment and advice to Masdar Institute. Masdar Institute was established on February 25, 2007.
10. King Abdullah University of Science and Technology (KAUST) is a public research university located in Thuwal, Saudi Arabia. KAUST was built and operated for the first three years by Saudi Aramco. KAUST was founded in 2009 and focuses exclusively on graduate education and research, using English as the official language of instruction. It offers programs in life Sciences, engineering, computer Sciences, and physical sciences.

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