Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Clean Development Mechanism through Geothermal, Saudi Arabia

Chandrasekharam, D.[1,2], Aref Lashin[3,4], Nassir Al Arifi[2], Varun Chandrasekhar[5] and Abdulaziz Al Bassam[2]

[1].Department of Earth Sciences, Indian Institute of Technology Bombay, Mumbai, India 400076, [2].King Saud University, College of Science -Geology and Geophysics Department, P. O. Box 2455, Riyadh 11451 - Saudi Arabia, [3].King Saud University, College of Engineering - Petroleum and Natural Gas Engineering Department, P.O. Box 800, Riyadh 11421 - Saudi Arabia, [4].Benha University, Faculty of Science - Geology Department, P.O. Box 13518, Benha - Egypt. [5] GeoSyndicate Power Pvt. Ltd, Mumbai, India.

dchandra50@gmail.com

Keywords: Saudi Arabia, EGS, CO_2, Geothermal, Granite, CDM

ABSTRACT

CO_2 emissions and fresh water for power generation are going to be the main issues in future for Saudi Arabia. By the year 2020, CO_2 emissions from fossil fuel combustion will exceed 750 billion Gg and the fresh water requirements for generating primary energy will exceed 88 billion cubic meters. This amount excludes the drinking water requirement of 275 L/day per person , which will grow exponentially with the increase in population. The magnitude of the these issues, together with declining oil reserves by 2020, will be a cause of concern. The energy source mix and energy policy and development strategies should be in the national agenda in the coming years for the country. The country's geothermal energy resources, both wet and EGS sources, are currently untapped and the country needs to plan its development now to mitigate the problems described within the next decade. By the time the oil reserves show a declining trend, EGS technology will mature and will be able to provide affordable electricity to millions.

1. INTRODUCTION

Access to energy offers several economic and social benefits. These benefits are accessible only to very few countries and, within the countries, to a few communities. Nearly 1.3 billion people have no access to electricity and more than 2.6 billion people still live on biomass in the world (IEA, 2013a,b). A major proportion of the population who have access to electricity spend it for cooling purposes. It is observed that the annual maximum temperature in urban regions is increasing faster than the global average due to island heat effect (IEA, 2013b). This is true in the case of many cities in Saudi Arabia, where the temperature over the past decade has increased by 0.76 °C (Almazroui et al., 2012). Like other urbanized countries, Saudi Arabia spends 80% of its electricity produced for space cooling (IEA, 2013b). According to the recent report by the IEA (IEA, 2013b), Saudi Arabia has greater than 3000 CDD (Cooling Degree Days, IEA, 2013a). At present, 192 terawatt hours of electricity is being consumed for space cooling and by 2020 this demand will increase to 605 terawatt hours (EIA, 2013). The entire energy sector in Saudi Arabia depends on oil and gas, with domestic consumption amounting to 3 million barrels of oil per day which amounts to a per capita electricity consumption of 8500 kWh (WB, 2009, IEA 2012). The current oil consumption is 500 000 barrels per day and for 3000 CDD in summer, the consumption is 900 000 barrels/day (IEA, 2013b). The country has options to reduce oil consumption and control CO_2 emissions by using a diverse energy source mix. The western Arabian shield has considerable untapped geothermal resources that can be explored and exploited. This will help the country to control local and global climate change. The geothermal potential of this country is discussed in this paper.

2. CARBON DIOXIDE EMISSION

By using fossil fuels for meeting the ever growing electricity demand, the country is generating large volumes of CO_2. The global CO_2 emission has reached 31.6 Gt in 2012 over the 2011 level (IEA, 2013a).

Table 1: CO_2 emissions from the different sectors in Saudi Arabia (Gg) (modified after IEA 2012)

Total CO_2 emissions from fuel combustion	Electricity and heat production	Manufacturing Industries and construction	Transport
446000	181000	161000	104000

The total CO_2 emissions from different utilities is shown in Table 1. Saudi Arabia's CO_2 emissions through fuel combustion jumped from 252000 Gg in 2000 to 446000 Gg at present. The contribution from oil alone is 175000 Gg, while from gas alone it is 7000 Gg (IEA, 2012). The current per capita emission of CO_2 has increased from 0.012 Gg in 2000 to 0.016 Gg in 2012. With the population growing at a rate of about 6 % annually (WB, 2012), the CO_2 emissions will only rise further in future. The present and future per capita electricity consumption is shown in Figure 1. The building sector is another major consumer of electricity, as mentioned above, utilizing it for space cooling.

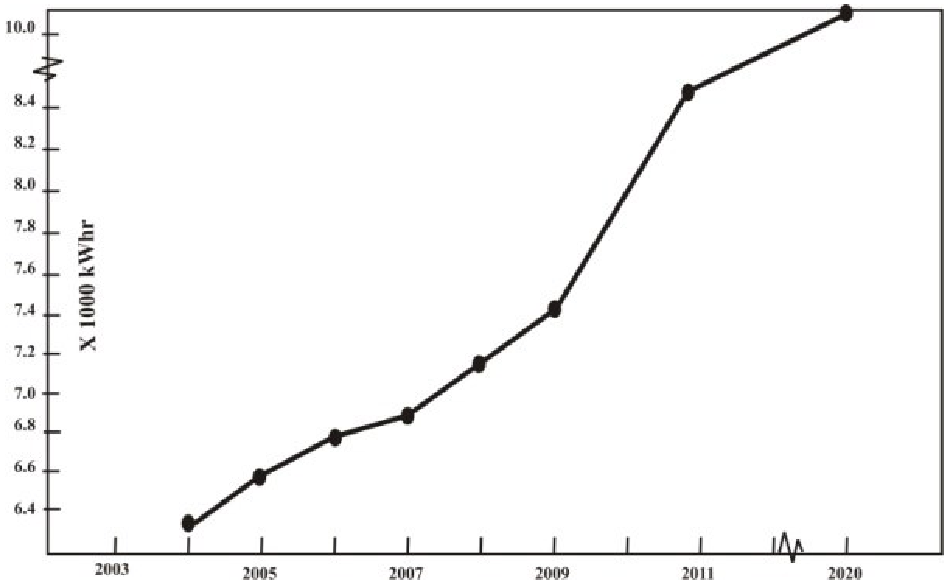

Figure 1. Per capita electricity consumption

The present per capita CO_2 emission is 16.1 Gg and the projections are that it will reach 756 million Gg by 2020 (IEA, 2013a). For the residential, commercial and public services, where the maximum consumption is for space cooling, the CO_2 emissions at present is 900 Gg. Unlike other countries, Saudi Arabia utilizes a considerable amount of oil and gas for desalination to supply about 275 L/day of fresh water per person. The CO_2 emissions from desalination plants is 13 billion kg if oil is used and 3 billion kg if gas is used (IEA, 2012). Such emissions, as reported above, are causing thermal aureoles over the continent, resulting in changes in weather patterns. However, there are solutions to these problems that the country should adopt. A change in national energy policy by encouraging clean development mechanisms and adopting a structure to promote renewable energy in the energy source mix are the solutions that the country should encourage. Geothermal energy from wet and hot dry rock sources can partly mitigate the issues above.

3. GEOTHERMAL ENERGY RESOURCES

The entire western Arabian shield evolved with the initiation of a plume below the Afar region that triggered volcanic activity over the shield. The plume related volcanic centres, also so known as the Harrats, extended over the entire western margin starting from the southern tip of the continent, now with Yemen, to the northern tip of the continent, now represented by the gulf of Aqaba (Figure 2). This plume activity continued until the shield broke into two, giving rise to the Nubian shield and the Arabian shield, separated by the Red Sea.

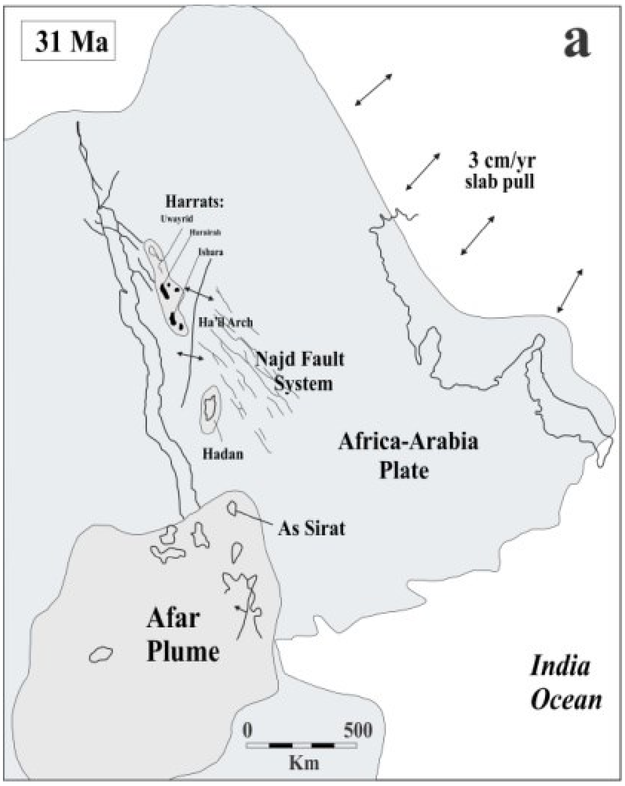

Figure 2. Plume initiated volcanic centres along the western Arabian shield (modified after Bosworth et al., 2005).

The Red Sea opening started with the initiation of the rift from the south that propagated north with time and rotated the shield counterclockwise. The rising plume that stretched on the continental crust along the west coast triggered dike swarms parallel to the Red Sea rift axis at about 30 to 25 Ma. This was followed by a series of volcanic eruptions that poured enormous volumes of lava. These Harrats covered all the preexisting drainage and paleochanels resulting in the creation of boiling aquifers below the Harrats. Water vapor from the basaltic magma and steam from the hot aquifers emerged on to the surface as fumaroles (Coleman et al, 1983; Chandrasekharam et al., 2014). The volcanic activity continued with the intrusion of dikes and appearance of a magma chamber at about 8 km depth below the Harrat Lunayyir (Al-Zahrani et al., 2013; Duncan et al., 2013). These magmatic and tectonic activities gave rise to wet geothermal systems associated with the Harrats. The effect of the mantle plume resulted in, as recorded by seismic refraction survey (Milkerieit and Fluh, 1985; Mooney et al., 1985; Prodehl, 1985), the rise of Moho from 38 km to 18 km below Al Lith wadi region that in turn gave rise to the Al Lith and Jizan geothermal provinces towards the southern part of the Shield (Figure 3). This position of the Moho gave rise to elevated heat flow value of 115 mW/m^2 between Al Lith and Jizan regions (Gettings et al., 1986).

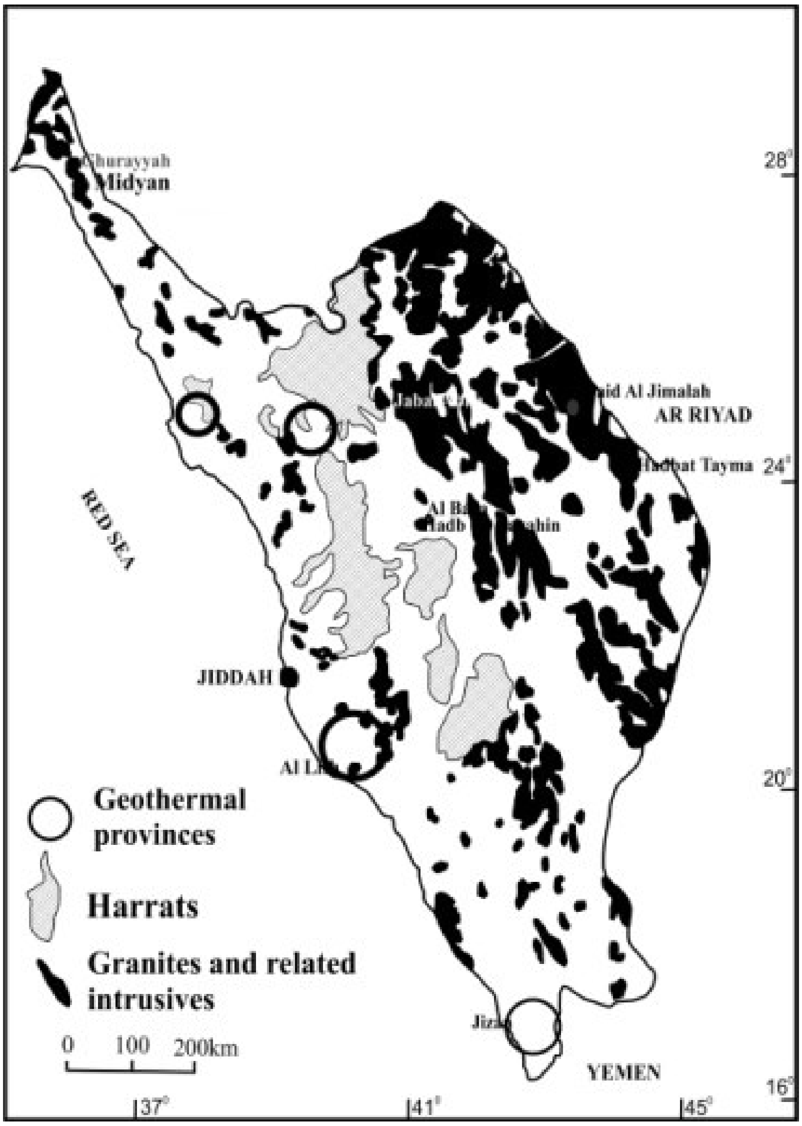

Figure 3. Saudi Arabian shield showing the Harrats, geothermal provinces and granite intrusives (modified after Chandrasekharam et al., 2014).

4. GRANITES

The most remarkable feature of the western Arabian shield is the presence of a large number granite intrusives (Figure 3) with very high radioactive element concentrations. These post tectonic granites intruded into the crust, following the cessation of the arc tectonism that prevailed prior to the plume activity along the western margin of the Arabian shield. The pre plume arc tectonism, together with the plume activity, resulted in a lithosphere with high seismic velocity along the western Shield margin (under plating, Figure 4) that appears to be the site for subsequent magma generation along the coast (Chandrasekharam et al., 2014).

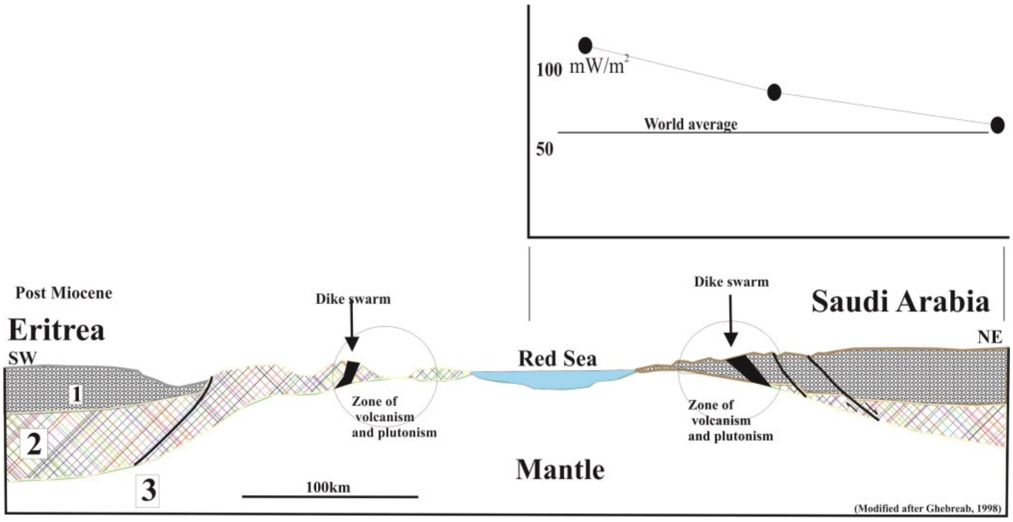

Figure 4. Subsurface structure across Eritrea-Red Sea-Western Arabian Shield (modified after Chandrasekharam et al., 2014).

These granites, due to the high concentration of radioactive elements, generate heat and are unique. The concentration of radioactive elements in these granites and the amount of heat generated by the granites are shown in Table 1.

Table 1. Concentration of radioactive elements and heat generation by the granites (for location see Figure 3).

Location	U(ppm)	Th (ppm)	K (%)	(μWm^{-3})
Baid al Jimalah	13.3	35.2	3.87	6.2
Hadb ad Dayahin	13.7	28	2.4	5.6
HadbatTayma	14.6	25	3.9	5.8
JabalKhinzir	30	8	3.5	8.5
JabalSaqrah	26	49	4	10.4
Ghurayyah 4	104	625	3.12	70.2
Ghurayyah 5	88	160	3.17	33.9
Ghurayyah 6	363	590	1.4	134.2

With the successful technological advancement made in extracting heat from such granites for power generation by France (Soultz hot dry rock project), Australia (Cooper basin EGS project), and the MIT report of 2006 (MIT, 2006); high heat generating granites are attracting the attention of countries for mitigating problems related to global warming and climate change. According to estimates by Somerville et al. (1994), 1 km^3 of such granite could generate 79 x 10^6 kWh of electricity for a period of 30 years. Similarly, the high heat generating granites are going to be the main source of energy in the 21st Century in USA, and it is anticipated to generate 100,000 MWe of baseload electricity by 2050 (MIT, 2006). The area occupied by the high heat generating granites (Figure 3) in Saudi Arabia is about 161467 sq. km (Stoeser. 1986, Lashin et al., 2014, Chandrasekharam et al., 2014). A rough estimate of the power generating capacity of the Ghurayyah granite, with a heat generating capacity of 134 $\mu W/m^3$ (Table 1, Figure 3) is 160 x 10^{12} kWh. Assuming a 2 % extraction ratio of the heat from all the granites for power generation, the amount of electricity that can be produced would be of the order of 120 x 10^6 terawatt hour electricity (Chandrasekharam et al., 2014b). Geothermal sites in Al Lith and Jizan are located within in such granites (Lashin and Al Arifi, 2012).

5. CLEAN DEVELOPMENT MECHANISM

As described above, the CO_2 emissions from fossil fuel combustion will exceed 750 billion Gg by 2020. Changes in the weather patterns, as experienced in recent times, and the population growth will both create a huge demand for fresh water and the country's attention will be focused on providing drinking water to the population, agriculture, and livestock. At present, the country is providing drinking water to the population, at a rate of 275 L/day per person, by consuming 17 x 10^6 kWh of energy through fossil fuel sources and emitting 13 million Gg of CO_2. By 2020, the demand for fresh water, as well as the amount of CO_2 generated from desalination plants, will only grow. In fact, water is required not only for the above purposes but also for power generation, extraction, transport, and processing of fossil fuels and irrigation of biofuel feedstock crops. Global water consumption for energy production in 2010 was 583 billion cubic meters (IEA, 2013). Saudi Arabia, with its primary energy production of 79288 petajoules from oil and gas based power plants, requires 88 billion cubic meters of fresh water. It may not be able to sustain this magnitude of demand of fresh water for power generation, given the fact that oil reserves in the future will decline and will not be replenished. The best future option for the country is its vast geothermal resources. Considering the land requirement, geothermal power plants need only 1 acre of land for generating 1 MWe of power while solar PV sources need 7 acres of land for generating 1 MWe. Since CO_2 is being suggested as working fluid to extract heat from EGS systems (Brown, 2000, Atrens et al., 2010), generation of electricity from EGS may not require water in future. By the time oil reserves have shown a declining trend, EGS systems will mature and provide affordable electricity to millions. In order to achieve this goal, governments should initiate projects now by adopting a sound renewable energy policy in its national agenda. If heat extraction technology through CO_2 matures, geothermal energy (through EGS) will have the dual benefit of CO_2 reduction as well as conserving fresh water resources.

6. CONCLUSIONS

CO_2 emissions and the demand for fresh water are the future concerns for Saudi Arabia. The country cannot be a spectator and get engulfed by these issues by 2020. The country has tremendous alternative energy sources that need to be developed and kept in place before the oil resources show a declining trend. By using geothermal resources, the country can maintain constant level of extraction of the oil resources and prolong the life of the reservoirs and maintain its supremacy in the world. By the time oil reservoirs show a declining trend, EGS technology will mature with CO_2 as the heat extraction medium. What the country needs is a strong energy policy and renewable energy sources need to be in the energy agenda of the country. Geothermal power plants do not consume large volumes of water, unlike other energy sources (see Section 5) and it can generate fresh water at lower costs. With respect to land requirements, geothermal power plants need much less land compared to other renewable energy sources like solar PV and wind. Geothermal power plants need 1 acre / MWe (4047 sq m) while solar PV and wind power need 7 and 2 acre/MWe. The estimated electricity that can be generated from Harrats that occupy an area of 90000 km^2, is in the order of 200 million kWh, respectively. In addition, high heat generating granites, assuming that only 2 % of the heat is extracted, can still generate 120 x 10^6 terawatt hour electricity (Chandrasekharam et al., 2014). Moreover, ground sources heat pump (GHP) technology is now very well established. Since, 80% of the primary energy is being used for space cooling, GHP can be a major CO_2 reduction scheme for the country. There are, as discussed above, several options available to adopt clean development mechanisms (CDM) in the country.

ACKNOWLEDGMENTS

The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding the work through the research group project No RGP VPP-122. D. Chandrasekharam also thanks Hemant K Sing for his help in editing the manuscript.

REFERENCES

Almazroui, M., Islam, M.N., Athar, H., Jones, P.D. and Rahman, M.A. 2012. Recent climate change in the Arabian peninsula: annual rainfall and temperature analysis of Saudi Arabia. Inter. J. Climatology, 32, 953-966.

Al-Zahrani. H, Al-Amri, A. M., Abdel-Rahman. K. and Fnais M. 2013. Aftershock sequence analysis of 19 May, 2009 earthquake of Lunayyir lava flow, northwest Saudi Arabia. Inter. J..Physical Sci. 8, 277-285.

Atrens, A.D., Gurgenci, H. and Rudolph, V. 2010. Electricity generation using a carbon-dioxide thermosiphon. Geothermics 39, 161–169.

Bosworth, W., Huchon, P. and McClay, K. 2005. The Red Sea and Gulf of Aden Basins. J. African Earth Sci. 43, 334–378.

Brown, D.W. 2000. A hot dry rock geothermal energy concept utilizing supercritical CO2 instead of water. PROCEEDINGS, Twenty-Fifth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 24-26, 2000

Chandrasekharam, D., Lashin, A., Al-Arifi, N. 2014. CO2 mitigation strategy through geothermal energy, Saudi Arabia. Renewable & Sustainable Energy Reviews (under review).

Chandrasekharam, D., Lashin, A. and Al Arifi, N. and Singh, H.K. 2014b. Meeting future energy demand of Saudi Arabia through high heat generating granites. Intern. J. Earth Sci. Engg. 7, 1-4.

Coleman, R.G., Gregory, R.T. and Brown, G.F. 1983. Cenozoic volcanic rocks of Saudi Arabia, USGS Open file report 83-788.

Duncan, R.A., Al-Amri, A. M. 2013. Timing and composition of volcanic activity at Harrat Lunayyir, western Saudi Arabia. J. Volcanol. Geothermal. Res., J. Volcanol. Geothermal Research 260, 103–116.

EIA, 2013. Annual Energy outlook 2013 with projections to 2040. U.S. Energy Information Administration. 223p.

Gettings, M.E., Blank, H.R., Mooney, W.D., Healey, G.H., 1986. Crustal structure of south-western Saudi Arabia. J. Geophys. Res., 91, 6491-6512.

IEA (International Energy Agency) 2012: World Energy Outlook, 2012. France, Pub., 538p.

IEA (International Energy Agency) 2013a. Redrawing the energy-climate map, World energy outlook special report. 134

IEA (International Energy Agency) 2013b: World Energy Outlook, 2013. France, Pub., 674.

Lashin, A., Chandrasekharam, D., Al Arifi, N., Al Bassam, A. A . and Varun, C. 2014. Geothermal energy resources of Wadi Al-Lith, Saudi Arabia. J. African Earth Sci. (under review).

Lashin, A., and Al Arifi, N., 2012: The geothermal potential of Jizan area, South-western parts of Saudi Arabia. Inter. J. Phy. Sci., 74, 664-675.

Milkereit, B., and Fluh, E.R., 1985, Saudi Arabian refraction profile: Crustal structure of the Red Sea-Arabian shield transition: Tectonophy, 111, 283-298.

Mooney, W.D., Gettings, M.E., Blank, H.R., Healy, J.H., 1985. Saudi Arabian seismic refraction profile: a travel time interpretation of crustal and upper mantle structure. Tectonophy, 111, 173-246.

MIT, 2006. The Future of Geothermal Energy –Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, MIT -Massachusetts Institute of Technology, Cambridge, MA. (2006), 358 p.

Prodehl, C, 1985. Interpretation of a seismic refraction survey across the Arabian Shield in western Saudi Arabia. Tectonophy. 111, 247-282.

Somerville, M., Wyborn, D., Chopra, P., Rahman, S., Don Estrella. and Theo Van der Meulen. 1994. Hot Dry Rock Feasibility Study. Energy Research and Development Corporation, unpublished report.

Stoeser, D.B. 1986. Distribution and tectonic setting of plutonic rocks of the Arabian Shield. J. African Earth Sci., 4, 31-46.

WB. 2009. World Bank. State and Trends of the Carbon Market, World Bank, Washington.

WB. 2012. World Bank. State and trends of the Carbon Market, World Bank, Washington.