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Climate Change Mitigation Strategy through Utilization of Geothermal Energy Resources from Western Arabian Shield, Saudi Arabia

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Abstract: Stable The CO_2 emissions by Saudi Arabia now stands at 446,000 Gigagrams. Most of it comes from fossil fuels based power and desalination plants. As a consequence of it the country is experiencing changes in the microclimate, indicated by an increase in the atmospheric temperature by about 0.76 °C over the last decade. Saudi Arabia has considerable geothermal energy sources represented by hydrothermal and hot dry rock (EGS) sources along the western shield margin. By using energy source mix the country can offset part of its domestic oil demand and reduce considerable amount of CO_2 emissions. By using geothermal energy for desalination alone can save about 13 million Gg of CO_2. New energy policies have to be developed and adopted to mitigate CO_2 related climate change scenario in the future.

Keywords: CO_2 emissions; Hydrothermal sources; Microclimate; EGS.

Introduction

Geothermal energy is a clean source of energy with minimum emission of CO_2 compared to other fossil fuel energy resources. The present electricity generation through geothermal source is touching over 13,000 MWe (Bertani, 2015) and several countries have realized the benefits of geothermal energy and developing all the available low enthalpy geothermal resources for power generation as well as for direct application. On an average geothermal power plants emit 0.893 kg CO_2/MWh while oil-fired power plants emits 817 kg CO_2/MWh and gas-based power plants emit 193 kg CO_2/MWh (Chandrasekharam and Bundschuh, 2008). Saudi Arabia has reasonable wet geothermal and abundant EGS (Enhanced Geothermal Systems) resources that are yet to be developed along the western margin of the Arabian shield. Due to the availability of large volumes of oil and gas reserves, these resources have not drawn the attention it deserves by the country.

The annual maximum temperature in the urban regions of Saudi Arabia is increasing faster than the global average due to island heat effect (IEA, 2013b). It is reported that many cities in Saudi Arabia

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are experiencing temperature anomalies, where the temperature over the past decade has increased by 0.76 °C (Almazroui et al., 2012). This temperature variation is apparently due to high volume of CO_2 emissions from domestic and industrial and transport sectors. Saudi Arabia spends 80% of its electricity produced for space cooling (IEA, 2013b) and the country has more than 3000 CDD (Cooling Degree Days, IEA, 2013a). Thus 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 Saudi Arabia's energy sector is supported by oil and gas, with domestic consumption touching three million barrels of oil per day and with per capita electricity consumption of 8500 kWh (WB, 2009; IEA 2012). The temperature anomaly apparently is caused by CO_2 emissions from fossil fuels. However, the country has option to reduce oil consumption and control CO_2 emissions by using energy source mix thereby adopting strategy to mitigate climate change. The western Arabian shield has considerable untapped geothermal resources that can be explored and exploited. By implementing clean development mechanism (CDM) through geothermal energy source, the country can mitigate CO_2 emissions and exploit the oil and gas resources for a longer period of time and gain carbon credits as well. The advantage of harnessing this green energy to reduce CO_2 emissions is the main focus of this paper. Utilization of geothermal energy will help the country to control local as well as regional climate change.

Carbon Dioxide Emission by Saudi Arabia

The total CO_2 emissions and CO_2 emissions from different utilities in Saudi Arabia are shown in Table 1. Saudi Arabia's CO_2 emissions through fuel combustion rose from 252,000 Gg in 2000 to 446,000 Gg in 2013 out of which the contribution from oil source is 175,000 Gg and from gas source is 7000 Gg (Chandrasekharam et al., 2014a, b, 2015a, b). The current per capita emissions of CO_2 has increased from 0.012 Gg in 2000 to 0.016 Gg in 2012. With an annual population growth of 6% (WB, 2012; Chandrasekharam et al., 2015b) the CO_2 emissions will increase further in future due to increase in per capita electricity consumption from the present 7400 kWh to 10000 kWh in 2020 (Figure 1). The building sector is another major consumer of electricity, as mentioned above, utilizing it for space cooling.

Table 1: Total CO_2 emissions and emissions by different sectors of Saudi Arabia (Gg: Gigagrams)

Total CO_2 emissions from fossil fuel combustion	*Electricity and heat production*	*Manufacturing Industries and construction*	*Transport*
446,000	181,000	161,000	104,000

(modified after IEA 2012).

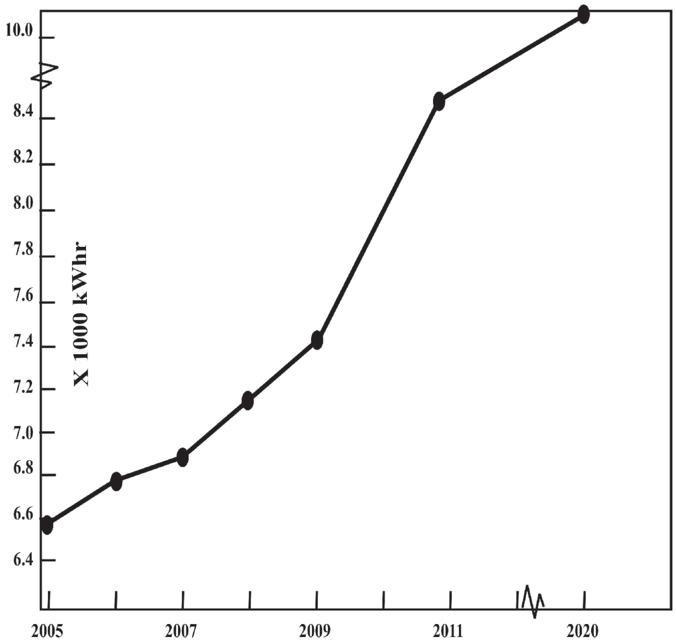

Figure 1: Per capita electricity consumption.

The residential, commercial and public services are the main utilities that use electricity for space cooling and these establishments are emitting nearly 900 Gg of CO_2 (Chandrasekharam et al., 2014a). Besides power, Saudi Arabia spends considerable quantity of oil and gas for desalination to support per capita water consumption of 275 L/day. Thus desalination process also contributes to CO_2 emissions amounting to 13,000 Gg (IEA, 2012). Such emissions are, as reported above, causing thermal aureoles over the continent resulting in change in weather pattern. A change in national energy policy by encouraging clean development mechanism and adopting a structure to promote renewable energy as an alternate source to mitigate climate change to each country. Utilization of geothermal energy available along the western Arabian shield can partly mitigate the above climate related issues.

Geothermal Energy Resources

The western Arabian shield evolved with the initiation of a mantle plume below the Afar triple junction at about 31 Ma, resulting in extensive volcanic activity over the shield, extending from Midyan in the north to southern tip of the continent that is now with Yemen (Figure 2). This plume activity continued till the shield broke into two giving rise to the Nubian shield towards the western part of the Red Sea and the Arabian shield. This process also gave rise to the Red Sea spreading axis. The initiation of the Red Sea started with the break up of the southern part of the ocean floor, near the Gulf of Aden. Over a period of time the rift propagated northwards and rotated the shield anti-clock wise. The plume activity gave rise to dikes swarms that intruded parallel to the Red Sea rift axis around 30-25 Ma. This activity was followed by series of volcanic eruptions that poured enormous volumes of lava that are known as "Harrats" (lava fields). The Harrats covered the then existing drainage systems and paleochannels giving rise to boiling aquifers below the Harrats. Water vapour 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, 2015).

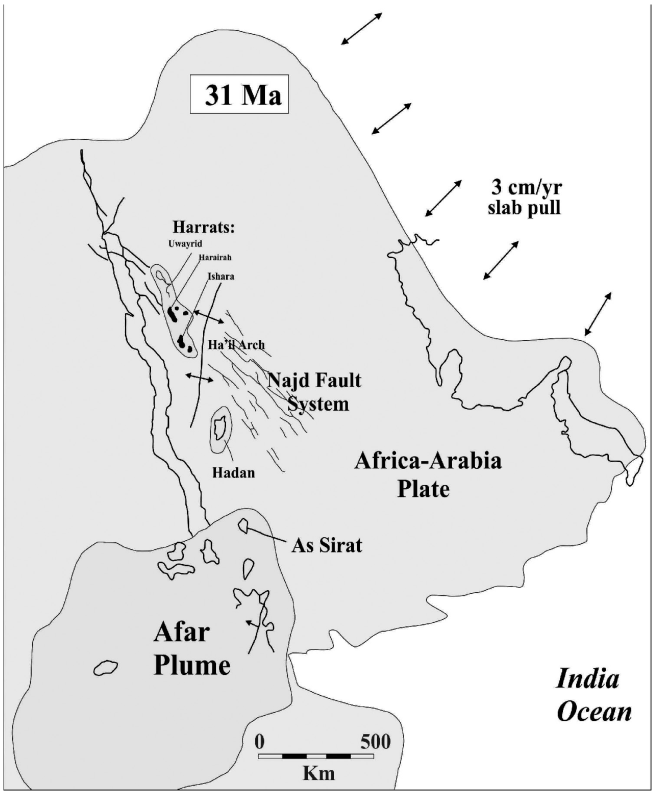

Figure 2: Plume initiated volcanic centres along the western Arabian shield (modified after Bosworth et al., 2005).

The volcanic activity continues till date with the intrusion of dikes and appearance of 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), rise of Moho from 38 km to 18 km below Al Lith wadi region that 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 region (Gettings et al., 1986). Such high flow values due to the disposition of the Moho aided the evolution of the geothermal systems along the western shield region. Besides these wet geothermal systems, the western Arabian shield experienced several episodes of plutonic activities between 900 and 500 Ma (Stoeser, 1986) resulting in the intrusion of granite and related batholiths over the shield region (Figure 3) and these intrusives, due to their inherent heat generating capacity, host high temperature geothermal systems described below.

Granites

The western Arabian shield hosts large number of granite intrusives (Figure 3) that contain high concentration of radioactive elements (U, Th and K). This pre-plume related plutonism and plume induced crustal extension and opening of the Red Sea gave rise to a lithosphere characterised by high seismic velocity along the western shield margin (Figure 4). This high seismic velocity zone became the loci for later magma generation along the coast (Chandrasekharam et al., 2014b, 2015a). Due to high concentration of radioactive elements, these granites are able to generate high heat thereby acting as an excellent heat source (Table 2) for circulating fluids. Such high heat generating granites are considered as future source of energy that can support electricity generation through induced fractures and circulating of water through the fracture to produce high pressure steam (MIT, 2006).

Technological advancement made by France (Slutz hot dry rock project) and Australia (Cooper basin EGS project) to extract heat from such high heat generating granites for production of electricity has now made high heat generating granite as the potential source for supporting electricity production with zero CO_2 emissions (MIT, 2006). It has been estimated that

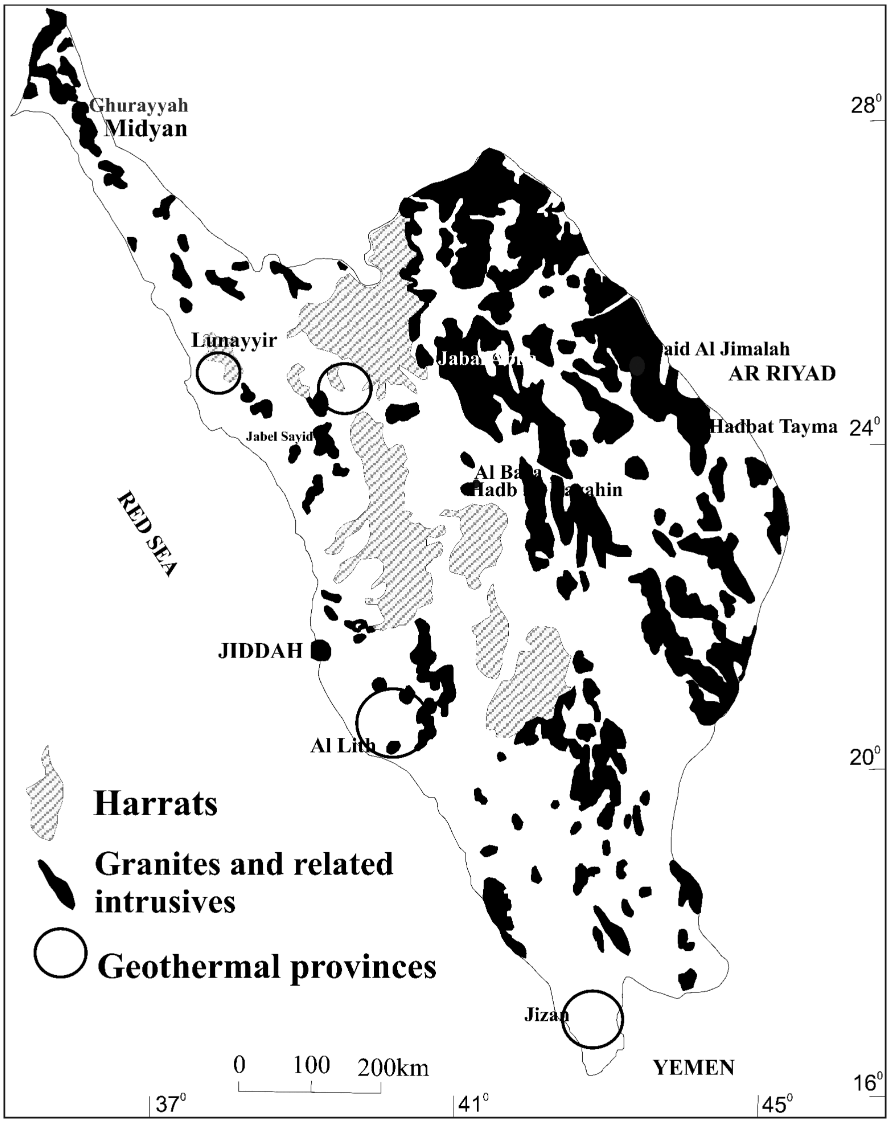

Figure 3: Saudi Arabian shield showing the Harrats, geothermal provinces and granite intrusives (modified after Chandrasekharam et al., 2014a, 2015a).

(Somerville et al., 1994) 1 km^3 of such granite can generate 79 × 10^6 kWh of electricity for a period of 30 years. The area occupied by the high radiogenic granites (Figure 3) in Saudi Arabia is about 161,500 sq. km (Stoeser. 1986; Lashin et al., 2014; Chandrasekharam et al., 2014, 2015a,b). A rough estimate shows that the power generating capacity of Ghurayyah granite (134 μW/m^3, Table 1, Figure 3), located in Midyan region is around 160 × 10^{12} kWh. If one assumes that about 2% of this energy is extracted, through EGS technology, the amount of electricity that can be generated would be of the order of 120 × 10^6 terawatt hour (Chandrasekharam et al., 2014b, 2015a,b). Electric power that can be generated from such granites located in Al Lith and Jizan has been reported earlier (Lashin and Al Arifi, 2012; Lashin et al., 2014; Chandrasekharam et al., 2015a,b).

Clean Development Mechanism

Estimates indicate that the CO_2 emission from fuel combustion will exceed 750 billion Gg by 2020 (IEA, 2014). With changes in the weather pattern, as reported in Saudi Arabia, and 6% annual population growth the country will be forced to generate more electricity and increase the capacity of desalination process to meet the growing demand for fresh water using fossil fuels thereby enhancing the CO_2 emissions as per the projections described earlier.

Table 2: Radioactive element concentrations and heat generation by the granites

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
Hadbat Tayma	14.6	25	3.9	5.8
Jabal Khinzir	30	8	3.5	8.5
Jabal Saqrah	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

(*Source*: Chandrasekharam et al., 2015a,b; location of the sites are shown in Figure 3).

Currently the country is supplying drinking water to 29 million people (and live stock) by consuming 17 × 10^6 kWh through fossil thereby emitting 13 million Gg of CO_2. By the year 2020, if the business as usual situation continues, fresh water demand will grow at an exponential rate thereby generating large quantities of CO_2 from desalination plants. The best mitigation strategy the country can adopt to combat climate change caused due to CO_2 emissions is to develop its vast geothermal resources for power generation and for desalination. Now that CO_2 is being suggested as a working liquid to extract heat from EGS systems (Brown, 2000; Atrens et al., 2010), generation of electricity from EGS may not require water in future and will act as a process of CO_2 sequestration. In order to achieve clean development strategy, the government should adopt energy source mix for power generation by adopting sound renewable energy policy. If heat extraction technology through CO_2 matures, geothermal (EGS) will have the double benefit of CO_2 reduction as well as generating fresh water for the growing population.

Conclusions

Saudi Arabia is concerned about the changes in the micro-climate systems due to large CO_2 emissions from its power and desalination plants. By using geothermal energy resources Saudi Arabia can offset the domestic oil demand and reduce the level of extraction of the oil thereby reducing the dependency on fossil fuels to meet the future energy and water demand. The country needs a strong energy policy to mitigate CO_2 emissions and mitigate changes in the micro climate systems in major cities. With respect to land requirement, geothermal power plants need much less land compared to other renewable based power plants 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.

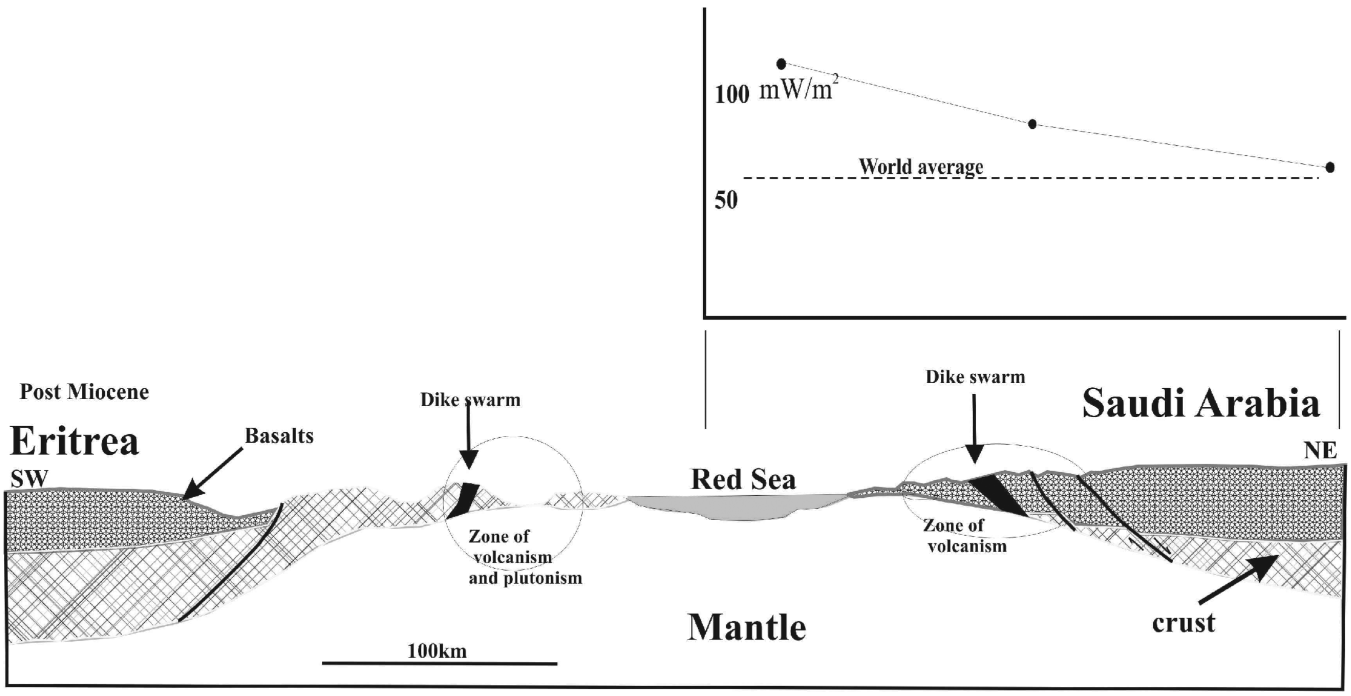

Figure 4: Subsurface structure across Eritrea-Red Sea-Western Arabian Shield (modified after Chandrasekharam et al., 2015c, 2015b).

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