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Geothermal power corridor-connecting the Middle East Countries

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Research Article

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ABSTRACT

The Middle East economy and life depend on imports, be it food, water, or energy, despite each country in the region having enormous energy resources to exploit and reduce dependency on countries outside the region and develop a socioeconomic model of regional cooperation and synergy. An estimated 371 TWh of electricity available from geothermal energy resources can be utilized by these countries to support basic needs and be free from food-energy-water imports by sharing their energy resources. The total amount of CO_2 emissions from these countries is currently 945 x 10^6 kg, so these countries can further earn about 92 million euros from carbon savings, by using geothermal energy along this corridor. This amount can be utilized for augmenting the energy supply from geothermal sources. In this work, the available geothermal resources are evaluated, and suggestions are made how this energy can be best utilized for peaceful existence and cooperation in the region.

1. Introduction

This communication is aimed at countries that have scarce water resources and hence depend heavily on imported food and/or desalinated water using enormous amounts of high CO_2 emitting fossil energy sources, even though they have huge untapped geothermal energy resources and countries that have plenty of green energy potential and water but still depend on imported energy due to poor infrastructure to develop the green energy resources. Although the regions discussed in this paper have other sources of energy such as solar photovoltaics (PV) and Wind, these sources can not provide base load electricity and their efficiencies are about 20%. The energy densities of these two sources are very low and the reliability is also low (Shanmugam, 2023). Hence these sources are not included for review in this paper. Here we consider Saudi Arabia as a glaring example of the first group of countries and Türkiye which belongs to the second group. Between these two groups, fall other countries that lie between Türkiye and Saudi Arabia. We will focus on geothermal energy that is available in these countries and analyze how sharing this energy, like transboundary aquifers, will help them.

In today's world, transboundary rivers, aquifers, and oil fields are common, which supply water or oil to different countries. Transboundary aquifers, viz. Guarani Aquifer, spread over Argentina, Brazil, Paraguay, and Uruguay, in Europe and GCC countries (Kuwait, Saudi Arabia, Oman) share common formations producing hydrocarbons as well as aquifers (Chandrasekharam et al., 2016*a*). Similarly, electricity is also shared through a grid system within a country or across the countries; for example, nuclear

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power, thermal and hydropower are shared in Europe (https://ec.europa.eu/eurostat/statistics). Sharing through a grid within the country is very common since most of the thermal power plants are located near the coal source while hydropower is within a suitable water drainage system. So, it is possible to share geothermal power using interregional grid systems for sustainable development of the regions and to collectively contribute to the climate change control goal. Geothermal power transmission using grids and mini-grid within countries is common. It is possible to use a transboundary transmission system to supply geothermal power across the countries.

The focus here is to evaluate the geothermal energy potential of the Red Sea, Saudi Arabia, Jordan and Türkiye and suggest ways to involve all the Middle East countries to provide carbon free food-energy-water (FEW) and support their United Nations (UN) Sustainable Development Goals through a common geothermal power corridor (GPC).

2. Methodology and Status of Potential

2.1. Methodology

The radioactive heat production of the granites has been calculated using the procedure of Rybach (1976). Electricity generation from such granites is calculated using the procedure adopted by Somerville et al. (1994) for hot dry rock project in Cooper Basin, Australia.

2.2. Power from The Red Sea Ridge Flanks

According to a recent study (Chandrasekhar and Chandrasekharam, 2023), the Red Sea together with the high radiogenic granites and Harrats (volcanic fields) of the western Arabian Shield have very high geothermal energy potential.

This region can generate 49 x 10^{11} kWh of electricity while the annual electricity consumption of Saudi Arabia is only 2.89 x 10^{11} kWh. This region together with the granites and Harrats of Syria, eastern and central volcanic provinces and the western geothermal province of Türkiye can form a transboundary geothermal power grid (Figure 1), which is termed here, the Geothermal Power Corridor (GPC). The heat flow value of the eastern flank of the Red Sea ridge, along its 2000 km length from the Gulf of Aden to the Gulf of Aqaba, varies from 96 to 205 mW/m^2 (Girdler, 1970; Girdler and Evans, 1977). This is a locus of geothermal zones, with supercritical temperature (378 °C) encountered at a depth of 2 to 3 km. This is due to the presence of the 1200 °C isotherm (melting temperature of basalts) at a depth of 10 to 12 km, which is indicated by the presence of hot brine pools at shallow depth in the axial valley (Degens and Ross, 1969) and the presence of shallow sheet-dike intrusions along 20° Parallel on the eastern side of the ridge axis (Cochran et al., 1986; Follmann et al., 2021; Chandrasekhar and Chandrasekharam, 2023). 3D THM (Thermo-Hydro-Mechanical model using COMSOL V6) modelling of a supercritical geothermal zone below an active volcanic terrain (with single loop EGS configuration: shown in Figure 2) indicates that temperatures of 275 °C can be obtained at the production wellhead that can generate 53 MWe (Chandrasekharam et al., 2023).

Two hundred off-shore geothermal platforms, between the transform faults (with 10 km spacing between the wells), over 2000 km long, western flank of the Red Sea ridge tapping this supercritical heat should generate, according to the above model, 10600 MWe. This is equivalent to 84 billion kWh per year. When oil rigs can operate off-shore, much smaller geothermal platforms can operate as well. The number of geothermal wells over the eastern flanks can be increased subsequently once the power production system is established. After all, there is a constant supply of heat to tap along the spreading ridge.

2.3. Power from Western Arabian Shield Margin

The hydrothermal sources at Jizan and Al Lith, the Harrats (volcanic fields) and the high radiogenic granites are the main geothermal sources along the western Arabian Shield margin. The Ocean ridge slice, with its dike swarms and ophiolites, in association with acid differentiates thrusted over, the thin continental margin at Jizan and Al Lith, with high heat flow (100 mW/m^2) and geothermal gradient (90 °C/km) (Figure 3 and 4), form the main loci of hydrothermal reservoirs, with a capacity to generate 1.2 x 10^9 kWh and 134 x 10^6 kWh respectively (Chandrasekharam et al., 2014; 2015; 2016*a*; 2016*b*).

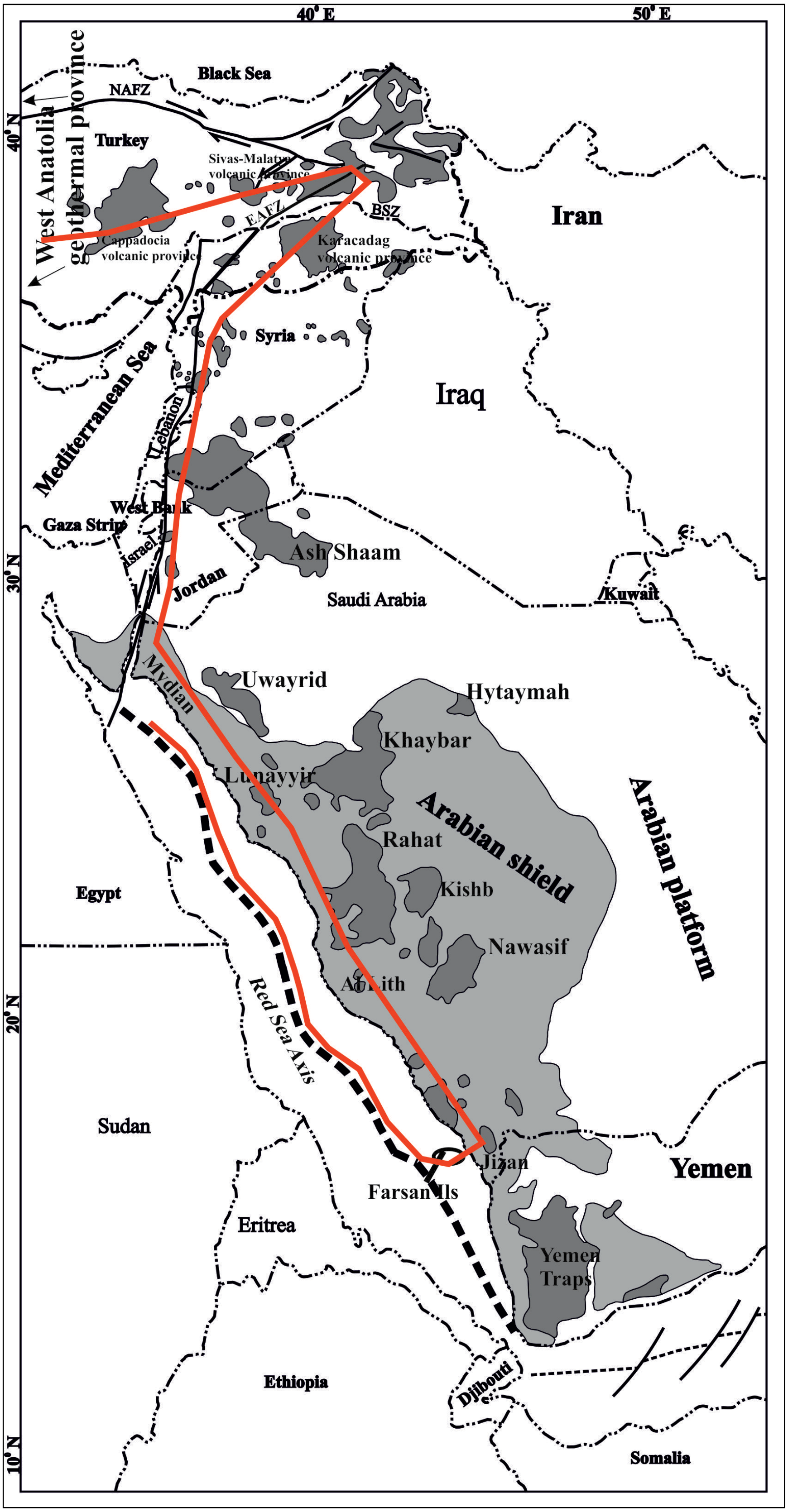

Figure 1- The red line indicates the Geothermal Resources Corridor connecting geothermal provinces of the Red Sea ridge, Western Arabian Shield, Jordan and Türkiye.

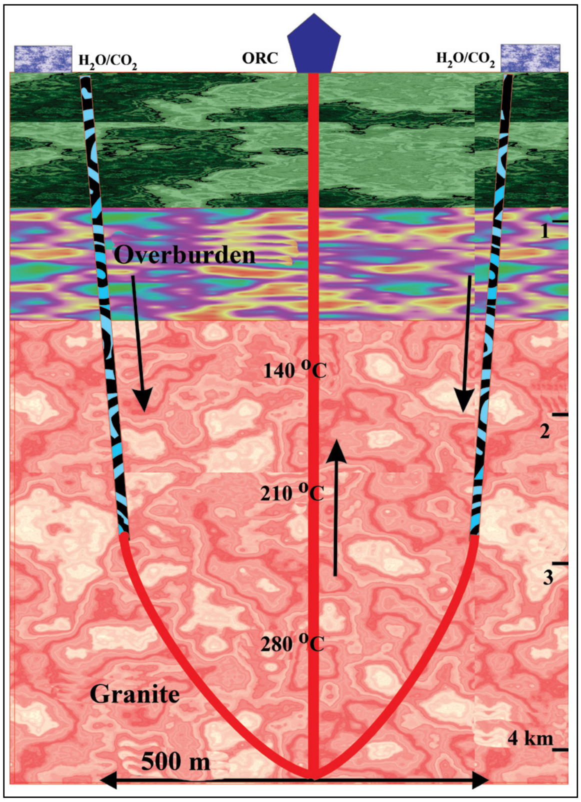

Figure 2- Schematic Closed loop Enhanced Geothermal System model used for THM modeling using COMSOL V6 described in the Section 2.6.

2.4. Power from High Radiogenic Granites of The Shield

The granites, with a cumulative outcrop area of 162000 km^2, spread over the western Arabian Shield, are very fertile rocks with radiogenic heat generating capacity of 5 to 134 µW/m^3 with high heat flow values (50 to 1382 mW/m^2) (Chandrasekharam et al., 2015). The Mydian granites, located in the NW part of the Shield (Figure 4) are the most fertile rocks with the highest heat generation capacity of 134 µW/m^3. Now that technology (closed loop EGS technology) to tap this energy is mature, all these high radiogenic granites (162000 km^2) along the western margin of Saudi Arabia can be utilized for power generation. Assuming about 2% of the heat energy is recovered for power generation from the entire volume of high radiogenic granites (1m thick), the amount of power that can be generated is around 256 x 10^9 kWh. Assuming daily per-capita electricity consumption of 2000 kWh, these granites alone can support 128 x 10^6 people (Chandrasekharam et al., 2015). Thus, as discussed above, the minimum energy that can be tapped from the Red Sea ridge flanks, hydrothermal sources in Jizan and Al Lith and the high radiogenic granites is about 340 TWh.

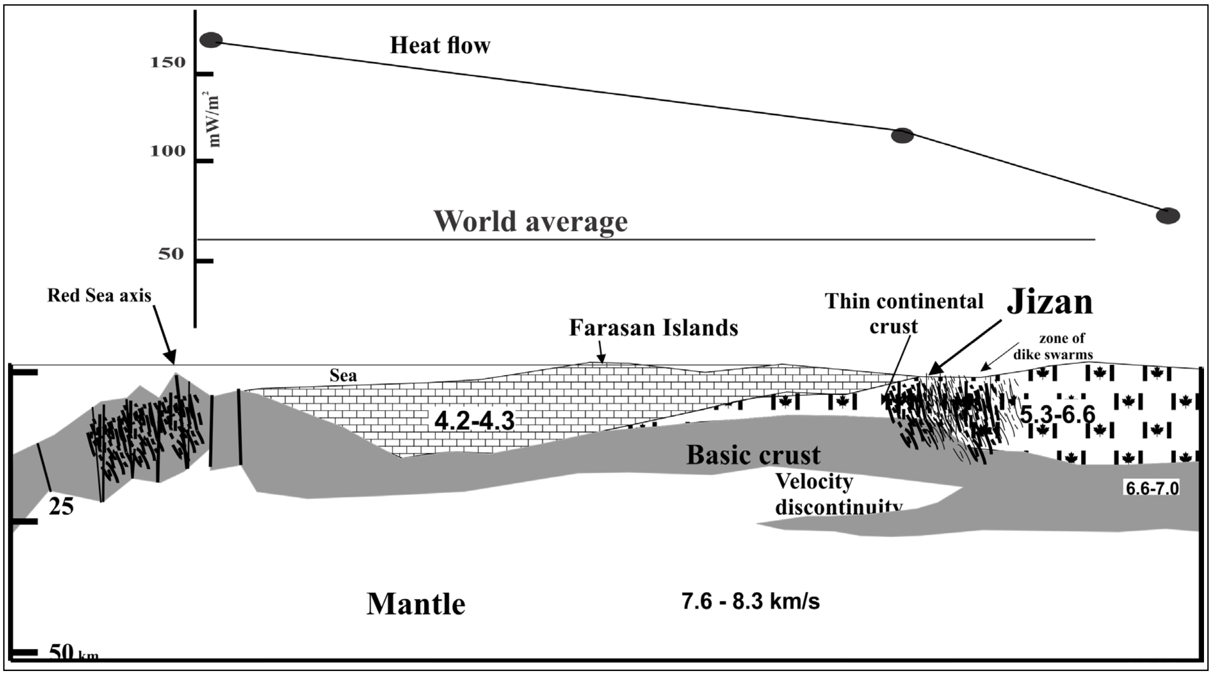

Figure 3- Heat flow and subsurface structure below Jizan, Western Saudi Arabia.

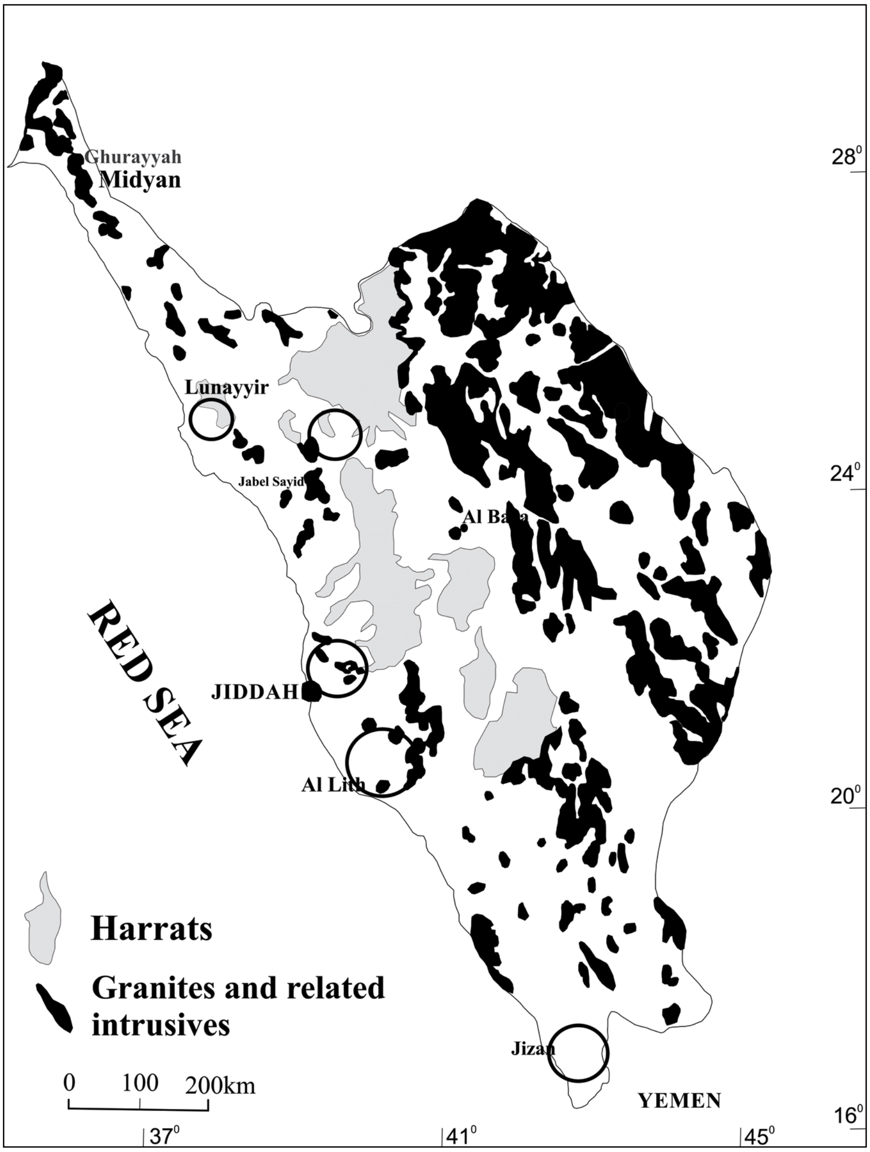

Figure 4- Western Saudi Arabian Shield showing the Harrats and high radiogenic granites.

2.5. Curie Isotherm of Red Sea and Western Arabian Shield

The curie depth isotherm is very shallow ~10 km over the ridge flanks, as anticipated, and below the Farasan islands, Jizan and Al Lith hydrothermal provinces. All along the coastal region, extending from Al Lith to Mydian, the Curie isotherm depth is below 30 km (Aboud et al., 2016). The Curie isotherm supports a shallow high-temperature regime over the entire eastern Red Sea margin and the western Shield region, including the Harrats.

2.6. Power from Türkiye Geothermal Provinces

Türkiye has hydrothermal as well as EGS sources. Currently, the hydrothermal sources in western Anatolia are generating 1680 MWe (Baba and Chandrasekharam, 2022). The high radiogenic granites spread over the entire country, with an outcrop area of 6910 km^2, recorded radioactive heat generation varying from 7 to 20 µW/m^3 and heat flow value > 100 mW/m^2 (Chandrasekharam et al., 2022). As an example, the power that can be generated from 3 such granites from Kestanbol, Hamit and Eskisehir regions is 716 x 10^6 kWh (Chandrasekharam and

Baba, 2021; Tolga et al., 2022; Chandrasekharam et al., 2022; Chandrasekharam, 2022). Thus 2% of the power (assuming that this is the minimum that can be extractable) that can be generated from the 6910 km^2 high radiogenic granites is of the order of 10900 x 10^6 kWh. Besides these granites, Türkiye has super-hot EGS provinces in Central and Eastern Anatolian regions where the critical temperature geothermal regime lies at a shallow depth (3 km) and magma chambers at a 5 km depth. COMSOL V6 three-dimensional thermo-hydro-mechanical (THM) model on one such supercritical province in Central Anatolia indicate that, adopting a closed loop extraction method (Figure 2), the temperature that can be obtained is around 275 °C from a production well, with an injection volume of water of 500 L/s (Chandrasekharam et al., 2023). This well-head temperature is very similar to some of the hydrothermal systems that are currently generating 53 MWe (Di Pippo, 2012; Miravallis, Costa Rica). About 15 such closed-loop supercritical EGS sites from the central and eastern Anatolia regions can supply a minimum of 750 MWe (~6 x 10^9 kWh).

2.7. Curie Isotherm of Türkiye

Among the countries that fall under the GPC, Türkiye occupies a unique place with its high thermal regime represented by a shallow Curie Isotherm at 6 to 20 km due to the presence of subduction zones, thin and fragmented continental crust, shallow Moho depth, presence of magma chambers at crustal levels and high heat flow from the mantle as well as from the high radiogenic granites discussed above. This region is the only continental segment where such a high thermal configuration is present. The geothermal potential of this country has not been exploited to the fullest extent (Chandrasekharam et al., 2023).

2.8. Jordan

Although geologically Jordan is the northward extension of the western Arabian shield, with its high radiogenic granites and harrats, there is no significant research carried out on the geothermal resources of this country (Figure 1). However, the regional Curie Isotherm lies at 5 km SE of Harrat Ash-Shaam. A critical temperature thermal regime is envisaged at about 3 km depth in this region. Based on THM modeling (using COMSOL V6) results obtained over a stratovolcano in Türkiye (Chandrasekharam et al., 2023), it is reasonable to assume minimum extractable power of about 150 MWe (~2 x 10^9 kWh, three wells with loop-technology).

3. Discussion and Conclusions

The geothermal energy available along the GPC (371 TWh) is a conservative estimation. This can be increased in future with new developments in drilling and heat extraction technologies. There are high heat flow sites (125 to 472 mW/m^2) in Jordan along 31°-30' N parallel, along the Wadi Zerqa fault zone. These unexplored sites may add an additional quantity of energy to the GPC in future. This energy (371 TWh) can be shared by the countries discussed here, depending on sustainable development and disaster mitigation programmes. Geothermal energy sources, irrespective of the natural hazards, will be able to provide an undisrupted supply of power with > 90% efficiency and for 95% of the year. The best way to utilize this energy is to get fresh water to support domestic and agricultural sectors. On an average, 5 kWh of electrical energy is required to get 1000 L of freshwater using desalination technology. GPC can generate about 75 x 10^{12} L of freshwater that can support about 5.87 billion people (current total population of Saudi Arabia, Jordan and Türkiye is 131 million) with a per-capita water consumption of 35 L/day (this is the global average per-capita consumption). The food-energy-water (FEW) benefits derived from this corridor can be utilized by other countries along this corridor that have poor FEW security.

Geothermal energy, with a very low carbon footprint, can benefit all the countries along this GPC with large carbon savings. The total amount of CO_2 emissions from Saudi Arabia (524 x 10^6 kg), Jordan (24 x 10^6 kg) and Türkiye (397 x 10^6 kg) are 945 x 10^6 kg. The amount that can be earned from carbon savings is about 92 million euros (carbon credit value: 97 euros /1000 kg, https://carboncredits.com/carbon-prices-today/26 Feb 2023). This amount can be utilized for augmenting the energy supply from the sources discussed above and can be utilized for making this corridor a green society with inclusive growth with self sufficiency in food and water. Once this GPC is fully established, it can integrate the entire landmass along this corridor into a green zone, a zone free from carbon emissions.

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