PROCEEDINGS, 44th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 11-13, 2019
SGP-TR-214

Electric Power Generation Potential Based on Waste Heat and Geothermal Resources in South Africa

B.M. Mahlalela[1] · Changwei Liu [1] · Kewen Li[1,2,*] Yuhao Zhu[1]

[1]China University of Geosciences (Beijing), China

[2]Stanford University, USA

Keywords: *Waste heat recovery, South Africa, Thermo-electric generator, geothermal energy, electricity generation*

ABSTRACT

Low to medium temperature geothermal resources widely exists in South Africa with a great potential for exploitation and utilization to generate electricity, but they remain untapped. On global scale, such resources have become one of major renewable energy resources for decades, but in South African they have been overshadowed by the usage of coal as a means of primary energy generation. However, due to energy crisis, the state has begun considering the potential of renewable resources as alternative and a possible long term energy supply. Geothermal energy is excluded partly due to convenient technology barrier and also lack of government support. To tackle this problem, we investigated the potential of geothermal energy using variety of available geologic data such as heat flow measurements, hot springs, and petroleum & mining exploration boreholes. Data shows that geothermal potential areas with good heat flow include the Namaquland, south and west of Upington; northern part of Kwazulu-Natal; thermal springs at Tshipise, Brandvlei, and Siloam hot spring in the Limpopo Province shown in figures on text.

On tapping these untapped heat resources, a thermoelectric generator (TEG) is proposed for geothermal power generation in this study. TEG technology is capable of converting heats into electricity directly with less or no mechanical work involved, and at a cheaper cost as compared to the traditional high-cost technologies, such as Steam Rankine Cycle (SRC), Organic Rankine Cycle (ORC) technology and etc. Moreover, economic appraisal of a Binary system proves not to be economic friendly than a TEG system because it cost high, making the TEG a better viable energy option for South Africa. With the generation of electric energy using TEG, not only does the waste heat provide heat source but also reduce carbon emission while improving the efficiency of TE based systems. Finally, after considering the nature of the resources in South Africa and the cost of the available heat recovery systems, we laid down a proposal for using Thermoelectric Generators (TEGs) as the suitable and convenient technology.

1. INTRODUCTION

In our increasingly connected world, energy consumption is emerging as a major area of both public and political concern worldwide. This may be due to the rapid rise of carbon emission witnessed by the globe over the past few decades which is caused by the excessive usage of fossil fuels energy. South Africa is no exception, and is amongst the top 10 producers of coal worldwide, and is a leading carbon emitter in Africa (DMR, 2015). The carbon emission status of the country could be linked with the country's development and the economy, because its economy is energy intensive and is heavily dependent on coal as primary energy source, and as well as a source of revenue for the country.

Up to date, about over 92 percentile (%) of the country's power generation is based on the indigenous production of coal, and this share exceeds the global average of 40% (DMR, 2015). This is unlikely to change significantly anytime soon owing to the relative lack of suitable alternatives to coal as energy source, and the continuous mounting pressure on the country's energy sector to meet the immediate and ever-increasing energy demand. Figure 1 below shows the pie chart in percentile of total primary energy supply and energy sources in South Africa.

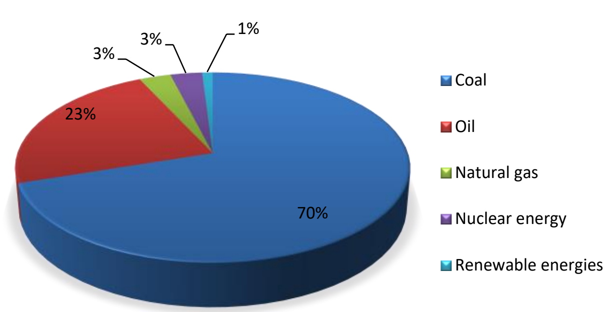

Figure 1: Primary energy supply in South Africa, Source: DMR, 2015

Continual dependence on coal is not good for the country, because coal possesses an adverse impact of climate change and carbon emissions. Besides environmental impacts, current energy supply capacity does not meet the required energy demand. Some parts of the country remain un-electrified, and even those electrified continue to experience severe load-shedding daily. Over recent years, the South African state began considering the potential of renewable resources as alternative and a possible long term energy supply. The renewable energy mix by the state includes technologies such as solar, hydro, biomass and wind. Geothermal energy is excluded in the energy mix due to lack of government support. Even with this energy mix, crisis of electricity supply in the country still remains a major problem because the added renewables are not reliable rather they work seasonal. To tackle this problem, this paper demonstrates that tapping existing geothermal and waste heat resources could be a solution to the country's energy crisis. Geothermal energy can benefit the country with sufficient clean and sustainable energy supply, and also promote low carbon economy because it is reliable and can work year round with no fluctuations over the seasons.

Table 1. The total number of electrified and non-electrified houses in South Africa

PROVINCE	PROJECTED HOUSEHOLDS (APRIL TO MARCH 2017)	HOUSES WITHOUT ELECTRICITY	HOUSES ELECTRIFIED	ACCESS PER PROVINCE
EASTERN CAPE	1,826,480	353,125	1,473,355	80.67%
FREE STATE	891,184	110,352	780,832	87.62%
GAUTENG	4,231,251	704,248	3,527,003	83.36%
KWAZULU NATAL	2,748,760	501,262	2,247,498	81.76%
MPUMALANGA	1,164,143	98,533	1,065,610	91.54%
NORTHERN CAPE	326,250	41,071	285,179	87.41%
LIMPOPO	1,534,999	50,689	1,484,310	96.70%
NORTH WEST	1,149,559	152,075	997,484	86.77%
WESTERN CAPE	1,768,694	160,547	1,608,147	90.92%
TOTAL	**15,641,320**	**2,171,902**	**13,469,418**	**86.11%**

Source: Department of energy, 2017

Variety low to medium temperature resources widely exist within South Africa with great potential for utilization to generate electricity, but they remain untapped or rather directly exhausted. Most of these sources are static, and can be recovered for electricity generation. It is imperative to evaluate the potential of geothermal resources and waste heat recovery to assist the country in formulating an efficient diversified energy mix with regard to meeting and securing future, cleaner, and sustainable energy supply with low carbon footprints. Using thermoelectric generators (TEGs), energy could be harnessed from both geothermal and waste heat sources and generates electricity which can significantly help shorten the gap of energy demands in the country. There are many various technologies available for harnessing energy from such heats in the commercial market including Organic Rankine Cycle (ORC), Steam Rankine Cycle (SRC) technology and so on. This paper is aimed at demonstrating the TEGs as suitable technology for the existing heat resources across South Africa.

2. ENERGY STATUS OF SOUTH AFRICA

From Table 1, it can be seen that millions of residential areas are still un-electrified, but even the electrified ones (including industrial places) continuously experience severe load-shedding, and this affect economic growth and industrial development in the country (DOE, 2017). In 2011, South Africa ran a Renewable Energy Independent Power Producer Programme (REIPPP), which resulted in 79 projects being commissioned, with 1,500 MW of the total of 5,200 MW added to the country's main grid (Forder, 2015). Currently, the country has set a target of about 17800 MW of renewable energy to be achieved by 2030 (DMR, 2015). Figures 2 and 3 show the status of total electricity consumption (190396GWh) versus the total electricity demand (31928 MW) per sector in the country.

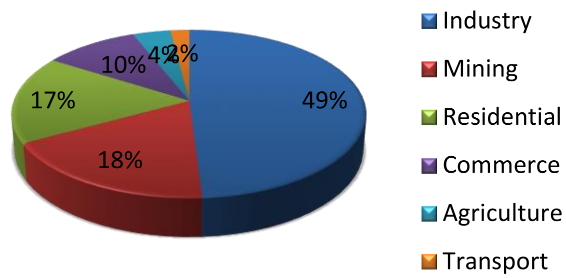

Figure 2: Electricity consumption per sector in SA. (Source: www.eskomidm.co.za, 2017)

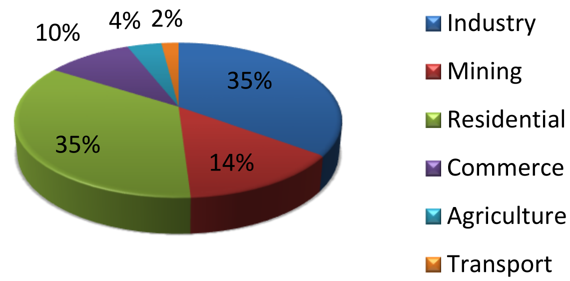

Figure 3: Electricity demand per sector in SA. (Source: www.eskomidm.co.za, 2017)

Given the country's energy status, it is unlikely that its 2030 goal (reflected in figure 4) and its commitment to low carbon economy will be achieved. Figures 4(a) and 4(b) show the country's integrated resources plan (IRP) for electricity to be achieved in 2030. This is not sufficient enough because most of the proposed renewables are not reliant; rather they work seasonal since they depend on external natural factors such as wind or sun and etc.

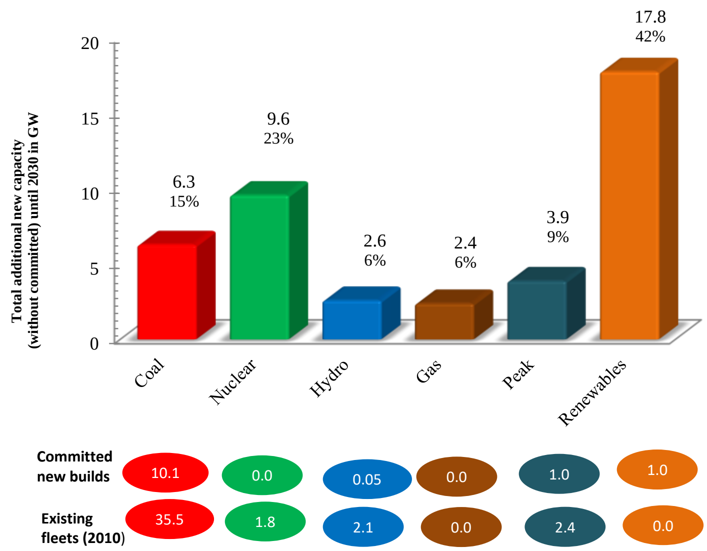

Figure 4(a): South Africa's integrated resources plan (IRP) for electricity (Source: IRP, 2010).

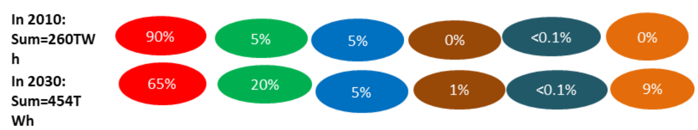

Figure 4(b): Indicating the energy share of South Africa (Source: IRP, 2010).

According to the U.S. Energy Information Administration's (EIA) latest International Energy Outlook 2017 (IEO2017) project, the world energy consumption will grow by 28% between 2015 and 2040 (EIA, 2017). Renewables are expected to be the fastest-growing energy source, with consumption increasing by an average 2.3% per year between 2015 and 2040 (EIA, 2017). This is more than convincing that renewables are the future and many countries such as China, the US, New Zealand, Ice Land, Turkey and etc. are committed to achieving this goal. These countries focus more on geothermal energy because of its long term reliant. In this regard it is clear that South Africa, given its coal dependence energy profile, should add geothermal into its energy mix to lower energy crisis and achieve the 2030 goal.

Tapping heat resources could be a better alternative solution for long term energy supply in the country and the potential is huge. There is currently no large-scale geothermal production in South Africa, but there are numerous known and numerous anonymous hotter regions with thinner crust, vast amounts of heat-producing igneous rocks and numerous natural hot springs existing across the country (Chevallier et al. 2014). The barrier in South Africa has been the lack of government support and finding the suitable economic technology.

Furthermore, South Africa as a developing country is dominated by industries which consume more than half of the total energy generated in the country. In those industries huge amount of energy is lost or directly exhausted in a form of waste heat during operation processes. Most of these heat sources are static such as: industries, residential，Automobiles and etc. To date, many heat recovery systems are available, but their application is limited by temperature and profitability.

3. EXISTING TECHNOLOGIES FOR RECOVERING GEOTHERMAL AND WASTE HEAT RESOURCES

For long time economics has often limited the feasibility of low temperature resources. But with the daily advancement of technology, there are now various technologies in the commercial market, and there are various applications where low grade waste heat has been cost effectively recovered for use in some industrial facilities. For example, one integrated steel mill in Japan successfully installed a power generation plant with a 3.5 MW capacity using cooling water at only 208° F (98° C) (IEA, 2002). Heat recovery technologies involve traditional systems and the newly well-developed technologies which generate electricity directly from the heat source. Table 1 summarizes the available different power generation technologies. Steam Rankine Cycle (SRC), Organic Rankine Cycle (ORC) and Kalina Cycle (KC) are amongst the first traditional generation recovery systems which involve the mechanical work of using the heat for steam or liquids to turn the turbine to generate electric power (Duffy, 2005). Thermoelectric Generation (TEG), Piezoelectric Power

Generation (PEPG), Thermionic Generation and Thermo Photo Voltaic (TPV) Generator are amongst the newly well-developed technologies which can generate electricity directly from heat, with less or no mechanical work involved.

The traditional systems are hardly preferred because they cost high compared to the modern systems. Although the modern systems cost less than the traditional systems, but there are still some challenges which result in limitations of their applications. TEG is widely preferred because of its advancement, simplicity, and is advantageous because is applicable in both small and larger scale heat resources of different temperatures ranging from low to medium to high degrees Celsius. TEG can easily capture heat at lower cost compared with the traditional high cost systems. Most importantly, TEGs can work year round while its rival technologies such as Solar, wind, Thermo Photo Voltaic (TPV) Generator work seasonal because they depend on external factors such as wind or sun and etc. This means electricity generated by TEGs will not have load shedding once accessed from the main supplying grid.

Table 2: Options for heat recovery via power generation

Thermal Conversion Technology	**Temperature Range**	**Possible Typical Sources of Waste Heat**
Traditional Steam Cycle	Medium ,High	Exhaust from gas turbines, reciprocating engines, incinerators, and furnaces.
Kalina Cycle	Low, Medium	Gas turbine exhaust, boiler exhaust, cement kilns
Organic Rankine Cycle	Low, Medium	Gas turbine exhaust, boiler exhaust, heated water, cement kilns
Thermoelectric Generation	Low-Medium - High	Demonstrated in Automobiles
Piezoelectric generation	Low	Not yet demonstrated in industrial applications
Thermal Photovoltaic	Medium - High	Not yet demonstrated in industrial applications

Source: U.S. Energy Information Administration, International Energy Outlook

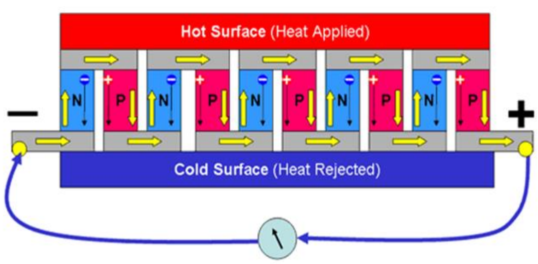

Figure 5. Thermoelectric Generator with five coupled devices.

3.1 Why is TEG a suitable method over the other recovery methods?

TEG materials are semiconductor solids that allow direct generation of power when subject to a temperature differential based on a phenomenon known as the Seebeck effect; figure 5 and 6 (Riat and MaX, 2003). Seebeck effect phenomenon (Figure 6) states that when two different semiconductor materials are subject to a heat source and heat sink, a voltage is created between the two semiconductors. Consider for example, the exhaust gas temperature at the exhaust manifold can easily exceed 1400 degrees F making it more than possible to use TEGs in cars (Duffy, 2005). TEGs are applicable to both small scale (fields of low power electronics milli-watts) and larger scale (fields of Kilo watts or megawatts). TEGs are unique because of their: solid state construction, no moving part and no vibration; available 24 hours a day; No noise and low maintenance; convenient power supply; Stabilize power supply; Stabilize temperature of devices; increase operation life under all environment; free greenhouse gases; performance output highly scalable; portable power; less weight, and with its fast development it will lead to interesting applications in the future.

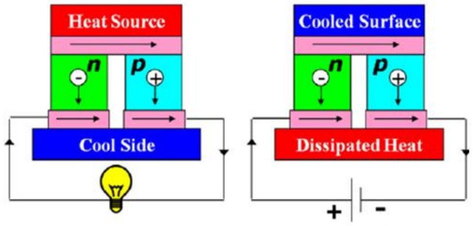

Figure 6. A schematic showing the principle of Seebeck (left) and Peltier effects (Right).

On the other hand, most heat recovery systems such as Organic Rankine cycle (ORC) and piezoelectric generators can convert converts low grade heat source to electricity but factors such as high investment cost, larger equipment weight and increased complexity during manufacturing limits their applications. Other systems such as Binary Rankine Cycle (BRC) works well in recovering high temperature heat and become ineffective for low temperature heat. BRC which is currently the most used system to harness energy from geothermal resources suffers from serious drawbacks, one being high maintenance and minimum temperature of above 450K. TEGs can produce electricity at low temperature as 350K with low maintenance.

3.2 TEG Application

In waste heat recovery from industrial, the TEG can produce electricity reliably and with minimal maintenance (including in remote areas), and just recently, the advancement in the modern thin layer and nano-scale manufacturing technologies have enabled to achieve efficiencies of greater than 15% for thermoelectric materials. This means conventional power producing techniques could be replaced with more efficient, reliable and economical TE power generators. Another benefit of TEG is that they are environmental friendly and can produce electricity day and night unlike the solar cells. Further to that, for the industrial waste heat recovery, high temperature discharges is mostly above 5000F are used to run steam turbines, and TEG of discharge temperature above 5000F is indeed suitable and gives 10 to 15% efficiency.

Lastly, the TEG can be employed in both concentrated and non-concentrated systems. A recent update on advances confirmed that the TEGs are more efficient than photovoltaic cells, and can be used for as an alternative to photovoltaic cells for heat recovery from solar energy sources. Solar thermoelectric generators (STEG) are new promising alternatives to largely used photovoltaic solar cells. STEG simple combines a solar thermal collector with a thermoelectric generator, and STEG is more beneficial when used with concentrated solar intensity; it is 50 times more efficient than non-concentrated type and helps in shrinking the size of cell reducing external heat losses (Mohak, 2014). As an example, Dent and cobble (1982) built a prototype STEG comprising a sun tracking heliostat which directs the incident sunlight to a parabolic mirror which indeed finally concentrates it on STEG, while using PbTe as thermoelectric material they were able to achieve an efficiency of 0.63% at one sun and 3.35% at 50 suns.

4. GEOTHERMAL PROSPECTIVE IN SOUTH AFRICA

Not much has been done on geothermal but known Hot Dry Rocks (HRD) and hot springs distributed across the country have been recorded. Temperature in these resources ranges between low to medium grade and is good enough for energy generation using TEGs. According to the known information, descriptions of these resources and their potential are shown in figures in this section.

4.1 Heat flow system in South Africa

Temperature is a very important factor in harnessing geothermal energy. Heat flow measurements elaborate the exact temperatures below the surface and could identify the shallowest potential regions (Jones, 1992). The average heat flow for the Earth is 70 mW/m^2 corresponding to a gradient of 2.5 – 3 °C/100 m (Dhansay et al., 2014 and Schmitz, 2004). A heat flow above average is usually the main indicator of possible geothermal source at depth. Figure 7 is map showing South Africa's heat flow measurements. From the map, it can be seen that regions like Namaqualand, south and west of Upington show heat flow values of above the Earth average. These heat flow values suggest much higher potential for geothermal energy (Carte and Van Rooyen, 1969). According to Andreoli et *al.* investigation, those signatures in the Namaqua-Natal and Limpopo Belts (figure 7) highlight regions with high concentrations of U and Th (and K), such as in the Proterozoic granites which are good sources of heat (Jones, 1992).

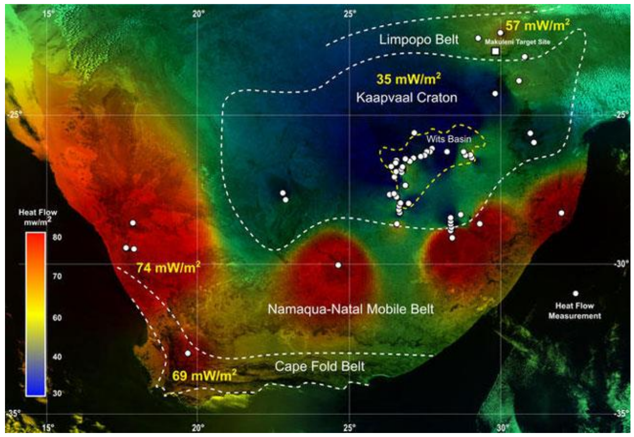

Figure 7: Geothermal energy potential map of South Africa (after Dhansay et al., 2014).

Figure 8 is a supplement to the heat flow measurement according to Jones (1992), and it also confirms that possible geothermal sites are on the Namaqua-Natal belt and Lesotho. Thus observation on both figure 7 and 8 confirms higher potential for geothermal energy, and the suitable technology could be TEG because these are low temperature resources.

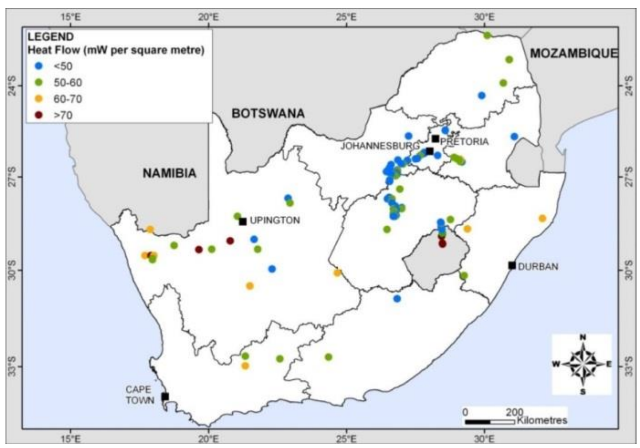

Figure 8: Heat flows measurements in South Africa (after Jones 1992). Heat flows above average of 70 mW/m2 are found in Namaqualand and Lesotho (Chevallier et al. 2014 using heat flow data from Jones, 1992).

4.2 Potential geothermal hot dry rocks in South Africa

Hot dry rocks are the radioactive granites with high concentrations of U and Th (and K), and found in south of Upington and Namaqualand region and in the young tectonic basin located northern part of Kwazulu-Natal figure 9 (Jones, 1987, 1988). Temperatures of about 100°C to 150°C at depths of 3000 to 5000 m can be measured in these areas (Chevalier et al., 2014). Other studies also confirmed that the deep fractured aquifers in Limpopo belt and Cape folded belt (figure 7 and 9) have temperatures of about 60° to 80°C at depths of 1000 to 2000 m (Chevalier et al., 2014). Heat flow and radioactivity investigation is still needed in South Africa, but the current identified HDR regions represent a large volume of rocks with higher potential for geothermal energy.

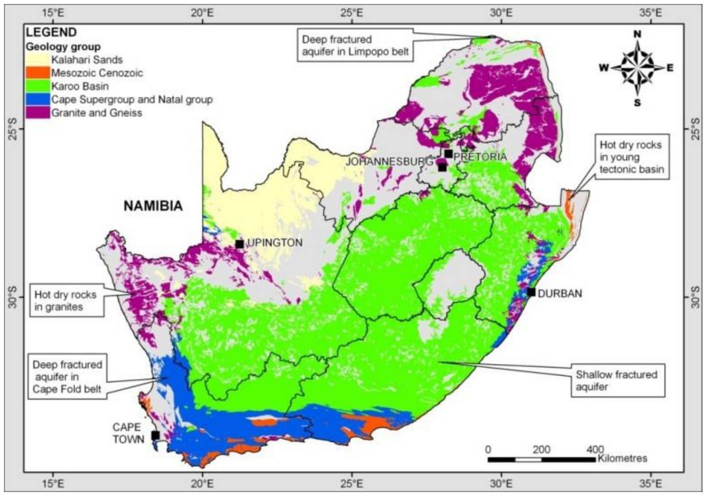

Figure 9: Geothermal resources of South Africa and their associated geological systems divided into hot dry rocks and hydrothermal fractured aquifers (Chevallier et al. 2014).

4.3 Hydrothermal systems and hot springs in South Africa

South Africa is natural blessed with numerous hot springs and some of them have surface temperatures of more than 50°C. Hot surface temperature is a good indicator of deep water circulation and active hydrothermal systems linked to specific geological structure. Figure 10 shows hot springs with their surface temperatures across South Africa. These temperatures were recorded on surface, no drilling has been done. This means that when drilling is done at depth of few meters, high temperatures of great potential could be reached.

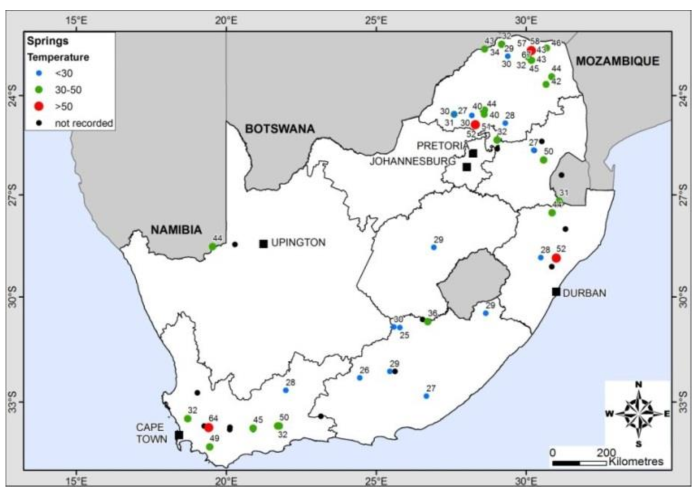

Figure 10: Hot springs of South Africa. Very hot springs (above 50°C) are found in the Limpopo Province in the North of the country (Tshipise – Sagole – Siloam group between 45° and 60°C) and in the Western Cape Province in the South West (Brandvlei, 64°C) (after Chevallier et al. 2014).

4.4 Geothermal Potential by TEG

Considering the temperatures of the Heat Flow Measurement, Hot Springs, and Hot Dry Rocks (HDR) presented in figure 7, 8, 9 and 10, it is evident enough that geothermal resources exist in South Africa and the potential is great for producing geothermal electricity. Typically, a geothermal project cannot produce electricity economically at a scale less than 5 MW and there is a very large economy of scale for projects above 30 MW in size. TEG technologies, however, have the potential to produce geothermal electricity without the complex infrastructure such as turbines, steam piping, etc., thus making small scale production and geothermal-source micro power grids both practicable and affordable. Although their efficiency is not as higher like fossil fuel energy, but considering reuse of waste energy gain, and the development of untapped and localized geothermal resources, their efficiency cannot be ignored. Small (<5 MW) geothermal projects could provide consumers with the same distributed power flexibility provided by solar and wind production with the additional benefit of being a more reliable base load source of electricity that runs year round.

5. WASTE HEAT RECOVERY PROSPECTIVE IN SOUTH AFRICA

Much energy is lost in a form of waste heat in industries, vehicles, and households. Recovering all waste heats and add them back to the primary supplier or main grid in a form of energy cannot only increase the efficiency but can also reducing carbon emission. Waste heats exist in smaller scale to larger scale in South Africa, and most traditional heat recovery systems such as ORC, BRC, cannot be used because their installations cost high and they need large power plants and large scale infrastructure for economic production. But TEG technologies may be suitable because they are intact, flexible and portable, thus making small scale production and scattered waste heat-source micro power grids both practicable and affordable without any need of larger and costly infrastructures.

5.1 Available sources of waste heat

Sources of waste heat vary in temperatures from low to high temperatures. Figure 11 shows statistic of total energy loss versus energy used by industries, vehicles and households. Of the total primary energy, about 34% is purposefully used and about 66% is lost as waste heat. TEGs have the potential to retrieve and produce electricity from waste heats as input source, and allow the efficient use of energy. Even though their efficiency is about 5–10%, but considering reuse of waste energy gain, their efficiency cannot be ignored.

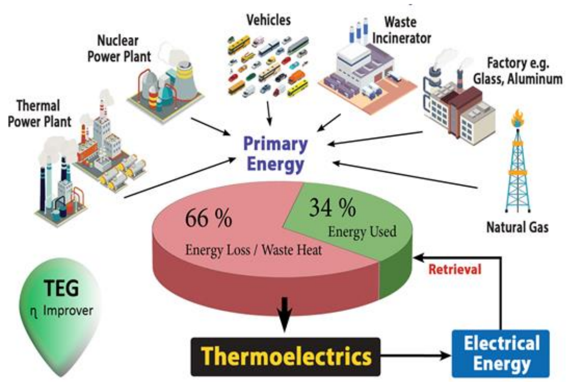

Figure 11. Energy statistics: Thermoelectric Generators (Waste heat to electricity)

As for automobiles, various leading automobiles manufactures such as: Volvo, Volkswagen, BMW, and Ford are designing WHRS in order to improve the economy of fuel of automobiles with approximately 1 kW generation through TEGs. Almost 25–40% of energy recovery is possible from exhaust manifold through TEGs of ZT (1.25) and efficiency of 10% at average temperature of 250 °C (Yu and Chau, 2009). Transport energy consumption "Nelson Mandela Bay, South Africa", a study conducted in the Nelson Mandela Bay, a metropolitan city in South Africa about estimating car owner ship and transport energy consumption per vehicle (Ntholi, 2017). The investigation finds that in the entire diesel vehicle, 40% of the diesel fuel is lost through exhaust as waste heat. Similarly in the entire Petrol vehicles, about 40% of the petrol fuel is lost through the exhaust as waste heat. Taking the latest data on fuel consumption on Table 3, we can calculate how much total energy is transferred into waste heat per year in south Africa on both the diesel and the Petrol vehicles in liters.

Table 3. The total fuel consumptions from January to December 2017

2017-January to December South Africa Fuel Sales Volume / Consumptions					
Volume in Liters (L)					
Product Name	**Q1- Jan to March**	**Q2- April to June**	**Q3- July to Sept**	**Q4- Oct to Dec**	**Grand Total**
Diesel	2,782,952,746	3,023,438,016	3,220,953,364	3,119,901,042	**12,147,245,167**
Petrol	2,686,527,020	2,710,516,136	2,855,821,909	2,921,217,916	**11,174,082,980**
Jet Fuel	653,042,311	786,614,087	648,534,599	624,471,672	**2,712,662,668**
Paraffin	138,160,260	169,147,992	185,851,085	155,148,953	**648,308,291**
Furnace Oil	152,200,647	143,788,538	130,905,486	96,243,356	**523,138,028**
LPG	132,351,984	119,216,514	156,451,341	143,295,673	**551,315,512**
Aviation Gasoline	3,707,605	3,817,383	3,222,185	3,013,875	**13,761,048**
Grand Total	**6,548,942,573**	**6,956,538,665**	**7,201,739,970**	**7,063,292,487**	**27,770,513,694**

Source: Department of energy

Thus:

Diesel (lost) = 12,147,245,167 liters * (40 /100)

= 4 858 898 066.8 liters

Petrol (lost) = 11,174,082,980 liters * (40/100)

= 4 469 633 192 liters

Note: *Lost means lost as waste heat*

From the calculation we can see that 40% of the diesel which is lost as waste heat is about **4 858 898 066.8 liters,** and 40% of the Petrol lost is about **4 469 633 192 liters.**

From both fuels there is a huge loss of energy considering the fact that South Africa imports almost all of its liquid fuels, and that is too cost for the country and for the economy. Prototype of TEG has already been tested successful on vehicles in Europe.

This is one example that demonstrates the ability of TEG. Another case study conducted by Zeb et al. on power analysis of "Officer Colony, Abbottabad, in Pakistan" regarding waste heat recovery (WHR) find that, the colony is consisted of 30 homes, 150 room gas heater, 70 cooking stoves, and 50 gas geyser. The study concluded that by measuring the temperature available at various WH appliances almost 1300 °C temperature is available per home on average. So by applying the TEG on this area, more energy could be harvested on those waste heats at the colony area.

6. APPLICATION OF THERMOELECTRIC GENERATOR (TEG).

As mentioned above, thermoelectric generator applications can be subdivided by the direction of energy conversion. The Peltier effect which is used within thermoelectric cooling devices, and the Seebeck effect which is responsible for the conversion of temperature gradients to an electrical voltage (Riat and MaX, 2003). Thermoelectric power generators consist of three major components: thermoelectric materials, thermoelectric modules and thermoelectric systems that interface with the heat source (Afshar et al., 2012). The TE junction consists of p and n type materials based on figure of merit (FOM) (Figure 5) (Sprouse and Depcik, 2013). The auxiliary of TE array consist of heat sink that absorb heat from hot side and dissipate heat related to cold side. A single TE module generates power in range of 1–125 W and modularly arrangement enhances power up to approximately 5 kW (Zeb et al, 2016). The qualities of TEG are beneficial in a series of remote applications, and under extreme conditions new applications have even been enabled.

7 ECONOMICS OF GEOTHERMAL POWER GENERATION PLANT

7.1 Economic Appraisal of Geothermal Power Generation

The economical appraisal of possible geothermal power generation plant using TEG was conducted and compared with a previous geothermal Binary system power generation plant in South Africa. The basic data are cited from Binary cycle geothermal plant project conducted in South Africa by Tshibalo 2011. Another important factor to consider in the research and development of a new technology is the potential cost of manufacture. Since geothermal energy development in South Africa is a relatively new field, a thorough cost analysis is required to determine any viability. Dhansay, 2013 considered a hypothetical enhanced geothermal systems energy plant in the Soutpansberg, within the Makuleni Village.

This village falls within the region of the Siloam hot springs and forms an ideal area for considering the development of geothermal energy. The hypothetical energy plant is exposed to a stringent economic model. This model considers various parameters including the geology, engineering and financial aspects to determine the unit cost of energy produced. This model considered a 75 MW plant with a lifespan of up to 30 years. A maximum depth of 6 km and reservoir size of 1000 m3 are assumed. Production will occur under a flow pressure of 100 Pa and flow rate of 50 l/s. Economic factors are in line with South African tax and inflation rates. Readers seeking further information on other factors considered within the model are referred to Dhansay et al., 2013.

7.2 Results of the Economic Appraisal Model

The model has established that the LCOE of geothermal energy development in the Soutpansberg, Limpopo would be 14 USDc/KWh. Figure12 shows that this LCOE is the highest of all renewable energy sources, second only to solar photovoltaic energy.

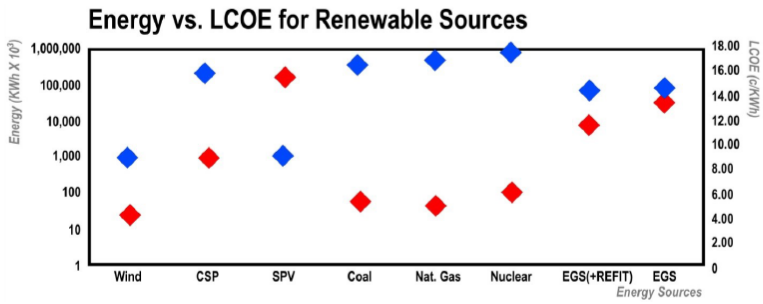

Figure12: Results of the LCOE as calculated within this model; against the LCOE of other renewable energy sources, where the blue points represent the total energy capacity, while the red dots express the LCOE. T Dhansay, 2014

Furthermore, when a REFIT of 250 USD/MWh is added to the model calculation, it results in the LCOE decrease to 12 USDc/KWh. The addition of this REFIT makes it more comparable with other similar geothermal energy plants in Australia and France. One reason for this relatively high LCOE is because of very conservative data estimations used where information was unavailable, i.e. precise fracture network directions and geothermal gradients. Herein the model has to consider parameters that are not ideal, but probable to ensure that the results are not falsely promising. The LCOE is most affected by the initial drilling depth and amount of hydraulic fracturing required on attaining an adequately porous fracture network. The LCOE model result considers a maximum drilling depth and corresponding hydraulic fracturing regime of 6 km. In the event that the heat flow and heat productivity is much higher than estimated, a shallower drilling depth and hydraulic fracturing regime may be implemented, and this could markedly lower the LCOE.

7. 3 Discussion of the economic model

The results of this study indicate that geothermal energy is a possible alternative, renewable energy source in South Africa, with a LCOE of 14 USc/KWh. However, this is a costly alternative to the current coal-generated electricity, almost a double LCOE. Point to note is that this LCOE was done for a Binary cycle geothermal system, which cost higher than TEG system. This means that a TEG system could be a better viable option because it has no or less mechanical work involved, thus cutting the cost to the lowest. Factors to consider here are: firstly, coal is a scarce commodity that has been estimated to run under critical values by 2017. A study done by LeBlanc et al, on material and manufacturing cost considerations for thermo-electrics showed that new thermo-electrics cost which incorporates material properties, device physics, material costs, manufacturing costs, and system costs could be achieved at lower cost than the stipulated one on the binary system, thus further confirms the viability of TEG. In addition, the continuous exploitation of coal has resulted in South Africa becoming the leading carbon emissive nation in Africa, and one of the leading rates of emission nations in the world. South Africa will therefore require strict measures to decrease carbon emissions and avoid UNFCCC financial penalties.

The South African government has already started this with the introduction of the carbon tax, a tax aimed at big industry to decrease their CO2 emissions. The model has established that the hypothetical geothermal energy plant has the potential to decrease at least 1.5 g/CO2 per MWh. However, the cost remains an issue and will need to be addressed. Here the government will need to incorporate a REFIT scheme to make it a more viable energy option. Development of this technology in South Africa will rely heavily on further analyses and accurate geological and engineering data acquisition. This could make the model more precise and attain very specific parameters for development.

8. CONCLUSIONS AND FUTURE PROSPECTS

In conclusion, not much has been done on geothermal in South Africa; the information presented here is based on a very limited available geological data. Overall the data shows that some regions in South Africa have high potential for geothermal energy potential for low to medium temperatures. As for high temperature energy, more investigation on flow heat is still needed. High geothermal Potential areas with good heat flow include the Namaquland, south and west of Upington; northern part of Kwazulu-Natal; thermal springs at Tshipise, Brandvlei, and Siloam hot spring in the Limpopo Province shown in the figures above.

Considerable amount of electrical power can be generated by a thermoelectric module when temperature difference is maintained between two terminals. Thus TEG systems are regarded as viable energy option because they are cheap, flexible, environmental friendly and applicable in small scales and larger scales. With the generation of electric energy using TEG, not only does the waste heat provide heat source but also reduce carbon emission while improving the efficiency of TE based systems. Economic appraisal shows that Binary system will cost 12 USDc/KWh, but the TEG will cost lesser than this amount because there is no larger and costly infrastructures needed for TEG system, this further confirms that a TEG system will be good for the thermal resources in South Africa. It should be noted that although the potential is there, but more and clear information is still needed and investment is highly needed.

REFERENCES

Andreoli M, Hart R, Ashwal L, Coetzee H. Correlations between U, Th and metamorphic grade in the western Namaqualand Belt, South Africa, with implications for radioactive heating of the crust. J Petrol. 2006; 47(6):1095–1118. http://dx.doi.org/10.1093/petrology/egl004.

Afshar O, Saidur R, Hasanuzzaman M, Jameel M. A review of thermodynamics and heat transfer in solar refrigeration system. Renew Sustain Energy Rev 2012;16:5639–48.

Carrasco JM, Franquelo LG, Bialasiewicz JT, Galvan E, Portillo-Guisado RC, Prats MAM, Leon JI, Moreno-Alfonso N. Power-electronic systems for the grid integration of renewable energy sources: a survey. IEEE Trans Ind Electron 2006;53(4):1002–16.

Chevallier, L., Musekiwa, C. and Dhansay, T.: Geothermal energy potential in South Africa (Geological and socio-economical investigation). Progress report of the annual technical programme 2014. Council for Geoscience (CGS) open report: 2014-0128 (2014).

Carte AE, Van Rooyen AI. Further measurements of heat flow in South Africa. Geol Soc S Afr. Special Publication. 1969;2:445–448.

Department of Water Affairs, Republic of South Africa. Ground WaterResource Information Project [homepage on the Internet]. No date [update2002 Apr 01; cited 2014 Mar 03]. Available from: http://griplimpopo.co.za/.

Dent C. L. and Cobble M. H., “Proceedings of the 4th international conference on thermoelectric energy conversion”, p. 75-78, IEEE, 1982.

Department of Minerals and Energy, Republic of South Africa. White Paper on Renewable Energy, November 2003 [document on the Internet]. c2003[cited 2014 Mar 03]. Available from: http://unfccc.int/files/meetings/seminar/application/pdf/sem_sup1_south_africa.pdf.

Department of Mineral Resources (DMR) (2015) South Africa’s Mineral Industry 2013/2014. DMR,Pretoria.

Duffy, D., Better Cogeneration through Chemistry: the Organic Rankine Cycle, Distributed Energy, November/ December 2005, SOWA and Distributed Energy

Dhansay T, De Wit M, Patt A. An evaluation for harnessing low-enthalpy geothermal energy in theLimpopoProvince,SouthAfrica.SAfrJSci.2014;110(3/4),Art.#20130282,10pages.http://dx.doi.org/10.1590/sajs.2014/20130282.

Dhansay T, Brandl G, De Wit MJ. Fractal geometry of the fault network across the Soutpansberg Mountains,Limpopo,SouthAfrica.SAfrJGeol.2016;119(1):235242.http://dx.doi.org/10.2113/gssajg.119.1.235.

Forder, Stephen (2015) REIPPP window 4 preferred bidders. http://energy.org.za/reipppp/175-reipppwindow-4-preferred-bidders accessed on 22 Jul. 15.

Huenges E, Ledru P. Geothermal energy systems: Exploration, development, and utilization. Hoboken, NJ: John Wiley & Sons; 2011. http://dx.doi.org/10.1002/9783527630479.

International Energy Agency, CADDET, A Power Generating System by Low temperature Waste Heat Recovery, http://lib.kier.re.kr/caddet/ee/R435.pdf, September 2002

Jones MQ. Heat flow in the Witwatersrand Basin and environs and its significance for the South African shield geotherm and lithosphere thickness. J Geophys Res-Sol Ea. 1988;93(B4):3243–3260. http://dx.doi.org/10.1029/jb093ib04p03243.

Jones MQ. Heat flow and heat production in the Namaqua mobile belt, South Africa. J Geophys Res-Sol Ea. 1987;92(B7):6273–6289. http://dx.doi.org/10.1029/jb092ib07p06273.

Jones MQ. Heat flow anomaly in Lesotho: Implications for the southern boundary of the Kaapvaal craton. Geophys Res Lett. 1992;19(20):2031–2034. http://dx.doi.org/10.1029/92gl02207.

Jones MQW. Heat flow in South Africa. Pretoria: Department of Mineral and Energy Affairs; 1992.

Krige LJ. Borehole temperatures in the Transvaal and Orange Free State. Proc Roy Soc Lond A. 1939;173(955):450–474. http://dx.doi.org/10.1098/rspa.1939.0158.

Ntholi T. A technical and economic evaluation of a Passive Underground Mine-water Purification System (PUMPS): A geothermally powered geoengineering system designed for in-situ bio-remediation of acid mine water [PhD thesis]. Port Elizabeth: Nelson Mandela Metropolitan University; 2017.

Mohak Gupta :Review on Heat Recovery Unit with Thermoelectric Generators,2014

Riffat SB. MaX. Thermoelectrics: a review of present and potential applications. Appl Therm Eng 2003;23:913–35.

South Africa Department of Energy. (2011). Integrated resource plan for electricity 2010–2030,

www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf

Schmitz MD, Bowring SA, De Wit MJ, Gartz V. Subduction and terrane collision stabilize the western Kaapvaal craton tectosphere 2.9 billion years ago. Earth Planet Sci Lett. 2004;222(2):363-376. http://dx.doi.org/10.1016/s0012-821x(04)00220-1.

South African Department of Energy. Annual report 2015/16. Pretoria: Department of Energy; 2016. Available from: http://www.energy.gov.za/files/Annual%20Reports/DoE-Annual-Report-2015-16.pdf.

Sprouse C, Depcik C. Review of organic Rankine cycles for internal combustion engine exhaust waste heat recovery. Appl Therm Eng 2013;51:711–22.

Schmitz MD, Bowring SA, De Wit MJ, Gartz V. Subduction and terrane collision stabilize the western Kaapvaal craton tectosphere 2.9 billion years ago. Earth Planet Sci Lett. 2004;222(2):363-376. http://dx.doi.org/10.1016/s0012-821x(04)00220-1.

LeBlanc S, Shannon K, Matthew L, Chris D, Kenneth E, RenewableandSustainableEnergyReviews32(2014)313–327.

Yu C, Chau KT. Thermoelectric automotive waste heat energy recovery using maximum power point tracking. Energy Convers Manag 2009;50:1506–12.

Zeb K, S.M. Ali, B. Khan,*, C.A. Mehmood, N. Tareen, W. Din, U. Farid, A. Haider: A survey on waste heat recovery: Electric power generation and potential prospects within Pakistan;2016