Geothermal Energy Policy Brief

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Author and Primary Contact
Eugéne Joubert
ecjoubert@sun.ac.za
+27 (0)21 808 4041

CENTRE FOR RENEWABLE AND SUSTAINABLE ENERGY STUDIES

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

Summary:

In this policy brief geothermal energy is introduced as the energy available in naturally occurring heat in the earth's crust that can be harnessed to produce electricity or directly heating and cooling. Geothermal power plants usually require shallow hydrothermal resources associated with volcanic activity but with enhanced geothermal systems the energy can also be extracted from hot dry rock. Another application of geothermal energy is ground-sourced heat pumps that make use of the relatively constant temperatures in the earth for heating and cooling purposes.

Due to the lack of shallow volcanic activity in South Africa traditional geothermal power production is not feasible. Even, through enhanced geothermal systems do show promise to extract heat from dry rock in some areas of South Africa, this technology is still under development, relatively expensive and with some drawbacks such as the related seismic activity. Ground-sourced heat pumps, on the other hand, have a high potential in South Africa since it can be applied almost anywhere and has significantly higher efficiency than other heating and cooling systems.

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Nomenclature:

ASHP	Air source heat pump
COP	Coefficient of performance
EGS	Enhanced (or engineered) geothermal systems
GHG	Greenhouse gas
GHP	Geothermal heat pumps
GSHP	Ground source heat pumps
LCA	Life cycle assessment
LCOE	Levelized cost of energy
LCOH	Levelized cost of heat

1. Introduction to Geothermal Energy

Geothermal energy refers to making use of higher or lower temperatures in the earth's crust to meet energy needs for various processes. The heat in the earth originates predominantly from radiogenic heat due to radioactive decay of material deep within the mantle and crust as well as primordial heat retained since the original formation of the planet. The Earth's crust acts as an insulating barrier for the heat within. This heat is brought closer to the surface through volcanic activities mainly around tectonic plate boundaries (see Figure 1) creating what is often referred to as "hot spots". The flow of heat to the surface is estimated to be in the order of 44.2 terawatts (Pollack et al., 1993).

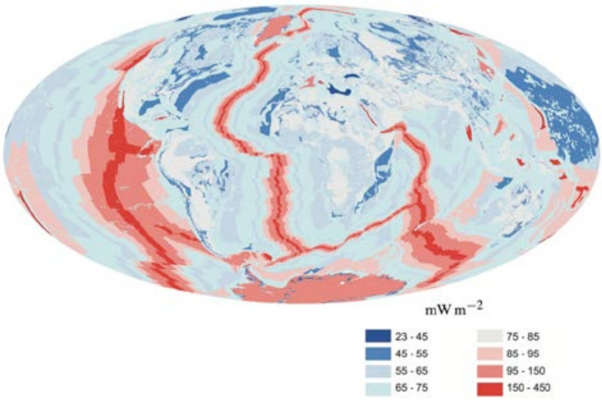


Figure 1: Heat flowing to the Earth's surface (Davies, 2010)

The high temperatures of magma will heat nearby rock and water which seeps down through permeable rock or fissures as shown in Figure 2. The heated water or steam can rise to the surface to form hot springs or geysers but in some cases it can get trapped underground by impermeable rock layers forming geothermal reservoirs. In areas where these high temperature rock, water and steam is close enough to the surface to be exploited by drilling, geothermal electricity generation and process heat applications are possible. Geothermal plants are mainly independent of solar energy and can, therefore, function as base load plants.

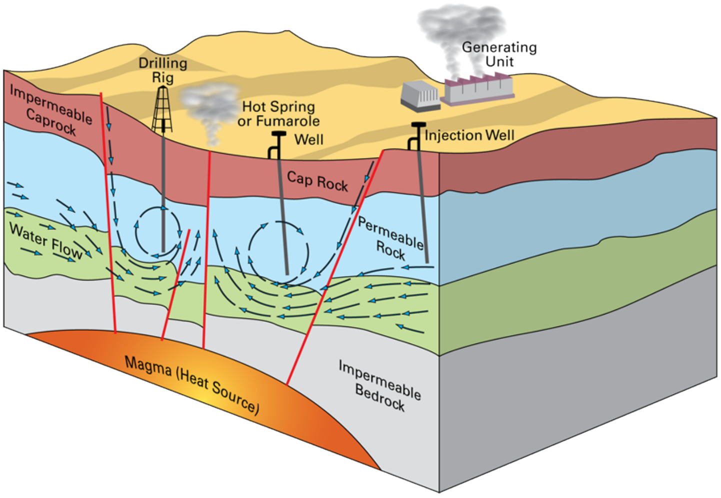


Figure 2: Geothermal energy processes (British Geological Survey, 2014)

Geothermal energy is also available in the near surface soil due to absorbed solar energy and thermal inertia. Near the surface more than 50% of incoming solar energy is absorbed in the ground and water. This heat is retained in the soil, ground water and larger water bodies from summertime throughout the year due to thermal inertia. As a result relatively constant temperatures can be found only a few meters deep all year round with temperature variations disappearing below 10m. This energy can be utilised for space heating in winter when the ground temperature is higher than winter air or cooling in summer when the ground is cooler than the summer air. This is usually accomplished through geothermal assisted heat pumps (GHP) also known as ground-sourced heat pumps (GSHP).

Geothermal energy can be divided into two categories:

- <u>Electricity generation</u>. High temperature fluid is extracted from deep within the earth through a collection well. This is heat used to drives a turbine, making use of an organic Rankin cycle (ORC), to generate electricity and then the returned to the source. Typical power plants need temperatures exceeding 180°C in depths less than 3km but with recent advances in binary power plants electricity generation is possible with temperatures as low as 74°C.
- <u>Direct use</u>. High temperatures within the earth is used for direct heating applications (district heating or process heating). Alternatively, ground-sourced heat pumps make use of favourable temperatures in the soil to drive heat pumps for more efficient heating and cooling.

Geothermal energy is considered a renewable resource due to the essentially limitless heat within the earth, abundnt solar energy that is absorbed in the near surface soil and continuous natural replenishing of the ground water from rain. It is clean, renewable and relatively constant compared to other renewable energy resources that fluctuate. However, for power generation and other high temperature applications, geothermal energy is limited to regions with shallow volcanic activity for affordable drilling costs. The challenge lies in finding the appropriate technology to effectively and economically harness the available resource.

Geothermal power production has increased by 3% per year from 1999 to 2004 and direct use of geothermal by 7.5% during this same period (Fridleifsson, 2008). The growth in direct use of geothermal resources is mainly due to the contribution of GSHP which can be used anywhere. On a global scale the largest installed capacity of geothermal power plants is in the United States, Philippines, Mexico and Indonesia (see Table 1). For direct use, on the other hand, China is the leading country followed by Sweden, USA and Turkey.

Table 1: The top countries using geothermal energy in 2005 (Fridleifsson, 2008)

Electricity generation		Direct use	
Country	GWh/yr	Country	GWh/yr
USA	17,917	China	12,605
Philippines	9,253	Sweden	10,000
Mexico	6,282	USA	8,678
Indonesia	6,085	Turkey	6,900
Italy	5,340	Iceland	6,806
Japan	3,467	Japan	2,862
New Zealand	2,774	Hungary	2,206
Iceland	1,483	Italy	2,098
Costa Rica	1,145	New Zealand	1,968
Kenya	1,088	Brazil	1,840
El Salvador	967	Georgia	1,752
Nicaragua	271	Russia	1,707
Guatemala	212	France	1,443
Turkey	105	Denmark	1,222
Guadeloupe (France)	102	Switzerland	1,175

According to a study by Lund et. al. (2005) the worldwide breakdown of direct geothermal applications in 2004 are as depicted in Figure 3. The largest contributors are GHP, bathing and swimming and space heating together making up 82.6% of the total direct use.

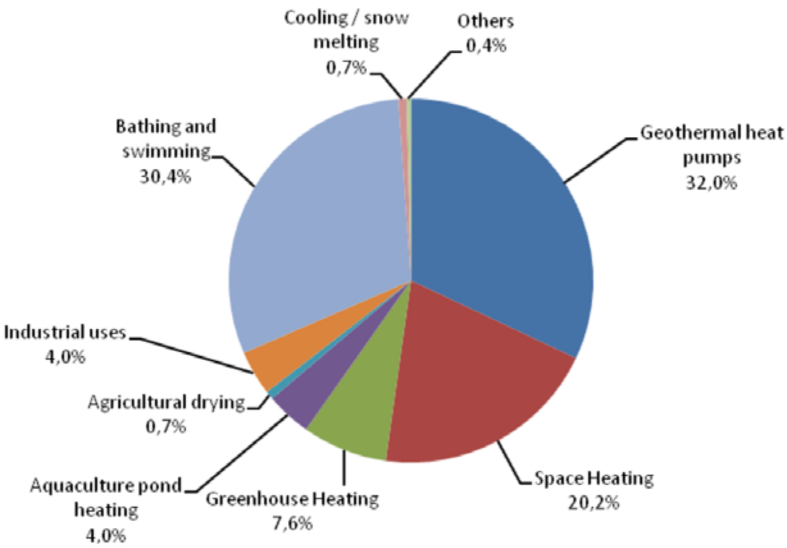


Figure 3: Breakdown of direct use of geothermal energy as percentage of total energy (Fridleifsson, 2008)

Advantages of geothermal power generation are:

- It is regarded as a renewable resource due to the essentially limitless heat in the earth as well as continuous replenishing of ground water and solar energy.
- The constant nature means that geothermal systems can be used for base load production
- Due to the free heat in the earth the operating cost of geothermal systems are very low.
- Geothermal systems have very little greenhouse gas (GHG) emissions contributing to a cleaner environment and limiting climate change.

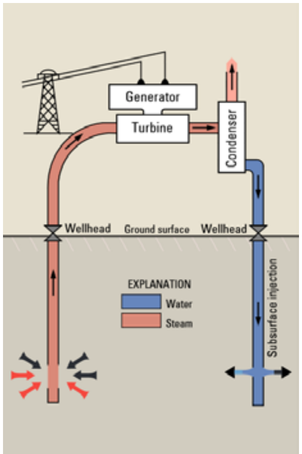
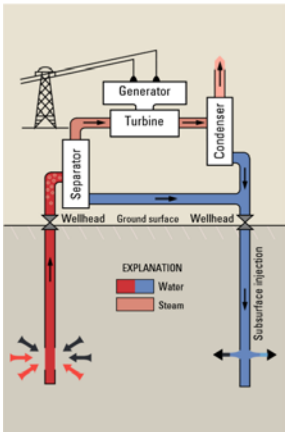
Challenges in geothermal power generation are:

- Accurate geological understanding and measurements are required before site development which can be complex and expensive.
- High drilling costs results in large start-up costs for power stations.
- Non-condensable chemicals have are often present in the brine and to be treated before it can released to the atmosphere.
- Sediment deposits, scaling and chemicals in the brine cause can damage in piping and heat exchangers.
- Limited sites with sufficiently high temperatures at affordable drilling depth are available.
- Geothermal power plants are associated with seismic risks by changing the pressures within the earth.

2. Technology to Harness Geothermal Energy

Geothermal technology has a wide range of applications ranging from deep drilling power stations to near surface ground source heat pumps. The most prominent technologies can be summarised in the follows:

Table 2: Geothermal technologies

<table>
<tr><th>Type</th><th>Technology</th><th>Description</th><th>Status & Motivation</th></tr>
<tr><td rowspan="2">Electricity generation</td><td>Dry steam power stations

</td><td>Dry steam power plants accesses pockets of steam of 150°C or greater through deep drilling. The steam is used to drive turbines to generate electricity after which non-condensable gasses are treated and exhausted to the atmosphere and condensate is pumped underground to the source.</td><td>This is the oldest geothermal power plant type. First used in Italy in 1904. The Geysers north of San Francisco, California is the world's largest geothermal generation field. Of the 22 dry steam power stations 15 are owned by Calpine. Production dropped in 1999 as the reservoir started to become depleted but increased again after injection of treated sewage effluent started in 2004. These systems require minimal cleaning devices but applications are limited since sources of direct steam geothermal reservoirs are extremely rare.</td></tr>
<tr><td>Flash steam power stations

</td><td>Hot fluid in the earth is under high pressure. As it is brought to the surface the fluid boils. Through the use of a separator (flash tank) the fluid is caused to vaporise. Fluid that does not vaporise can be sent to secondary separators. All the steam is used to drive a turbine to generate electricity. Remaining condensate is pumped to the source and non-condensable gases are released to the atmosphere. These plants typically need source temperatures typically between 177°C to 260°C.</td><td>Flash steam power plants are the most common of all geothermal power stations. These systems are used where hydrothermal resources are available not only steam and, therefore, a greater range of possible locations can be utilised with these systems. Great care should be taken for materials and to clean the extracted fluid to prevent scaling and corrosion due to greater interaction with the working fluid. Despite drawbacks of chemical concentration, generally double flash systems are preferred over single flash systems because more of the energy is</td></tr>
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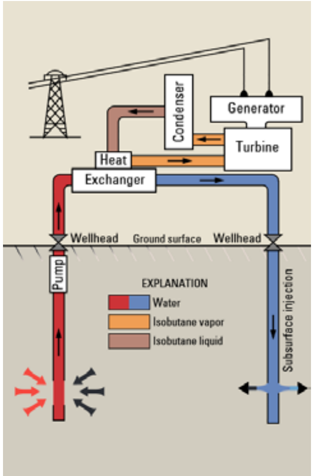
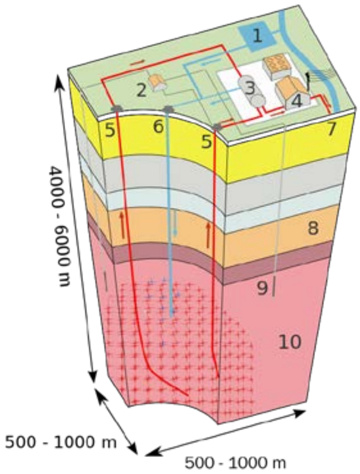
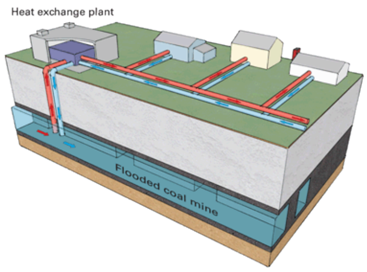
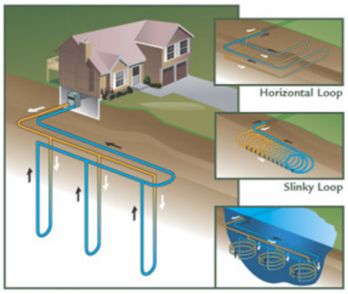
			extracted.
Electricity generation	Binary cycle power stations  	Binary cycle power stations use the geo-fluid extracted to heat and vaporise a secondary working fluid through a heat exchanger. The generated vapour drives a turbine after which the working fluid leaving the turbine is cooled and returned to heating source typically using an organic Rankine cycle. Depending on the type of secondary working fluid different source temperatures can be utilised. These systems can be used at temperatures from 74°C to 177°C classifying these systems as low temperature geothermal power systems.	The benefit of these systems are: • Flexibility due to secondary working fluid to adapt the system optimally for a specific geothermal resource. • Low temperature utilisation increases number of suitable geothermal reservoirs. • No flashing means 100% of the geo-fluid is returned to the source maintaining geothermal pressure, life and reducing emissions to near zero. Ormat Technologies from Thailand is one of the world leaders in modular, binary Rankine power plants with proven products used in over 71 countries over the world (Kagel, 2008). In 2000 UTC Power produced the PureCycle® which can economically operate on a source temperature of 74°C in colder regions.
	Enhanced geothermal systems (EGS)  	Enhanced or engineered geothermal systems do not require naturally occurring hydrothermal resources in permeable rock for operation. Instead, artificial hydrothermal reservoirs are created through hydraulic stimulation. Water is pumped into the earth under high pressure to open up fissures in impermeable rock such as granite. This process is also called hydro-shearing as opposed to hydraulic fracturing. Water seeps through the high temperature rocks and returns through a collection well to drive steam turbines. After the energy is extracted the water is returned underground to for a semi-closed loop. Without being limited to naturally occurring hydrothermal resources far greater locations becomes available.	These systems are attractive since there is no need for hydrothermal resources only hot rock. The major challenges of these systems are sustaining the artificial reservoir, dealing with water losses and risks of induced seismicity. EGS is in the research and development stage and there are currently no commercial scale plants. There are currently demonstration systems in Europe, USA and Australia. The largest EGS application in the world is a 25 MW demonstration plant in the Cooper Basin in Australia by Geodynamics Ltd. The Cooper Basin has the potential for 5-10 GW generating capacity. In 2006 hydraulic shearing at a pilot project in Basel, Switzerland resulted in 3 earthquakes which brought the project to a halt and dampened the attractiveness of these systems in general. Despite these setbacks, in 2007 a 2.5-2.9MW$_e$ EGS plant went into operation in Landau, Germany. USA

Direct use	Direct heating  	Hot water is drawn from underground reservoirs, flooded mine shafts or obtained from geothermal power stations. Heat is distributed via a heat exchanger to factories, district heating, agriculture and recreational facilities.	Direct heating from geothermal resources has been occurring since before recorded time. Past applications were primarily for recreation and health. Currently Iceland is one of the world leaders in direct use of geothermal resources. Due to the abundant volcanic activity, 87% of the space and water heating needs are met using geothermal resources.
	Ground-sourced heat pumps  	GSHP or GHP makes use of the earth's relatively constant temperature all year round to more efficiently heat or cool buildings and water. Normal heat pumps heating buildings in winter have to extract heat from the cold winter which would be easier if the heat is absorbed from the warmer earth. In summer the normal heat pump has to reject heat to the hot summer air which would be easier if the heat is released to the cooler earth. For these reasons geothermal heat pumps are more efficient than normal heat pumps.	In some cases coefficient of performance (COP) to heat air from 5°C to 35°C have been found to be 5 for the GSHP, 3.6 for the air source heat pump (ASHP) compared to a COP of 1 for a resistive element. Ground source heat pumps have also been reported to use 77% less energy than normal resistive heater and 44% less than air source heat pump. There is, however, a larger initial investment compared to air source heat pumps due to the required excavation and piping. It is estimated that it is possible for the world installed capacity of direct use geothermal resource to increase from 60 GW_{th} in 2010 to 800 GW_{th} in 2050 of which 90% is due to ground source heat pumps reducing CO_2 emissions by 300 million tons per year in 2050 (Fridleifsson, 2008). In 2009 70% of the world installed geothermal heating capacity was through GHP (IPCC, 2011).

3. Geothermal Energy Resources in South Africa

In an effort to reduce carbon emissions, due to a raised awareness of its effect climate change and increase in global legislation, as well as the need for energy, South Africa is increasingly promoting the implementation of renewable energy alternatives. Geothermal energy, however, has not been considered of high potential due predominantly to the presence of tectonic stability resulting in a lack of geothermal resources, especially hydrothermal reservoirs, suitable for feasible geothermal power generation.

Having a look at the geology a large part of South Africa is underlain with what is called the Kaapvaal Craton (see Figure 4). The Kaapvaal Craton is highly stable due to underlying lithosphere mantle characterised as exceptionally thick, chemically depleted and with a low heat conductivity which effectively acts as a heat insulator (Dhansay et. al., 2014). This supports the findings of low heat flow to the surface and low geothermal gradients. Generally speaking, it means that due to the geological stability and thick crust and mantle in South Africa geothermal resources are deep within the earth which, due to the cost of drilling, makes such power plants unfeasible. For this reason geothermal power generation is largely not being considered in South Africa.

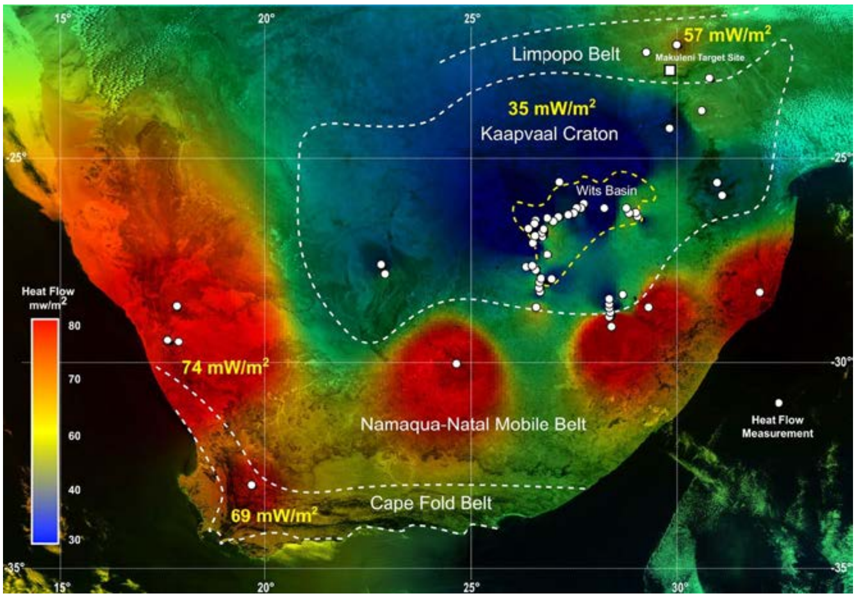


Figure 4: Heat flow to surface in Southern Africa as interpolated from measured data (Dhansay et. al., 2014)

In a study by Dhansay et. al. (2014) areas outside the Kaapvaal Craton were identified to have potential for low enthalpy geothermal power generation. Heat measurements within the Namaqua-Natal Mobile Belt show areas of higher geothermal gradients where EGS, using binary cycle power conversion technology, can potentially extract energy from hot dry rock. Interestingly, these measurements, displayed in Figure 4, appear as hot-spots around the measurement locations. It is expected that additional heat flow measurements would improve the accuracy.

The drawbacks of EGS systems are that the technology is relatively new, in some cases the hydraulic stimulation of rock may result in earthquakes and these systems can use a great deal of water which is not an abundant resource in South Africa.

Furthermore, in South Africa there are reportedly 89 geothermal hot springs of which 29 have been developed (Geothermal Energy Association, 2010).

Although South Africa lacks geothermal resource for feasible power generation one aspect of geothermal energy that have a high potential in South Africa is GSHP that can be implemented anywhere.

4. Cost of Geothermal Energy

Geothermal systems have a wide range of cost due to the many different of technologies as well as geological and climatic conditions. In general geothermal systems are characterised by high initial start-up costs and low running cost relative to alternative solutions. The cost of geothermal plants can be attributed to 1) exploration and resource confirmation, 2) well drilling, 3) related facilities and infrastructure and 4) the power plant.

Once in operation geothermal power production are comparable with other base load power systems such as coal costing between US$0.04-0.10/kWh$_e$ (R0.40-1.00/kWh$_e$ for R10/US$ exchange rate). The Installation costs can vary greatly due to the geology, temperatures, chemistry etc. These costs can be in the ranges of US$2.8-5.5 million/MW$_e$ (R28-55 million/MW$_e$) installed for a 50 MW$_e$ plant (Gehringer and Loksha, 2012). In a comprehensive review of renewable energy systems and its effect on climate change it was found that the average installation cost of flash steam power plant is approximately R30 million/MW$_e$ and for a binary power plant R40 million/MW$_e$ given a R11/USD$_{2005}$ (IPCC,2011).

The levelized cost of energy (LCOE) values for flash steam power plants were found to be in the range of R0.54-0.80/kWh$_e$ and for a binary power plants slightly higher in the range of R0.58-1.00/kWh$_e$ (IPCC,2011). Although there is no existing EGS data available to determine actual LCOE values estimates indicate R1.10-1.93/kWh$_e$ for 250-330°C at 5km depth and R3.30-4.00/kWh$_e$ for 125-165°C at 4km depth (IPCC,2011). Furthermore, in the study by Dhansay et. al. (2014) a 75 MW$_e$ an EGS power plant was investigated for a location in the Limpopo province resulting in a LCOE of 14USc/kWh$_e$ or R1.40/kWh$_e$ given a R10/US$ exchange rate. This shows that geothermal power is expensive compared to coal which typically have a LCOE between R0.52-0.59/kWh$_e$ but less expensive than concentrated solar power (CSP) which is calculated to be R2.65/kWh$_e$ (Du Plessis, 2011).

Table 3: Geothermal cost summary (R10/$ exchange rate)

Technology	Installation cost	Reference	LCOE or LCOH	Reference
Coal			R0.52-0.59/kWh$_e$	
CSP			R2.65/kWh$_e$	Du Plessis, 2011
General geothermal	R28-55 million/MWe (50 MWe plant)	Gehringer and Loksha, 2012		
	R10 - 63 million/MW$_e$	Augustine et. al., 2012		
Flash	R30 million/MW$_e$	IPCC,2011	R0.54-0.80/kWh$_e$	IPCC,2011
	R10 - 20 million/MW$_e$	Augustine et. al., 2012	R 0.79/kWh$_e$ (30 MW plant)	CEC, 2010
			R 0.50-0.80/kWh$_e$	IEA, 2011
Binary	R40 million/MW$_e$	IPCC,2011	R0.58-1.00/kWh$_e$	IPCC,2011
	R23 - 63 million/MW$_e$	Augustine et. al., 2012	R 0.83/kWh$_e$ (15 MW plant)	CEC, 2010
			R 0.60-1.10/kWh$_e$	IEA, 2011
EGS			R1.10-1.93/kWh$_e$ (250-330°C at 5km depth)	IPCC,2011
			R3.30-4.00/kWh$_e$ (125-165°C at 4km depth)	IPCC,2011
			R 1.00-3.00/kWh$_e$	IEA, 2011
			R1.40/kWh$_e$	Dhansay et. al., 2014
District heating	R5 700 - 15 700/kW$_{th}$	IEA, 2011		
GSHP	R10 340 – 41 250/kW$_{th}$	IPCC,2011	R0.55-2.70/kWh$_{th}$	IPCC,2011

Geothermal heat pumps have an investment cost in the range of R10 340 – 41 250/kW$_{th}$ and a levelized cost of heat (LCOH) in the range of R0.55-2.70/kWh$_{th}$ (IPCC,2011). The wide range is attributed to different installation types such as residential, commercial, horizontal loop, vertical loop or water body loop applications. These calculations were done on international basis assuming 25-30% as the load factor and 20 years system life but these values are highly dependent on local electricity tariffs and climate which makes it difficult to determine the exact values for South Africa.

5. Environmental and Social Impact of Geothermal Energy

Geothermal power plants are accompanied by drilling activities, roads, land clearing similar to other power generation activities. For this reason a general environmental impact assessment should be carried out. The net befit comes in the form of reduced greenhouse gas emissions. The specific environmental impacts focussed on in this report are greenhouse gas emissions, chemicals, water, seismicity ad socio-economic.

Greenhouse gas emissions

Geothermal systems do not involve combustion and, therefore, have very little GHG emissions. For example, comparing a coal plant, with installed scrubbers and other emission control systems, to a geothermal steam plant the geothermal plant releases 24 times less carbon dioxide (CO_2), 10 837 times less sulphur dioxide (SO_2) and 3 865 times less nitrous oxides (NO_x) per MWh (Kagel et. al, 2007).

Gasses typically related to geothermal systems originate from chemicals in the brine (geo-fluid) which are released when the pressure is reduced such as during the flashing process. The non-condensable gasses associated with geothermal plants include CO_2, SO_2, NO_x, hydrogen sulphide (H_2S), hydrogen (H_2), methane (CH_4), ammonia (NH_3) and nitrogen (N_2) of which CO_2 constitutes 90% (IPCC, 2011).

H_2S is a toxic gas and, therefore, it is standard practice to closely monitor concentrations and provide assurance that concentrations are not harmful. The gas is usually treated and then used as part of fertilizer. Binary power plants have zero operating emissions. In Iceland the substitution of geothermal energy for fossil fuels has reduced CO_2 emissions by 2 Mton annually (Fridleifsson, 2008). The complete life cycle assessment (LCA) shows that the GHG emissions for flash plants are less than 50 g CO_2 eq/kWh$_{th}$ and for EGS plants less than 80 g CO_2 eq/kWh$_{th}$.

Chemicals

Most harmful chemicals in geothermal plants are dissolved in the brine and, therefore, gets pumped back underground to sustain the hydrothermal pressure. Boron and arsenic are examples of some chemicals that could be harmful to ecosystems if released at the surface. Other measures are concrete linings of wells, pre-operation hydrothermal chemical analysis and careful material selection.

Water

If geothermal power plants extract water from the earth at a higher rate than it can naturally be replaced it could result in a depletion of reservoirs. In general, however, geothermal systems do not directly compete with other water users since the working fluid is mostly brine which after use to generate power gets pump back underground to sustain the reservoir pressure. For high temperature plants water is sometimes used for cooling purposes but Binary plants can make use of dry (air) cooling. In The Geysers in California, USA, treated sewage effluent is pumped underground to sustain the hydrothermal reservoir pressure and life which increases plant life and output while saving usable water.

Seismicity

Geothermal systems are associated with micro earthquakes that occur due to changing pressures or temperatures in the earth by either extracting or injecting fluids. Even so in a 100 years of development no geothermal plant related seismic activity has resulted in significant damage or injuries (IPCC, 2011) only some reports of human discomfort. Seismic activity can be successfully mitigated through geological risk assessments and routine seismic monitoring.

Socio-economic

The successful implementation of a geothermal power plant is highly dependent on the support of the local community. The key factors for successful community support are providing direct and ongoing benefits and making sure the application has no negative impact on the environment, economy and people. Educating the local community and raising awareness is also important. Geothermal systems creates jobs during exploration phase through drilling activities, construction and operation (see Table 4). Creating jobs reduce rural poverty. Other ways in which geothermal plants can influence the socio-economics is by improving infrastructure, services and security in remote areas and communities. GSHP, on the other hand, creates jobs in factories through manufacturing and assembly.

Table 4: Comparative job creation (U.S. DOE, 2004)

Power Source	Construction Employment (jobs/MW)	O&M Employment (jobs/MW)	Total Employment for 500 MW Capacity (person-years)
Geothermal	4.0	1.7	27 050
Natural Gas	1.0	0.1	2 460

6. Conclusions and Recommendations

In this technology overview it was found that geothermal power production is a sustainable form of energy and has the benefit to provide base load power production but it is still expensive, especially in areas with only deep volcanic activity such as in South Africa. Due to the lack of volcanic activity and hydrothermal resources traditional geothermal power production is not feasible in South Africa.

Enhanced geothermal system (EGS) plants, that make use of hot, dry rock, have been found to be feasible in the Limpopo province and other areas within the Namaqua-Natal Mobile Belt. These systems, however, are still in experimental phase and therefore require full scale pilot plants to demonstrate the feasibility of the technology. At present EGS plants are more expensive than other geothermal power plants, require water resources and are associated with seismic activity making them still unfavourable for South Africa in the near future.

GSHP, on the other hand, can be used throughout South Africa successfully for heating and cooling purposes of residential and commercial applications. It is, therefore, expected that these systems would be the most common application of geothermal energy in the country.

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