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THE ROLE OF GEOTHERMAL IN COMBATING CLIMATE CHANGE

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ABSTRACT

Climate change is one of the biggest threats facing the Earth today. It has been a popular topic in recent decades, and in particular the concept of global warming. Some debates still continue whether the changes are due to natural or anthropogenic causes, or even if it is occurring at all. To estimate the effects of these changes, several climate forecasting models have been constructed to help deal with the possible consequences. The climatic changes are not expected to have equal *effects* around the world, e.g. Iceland, will likely experience different effects than China due to the different geographical locations, size, geomorphology etc. However, the changes will likely affect all *parts* of the world, in one way or another, and therefore it is essential to find out what changes are likely to occur and try to find ways to mitigate them.

The most important and significant way of mitigating the effects of climate change is to increase the share of renewable energy sources in the global energy system which is currently dominated by fossil fuels. The combustion of fossil fuels emits an enormous amount of CO_2 into the atmosphere. This addition of anthropogenic greenhouse gasses is expected to lead to higher temperatures around the world i.e. global warming, as historically, fluxuations in CO_2 have shown a correlation with fluxuations in global average temperatures. Geothermal energy is a relatively environmentally friendly resource which has numerous benefits compared to other the renewable energy sources. It has the potential to contribute substantially in combating climate change in the near future if given the opportunity.

1. INTRODUCTION

Climate change is one of the biggest threats facing the Earth today. Whether the changes are due to natural or anthropogenic causes, the effects remain the same. Therefore, it is essential to find ways to mitigate them and to minimise the possible human impact. Through history, the human impact has generally been due to development. Development requires energy and as all countries strive to increase their development index and improve the living standards, it is paramount that it is done in an environmentally and sustainable way. Geothermal energy is considered as a sustainable renewable energy alternative to fossil fuels but a substantial increase in its development is needed for it to make a difference in the combat against climate change.

1.1 Climate change vs global warming

The climate has a significant effect on the physical and biological/ecological systems which in turn affect both the society and the economy. Changes in climate therefore influence the interaction between all these aspects. However, the terms *climate change* and *global warming* are terms frequently used and they have been a popular topic over the recent years both in the academic community as well as in public media. However, the wide variety of information available, from the aforementioned mediums, has caused some confusion over their scientific meaning so it is important to clarify this ambiguity.

The term *climate change* refers to a change in climate compared to the 'normal state' (normal state is an average over period of time ranging from decades to millions of years, all depending on which criteria is suitable in each case). *Global warming* indicates the rise in global temperatures compared to the normal state. The question whether climate change or global warming is occurring is therefore simple. It is! In fact, it has occurred multiple times throughout the Earth's history, i.e. both global warming and global cooling. There is now a global consensus that climate change and specifically global warming is occurring (IPCC, 2014; Cook et al, 2016; State of California, 2017). The facts clearly state that temperatures are rising globally (IPCC, 2014). Globally does however, not mean that temperatures are rising at all weather stations, in all countries, all over the world at the same time but that they are rising in all parts of the world, all climatic zones, all continents etc. on average. *Average* is the keyword in this context. On average, temperatures have been rising globally and are still rising (Figure 1).

Climate change critics often single out isolated weather related incidents as examples that global warming is not occurring. However, short-term changes in weather do not affect changes in climate. Weather relates to day-to-day measurements whereas climate is an average of atmospheric conditions over longer periods, usually 30 years, and up to millions of years depending on what criteria is used. It is only when the weather changes become prolonged and last for a significant amount of time when they start to affect the climate. Therefore, it is not viable to make estimations on the effects of climate change based on short-term weather changes. Global average measurements are needed to get an overview of the changes occurring and to assess whether they are normal or not. The climate has changed many times through the Earth's history so changes in climate are per se *normal*. Temperatures have risen and fallen globally for millions of years along with changes in CO_2 concentrations in the atmosphere so that alone is not unusual. However, the question now is whether the current changes are anthropogenic, i.e. human induced from the addition of greenhouse gasses from the various human activities, or natural, and to what extent. Even though global warming and cooling has occurred throughout Earth's history, the main issue that differentiates the current changes from the previous ones, is the speed of the changes, which makes it a major concern whether the biosphere will be able to adapt in time, this time around. The main problem being that humans have adapted to the current climatic conditions and therefore significant changes in the climate would mean massive impacts on all main aspects of human societies, i.e. social, economic and ecological.

1.2 The current climate situation

The fact is that significant climatic changes have been observed over the last ±100 years, global temperatures have risen 0,7°C, greenhouse gas (GHG) emissions have increased, sea level has risen 0,19 m, and snow cover is decreasing (IPCC, 2014; Figure 1). Extreme weather incidents, such as storms, floods, and heat waves have become more frequent. Climate experts state that it is extremely likely that these changes can be directly related to the increased greenhouse effect due to anthropogenic emissions of greenhouse gasses (Rosenzweig et al., 2008; IPCC, 2013). As with climate change, the greenhouse effect is normal, in essence. The GHG in the atmosphere protect the Earth form the sun's harmful rays as well trapping the sun's heat making the Earth inhabitable. The average temperature on Earth is about 15°C. If it were not for the GHG the average temperature would be -18°C (Hay, 2016). Therefore, GHG are essential, but in the *required* amount.

The natural causes of climate change are due to a variety of reasons such as naturally different concentrations of CO_2 and other GHGs in the atmosphere, small particle emission of volcanic eruptions, variations in the Earth's axial tilt, and to a lesser extent, solar activity and sunspots (Haigh, 2011; IPCC, 2013). Most of these natural causes affect the climate on a large timescale so the sudden anthropological addition of GHG, experienced today, are unprecedented in Earth's history and therefore the effects are still unknown. Throughout Earth's history, there have been enormous oscillations of CO_2 in the atmosphere. These oscillations have been intertwined with changes in temperature. Whenever CO_2 concentrations have been high in the atmosphere, temperatures have been high and vice versa. It is therefore reasonable to suggest that there is a relationship between CO_2 concentrations and temperature.

However, it is not a linear relationship. It is much more complicated than that. However, they do show correlation through time (Shakun, et al., 2012; Stips, et al., 2016; Figure 2). It is therefore reasonable to conclude that increased CO_2 concentrations result in an increase in global temperatures. Changes in the climate are inevitable. As mentioned before, they have occurred many times throughout Earth's history for millions of years. Global warming is not a new phenomenon. However, now the question is, whether the anthropological addition of CO_2 is the cause of the global average temperature rise.

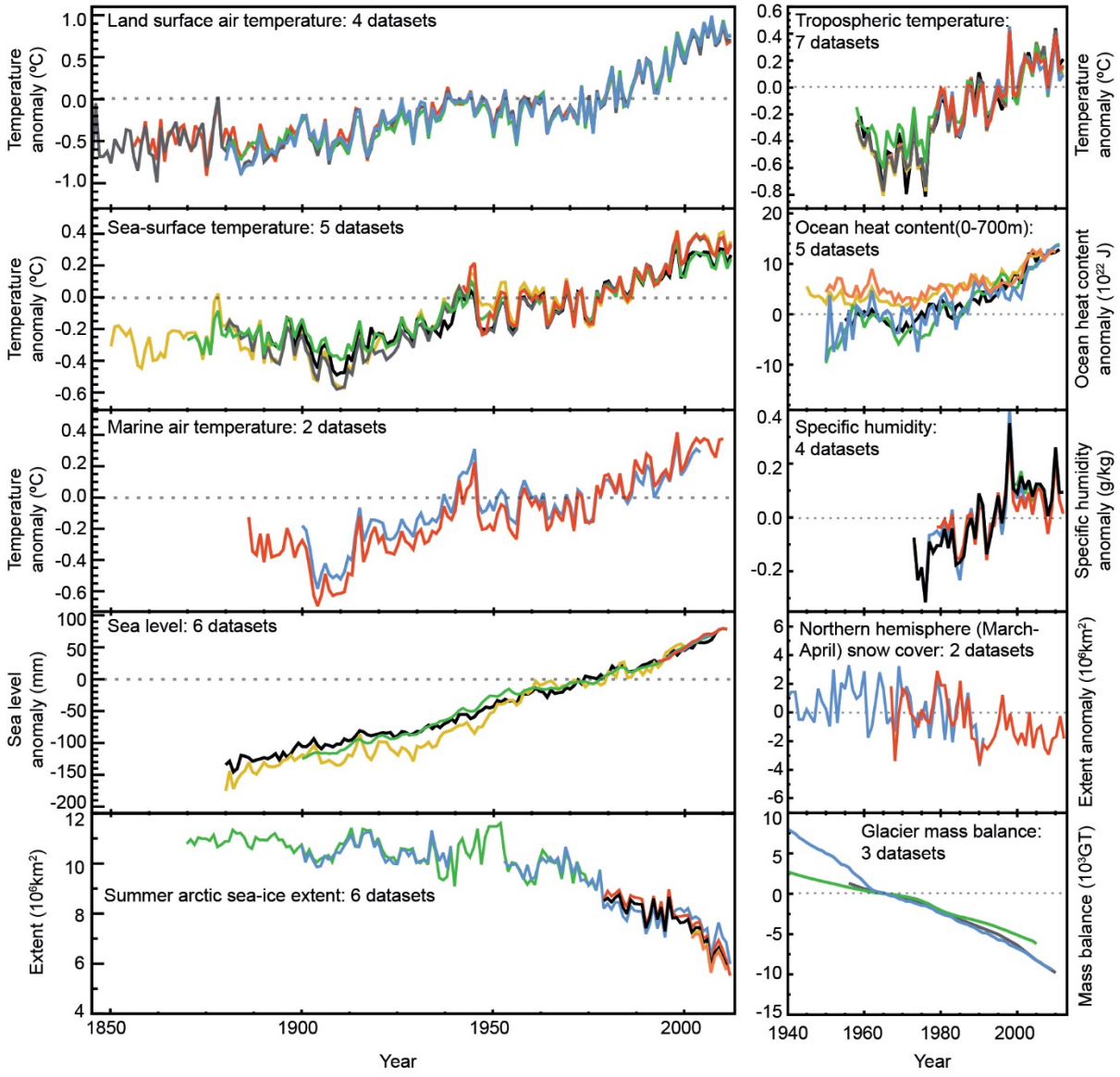

FIGURE 2: Various climatic indicators of global changes, e.g. temperature, sea level, snow and ice cover (the colours indicate different datasets) (IPCC, 2014)

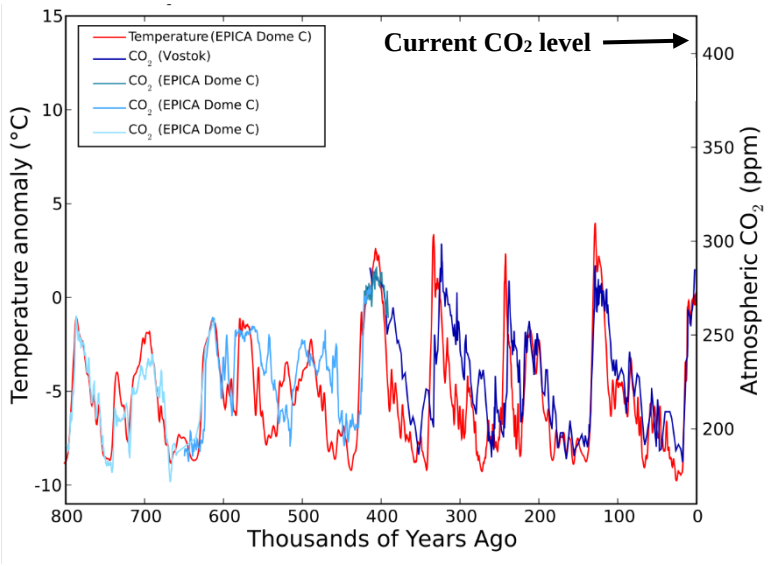

FIGURE 2: The non-linear but correlating relationship between temperature and CO_2 over time (Modified from McInnes, 2006)

1.3 The facts

Numerous climate models have been developed to try to predict the changes in climate as the effects will have a huge impact on all human existence. However, it is only when human induced additions of GHG and aerosols are included in climate models that they can simulate temperature changes during the last century (IPCC, 2007; IPCC, 2014; Figure 3). This strongly suggests that the human factor is a major component in the current climate changes. So how do we react to the facts at hand? Todays' modern society relies on energy. Humans emit additional GHG into the atmosphere to meet growing demands for energy. Presently, energy demands are growing every year, especially in the developing countries (EIA, 2013). It is clear that the continuous emission and utilisation of fossil fuels as an energy source will only add to the problem so therefore a conscious effort has to be made to inhibit, or at least limit emissions from fossil fuels use. Renewable energy sources provide a more environmentally friendly alternative but are they all the same? Are they all equally clean?

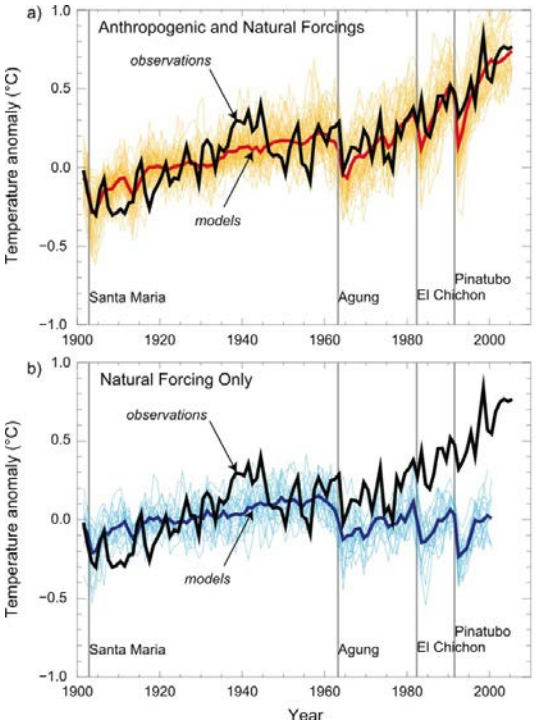

FIGURE 3: a) Climate model prediction considering anthropogenic additions of GHG, b) Climate model prediction without considering anthropogenic additions of GHG (IPCC, 2007)

Every source of energy creates some sort of pollution but of different varieties and intensities. The first law of thermodynamics states that energy can neither be created or destroyed. Electricity and heat production are the key contributors to global GHG emissions (IPCC, 2014). Geothermal energy comes from harnessing the Earth's heat and turning it into electricity. When managed correctly it can be an environmentally friendly renewable energy alternative.

2. THE ROLE OF GEOTHERMAL ENERGY

2.1 The current global energy system

The current global energy system is dominated by fossil fuels. Fossil fuels account for 81,1% of the total global primary energy supply. Nuclear energy accounts for 4,8% and the rest is accounted by the so called traditional renewable energy sources or 14,1%. They are biofuels (10,3%), hydropower (2,4%), wind energy (0,2%), direct solar energy (0,1%), ocean energy (0,002%), and geothermal which has a very small part in the total global energy scenario or only about 0,1% (IPCC, 2012; EIA, 2016). So how can geothermal make a difference in combating climate change?

2.2 The geothermal potential

In 2016, the Annual Greenhouse Gas Index (AGGI) was 1.4, which represents a 40% increase in radiative forcing (a net warming influence) since 1990 (Figure 4). The AGGI measures the commitment society has made to living in a changing climate. The uncertainty level of these measurements is very low as they are based on the highest quality atmospheric observations from sites all around the world. Figure 4 shows the amount of radiative forcing caused by various greenhouse gases, based on the change in concentration of these gases in the Earth's atmosphere since 1750 (NOAA/ESRL-GMD, 2017). Radiative forcing is calculated in watts per square meter, which represents the size of the energy imbalance in the atmosphere, i.e. it measures the capacity of gas, or other forcing agents, to affect the energy balance and thereby contributing to climate change. It means simply phrased, the change in energy in the atmosphere due to GHG emissions (SEI/GGM, 2011; Myhre et al., 2013). On the right side of the graph, radiative forcing has been converted to the AGGI, which is set to a value of 1.0 for 1990. From Figure 4, it is clear that CO_2 has the most effect due to the amount emitted. It is the largest contributor to a warming planet.

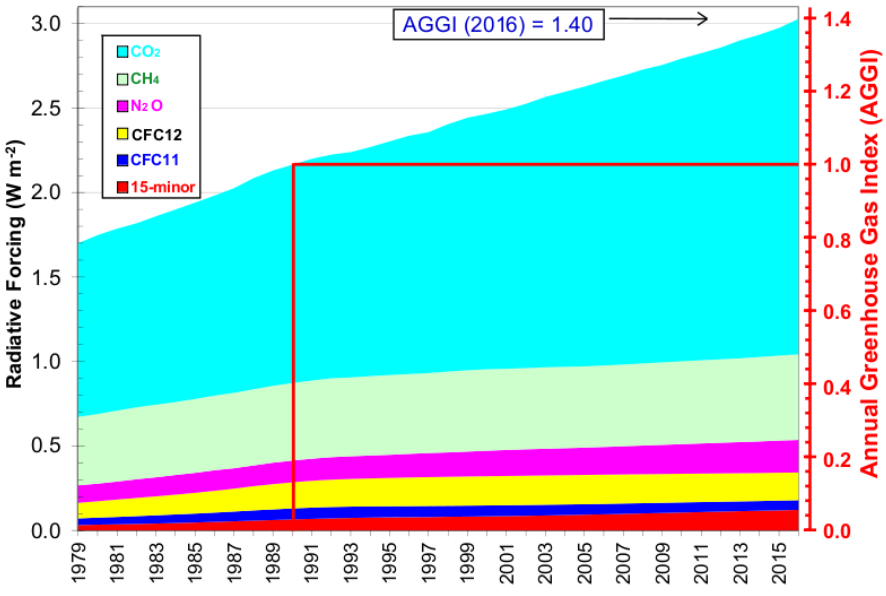

FIGURE 4: Radiative forcing caused by major long lived GHG (NOAA/ESRL - GMD, 2017)

According to data aggregated by the International Panel on Climate Change (2012), life-cycle global warming emissions associated with renewable energy, including manufacturing, installation, operation and maintenance, and dismantling and decommissioning, are minimal. Compared with electricity generated by fossil fuels like natural gas and coal, which emit between 0.6 and 3.6 pounds of carbon dioxide equivalent per kilowatt-hour (CO_{2e}/kWh), geothermal emits only 0.1 to 0.2 of CO_{2e}/kWh. Given that CO_2 emissions are the largest contributor to global warming, geothermal can make a significant

difference in combating climate change in terms of CO_2 emissions, but only if it gains a larger share in the global energy system. Presently, geothermal energy does not play a large role in combating climate change but its potential is high. The reasons why it does not have a larger share in the energy mix are rather complex as well as ambiguous as they depend on different variables inherent in each place. Generally, the main common challenges with developing geothermal resources are:

- The high start-up cost
    - After geological and geophysical exploration surveys have been completed then exploratory drilling can commence. However, drilling one exploratory well costs between 5-6 million USD (GEOCOM, 2010; Kipsang, 2015) and there is no certainty that the drilling will be successful (although it is essential to mention that costs vary between places and projects). Many developing countries refrain from developing their geothermal resources because of this high starting cost. In addition to that even though the starting cost of drilling has been covered, often many experimental holes need to be drilled, before a successful development of the resource can begin. In some cases, the experimental wells show that the resource is not viable for production, meaning a substantial financial loss with no benefits.
- Complicated and expensive technologies
    - Developing geothermal resources requires expensive and high-tech equipment which in return requires highly trained staff to manage and operate. Geothermal drilling basically uses the same technologies and methods as that of oil and gas drilling, but with engineered solutions to solve problems associated with geothermal environments such as higher temperatures, thermal expansions of casing strings, drilling hardness and lost circulation. These adaptations increase the inherent costs of geothermal drilling (GEOCOM, 2010).
- The long production time
    - For a successful utilisation of geothermal resources, it is important that the respective government is supportive of the development (Ouko and Ómarsdóttir, 2015). Frequently government agents are deterred by the long payback time of geothermal development as generally the time from exploration to utilisation takes around 12-15 years (Steingrímsson, 2009).

So what is needed to increase the share of geothermal energy in the global energy system? That is a multifaceted and a rather difficult question to answer as it depends on the respective location, e.g. geography, GDP, human capacity available, among other factors. However, one of the main supportive forces for a successful development of geothermal resources is the support and backing of the respective government through committed policies. If the government is committed to switching from fossil fuels to renewable energy sources, and is supportive of geothermal development, it increases its chances of a greater share in the energy system (Ouko and Ómarsdóttir, 2015). Furthermore, as mentioned before, geothermal utilisation requires expensive high-tech equipment so local capacity of experts is essential for keeping the development costs low as hired expertise and equipment is expensive. Iceland is a good example of a successful development of geothermal recourses. Up until the 1970s, Iceland was a developing country. It went from being one of Europe's most poorest countries in the early 20th Century, dependent on imported coal and fossil fuels for its energy, to a country with high living standard that presently almost all stationary energy, and about 86% of primary energy, comes from indigenous renewable sources, i.e. 68% geothermal and 18% hydropower. The country has one of the highest energy use per capita in the world and the proportion provided by renewable energy sources exceeds most other nations. Hardly anywhere else does geothermal energy play a larger role in providing a nation's energy supply (NEA and MIC, 2006a). The Government of Iceland made the decision of switching from fossil fuels to geothermal energy by promoting the expansion of district heating utilities, following the oil price hikes of the 1970s. As a result, the share of geothermal energy used for space heating increased from 43% in 1970 to 83% in 1984 and 89% by 2005 (Orkustofnun, 2006). Currently, geothermal energy represents about 90% of heating is by geothermal energy and about 30% of the electricity production (Orkustofnun, 2016). Furthermore, this Governmental support to emphasise

geothermal utilisation opened up a wide range of jobs related to geothermal exploration and development resulting in the country's high quality capacity of experts in all geothermal related fields. This acquired expertise has then further enabled the country to develop and maintain its geothermal resources as well as export the knowledge and equipment to other countries through training initiatives such as UNU-GTP and private companies such as ISOR. It is therefore safe to say that the support of the Icelandic Government was a vital part in the success of geothermal development in Iceland.

Therefore, it is reasonable to conclude that to increase the share of geothermal energy in the global energy system, it is highly important that the respective governments are committed in the combat against climate change and they turn to renewable energy sources such as geothermal energy for their energy needs. Furthermore, research is needed in lowering the related costs and to achieve more efficiency in the development. Before mentioned capacity of trained local experts and own equipment is also important to keep the costs low and the development continuous.

3. THE FUTURE OF GEOTHERMAL ENERGY

Renewable energy growth has been increasing rapidly in recent years although the growth in geothermal energy has remained relatively slow in comparison with other resources for example biofuels and solar energy (Figure 5).

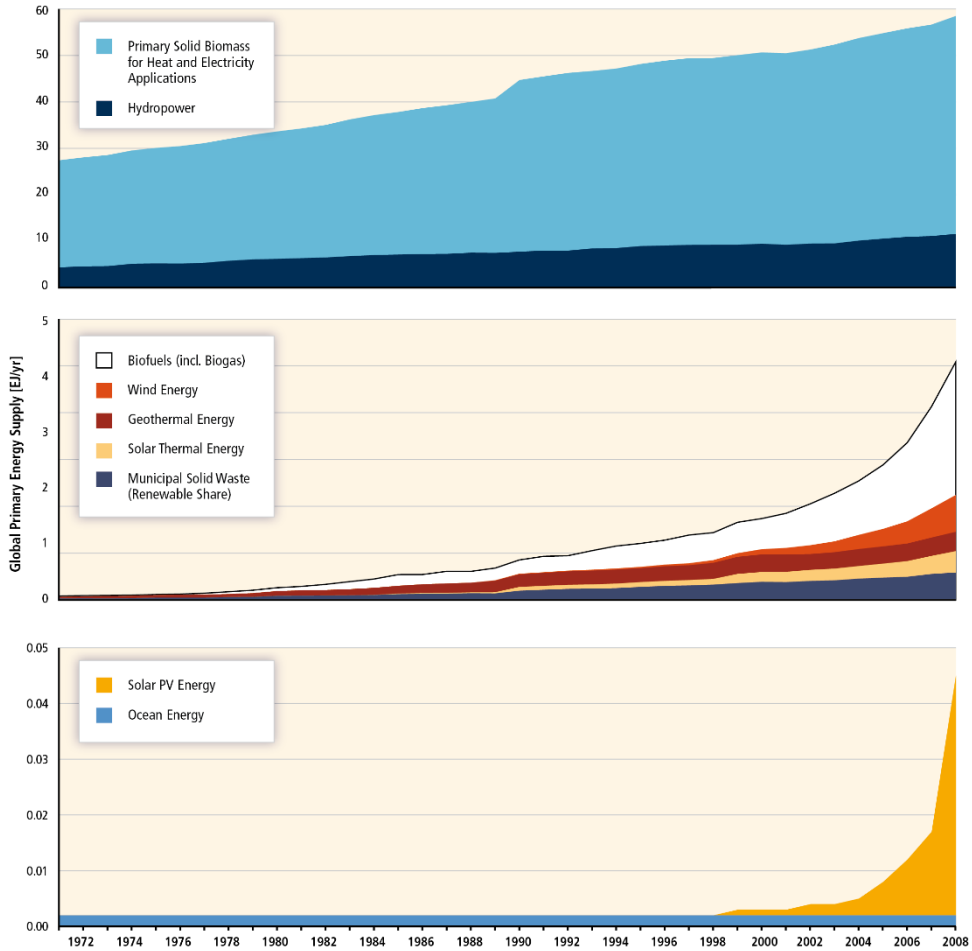

FIGURE 5: In comparison with the other renewable energy sources, the share of geothermal energy in the global primary energy supply has not increased as fast. Little has changed since 2008 (IPCC, 2011)

However, geothermal energy has numerous benefits over the other renewables.

The main ones are as follows:

- Geothermal energy development is well suited to climate change mitigation as it provides base-load power from an indigenous source that is also independent of seasonal weather effects and climate change impacts.
- The energy source is not geographically restricted and can be found in all parts of the world. This global distribution limits the number of energy monopolies that are exclusive to certain countries or areas and therefore also helps to balance the world's political energy dynamics.
- The technology to develop geothermal sources already exists and is well established so both developed and developing countries can utilise it relatively easily.
- Geothermal production has a good track record of sustainable production and is a cost effective and dispatchable power source.
- Geothermal heat pumps are already used worldwide, enabling substantive gains in heating and cooling efficiency of buildings.
- Relative to other renewable energy technologies, geothermal resources are utilized at high average availability factors typically >90% for electricity generation.
- The geothermal wells can even serve as injection channels for CO_2 and therefore even further limit the emissions into the atmosphere. The CarbFix project in Iceland is a good example of this where 95% of the captured and injected at the Hellisheiði geothermal power plant was mineralised within 2 years. That is much faster than the previous estimates claiming it would take hundreds to thousands of years (OR, 2017).

It is clear that geothermal energy has a lot to offer in the battle against human induced climate change. The U.S. Energy Information Administration projected the future development of geothermal energy in the world until 2040 (2013; Figure 6). Most growth is expected in the Non-OECD countries where the economic growth is high and populations are expanding. Demand for energy in the Non-OECD countries is projected to rise by 71% from 2012 to 2040. This is due to the fact that as countries develop and living standards improve, energy demand grows rapidly. Central and South America are projected to have the highest growth in installed geothermal generating capacity. Therefore, it is important that these areas have the expert capacity to be able to develop their resources. Several knowledge exchange projects and capacity building programmes on renewable energy have been established between developed and developing countries in recent years, one worth mentioning specifically is the United Nations University Geothermal Training Programme which offers training in geothermal development for experts in developing countries.

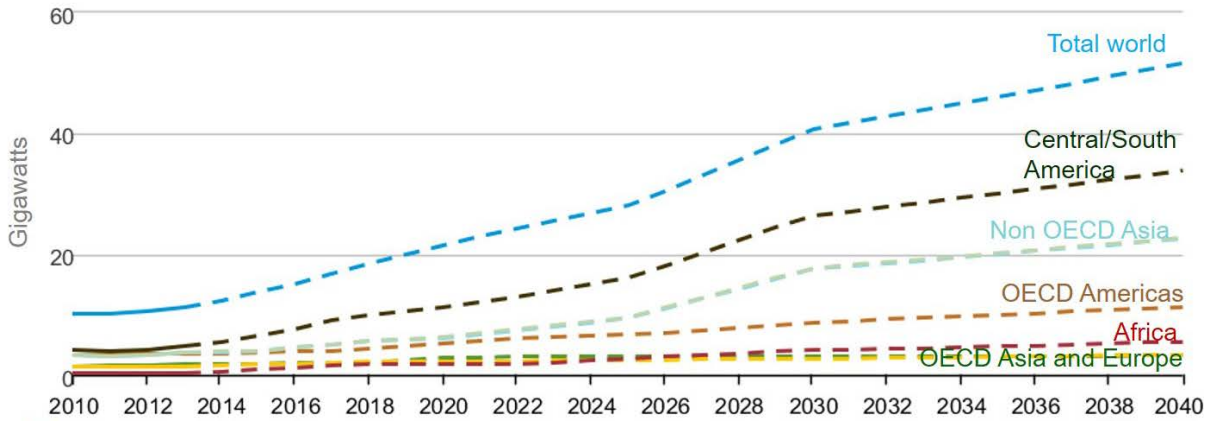

FIGURE 6: Future projection of installed geothermal generating capacity (EIA, 2013)

The Earth's accessible thermal energy reserves are estimated to be around $43x10^6$ EJ (EPRI, 1978), which is considerably higher compared to the world's primary energy consumption of 560 EJ in 2012 (WEC, 2016). Furthermore, the accessible electrical potential range is about 35-200 GW (Stefánsson, 2005; Tester et al., 2005; Bertani, 2009) which is 16 times the current installed generation capacity, so the potentials for further utilisation is immense (WEC, 2016).

3. CONCLUSIONS

Geothermal energy is an energy source with numerous advantages and it has the potential to significantly contribute in the combat against human induced climate change. One of the main drives in increasing the share of geothermal energy in a country's energy system is governmental support and the implementation of domestic renewable energy policies which may also be supported or complemented by international assistance as appropriate (IPCC, 2012; Ouko and Ómarsdóttir, 2015). An established group of local experts and preferably privately owned equipment is also important for a successful development of geothermal resources and keeping the inherent costs down. However, realistically there is no single renewable energy source available today that will substitute fossil fuels and solve the emission problem. Therefore, a combination of renewable energy sources is needed to shift the focus from fossil fuels to meet the worlds growing energy demand. By relying on more than one energy source supports a more stable, reliable, and resilient energy environment because most renewable energy sources are not bound to one geographical location and this also provides security in which each country can produce their own energy and is less dependent on a few others.

Essentially, there are three main responses available in combating climate change, i.e.:

- Mitigation: the steps aimed to reduce the pace and magnitude of the changes by for example limiting emission of GHG by switching to energy sources with lower emissions such as geothermal resources
- Adaptation: the measures taken to reduce harm that results from unavoidable climate changes.
- Suffering: entails no action at all and simply accepting the effects of climate change.

The decision of how much is done of each depends on the commitment and determination of each country. Therefore, it is important that those countries that have the potential of utilising renewable energies, whether they are geothermal resources, hydro power, biomass, or other, do their upmost efforts in shifting their energy focus from fossil fuels to renewables and do their part in combating global climate change.

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