Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

The Geothermal Journey - A Case Example of Iceland and Kenya

Edna Achieng Ouko[1], Malfridur Omarsdottir[2]

4410 Nina lee Lane, Houston Texas, Zip 77092[1]

Orkustofnun, Grensásvegur 9, 108 Reykjavík, Iceland[2]

ednapet@gmail.com[1]

malfridur.omarsdottir@os.is[2]

Keywords: Renewable energy, geothermal, developing countries, environmental impacts, sustainability

ABSTRACT

The need for renewable energy has never been greater. The effects of global warming have forced many countries to seek alternative forms of energy production that are considered 'green' e.g. geothermal, solar and wind. However, it is widely believed that only developed countries can successfully harness these alternative forms due to the high initial costs and the challenging technologies associated with their development. Today, many countries have successfully developed geothermal energy resources. This paper discusses the journey of two such countries: Kenya and Iceland. During the 20th century, Iceland developed from being one of Europe's poorest countries, dependent on imported coal for its energy, to a country with a high standard of living where around 82% of its primary energy is derived from indigenous renewable sources such as geothermal and hydropower. Kenya, on the other hand, began geothermal exploration in the mid-20th century, and the first well was drilled in 1973. Today, the developing nation has an installed capacity of 311 MWe, with an additional 280 MWe planned for early 2015. The journey towards successful geothermal energy production in these countries has been challenging in many ways but also full of beneficial lessons. These lessons could be useful to other countries that are just beginning, or are yet to begin the 'geothermal journey'. This paper discusses such challenges, the technologies used, funding sources, impacts on the environment, both positive and negative, as well as the current status of geothermal development.

1. INTRODUCTION

Global warming has encouraged numerous countries to move towards renewable energy resources like hydro, solar, wind, and geothermal resources. However, the high initial cost and advanced technologies needed to change over from fossil fuels to renewable resources has discouraged many developing countries from taking that step. The example of how Iceland and Kenya successfully developed their geothermal resources and the challenges they overcame shows that other countries can follow in their footsteps and learn from their journey towards geothermal utilization.

Iceland and Kenya are endowed with abundant geothermal resources. However, Icelanders didn't start utilizing their full energy potential until the late 1970s. Until the 1970s, Iceland was a developing country but in a relatively short time it went from being one of Europe's most poorest countries, dependent on imported fossil fuels and coal for its energy, to a country with a high standard of living where most of its energy comes from indigenous renewable sources (NEA and MIC, 2006).

As the world's fossil fuel prices rose in the early 1970s, the Government of Iceland made the decision to switch from imported fossil fuels to geothermal energy to reduce heating and energy prices. Presently, 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. In fact, hardly anywhere else does geothermal energy play a larger role in providing a nation's energy supply (NEA and MIC, 2006), i.e. about 90% of domestic heating is by geothermal energy and about 30% of the electricity production (Orkustofnun, 2013).

In Kenya it took almost 30 years for the first geothermal field to be developed due to, among other things, long negotiation processes to secure funding required to build the power plant. Technological challenges also slowed the pace down which also can be contributed to funding issues as Kenyans depended mostly on hired rigs, which were extremely costly. Furthermore, the human capacity was inadequate as well as appropriate legal framework and government policies.

Switching over from fossil fuels to indigenous renewable energy sources is beneficial in many ways. First and foremost it is the economic benefits, or the avoided costs of importing foreign oil. Secondly, it is innovation and employment opportunities. Thirdly, it's regional development of the communities around the geothermal areas. Finally, the environmental impact is less as emissions of greenhouse gasses and other chemicals formed by burning fossil fuels are lower.

2. CHALLENGES OF GEOTHERMAL DEVELOPMENT

There are many issues that need to be taken into consideration before a geothermal area can be developed. Land permits, environmental impacts and societal affects are among some of the issues that need to be dealt with before drilling begins. Even after the development starts there are many things like reservoir pressure and temperature, production capacity, reinjection behavior, pipeline and power plant maintenance that need to be continuously monitored and therefore it is imperative to have experts on hand through all the development stages.

2.1 High initial costs

Many developing countries refrain from switching to geothermal resources as the development has very high starting costs. 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.

2.2 Complicated technologies

Countries that are looking into starting their geothermal journey often get discouraged due to the complicated technologies and the subsequent high initial costs. Frequently government agents are deterred by the long payback time of geothermal development as their election periods usually don't cover the whole development stage as generally geothermal power plants only start to generate profits around 12 years after drilling commences.

3. ICELAND'S GEOTHERMAL JOURNEY

3.1 Historical background

Iceland is endowed with abundant geothermal resources. However, Icelanders didn't start utilizing their full energy potential until the 1970s when the price of crude oil rose of about 70% worldwide in 1973 and again in 1979 (figure 1) which put pressure on the Government to react. The Government decided to change their energy policy and start utilizing the country's indigenous resources. A lot of emphasis was placed on the extensive geothermal resources. This reduced the importation of fossil fuels and therefore created savings for the national economy (or to term it more accurately *avoided costs*). It also reduced pollution significantly and now Iceland is considered among one of the cleanest and greenest countries in the world.

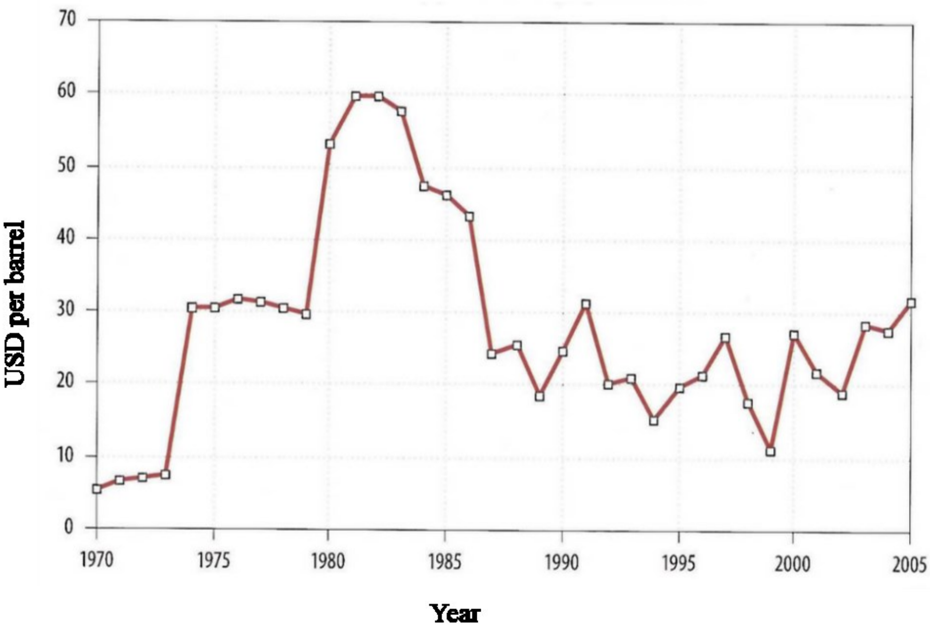

Figure 1: Average price of crude oil 1970-2005.

Up until the 1970s, Iceland was a developing country. Iceland 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 standard of living 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, 2006).

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, 2013).

However, the Icelandic Government had taken initiatives concerning energy much earlier, or in 1923, with the Inland Water Act legislation. It was regarded as the necessary and natural step for the Government to take the initiative in the utilization of domestic resources, by carrying out exploration for potential energy resources and participating directly in developing energy production and distribution facilities. The utilization of hydropower and geothermal power increased steadily during the past century, with the first experiments in using geothermal steam to create electricity starting in 1944 (Ragnarsson, 2006). Earlier the same year the parliament had been discussing the geothermal electric power generation and hot water production which led to the foundation of the State Drilling Contractors in 1945. In the years that followed, extensive geothermal studies and drilling were carried out in the south west of the country (Gudmundsson, 1983). At the same time the first geothermal specialist was recruited and modern exploration and exploitation began with great advancements in 1958, when the Government and the city of Reykjavík bought the first rotary drilling rig (Palmason, 2005). In the early 1960, Icelanders realized that the traditional fishing industry and agriculture would not be able to sustain reasonable economic growth and that new energy intensive industries such as aluminum smelting, had to be introduced (Gudmundsson, 1983).

The first commercial geothermal steam turbine was connected to a high temperature geothermal well in 1969 (Orkustofnun, 2006). Since 1998, the Icelandic Government has supported projects in finding usable geothermal sources in so-called cold areas, i.e. areas where there are no signs of geothermal sources on the surface. Over the last few years, several of these areas have received geothermal district heating systems with the help of new and more efficient methods in geothermal exploration (Ragnarsson, 2006).

Private enterprises have always been the both the importer and distributer of fossil fuels in Iceland, but the power production and distribution of electricity and geothermal energy have almost completely remained in the public domain or have been carried out by publicly owned corporations. Presently the Governmental part of geothermal research has decreased and privately owned energy companies are increasingly taking over.

Presently, Iceland is one of the world's most developed countries that gets most of its energy with its indigenous renewable energy sources. However, there were a number of stages along the way to prosperity. Switching to indigenous energy sources alone is not enough to push a nation up to the developed level. In Iceland's case it was most notably the mechanization of fisheries and agriculture, the development of a communications infrastructure followed by the advancements of electrifying towns and rural areas that was the additional driving force behind the country's development. For Icelanders though it was the creation of geothermal district heating services which was of most importance, as in enabled them to enjoy precious and inexpensive heat from geothermal resources (Orkustofnun, 2006).

3.2 Installed capacity

The installed capacity of geothermal power plants in Iceland for 2013 was 665 MW (24% of the total generation) and the electricity production was 5.245 GWh (29% of the total production). The utilisation was follows: space heating 45%, electricity generation 39%, swimming pools, fish farming and snow melting 4%, industry and greenhouses 2%. Total of 42.2 PJ (Orkustofnun, 2013).

3.3 Future plans

The geothermal energy that is currently being used for heating and other direct uses is considered to be only a small fraction of the country's potential. The potential for geothermal electricity generation is more uncertain. Around 80% of the electricity is used in the energy intensive industries such as the aluminum and ferrosilicon industries and an increasing demand for electric energy from these industries means that Iceland will have to continue to explore and develop its indigenous renewable energy resources (NEA and MIC, 2006).

According to energy predictions, general electric use in Iceland is expected to increase on average of 1.8% per year over the next 25 years or of a total of 56%. At the same time the total electric use, including the current and expected industrial use, is expected to double or increase at 3% per year on average. The use of oil within Iceland will only increase by 2% until 2030, but at the same time the use of oil for international transport will increase of about 50%. The utilisation of geothermal direct use for domestic heating will increase by 50% or 1.4% per year on average until 2030. According to the predictions, the share of domestic heating by geothermal energy will increase slowly over the coming years and will reach about 92% in 2030 (Ragnarsson, 2006).

Presently there are four geothermal projects under construction. However, the geothermal power supply in Iceland is plentiful, local demand if fairly stagnant. To find a passage for the surplus energy the power company Landsvirkjun has conducted extensive research into a submarine transmission to connect to Europe's electricity grid (GEA, 2013).

4. KENYA'S GEOTHERMAL JOURNEY

4.1 Historical background and future plans

Prospecting for geothermal resources in Kenya began in the mid-20th Century with most of the exploration data favoring the Olkaria area along the Kenyan Rift Valley. This led to the drilling of two exploration wells, X-1 and X-2, which were not promising. In 1960, prospecting stopped and only resumed in 1970 with funding from the United Nations Development Program (UNDP). Then well X-2 was tested. This marked the re-start of exploration drilling in 1973. A breakthrough occurred in 1975 with well OW-2 producing 3 MWe. More wells were drilled between 1975 and 1981 with surface exploration being sponsored by UNDP, British Geological Survey (BGS), Japan International Cooperation Agency (JICA), Ministry of Energy (MoE) and KenGen (Omenda, 2011).

Kenya has identified more than ten geothermal fields mostly located along the Rift Valley, as shown in figure 2.

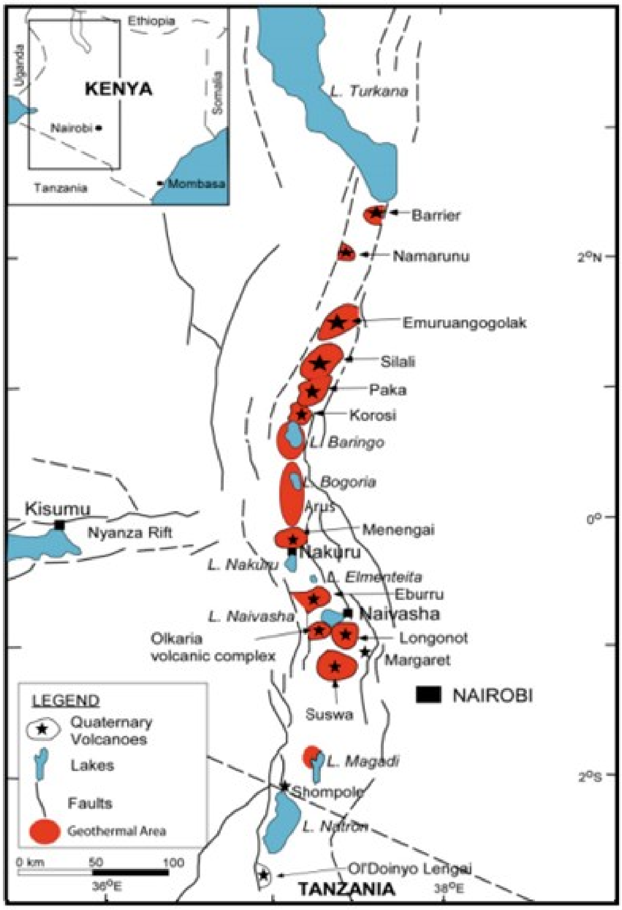

Figure 2: Identified geothermal fields in the Rift Valley in Kenya.

Recent studies concluded in Menengai, Korosi, Paka and Lakes Baringo and Bogoria geothermal prospects have revealed the possible existence of geothermal systems. High temperatures systems possibly exist at Menengai, Paka and Korosi while low to medium temperatures resources could be associated with the systems around Lakes Baringo and Bogoria. It is estimated that over 10,000 MWe can be generated from the geothermal systems in the Kenya rift (Omenda, 2011). It is notable that in Kenya, other than electricity production, geothermal water and carbon dioxide are used in an extensive complex of green houses for growing roses at Olkaria.

In the recent years, development of geothermal resources has taken a new turn in Kenya with the Government's Vision 2030, which envisions the country as a mid-income economy in the next 15 years. This has seen the formation of, amongst other institutions, the Geothermal Development Company (GDC), which is endeared with fast tracking the exploration and production of steam from various fields in Kenya. Exploration work is actively being undertaken in some more than fourteen fields in the country. Production drilling is already taking place in the Menengai Project with wellheads proposed to be installed in mid-2014.

4.2 Installed capacity

Currently, Kenya's installed capacity from geothermal power is about 311 MWe, with KenGen and Independent Power Producers (IPPs) generating 250 and 50 MWe, respectively (Albert Mugo, pers.comm.). Kenya's current effective installed (grid connected) electricity capacity is 1,429 MW. Electricity demand in Kenya has continued to grow steadily over the years and has put great pressure on the conventional sources of energy like hydropower, which is normally affected by weather changes. Electricity supply is predominantly sourced from hydro and fossil fuel (thermal) sources. This generation energy mix comprises 52.1% from hydro, 32.5% from fossil fuels, 13.2% from geothermal, 1.8% from biogas cogeneration and 0.4% from wind, respectively. Current electricity demand is 1,191 MW (~ 20% below the current demand) and is projected to grow to about 2,500 MW by 2015 and 15,000 MW by 2030. To meet this demand, Kenya's installed capacity should increase gradually to 19,200 MW by 2030 (Energypedia, 2014).

5. MAIN CHALLENGES FOR ICELAND

5.1 Technologies used, funding sources, impact on environment

Technologies were rather primitive in the beginning of geothermal development in Iceland due to lack of funding and interest. However, the country was able to develop its resources relatively quickly by the decision of the Government to switch to indigenous renewable energy sources. Therefore funding of geothermal projects has not really been an issue in Iceland through the years and project developers were able to buy the necessary equipment needed for the development. Most importantly though a group of highly qualified geothermal scientists was built up during those boom years which enabled the country to fully utilize and explore their capacity. In the early years of geothermal development the main challenges were silica scaling and corrosion in the pipelines. The Icelandic geothermal experts were however able to solve that problem through the 'trial and error' method and found out how to prevent oxygen corrosion by for example adding hydrogen sulphide to the water.

Even though geothermal energy is considered a 'green' energy source it has some negative environmental impacts nonetheless. In the initial stages of the development of geothermal sources the environmental impact was not a big issue. However, in recent years the public has become more aware of the environmental impacts of geothermal power plants and there is a lot of demand that all new projects have to undergo an Environmental Assessment Impact study to limit the detrimental environmental impacts of the development.

The impacts of geothermal development can be both negative and positive in fact. Environmental impacts will differ depending on the conversion and cooling technology used. In general, when a geothermal resource is utilized greenhouse gasses like H_2S and CO_2 are emitted into the atmosphere as well as ammonia, methane, and boron that are harmful to the local and broader environment (Kagel, et al., 2007). Geothermal power plants can have impacts on both water quality and consumption as hot water that is pumped from underground reservoirs often contains high levels of sulfur, salt, and other minerals. However, most geothermal facilities have closed-loop water systems, in which extracted water is reinjected into the geothermal reservoir after utilization to prevent contamination and land subsidence.

The amount of land required by a geothermal plant varies depending on the properties of the resource reservoir, the amount of power capacity, the type of energy conversion system, the type of cooling system, the arrangement of wells and piping systems, and the substation and auxiliary building needs (NREL, 2012). There is evidence that hydrothermal plants can lead to an even greater earthquake frequency. In May 2008 a series of earthquakes occurred in south Iceland due to reinjection of water causing some damage to buildings in a nearby town (Orkustofnun, 2011).

There is also a chance that hot springs and pools can disappear and some believe that power plants spoil the view and experience of outdoor recreational activities. Although in some cases power plants attract visitors interested in geothermal technologies. Switching to geothermal sources can also have a positive effect on public health. Geothermal spas have been popular as health spas to relax and to cure certain skin conditions like psoriasis. Furthermore, geothermal areas both natural and the power plants have in recent years become quite popular tourist attractions. (Ketilsson, et al., 2010). In addition to that it alleviates CO_2 emission significantly compared to fossil fuel use. Emissions of CO_2 due to domestic heating using geothermal sources was about 13.500 tons in 2008 compared to 2,14 million tons if domestic heating was done by oil. That's a saving of almost 2 million tons of CO_2 every year (figure 3) (Haraldsson et al., 2010).

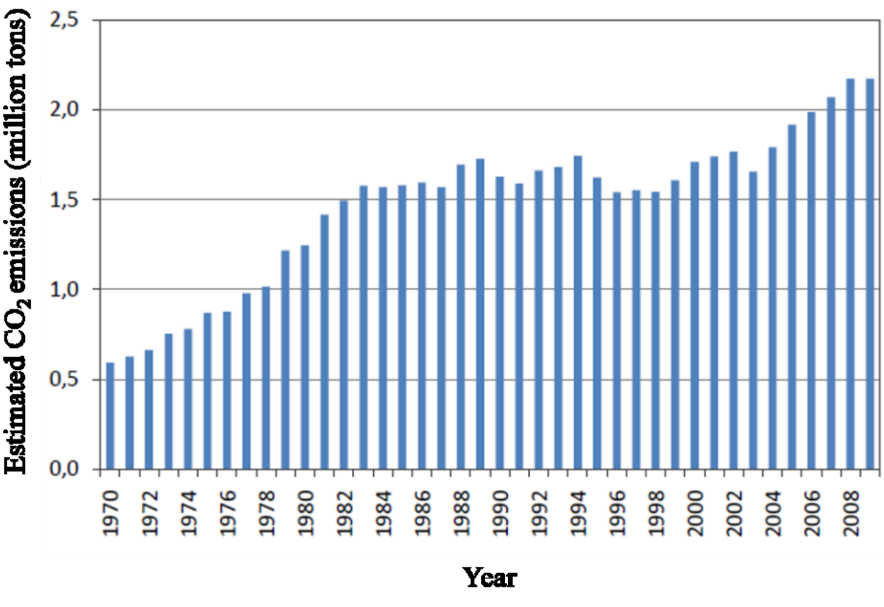

Figure 3: Estimated CO_2 emissions if oil was used for domestic heating instead of geothermal power in Iceland (Haraldsson et al., 2010).

5.2 Things that worked in Iceland's favor

The Icelandic Government played an important role in encouraging and supporting the development of geothermal resources. Mostly it involved initiating research on the nature of the geothermal systems and their utilization possibilities. This initiative first began in the 1940s and the main purpose was to acquire general knowledge of the resource to be able to use it to improve the national economy. This initiative turned out very successfully especially in terms of domestic heating. This success can be attributed mostly to the expert knowledge that was built up by decades of geothermal exploration at the National Energy Authority which later split into Iceland GeoSurvey. Recently the Governmental part of geothermal research has decreased and privately owned energy companies are taking over more and more the necessary research of geothermal areas which they are already utilizing or plan to utilize in the future. The Government has also supported geothermal utilization with an energy fund which has provided many loans for geothermal explorations over the last decades. In cases where drilling results have been unsuccessful compared to expectations, or the costs have been more than originally planned, the repayments of the loans have often been dropped (Ragnarsson, 2006). Therefore it is safe to say that the support of the Icelandic Government has been a vital part in the success of geothermal exploration in Iceland.

Iceland is one of the world's most successful countries in utilizing and developing geothermal resources. The country is in a unique position to lead other countries by example. One of the most important factor in the development is the social factor and therefore the energy companies are obliged to do their work towards higher technological development and sustainability on good terms with the environment and the public (Orkumal, 2006). The main prerequisite for Iceland's success was and is the full support of both the Government of Iceland and the Icelandic people. In addition, it is important that geothermal developers utilize the resources in an environmentally and socially friendly way. For a successful geothermal development a good and understanding cooperation between ministries, geothermal professionals, advising agents, energy companies, and last but not least the public is essential. The Icelandic public has in general a positive attitude towards geothermal development. One of the best examples is the formation of the Blue Lagoon. It could have been classed as an environmental accident and caused a major public uproar, but with the innovation of energy companies and the public's positive attitude towards geothermal pools and development it was turned into the country's most visited spas (Orkumal, 2006). To gain and keep the public's support it is important to design geothermal power plants and drill sites in such a way that they cause the least disturbance to the environment and the people.

6. MAIN CHALLENGES FOR KENYA

6.1 Technologies used, funding sources, impact on environment

Today, Kenya is the epicenter for geothermal development in Africa. This development has come with numerous challenges for the country. The main challenge has been funding. The first geothermal field to be developed, Olkaria I, took almost 30 years to develop. One of the primary reasons for the slow pace of development was the long negotiation process to secure the large funding required to build the actual plant. As discussed by Ngugi, the main challenge is not the availability of funds, but the bankability of the projects. (Ngugi, 2012a).

Technological challenges have also slowed down the pace of Kenya's developments over time. The country mainly depended on hired rigs, which were very costly, resulting in sky rocket costs of production. Recent technologies have made it possible to develop geothermal on a much more aggressive timescale, and at a lower the risk for investors. One such technology is the use of wellhead generators, which allow early generation of power before a conventional power plant is built (Cornel Ofwona, pers. comm.).

The human capacity has been a challenge for Kenya over the years. The country did not have appropriate institutions for the development of local capacities. This saw Kenya depend mainly on expensive foreign expatriate for capacity. Kenya has recently embarked on massive training of local capacity through various forums. One such forum is the United Nations University-Geothermal Training Program in collaboration with the Government of Iceland. Over 550 specialists have been trained in the programme which has in addition supported almost 40 Masters Students and one PhD candidate from Kenya through Fellowships and is currently supporting two PhD candidates from Kenya. Today, Kenyan geothermal professionals are providing their expertise to other African Countries such as Rwanda, South Sudan, and Saudi Arabia among others.

The lack of appropriate legal framework and adequate government policies to govern the development of geothermal resources in early years also greatly hindered the geothermal journey for Kenya. Only in the early 80s' did Kenya enact the Geothermal Resources Act of 1982 and its supplementary legislation of 1990. This was later followed by the Environmental Management and Coordination Act (EMCA) of 1999, with its associated regulations, which are directly concerned with geothermal development (Mwangi-Gachau, 2011). The country has recently passed the Energy Bill 2012 and Energy Policy 2012 which explicitly discuss the development and utilization of the resource (Kenya Law Reports, 2012).

6.2 Things that worked in Kenya's favour

Since 1996, Kenya has been undertaking power studies that are frequently updated culminating into a 20 years national Least Cost Power Development Plan (LCPDP). The plan showcases the aspiration of Kenya Vision 2030, which aims to transform the country to middle income economy by the year 2030. The LCPDP is prepared under the Ministry of Energy, coordinated by the Energy Regulatory Commission with participation by key National agencies including staff from the Ministry of Energy, the national power utility, Kenya Power & Lighting Company Limited, the leading power generator, KenGen, GDC and Kenya National Bureau of Statistics (Ngugi, 2012b). This plan has seen the country refocus on its energy needs thus channelling appropriate funds and human capacity towards these projects

7. CURRENT STATUS OF GEOTHERMAL DEVELOPMENT

7.1 Iceland

The energy market in Iceland is in some respect unusual as a large amount of geothermal water is sold for space heating purposes (43%). Presently Iceland is ranked in the top ten countries with 665 MW (figure 4).

7.2 Kenya

Today, Kenya also features in the global top ten in terms of geothermal production, as illustrated by the IGA (2013) (figure 4).

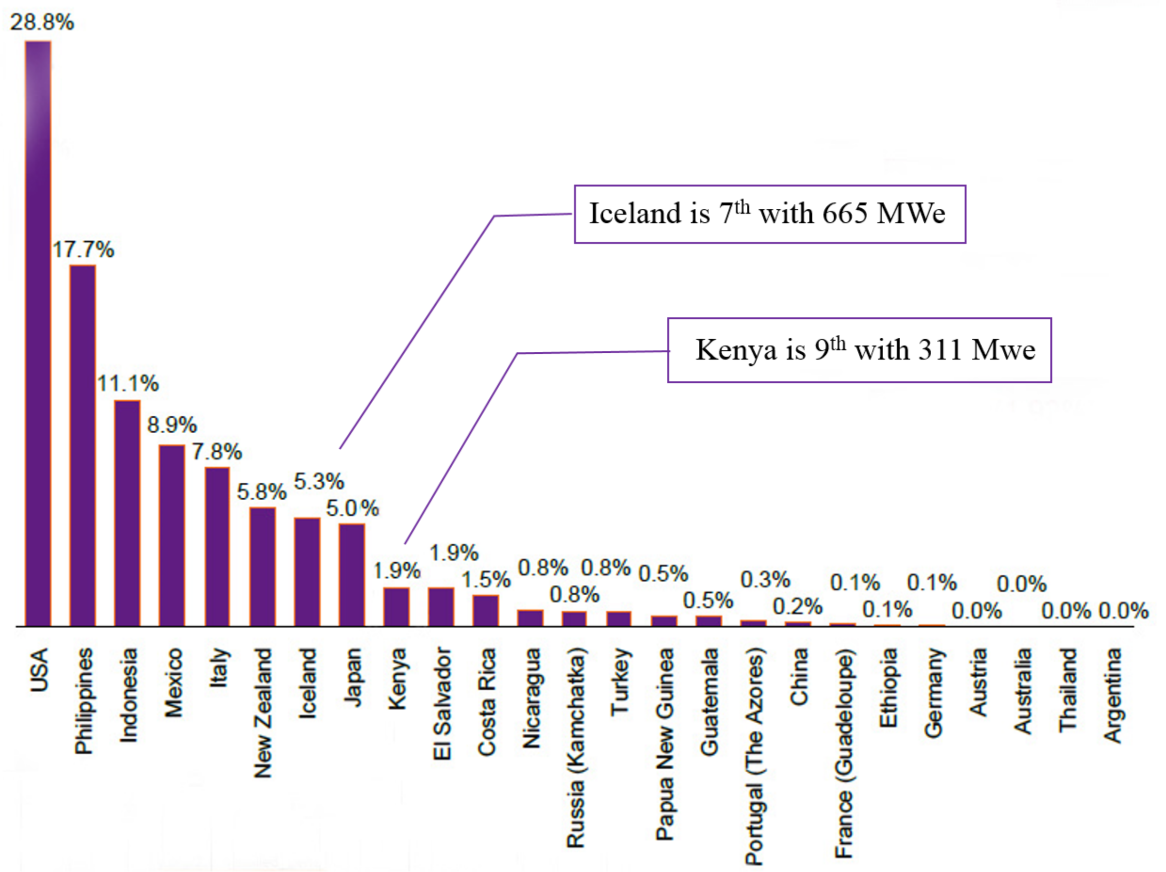

Figure 4: World geothermal installed capacity. Of the total 10.800 MWe, Iceland is in 7th place with 655 MWe, and Kenya is in 9th place with 311 MWe (TMO, 2013).

8. CONCLUSIONS

The benefits of changing from fossil fuels to geothermal energy are numerous. For example in Iceland the main benefits are:

- Avoided costs of importing foreign fossil fuels and savings in domestic heating expenditures
- Innovation and employment opportunities in the industry sector, tourism, greenhouse farming and the energy industry itself
- Regional development
- Environmental due to lower emissions of greenhouse gasses

The indigenous geothermal resources of Iceland and Kenya are an important resource that is more environmentally friendly than fossil fuels, has a good impact on the societies, and the national economies. For Iceland the economical savings are considerable as the yearly expenditure of purchasing and importing oil for domestic heating would be 50-80 million ISK. Utilizing indigenous energy resources increases energy safety and protects nations from variable exchange rates and price fluxes of international oil markets. Since the first oil price peak in 1973, the price of oil has fluctuated significantly but the real cost of using geothermal sources has been stable throughout. The cumulative savings in Iceland of utilizing geothermal sources for domestic heating instead of oil is considered to be about 1330 million ISK for the years 1970-2009 not to mention the other savings like electric generation, industry, fish farming, tourist attractions, spas, and greenhouses.

The success of geothermal utilization in Iceland can be attributed to a few main reasons:

- The international oil price peaks in the 1970s pushed the Government to seek alternative sources
- A strong and continuous Governmental support
- An indigenous accumulation of expert knowledge
- Relative proximity of communities to geothermal areas

Geothermal resources are a valuable natural asset that should be used for the good of the nation but it is important to keep in mind that the geothermal resource is not unlimited so knowledge of the production capacity of the geothermal system is essential but that is only acquired through extensive predevelopment research and good surveillance after development begins. By using the geothermal resource in a sustainable and sensible way it can provide energy to current and future generations with considerable savings to the economy and less negative impact on the environment compared to fossil fuels.

First and foremost, for a successful and fast development of geothermal resources, it is of upmost importance that governments fully support their country's development and utilization both in regards to funds and legal framework. Only then can countries utilize their geothermal resource capacities to the full. When countries are able to utilize their indigenous energy resources such as geothermal and hydro it enhances the security and independency and increases economic opportunities in the various economic sectors. The effects of utilizing geothermal resources can therefore be considered to be positive for the social, economic, and environmental factors. Although the utilization can also have negative environmental impacts then they are much less than when using fossil fuels.

Data compiled from a variety of sources point to geothermal energy as an environmental option for new power generation that is far better than other energy sources such as fossil fuels. In addition, geothermal is as environmentally friendly as most other renewable sources, while simultaneously offering reliability and a source of base load power that is unique among most other renewable options available. Geothermal energy can provide the clean, reliable, and plentiful renewable energy resource that is needed in the world today. However while only a fraction of its potential is currently being used, geothermal energy can substantially contribute to the energy needs of the twenty-first century.

REFERENCES

Energypedia: Kenya Energy Situation (2014), *Energy Pedia webpage*: https://energypedia.info/wiki/Kenya_Energy_Situation.

GEA: 2013 Geothermal Power – International Market Overview, *Geothermal Energy Association,* (2013), accessed May 28th 2014, http://geo-energy.org

Gudmundsson, J. S.: Geothermal electric power in Iceland – Development in perspective, *Energy*, **8** (1983), 491-513.

Haraldsson, I. G., Thorisdottir, Th. H., and Ketilsson, J.: Efnahagslegur samanburður húshitunar með jarðhita og olíu árin 1970-2009, *Orkustofnun*, Reykjavík (2010), OS-2010/4.

Kagel, A., Bates, D. Gawell: A Guide to Geothermal Energy and the Environment, *Geothermal Energy Association*, (2007), accessed May 26th 2014, http://www.geo-energy.org/pdf/reports/AGuidetoGeothermalEnergyandtheEnvironment10.6.10.pdf

Kenya Law Reports: *Kenya Law Reports* (2014), webpage: www.kenyalaw.org/kenyalaw

Ketilsson, J., Björnsson, A., Sveinbjornsdottir, A. E., Palsson, B., Bjornsson, G., Axelsson, G. and Sæmundsson, K.: Sjálfbær vinnsla og nýting jarðhita – Álitsgerð faghóps, *Orkustofnun*, Reykjavík (2010).

Mwangi-Gachau, E.: Legal requirements for geothermal development in Kenya, *Paper presented at "Short Course VI on Exploration of Geothermal Resources"* organized by UNU-GTP, KenGen and GDC, Naivasha, Kenya, October 27 - November 18, 2011, (2011).

NEA and MIC: Geothermal development and research in Iceland, *National Energy Authority and Ministires of Industry and Commerce*, Reykjavík (2006).

Ngugi, P.a: Financing the Kenya Geothermal Vision, *Presented at "Short Course on Geothermal Development and Geothermal Wells"*, organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 11-17, 2012, (2012).

Ngugi, P.b: Planning Large Scale Geothermal Drilling in Kenya, *Presented at "Short Course on Geothermal Development and Geothermal Wells"*, organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 11-17, 2012, (2012).

NREL: Renewable Electricity Futures Study, *National Renewable Energy Laboratory*, Golden, CO, (2012).

Omenda, P.O.: Geothermal exploration in Kenya, *Paper presented at "Short Course VI on Exploration for Geothermal Resources"*, organized by UNU-GTP, GDC and KenGen, Lake Naivasha, Kenya, October 27 - November 18, 2011, (2011).

Orkumal: Jarðhiti 2006, *Orkustofnun*, Reykjavík (2006).

Orkustofnun: Energy in Iceland - Historical Perspective, Present Status, Future Outlook 2nd edition, *Orkustofnun*, Reykjavík (2006).

Orkustofnun: Smáskjálftar af völdum niðurdælingar við Húsmúla við Hellisheiðarvirkjun, Minnisblað, *Orkustofnun*, Reykjavík (2011).

Orkustofnun: Orkutölur 2013, *Orkustofnun*, Reykjavík (2014)

Palmason, G.: Jarðhitabók – Eðli og nýting auðlindar, *Hið íslenska bókmenntafélag*, Reykjavík (2005).

Ragnarsson, A.: Orkunotkun á Íslandi, Orkuþing 2006, *Samorka* (2006), 45-57.

TMO: Geothermal energy, (2013), website: http://www.geothermal-energy.org/226,installed_generating_capacity.html