

# Hydrogen Sulfide Emission and Policy Barriers to the Sustainable Development of the Olkaria Geothermal Power Plant Facilities in Kenya

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## Abstract

Kenya is ranked first in the world in the percentage of geothermal energy in the national share of energy production. This is an amazing feat of renewable energy adoption for a developing nation, something that is not expected to diminish, as the nation's Vision 2030 development plan outlines expanding the total geothermal energy capacity over the next decade. This development has positive implications for Kenya, particularly as its other most-used renewable energy source, hydroelectricity, is becoming increasingly unreliable as a result of climate change-induced drought. One of the centers of Kenyan geothermal development is the Olkaria region. This is a geologically active region in Hell's Gate National Park. To date, five of the facilities, aptly named Olkaria I through V, have been constructed in the park, with a further three under construction or in advanced stages of planning. Furthermore, the existing facilities continue to be upgraded and expanded. This has made Olkaria the largest supplier of geothermal energy in the region. Now, the Kenyan government has worked to facilitate foreign investments to enter the Kenyan geothermal sector, leading to significant outside investor interest. This foreign capital will help towards the Vision 2030 target.

However, although from a developmental perspective these events are positive, some concerns are warranted, particularly regarding the emission of hydrogen sulfide (H<sub>2</sub>S) gas. This gas is toxic to human as well as plant and animal life in sufficiently high concentrations and a health concern as well as a general nuisance in lower concentrations. Reviewing the available literature has shown a lack of independent and verifiable measurements of H<sub>2</sub>S at the Olkaria facilities. Meanwhile, regulatory standards in Kenya as well as those maintained by the main developer of geothermal power, KenGen, short for the Kenya Electricity Generating Company, are based on WHO guidelines. These guidelines have been called into question by medical professionals. As such, other nations that are either active in geothermal development or have advanced industries that also release H<sub>2</sub>S tend to maintain their own regulations below WHO standards.

Countries that have implemented such regulations have shown innovation to limit H<sub>2</sub>S emissions by producing industries via the adoption of technological solutions.

This paper concludes that implementation of the currently available technologies is not too costly or infeasible. However, the fact that Kenya, unlike several other developed countries, follows WHO guidelines concerning H<sub>2</sub>S emission control is the main obstacle in preventing the adverse impact on human health and on the environment.

**Keywords:** Geothermal power plants, H<sub>2</sub>S emission, Olkaria, Geothermal regulations, Environmental safety standards

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## **I. Introduction**

Today, the Republic of Kenya, a nation of nearly 50 million on the East Coast of Africa, is considered one of the fastest-growing economies not just in the region, but among all developing nations. This economic growth has awoken many foreign investors to this land of new opportunities. In as much as it is a universal economic constant, the more an economy develops, the more it hungers for energy resources. However, the national government as of yet lacks the capacity and resources to keep up with the growth in demand and has, therefore, not wishing to stilt economic growth, opened the energy sector to foreign investment. Without skipping a beat, many international companies and organizations have now started to invest in the Kenyan power generation sector thereby becoming one of the most successful nations in attracting renewable energy investments (Kazimierczuk 2018, p.434).

Among the myriad sources of clean and renewable energy available for the powering of its economy, Kenya is blessed by abundance. The capital city Nairobi receives significant solar radiation (Onyango & Ongoma 2015); the 1,420-kilometer coastline in the east and White Highlands in the west offer some of the highest potential wind energy in all of Africa (Kazimierczuk 2018, p.435; Food and Agriculture Organization of the United Nations (FAO) n.d.); and the Great Rift Valley, running from the White Highlands north to Lake Turkana, is one of the premier places to access the geothermal energy of the geophysical processes at our earth's interior, with Kenya possessing a greater energy potential than the demand of nearly any of the nations on the continent (Merem et al. 2019). In particular, the latter was adopted as an opportunity by the Kenyan government as one of their best bets for sustainable growth, leading to several projects aimed to set up geothermal power plants in the Olkaria region, a region located in the Rift Valley (Adaramola 2014).

As the aforementioned rapid growth needs to be sustainable, this paper focuses on the sustainability aspects of geothermal power plants. After providing an overview of the Kenyan energy sector and an outline of the Olkaria facilities, we will have a critical view of the recent developments regarding specifically their environmental impacts. Olkaria is located inside Hell's Gate National Park as it fittingly called, on land that has been used by the pastoralist Maasai community and various kinds of wildlife since ancient times. As such, there have been some tensions and conflict between the Maasai community and the developers of the Olkaria power plants in recent years. One particular issue worth further scrutiny is the environmental impacts of releasing H<sub>2</sub>S into the atmosphere.

Neither Kenya's legislature nor its regulatory bodies have adopted any specific restrictions regarding H<sub>2</sub>S emissions, opting instead to follow guidelines set out by the World Health Organization (WHO). This paper aims to investigate why following these guidelines alone cannot guarantee the negation of severe health and environmental impacts, particularly in cases involving the large-scale concentration of geothermal facilities such as those found in states with the wide adoption of geothermal power. As such, we will outline some of the specific environmental concerns of H<sub>2</sub>S emissions by contrasting WHO guidelines with the regulatory standards of OECD members active in the geothermal industry, allowing us to formulate experience-based recommendations for the Kenyan geothermal sector.

## **II. Significance of Geothermal Power Generation in Kenya**

The energy sector in Kenya comprises its energy and electricity production, consumption, and imports. As a result of Kenyan economic growth, so too is the energy sector rapidly expanding. Today, energy production is divided among several renewable and non-renewable resources. The largest share is made up of geothermal at 47.1%, followed by hydro at 38.9%, and diesel at 12.4%. Wind makes up a tiny 1.04% share while the remaining 0.63% is purchased from the Uganda Electricity Transmission Company (KPLC 2020). The combined total effective grid-connected capacity was 2712 MW in 2018. Although lower than initially projected, this number is expected to grow to 7200 MW by 2030 (Obulutsa & Fenton 2019). Not only to meet the demands of the future but also to diversify the nation's energy mix, the Vision 2030 Strategy outlines expanding the usage of various forms of energy. Unfortunately, the largest-growing segments in this plan are composed of non-renewable resources, particularly nuclear, set to make up 19%, and coal at 13%, of the energy mix in 2030 (see figure 1).

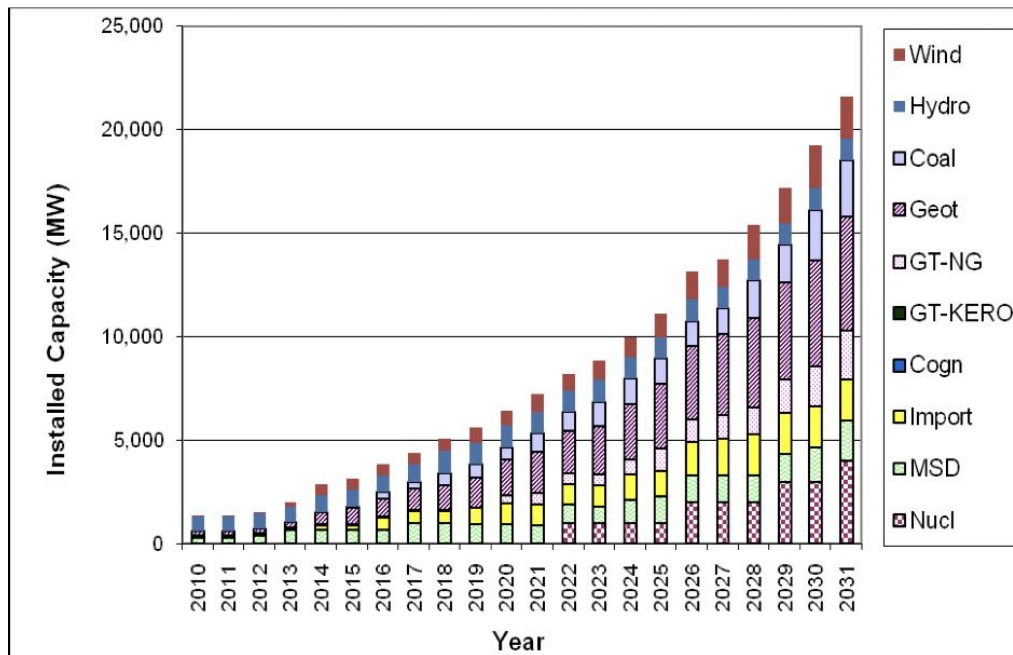


Figure 1. Projected energy mix by generation type as outlined in the Vision 2030 Strategy. (Source: Kianji 2012)

Although the expansion of non-renewable resources is part of Kenya's development plans, the nation is still aiming for climate-compatible economic development and as such has launched several initiatives to tackle issues of poverty, development, and climate simultaneously. This climate-compatible development (CCD) approach, developed by the Ministry of Environment and Mineral Resources (MEMR) in 2012, seeks to integrate CCD thinking within the frame of national development strategies. In particular, wind and geothermal are targeted to see significant growth in terms of installed capacity. By 2031, the expected geothermal capacity would exceed the entire nation's total 2020 capacity at 5530 MW. This is a planned growth of geothermal resource utilization of a massive 2,793% between the period 2012 to 2031, going from 198 MW to 5,520 MW (Kianji 2012). This would see geothermal energy maintaining its lead as the paramount source of Kenyan energy.

Geothermal power has many advantages over other forms of renewable energy. It is not affected by weather; resource depletion is not a major factor; and it is generally considered carbon neutral. Given such benefits and the abundance available to Kenya due to its geographic location, these developments make sense. Specifically, as the second-most-utilized renewable resource, hydroelectricity is becoming increasingly unstable as a result of climate change-induced drought (Micale et al. 2015, p.3). However, there are also some disadvantages such as the high barrier of entry in the form of high development costs, high

maintenance costs, and the adverse impact on tourism resources. Most notably for the purposes of this article is the environmental damage as a result of H<sub>2</sub>S emission into the atmosphere.

Before we investigate H<sub>2</sub>S emissions at the Olkaria facilities, it is important to first understand the primary actors involved in developing Kenya's geothermal industries. KenGen, short for the Kenya Electricity Generating Company, is the largest power production company by market share at approximately 75%. Furthermore, KenGen is a majority state-owned enterprise with 70% of shares in the hands of the national treasury (KenGen 2020a, p.2). Meanwhile, the company managing customer relations for distribution to consumers, handling all billing and metering, is the Kenya Power and Lighting Company (KPLC). It is to KPLC that KenGen sells its power through power purchasing agreements (PPAs). Meanwhile, KPLC contracts the Kenya Electricity Transmission Company (KETRACO), which handles the distribution over its transmission network, allowing KPLC to reach its customers and Kenya to sell its renewable energy to neighboring states.

Facilitating geothermal developments is the Geothermal Development Company (GDC), wholly owned by the Kenyan state. It is this company that both develops and exploits geothermal resources, selling its services to KenGen and other independent power producers or IPPs (GDC 2017). This includes selling the geothermally heated steam for the geothermal power plants in the Olkaria region, the details of which will be outlined in the following section. GDC also promotes alternative sustainability measures related to geothermal power including agricultural processes such as greenhouse heating, the drying of grain, and milk pasteurization as well as general-purpose heating applications.

Another significant player is Ormat Technologies. While KenGen owns the majority of the Olkaria facilities, this US firm operates the Olkaria III facility through their subsidiary OrPower Inc., making it the largest private power generator in the country (Richter 2019b). In line with the nation's Vision 2030 Strategy, such private sector participation is deemed to be necessary to raise the required capital for economic development. Via its own 20-year PPAs, the power generated by OrPower is also sold to KPLC (US Securities & Exchange Commission 2007, p.2; Micale et al. 2015, p.8). Beyond the Olkaria III facility, which is alternatively known as OrPower 4, Ormat also partners in projects for other facilities such as the Menengai I Geothermal Power Station, also known as OrPower 22. Ormat Technologies is a significant player in the geothermal industry with facilities in places such as California, Turkey, and New Zealand.

Altogether, the above stakeholders have contributed positively to Kenyan development as the quality of the electricity supply, measured by the frequency of interruptions and the fluctuations in voltage, is among the best in the region (World Bank 2017). According to the International Energy Agency, Kenya is nearing total universal energy access for all citizens (IEA 2020) with the 2018 Kenya National Electrification Strategy (KNES) having set a universal electricity access target for 2022 (Obulutsa & Fenton 2019; World Bank 2018).

### **III. Development of the Olkaria Geothermal Field: International Investments**

After an overview of the main players in power distribution, it is critical to understand the development process of the geothermal power plants in Kenya. As a result of the need for high initial investments, different international organizations and investors have played a significant role in developing the Olkaria power plants following their financial or political interests in the project. Furthermore, we should present a thorough site description: In the southern part of Kenya's Nakuru County, approximately 120 kilometers northwest of Nairobi, located directly south of the Naivasha Lake and Ololdien Bay lies Hell's Gate National Park with the villages of Kamere, Kongoni, and Watalii being the closest inhabited areas. Hell's Gate National Park roughly corresponds with the Olkaria volcanic complex that formed about 20.000 years ago (see figure 2). The last known eruption took place around 1770 CE (Smithsonian Institution 2013). The site is currently home to five geothermal power stations, aptly named Olkaria I through V, which each comprises several units.

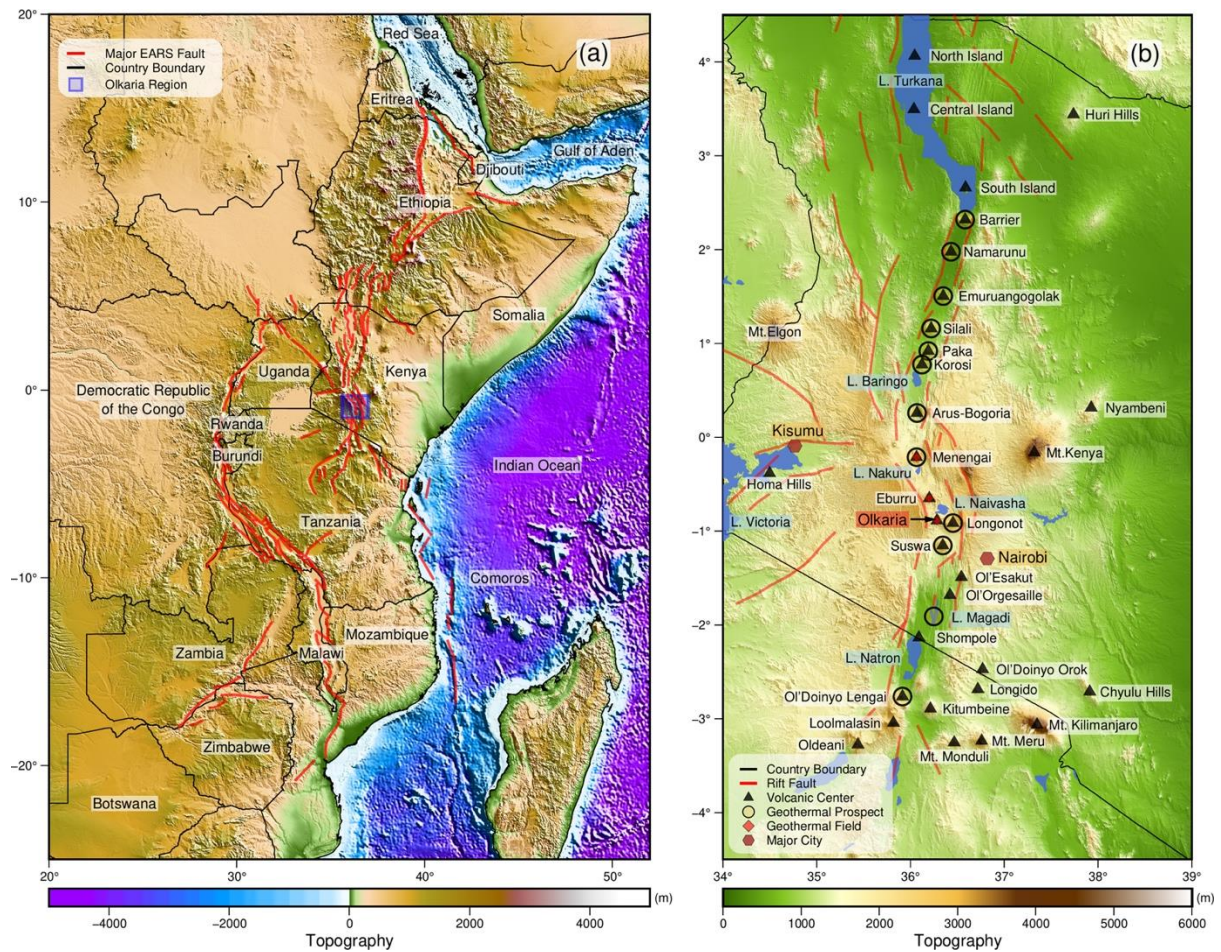


Figure 2. Location of the major fault lines (a) in Eastern Africa and the Great Rift Valley (b) in Kenya. The Olkaria site is highlighted just south of Naivasha Lake.  
(Source: Fadel et al. 2021)

The exploitation of the geothermal resources at Kenya's oldest geothermal power plant started in 1981 with the 15 MW Olkaria I plant, which was later expanded to 45 MW. By 2015, an additional 140 MW capacity was added via two new units, bringing the total to five units for Olkaria I (GeoSteam Services 2015). In 2018, the Japan International Cooperation Agency (JICA) provided a loan of 95 million USD to allow for the refurbishment of Olkaria I's units 1, 2, and 3, upgrading their capacity to 50.7 MW, bringing the total capacity of Olkaria I to 190.7 MW (Otuki 2018; JICA 2018), thereby nearly exceeding 2012's installed capacity with just a single plant (Kianji 2012).

Olkaria II was conceived around the same period as Olkaria I. However, problems with accessing adequate funding resulted in significant delays. In 2000, the project was restarted following funding by the World Bank, European Investment Bank (EIB), and the German development bank KfW, eventually



completing with a combined 70 MW capacity in 2003. The plant was expanded in 2010 with an additional 35 MW unit financed by the EIB, International Development Association (IDA), and French Development Agency as well as KenGen (Richter 2010).

Although generally referred to as Olkaria III, this plant actually started operation three years prior to Olkaria II in 2000. This plant is not owned by KenGen, but instead by OrPower Inc. It is made up of four units of varying capacity from one unit of 48 MW, one of 38 MW, to two units of 26 MW (Renewable Energy World 2016; Micale et al. 2015, 6; Ormat 2011). Being the first privately financed geothermal project in Kenya, the initial investment was shouldered entirely by Ormat Technologies. Once the viability of the project had been sufficiently proven, the project was refinanced and expanded, adding the two 26 MW generators, and undergoing a major upgrade of Unit 1, which was completed in January of 2009, bringing it to its current capacity from the 8 MW at its inauguration (UN 2018).

The development of Olkaria III was made possible through significant facilitation by the Kenyan government via its “Build, Own and Operate” scheme and risk-mitigating incentives. Also, KenGen supported the project via data sharing and the donation of the equivalent of 8 MW in geothermal wells to bootstrap the project. Experience gained from Olkaria III has contributed to the development of the aforementioned state-owned Geothermal Development Company, which now assumes the role that KenGen provided for Ormat for other potential IPPs (Micale et al. 2015). Although perhaps as of right now the exception in the Olkaria region, the project nevertheless indicates the potential of private investment in geothermal resources.

Olkaria IV is a 140 MW plant commissioned in 2014 that was financed by the World Bank, EIB, and KenGen. Consisting of two identical generator units with a nameplate capacity of 70 MW, the facility was designed as a more modern version of the Olkaria II plant (KenGen 2010).

Another JICA-financed project is the Olkaria V plant, the most recently completed plant that, according to a tweet by KenGen, started operation of its first unit in June of 2019 at 86.6 MW (KenGen 2019). This capacity was then roughly doubled with the activation of the second unit in October of the same year. Made possible by a JICA loan of 387 million USD, the largest loan ever granted by JICA in Japanese ODA history, the plant is currently the most modern active installation. This loan was provided on a concessional basis with a 0.2% annual interest rate and a 30-year repayment period (JICA 2018; Njini 2016).

At the time of writing, the next iteration, the 140 MW Olkaria VI, is under construction and is slated to be completed in 2022. This plant will be the first public-private partnership undertaken by KenGen. Starting with the PPP Act of 2013 and the promulgation of regulations in 2014, Kenya created the framework necessary for the next format to attract the necessary capital to develop its geothermal resources (KenGen 2019, pp.4-14). For the Olkaria VI project, similar agreements are outlined as in the case of Olkaria III: a 25-year steam supply agreement with KenGen and a 25-year PPA with KPLC. To facilitate this under a PPP, the project outlines a special-purpose vehicle (SPV), in which KenGen can have a maximum ownership stake of 25%. Furthermore, KenGen acquires the land lease agreement from the Kenyan Wildlife Service, which it then sub-leases to the SPV (KenGen 2019, pp.5-6). As of November of 2020, the interested parties to enter the PPP agreement and invest a majority of stake in the SPV are Ormat Technologies, Itochu Corporation, Sumitomo Corporation, and Enel Green Power (Richter 2020).

Beyond the facilities Olkaria I through VI, there are two more in the planning stages, Olkaria VII and VIII. Both are expected to be 140 MW facilities with two units each similar to Olkaria IV and V. VII is tentatively projected for 2022 with VIII to be completed at a later date. It is expected that developments will not halt as a projected 10,000 MW potential lies beneath the surface of the Great Rift Valley (Rotich 2016, p.6; Micale et al. 2015, p.3).

Table 1. Overview of the geothermal power plants in the Olkaria region

Power Plant	Owner	Unit	Date of Commissioning	Output	Notes
<b>Olkaria I</b>	KenGen	Unit 1	June 1981	50,7 MW	Initially, units 1, 2, and 3 were rated at 15 MW.
		Unit 2	November 1982	50,7 MW	
		Unit 3	March 1985	50,7 MW	
		Unit 4	December 2014	75 MW	
		Unit 5	February 2015	75 MW	
		Unit 6	Projected 2021	83.3 MW	
<b>Olkaria II</b>	KenGen	Unit 1	2003	35 MW	Construction of units 1 and 2 began in 1986 but was delayed due to a lack of funding.
		Unit 2	2003	35 MW	
		Unit 3	May 2010	35 MW	
<b>Olkaria III, aka OrPower 4</b>	Ormat Technologies	Unit 1	2000	48 MW	Olkaria III is the only plant on site not owned by KenGen. However, according to the power purchase agreement, KenGen is the buyer.
		Unit 2	2013	36 MW	
		Unit 3	2014	26 MW	
		Unit 4	February 2016	26 MW	Unit 1 originally had a generation capacity of 8 MW, before being upgraded in January 2009.
<b>Olkaria IV</b>	KenGen	Unit 1	October 2014	75 MW	In October of 2020, KenGen issued a procurement notice seeking a turbine upgrade to 85 MW at units 1 and 2.
		Unit 2	2014	75 MW	
<b>Olkaria V</b>	KenGen	Unit 1	June 2019	86.6 MW	

		Unit 2	October 2019	86.6 MW	
<b>Olkaria VI</b>	Public-Private Partnership		Projected 2022	140 MW	Potential PPP joint venture partners are Ormat Technologies, Itochu Corporation, Sumitomo Corporation, and Enel Green Power.
<b>Olkaria VII</b>			Projected 2023	140 MW	
<b>Olkaria VIII</b>			Planning stage	140 MW	

Compiled by the authors from the following sources: KenGen 2020 B; Richter 2020; Richter 2019 A; Richter 2018; Otuki 2018; Micale et al. 2015.

#### IV. Controversies Regarding H<sub>2</sub>S Emission Impacts in the Olkaria Region

The Olkaria site has become one of the largest producers of geothermal power in the world, bringing Kenya as a developing nation to the forefront of renewable energy development. Compared with fossil and nuclear energy resources, geothermal power plants are considered to have only a minor environmental impact. The main environmental concern is the discharge of non-condensable gases into the atmosphere, most notably hydrogen sulfide (H<sub>2</sub>S), carbon dioxide (CO<sub>2</sub>), and methane (CH<sub>4</sub>) (Ndeti 2010, p.442).

Of the geothermal byproducts, H<sub>2</sub>S is considered to be the single most significant health concern related to geothermal energy development due to the risk of it causing several physiological responses (Reiffenstein et al. 1992; WHO 2000). H<sub>2</sub>S is a colorless, flammable gas, with a distinctive smell of rotten eggs at low concentrations. It is toxic in higher concentrations when it becomes undetectable by humans (Irene 2009). Releasing this gas during the drilling process and later after steam utilization has been completed is one of the main sources of this type of air pollution and needs serious consideration both from the environmental protection perspective and its impact on the workplace of the personnel and the local communities living nearby.

The effects of H<sub>2</sub>S are toxic to the human body, though the actual results are dependent on the dosage. As such, these effects can be grouped into three classifications, namely acute, subacute, and chronic. When a person is exposed to a large amount of H<sub>2</sub>S, exceeding 1,000 ppm, the acute response is shown in the nervous system via the inhibition of cytochrome oxidase. The effect on this enzyme is similar to that of carbon monoxide; the enzyme fails to function as intended leading to cell death via cellular asphyxiation (Nicholls et al. 2013). The pace of breathing will increase, expelling carbon dioxide eventually leading to respiratory inertia, and without treatment to suffocation and potentially death. If the exposure dosage is not as severe, in the 100 to 600 ppm range, then a subacute response is noticeable in irritation of the eyes and

respiratory tract. Although such irritation is less severe than the acute response, it can nevertheless lead to complications and death. The third classification, chronic, is in the 50 to 100 ppm range and can lead to individual cases of illness that might be similar to those found in the subacute classification (Sinclair Knight and Partners 1994). The table below shows the pathophysiological responses to different levels of H<sub>2</sub>S in the air.

Table 2. Compilation of pathophysiological responses to hydrogen sulfide at various concentrations in air from various public institutions

Concentration (ppm)	Expected Effects/Symptoms
0.00011–0.00033	Normal range for background concentrations (OSHA)
0.0005	Lowest concentration by human olfactory senses (ATSDR)
0.01–1.5	Odor threshold (when a rotten egg smell is first noticeable to some). The odor becomes more offensive at 3–5 ppm. Above 30 ppm, odor described as sweet or sickeningly sweet (OSHA).
2–5	Prolonged exposure may cause nausea, tearing of the eyes, headache, or loss of sleep. Airway problems (bronchial constriction) in some asthma patients (OSHA).
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness (OSHA).
50 – 100	Slight conjunctivitis (“gas eye”) and respiratory tract irritation. May cause digestive upset and loss of appetite after 1-hour exposure (ANSI and OSHA).
100	Coughing, eye irritation, loss of sense of smell after 2–15 minutes. Altered respiration, pain in the eyes, and drowsiness after 15–30 minutes followed by throat irritation after 1 hour. Several hours of exposure results in a gradual increase in severity of these symptoms and death may occur within the next 48 hours (ANSI and OSHA).
100 – 150	Loss of smell (olfactory fatigue or paralysis) (OSHA).
200 – 300	Marked conjunctivitis and respiratory tract irritation after 1 hour of exposure (ANSI and OSHA). Pulmonary edema may occur from prolonged exposure (OSHA).
500 – 700	Staggering, collapse in 5 minutes (OSHA). Serious damage to the eyes. Loss of consciousness and possibly death in 30 minutes - 1 hour (ANSI and OSHA).
700 – 1000	Rapid unconsciousness, “knocked down,” or immediate collapse within 1 to 2 breaths, cessation of respiration, and death within minutes (ANSI, ATSDR, and OSHA).
1000 – 2000	Unconsciousness at once, with early cessation of respiration and death in a few minutes. Death may occur even if an individual is removed to fresh air at once (ANSI and OSHA).

Abbreviations: ANSI, American National Standards Institute; ATSDR, Agency for Toxic Substances and Disease Registry; OSHA, Occupational Safety and Health Administration. (*1 ppm = 1.5 mg/m<sup>3</sup>*)  
(1 g/m<sup>3</sup> = 1.5 ppm.)

(Source: Rubright et al. 2017; Selen et al. 2003)

In Kenya, environmental protection measures for the benefit of present and future generations are considered in Articles 69 and 70 of the Kenyan Constitution, according to which any release of noxious agents that may cause health or environmental problems are considered as a violation of constitutional rights

(Government of Kenya 2010). Protection of the environment was recently taken more seriously, with the promulgation of the Environmental Management Coordinating Act of 2015. In particular, Section 93 outlines the prohibition of discharging dangerous substances, either into water or otherwise into the environment. Administrative fines can be enforced on top of the cost of environmental restoration. For air quality standard, in particular, the Environmental Management and Coordination Regulations of 2009 outline the pollutants that are not allowed to exceed predefined ambient air limits in outside spaces.



Figure 3. Emissions (including  $H_2S$ ) from the cooling towers at Olkaria IV.  
(Source: Authors)



Figure 4. Emission (including  $H_2S$ ) from the discharge and flow testing wells at East Olkaria.  
(Source: Authors)

In line with WHO guidelines, these regulations set an acceptable H<sub>2</sub>S concentration at 150 µg/m<sup>3</sup> averaged over 24 hours, without being exceeded for more than two days consecutively (EMCA 2015). These WHO guidelines are also the guidelines that KenGen adheres to independently (KenGen 2010). As such, their annual reports of the H<sub>2</sub>S measurements at any of the Olkaria power plants all declare that the concentration of the gas is significantly below the WHO standards. However, there is a lack of third-party independent assessment of the H<sub>2</sub>S emission in the region, with most of the reports concerning the issue being prepared either by KenGen itself or affiliated individuals. In the absence of employing an independent third party to keep track of emission levels at the different sites, across the region, and at different periods, there are only a few academics who were granted permission to measure the exposure amount independently, though for only for short periods.

Another example of reports prepared by the KenGen-affiliated scholars is provided by Ndeti (2010), a former student in the United Nations University's Geothermal Training Programme, while still affiliated with KenGen at the same time. His predictive modeling of the Olkaria I and II plants suggests H<sub>2</sub>S concentrations equaling 118 µg/m<sup>3</sup> per 24 hours and 99 µg/m<sup>3</sup> respectively (Ndeti 2010, p.457). When attempting to predict the concentrations for the, at the time under construction, Olkaria IV plant, it too was estimated to be below the WHO guideline threshold (Ndeti 2010, p.458). As such, public acknowledgment of a potentially hazardous situation by Ndeti could be interpreted as having been problematic. Therefore, this study warrants both expansion to the now newly completed Olkaria facilities as well as independent verification. It is furthermore likely that for this reason the Olkaria III power plant (OrPower 4) was not included in the study, being outside KenGen control. This lack of independent verification challenges some of the data provided by KenGen due to the obvious conflict of interests.

In a study from the year 2000, conducted by Marani and his colleagues from the School of Environmental Studies at Moi University, Kenya, the concentrations of H<sub>2</sub>S at different distances from the power station as well as a discharging well were monitored. Their measurements showed that the H<sub>2</sub>S concentration exceeded 7.5 ppm over a half-hour period at least once in a two-week period, which is over the standards claimed by KenGen. The highest level of H<sub>2</sub>S was observed when the winds were calm, the humidity was high, and the atmospheric temperature was low. While their measurement was conducted over an 11-day period, they concluded that, depending on the weather conditions, the concentration of H<sub>2</sub>S may rise to an unsafe level

for human health, plants, and wildlife. Therefore, their report calls for the need to maintain a constant monitoring program and early warning system (Marani et al. 2000).

Irungu (2017) conducted a study where he dealt with the impacts of ambient H<sub>2</sub>S exposure to workers in Olkaria. His study focused on monitoring ambient H<sub>2</sub>S concentrations in 37 sampling points distributed in the Olkaria I and II power plants. The measurement method used gas monitors such as the QRAEII 4 gas monitor type at a height of 1.5 meters for a maximum of one-minute concentration in each of the 37 selected points. His experiment demonstrated that the level of exposure to ambient H<sub>2</sub>S level was below 10 ppm for a shift of eight hours during the measurement period on March 2012, which is in line with WHO standards. The average measured amount of H<sub>2</sub>S for Olkaria I reported by KenGen for the period between 1997 to 2011 was 0.67 ppm per hour, while Irungu measured 0.97 ppm in March 2012 (Irungu 2017, pp.66-70). Such differences are also reported in the case of Olkaria II, where the reported hourly amount of H<sub>2</sub>S was 0.23 ppm by KenGen while the measured amount in March 2012 illustrates emissions that were almost double at 0.41 ppm. While Irungu's measured amounts are still below WHO standards, such a big difference between KenGen's measured amount and his sample is difficult to ignore.

More importantly, Irungu (2017, pp.59-67) goes further to investigate the possible health issues of H<sub>2</sub>S emission on the KenGen staff working in the region. The number of visits to the nearby Mvuke Clinic in the period of 2009 to 2011 with the clinical symptoms of H<sub>2</sub>S exposure was 157, which comprise 37 individuals out of the sample of 40 (92.5%), working in the operation and maintenance sectors. They made 3.39 visits on average to the clinic compared to the 1.83 average visits by their co-workers in the other areas of the same department, which illustrates the need for serious consideration in revisiting the standards that KenGen follows (Irungu 2017, p.68). According to the clinical reports, some of the common symptoms were related to breathing problems, upper respiratory tract infections (URTI), bronchitis, coryza, mouth sores, pharyngitis, rhinitis, sinusitis, sore throat, and tonsillitis. Other symptoms reported by the clinic were reddening of the eyes, hypertension, and headache including chronic headaches that are related to strain.

Such an increase in health problems is also reported by some members of the Maasai community, the indigenous tribe residing in the Olkaria region. However, we could not find reliable data from the hospitals. It should also be considered that, as the Maasai tribal people have a traditional way of life, they barely visit the hospital for their health problems. But this should not be interpreted as H<sub>2</sub>S emission having no impact on their health. While there have been several protests and riots against their land acquisition, the noise, and

the environmental issues occurring in the region since the early stages of development of the Olkaria power plants (Koissaba 2014; Mwebe and Jika, 2018), the KenGen report does not mention such issues.

## **V. Problematic WHO Standards for Setting Tolerable H<sub>2</sub>S Emission**

The Kenyan situation is by no means historically unique, as all developed states have had to deal with the adoption of environmental regulations, including those dealing with H<sub>2</sub>S emissions. In the initial phase, states tend to adopt the World Health Organization's guideline of 150 µg/m<sup>3</sup> averaged over 24 hours (WHO 2000, p.33). These standards have, however, been called into question for nearly three decades. In a 1992 study conducted by a group of medical doctors on the acute health effects of H<sub>2</sub>S release at the South Karelia industrial site in Finland, it was revealed that, even with a 43 µg/m<sup>3</sup> hydrogen sulfide emission, which is more than three times below WHO standards, 63% of the respondents reported at least one symptom caused by exposure. They concluded that the WHO standard is too high and does not provide prevention of adverse health effects (Haahtela et al. 1992).

The fact that the H<sub>2</sub>S norms in ambient air are not considered in large parts of the regions and countries in the world might be the reason behind the reluctance of the WHO in reconsidering its regulations. H<sub>2</sub>S emissions have only become a major issue in the regions where heavy industry or geothermal power generation is utilized on a large scale. Therefore, many countries do not have ambient air quality standards for H<sub>2</sub>S. For example, the European Union's Air Quality Standards do not outline H<sub>2</sub>S (European Commission 2019). However, when looking at specific cases in Europe, such as in the Netherlands, a standard of 100 µg/m<sup>3</sup> averaged over 14 days is considered the health norm (Mooij 2011, p.54).

When narrowing our focus to other countries that have made remarkable strides in geothermal power adoption, we undoubtedly find Iceland. The OECD recognizes the achievements in renewable energy adoption that Iceland has made over the last decades. However, they warn that these developments are not without their own negative caveats, including the aforementioned H<sub>2</sub>S emissions (OECD 2015). So too have the local population near Hellisheiði Power Plant indicated that they are suffering under H<sub>2</sub>S emittance, which under certain weather conditions can reach settlements (Gunnarsson et al. 2011). In 2010, Iceland adopted Regulation No. 514/2010, aimed to set limits on the atmospheric H<sub>2</sub>S concentrations. This limit is set at 50 µg/m<sup>3</sup> averaged for a runtime of 24 hours with only three incidental yearly allowed exceedances (EIB 2016; OECD 2014, p.9). This limit is significantly lower than the WHO guidelines. Hellisheiði has



exceeded both WHO guidelines and Icelandic regulations on numerous occasions, leading to an EIB-funded upgrade program to install an H<sub>2</sub>S capturing system, “SulFix,” allowing for subterranean injection (EIB 2016; Kristjánsdóttir 2014).

As is often the case in the development of new industries, such as Icelandic geothermal power, the technology and its implications tend to outpace legislation. Such reactive policy is often the result of civil unrest originating from disturbances caused by the novel technological implementation within new geographic spaces. For instance, the Icelandic environmental policy has been considered to have developed at a relatively late stage (OECD n.d., p.2). As such, we will briefly outline the development of Icelandic policy towards H<sub>2</sub>S emissions and see what lessons Kenya can draw from these experiences.

During the planning phases of the Nesjavellir (2000) and aforementioned Hellisheiði (2005) geothermal power facilities, environmental impact assessments were carried out according to European regulations.<sup>1</sup> Originally outlined in European Council Directive 85/337/EEC, such assessments are designed to explain the direct and indirect project effects on, and interactions of, among others, soil, water, and air quality as well as human, plant, and animal life. This European directive was later expanded on in national legislation with Environmental Impact Assessment Act No. 106 (Iceland 2000). Both geothermal facilities were eventually completed and several studies on the effects of their H<sub>2</sub>S emissions have since been conducted, challenging the earlier environmental assessments and WHO guidelines. These include a study on the increased mortality rate over the period from 2003 to 2009 (Finnbjörnsdóttir et al. 2015), and another on increased drug distribution associated with H<sub>2</sub>S levels between 2006 and 2008 (Carlsen 2010). Since 2010, Iceland has strengthened its legislation to limit H<sub>2</sub>S emissions, primarily due to complaints from residents near geothermal power stations about the aforementioned 50 µg/m<sup>3</sup> limit (EIB 2016; OECD 2014, p.9).

Much like Kenya, Iceland is dependent on a green image for its economic development (OECD n.d., p.2). Two of the largest Icelandic industries are fisheries and tourism, which greatly benefit from environmental protection regulations. And while fisheries are not as important for Kenya as they are for Iceland, Kenya’s world-renown safari tourism is equally dependent on the protection of the environment. In the case of the Olkaria geothermal developments, this is a particularly significant issue due to their location within Hell’s Gate National Park.

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<sup>1</sup> Iceland is a member of the European Economic Area (EEA).

Beyond the Icelandic example, there are several other major adopters of geothermal power that have adopted regulatory standards stricter than WHO guidelines. For instance, the US Environmental Protection Agency (USEPA) of California, the US state that produces 71.2% of the nation's geothermal power, maintains an even more stringent H<sub>2</sub>S emission standard of 43 µg/m<sup>3</sup> averaged over one hour (USEIA 2020; Nolasco 2010, p.188). Also, the US state of Wyoming maintains regulations lower than the WHO guideline at 70 µg/m<sup>3</sup> averaged over a half-hour period, not to be exceeded more than two times per year, or 40 µg/m<sup>3</sup> averaged over a half-hour period, not to be exceeded more than two times in any five consecutive days (Wyoming Department of Environmental Quality 2015, p.4).

In New Zealand, the guidelines are even more strict than those of the Californian USEPA at 7 µg/m<sup>3</sup> average over an hour period. The rationale behind such a low limit is based not on health concerns per se but rather odor nuisance in a more general sense. However, the actual ministerial guidelines question the suitability of this limit for geothermal areas (Nolasco 2010, p.188; New Zealand Ministry for the Environment 2002, pp.16-17).

Examples such as these show the seriousness with which H<sub>2</sub>S emissions are treated among OECD member states. Given that the rationale in their adoption is not significantly divergent from the current situation in Kenya, it might be prudent to reconsider expanding environmental legislation beyond WHO guidelines.

## **VI. Possible Solutions and Suggestions**

Noting the shortcomings of WHO standards at various sites around the world, coupled with significantly divergent environmental legislation from WHO guidelines among OECD member states, one may ask why WHO standards have not been changed so far? One possible answer is that the H<sub>2</sub>S emission problem and concentration of geothermal power plants on large scales is not an issue among the majority of nations.

Here, we review some possible recommendations that the Kenyan government could consider mandating KenGen and other involved stakeholders to implement. Strict policies in the aforementioned countries to control the limit of H<sub>2</sub>S emission has encouraged the operators to install some facilities for the reduction of H<sub>2</sub>S released to the air by up to 99.9%, much like the previously outlined SulFix solution at the Hellisheiði Power Plant, some of which are presented in the table below.

Table 3. Compilation of different processes of H<sub>2</sub>S emission abatement

<b>Process Name</b>	<b>Condenser Design</b>	<b>NH<sub>3</sub>/ H<sub>2</sub>S ratio</b>	<b>Economics</b>	<b>Best Suitable For</b>	<b>Leading Region</b>
Liquid redox methods	Surface contact	Low	High capital costs	Large plants	Geysers geothermal Field
SulFerox process	Surface condenser	Low	High capital costs	Large plants	California
LO-CAT II	Surface condenser	Low	High capital costs	Large plants	Coso Geothermal Field
BIOX	Surface condenser and direct contact condenser	High and low	Low capital costs and low operational costs	Small and large plants	Hudson Ranch II geothermal power plant California
Selectox	Direct contact condenser	Low	High capital costs and low operational costs	Medium and large plants	Yanaizu-Nishiyama Geothermal Power Plant
H <sub>2</sub> O <sub>2</sub> process	Surface condenser and direct contact condenser	High	Low capital costs and high operational costs	Small units	Northwest Geysers Geothermal Resource Area

(Source: Rodríguez et al. 2014; Farison et al. 2010; Baldacci et al. 2005; Takahashi et al. 2000)

When considering the feasibility and the required initial investment costs in proposing a method to reduce the gas emission in the various Olkaria power stations, the options that could be implemented after completion of the power plant with lower cost are the most feasible options for the Olkaria power plant's context. For instance, in an instance similar to Olkaria, the BIOX (biocide-assisted oxidation) method is currently being used at the 49 MW Hudson Ranch II geothermal power plant in California (Gallup, 1992). It is a downstream process, in which the off-gases are compressed and mixed with the condensate before entering the cooling tower, which reduces both primary and secondary emissions of hydrogen sulfide.

As we observed during a site visit to Olkaria, another serious source of environmental pollution and H<sub>2</sub>S emission are the many discharging wells under construction. As we were told by a KenGen specialist, the duration of discharging for each well is about 60-90 days and its initial purpose is to test whether the pressure and other factors of the well would meet the standards for joining the system. Though the discharging period is not very long, the number of wells that are being tested regularly is considerably high, in line with the continued development of new Olkaria facilities, as well as the upgrading and expansion of units at the active

facilities. Thus, implementing the already-existing low-cost solutions to reduce the H<sub>2</sub>S emission during this process could be valuable in tackling H<sub>2</sub>S emission as a whole across the entire Olkaria site (Nolasco 2010).

## VII. Conclusion

Policy, regulatory, and geothermal innovations are occurring side by side as Kenya tries to balance developmental, economic, and environmental interests. New geothermal facilities are sprouting all over Hell's Gate National Park, using attractive new financing schemes to attract foreign capital, in line with the Vision 2030 development plan. As to be expected with the constitutionally enshrined environmental protection clauses, issues such as emissions have been given more consideration, especially from the Olkaria V facility onward with the introduction of the Environmental Management Coordinating Act (EMCA) in 2015.

One of the emissions of particular concern is hydrogen sulfite gas (H<sub>2</sub>S). This gas can be lethal in high concentrations and has been shown to cause health problems in lower concentrations. Regardless of the EMCA, Kenya still holds to WHO guidelines on tolerable H<sub>2</sub>S emission levels, which have been criticized by health professionals for decades. Other countries, which have developed geothermal industries of their own, have come to face similar issues regarding H<sub>2</sub>S emissions. Major players in geothermal energy adoption such as Iceland and California have drastically cut allowed H<sub>2</sub>S emission levels below WHO guidelines.

International investors involved in the geothermal sector such as the US-based Ormat Technologies are able to benefit from this as they are not required to keep to the same regulatory standards in Kenya as they are required at for instance their Californian facilities. Meanwhile, the Kenyan government is hard pressed to meet the Vision 2030 targets and is unlikely to be willing to promulgate new regulations that might make investors wary. This makes it seem like a dangerous situation where tough decisions between economic growth and environmental protection will need to be made.

However, there are cost-effective solutions available that would mitigate environmental and health impacts at a relatively low cost. Companies, however, cannot be expected to take the initiative in the implementation of these solutions. As with the case of the Hellisheiði facility in Iceland, only after legislative change mandating lower H<sub>2</sub>S emissions were mitigating steps taken, steps that were seemingly necessary due to the mounting evidence of negative health effects. Kenya too is currently at a similar stage. However,

uncertainty remains as long we are limited to KenGen data. We, therefore, recommend an independent inquiry into emission levels and health effects at the Olkaria site.

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