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ECONOMIC VALUATION OF COMMON ENVIRONMENTAL IMPACTS OF OLKARIA GEOTHERMAL PROJECT

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ABSTRACT

Environmental impact is one of the most significant considerations in the evaluation of economic development projects, yet an extremely difficult factor to measure. Regularly in the real world, decisions are made by governments on new development proposals that have significant economic and environmental implications. Decision-making in energy and environment calls increasingly for a better evaluation of the possible impacts of any envisaged policy and measure. While the benefits of geothermal energy are made explicit, the ensuing environmental impacts are merely identified and qualitatively described. This paper underscores the importance of valuing environmental impacts that are associated with the development of geothermal energy. Results of an economic valuation of the common environmental impacts of Olkaria geothermal project are presented.

1. INTRODUCTION

Environmental impact is one of the most significant considerations in the evaluation of economic development projects, yet an extremely difficult factor to measure. The ideal of sustainable development has led to a search for ways in which development projects can be assessed so that both project outputs and environmental effects can be included in the valuation process. This is in recognition of the fact that there are trade-offs between development and the goods and services provided by the environment. In order to make assessments and ultimately determine if a project should proceed and if so under what conditions, methods are required that allow comparisons of the project's direct project inputs and outputs and environmental effects (Dixon and Hufschmidt, 1986). Nevertheless, many environmental cost assessments are grossly understated, a problem that has yet to be fully resolved (Callan and Thomas, 2013). Development of geothermal energy at Olkaria is currently accelerated, in order to meet the nation's ever-increasing demand for power. Inevitably, this development is occurring against a backdrop of ecologically sensitive ecosystems, the Hell's gate national park and L. Naivasha.

2. ECONOMIC VALUATION OF ENVIRONMENTAL IMPACTS

"We must recognize that the goal of a cleaner environment ... will not be cheap or easy and the costs will have to be borne by each citizen, consumer and taxpayer."
Richard Nixon (1913-1994)

2.1 The concept of total economic value

2.1.1 Ecosystems and economic values

According to MNRE (2008), a general premise that underlies economic valuation of environmental impacts of projects is that the environment (or ecosystems) produce(s) multiple goods and services of a large variety of nature which are 'valued' by human beings as they contribute to human welfare and well-being. Thus, the environment produces economic values to the extent that this contribution is to human welfare and well-being. A further premise is that changes in the flow of goods and services provided by the environment impact the nature and extent of the economic values associated with these goods and services. Changes in the flow of goods and services provided by the environment are occasionally triggered by natural events, e.g. tropical storms may adversely impact the flow of agricultural outputs. Such changes may also be triggered by human actions, e.g. development policies and projects which may positively or negatively impact the flow of goods and services produced by the environment. In such cases, the main issue is to identify and quantify the changes in the flow of goods and services produced by the environment which are impacted by a development project, and then to monetize these changes into costs or benefits.

2.1.2 Total economic value and its components

Currently, the generally recognized suitable framework for guiding the economic valuation of environmental impacts is the concept of total economic value. The total economic value of the environment is made of different types of economic values, each corresponding to the respective use that is made of the environment. Figure 1 is an illustration of total economic value and its components (MNRE, 2008). A distinction between use and non-use values is described below:

Use values
They relate to the actual use of the good or service produced by the environment. Use values are sub-divided into direct use values, indirect use value, and option value (MNRE, 2008). Direct use values are further sub-divided into consumptive direct use value and non-consumptive direct use value.

Consumptive direct use value
Refers to the economic value of those goods and services produced by the environment which are actually extracted for the purpose of consumption. Examples of consumptive direct use include:

- Harvesting of fish either for commercial or recreational purposes;
- Extracting of timber or non-timber forest products;
- Harvesting of fruits from fruit trees;
- Abstracting surface water or groundwater for domestic, agricultural, or industrial purposes.

Non-consumptive direct use value
Refers to the economic value of those goods and services produced by the environment without actual extraction or abstraction taking place. Examples of non-consumptive direct use include:

- Using surface waters for purpose of transportation;
- Recreational swimming;

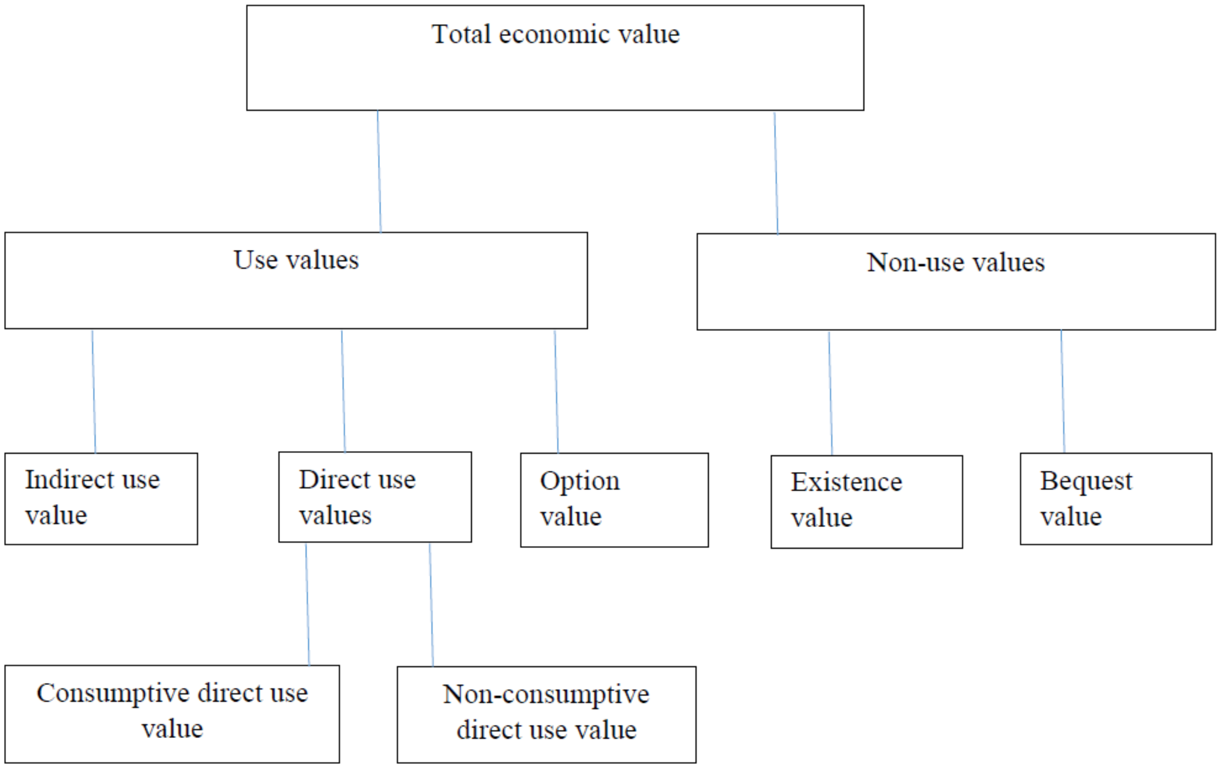

Figure 1: Total economic value and its components

- Bird watching in a protected area;
- Hydro-power production (in cases where the water is not diverted).

The sum of consumptive and non-consumptive direct use values defines the direct use value of the environment.

Indirect use value

Results from the use of services provided by the environment and ecosystems. Examples of indirect use of services include:

- Storm and flooding protection services provided by mangrove swamps;
- Water purification services provided by wetlands;
- Watershed protection services provided by forests;
- Carbon sequestration services provided by forests.

Option value

Refers to the benefit of potentially using a resource at a later point in the future. For instance, protected areas may be set aside for conservation purposes not only for the direct and indirect values they may currently generate, but also for keeping the option possible (in the future) to conduct these or other activities.

The sum of direct, indirect, and option values defines the use value of the environment, as shown in Figure 2 below:

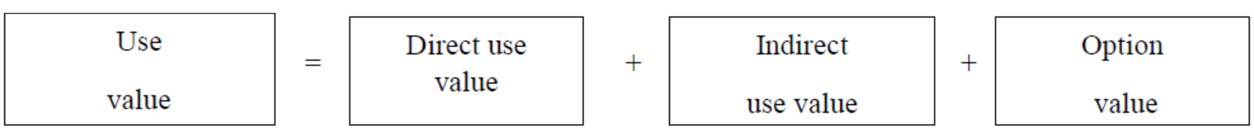

Figure 2: Use value

Non-use or passive use values

Refer to the fact that some individuals in our societies obtain satisfaction (welfare) simply from knowing that the existing flow of goods and services produced by the environment is maintained as it currently is, even if there is no current or potential use of these goods and services by themselves (EV, 2000).

Existence value
It is the non-use value that people place on simply knowing that something exists, even if they will never see it or use it.

Bequest value
It is the value that people place on knowing that future generations will have the option to enjoy something.
The sum of bequest and existence values defines the non-use value of the environment as displayed in Figure 3 below:

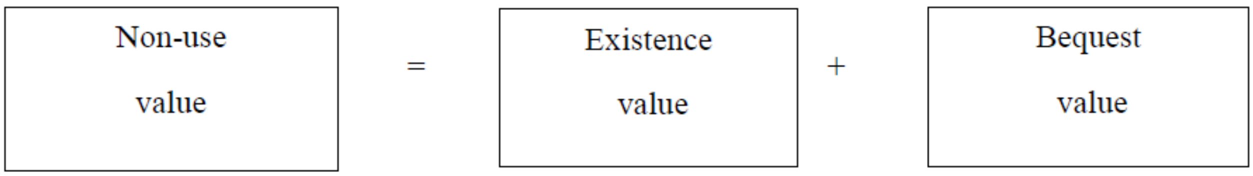

Figure 3: Non-use value

The sum of use and non-use values defines the total economic value of the good and services produced (delivered) by the environment, Figure 4 below:

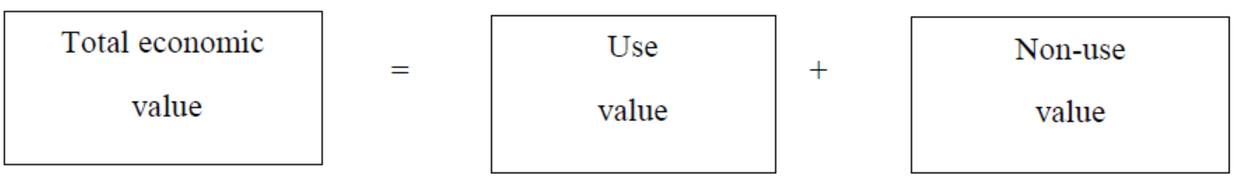

Figure 4: Total economic value

2.2 Economic valuation methods and techniques

Ecosystem valuation is quite difficult and fraught with uncertainties albeit we don't have a choice whether to do it or not. Rather, the decisions that we make as a society about ecosystems imply we are going through the process of valuation (Costanza et al., 1997). Traditional project appraisals consisted of economic evaluations accompanied by environmental impact statements. In the recent past though, new economic approaches have been devised that place monetary values on some environmental effects and place them in the overall balance of benefits and costs (Dixon and Hufschmidt, 1986). Nevertheless, many environmental cost assessments are seriously understated, a problem that has yet to be fully resolved (Callan and Thomas, 2013). Many impacts of projects and policies are intangible in nature and are non-market goods since they are not traded in actual markets, Pearce et al. (2006). In order to determine the value of environmental goods and services, economists try to identify people's willingness to pay (WTP) or willingness to accept (WTA) compensation for these services in the artificial markets (Munda, 1996). Different economic valuation techniques are used to undertake economic valuation of environmental impacts (EV, 2000; Pearce et al., 2006; MNRE, 2008). The following methodologies are presented and described:

- Revealed preference methodologies;
- Stated preference methodologies;
- Benefit-transfer methodology.

2.2.1 Revealed preference methodologies

The methods entail the valuation of non-market impacts by observing actual behavior, particularly purchases made in actual markets. The economic costs associated with this behaviour may *reveal* the extent to which individuals respond to a change in environmental quality (MNRE, 2008). The methods considered to fall under this category are: market price, productivity, hedonic pricing, travel cost, averting or defensive behavior, cost of illness, as well as damage cost avoided/replacement cost/and substitute cost methods.

Market price method estimates the economic value of ecosystem products or services that are bought and sold in commercial markets. The market price method can be used to value changes in either the quantity or quality of a good or service. Productivity method, also referred to as the net factor income or derived value method, is used to estimate the economic value of ecosystem products or services that contribute to the production of commercially marketed goods. It is applied in cases where the products or services of an ecosystem are used, along with other inputs, to produce a marketed good, e.g. water quality affects the productivity of irrigated agricultural crops. Hedonic pricing method is used to estimate economic values for ecosystem or environmental services that directly affect market prices. Mostly, it is applied to variations in housing prices that reflect the value of local environmental attributes like a scenic beach or mountain view (EV, 2000). Travel cost methodology attempts to estimate the economic value of sites which are essentially used for recreation purposes (such as beaches, coral reefs, or protected areas). The basic premise of the method is that the time and travel cost expenses that people incur to visit an unpriced recreation site represent the "price" of access to the site. Averting or defensive behavior methods are based on the notion that individuals and households can defend themselves from a non-market bad by selecting more costly types of behavior e.g. installation of double-glazed windows in houses to avoid exposure to noise from road traffic or airports (Pearce et al., 2006; MNRE, 2008). Cost of illness methodology relies on estimating expenditure associated with treating illnesses and diseases necessitated by changes in environmental quality e.g. respiratory diseases due to dust emissions. Damage cost avoided, replacement cost, and substitute cost methods are related methods that estimate values of ecosystem services based on either the costs of avoiding damages due to lost services, the cost of replacing ecosystem services, or the cost of providing substitute services. For example, valuing storm protection services of coastal wetlands by measuring the cost of building retaining walls (EV, 2000).

2.2.2 Stated preference methodologies

Stated preference methods offer a direct survey approach to estimate willingness-to-pay for changes in provision of (non-market) goods. They seek to estimate economic values by directly asking individuals to *state* such willingness-to-pay, based on a hypothetical scenario. It is only stated preferences methodologies that can be used to assess non-use economic values (EV, 2000; MNRE, 2008). There are two types of stated preferences methodologies: the contingent valuation methodology and the choice modelling methodology. The contingent valuation method involves directly asking people, in a survey, how much they would be willing to pay, or amount of compensation they would be willing to accept to give up, for specific environmental services. It is called "contingent" valuation, because people are asked to state their willingness to pay, *contingent* on a specific hypothetical scenario and description of the environmental service. Choice modelling methodology estimates economic values for virtually any ecosystem or environmental service. It is based on asking people to make trade-offs among sets of ecosystem or environmental services or characteristics. It does not directly ask for willingness to pay, this is inferred from trade-offs that include cost as an attribute (EV, 2000). It is most useful as a stated preference method where an environmental problem is complex or multidimensional, and proposed policy options are not only numerous but also provide different combinations of these multiple dimensions (Pearce et al., 2006; MNRE, 2008).

2.2.3 Benefit-transfer methodology

Benefit transfer is the adaptation and use of economic information derived from a specific site(s) under certain resource and policy conditions to a site with similar resources and conditions. The site with data is typically called the "study" site, while the site to which data are transferred is called the "policy" site. Benefit transfer is a practical way to evaluate management and policy impacts when primary research is not possible or justified because of budget constraints, time limitations, or resource impacts that are expected to be low or insignificant (Rosenberger and Loomis, 2001).

2.3 Economic valuation of environmental impacts

Decision-making in energy and environment calls increasingly for a better evaluation of the possible impacts of any envisaged policy and measure like a renewable electricity target or internalisation of external costs. The consideration of the external costs caused by energy production and consumption, i.e. the monetary quantification of its social-environmental damage, is one way of re-balancing social and environmental dimensions with purely economic ones. An external cost, or an externality, arises when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group (EC, 2003). Many types of environmental impact are multidimensional in character. Consequently, an environmental asset that is affected by a proposed project or policy often will give rise to changes in component attributes, each of which command distinct valuation techniques (Pearce et al., 2006).

Economic valuation of environmental impacts can be viewed as a four-step exercise. First, the most important environmental effects need to be identified. Next, the effects have to be quantified. The quantified changes must then be valued and monetary values placed on them. The last step is the actual economic analysis. Thus, economic valuation of a project's environmental impacts can only be as good as identifying and quantifying them (Dixon and Hufschmidt, 1986; MNRE, 2008).

2.4 Environmental impacts of geothermal projects

Maintaining the natural environment and the integrity of underlying ecosystems is an important consideration for any significant development project. Fundamentally, the concepts of environmental and social sustainability are now widely recognized by policymakers, development institutions, and the society at large (ESMAP/WB, 2012). Geothermal energy is generally accepted as being an environmentally benign energy source, especially in comparison to fossil fuel energy sources (Hunt, 2001). Nevertheless, like any infrastructure development, has its own environmental impacts and risks that have to be assessed, mitigated and managed, in order to advance its utilisation (ESMAP/WB, 2012). Environmental effects vary considerably from one geothermal field and power plant to another, due to the influence of the geology and structure of the underground, the nature of the reservoir, as well as the type of utilization (Kristmannsdóttir, H. and Ármannsson, H., 2003). According to Thayer (1980), geothermal plants are unique among thermal power plants since all steps of the fuel cycle are localized at the site of production facilities. The common environmental impacts that are associated with exploitation of geothermal energy are discussed below:

Landscape impacts
Power plants are built on the site of geothermal reservoirs since fluid transmission pipes would be expensive and result in pressure and temperature losses. Land is required for well pads, steam pipelines, power plant, cooling towers and electrical switchyard. Geothermal fields are often situated in places of outstanding natural beauty like national parks and forests, where tourism and historic interest are important. The presence of drilling activity, pipelines, transmission lines and electric generating facilities introduce forms, shapes, and colours that are inconsistent with the natural landscape. Installed pipelines can disrupt natural habitats and the surface morphology. Removal of the vegetative cover and exposure of raw soil in unnatural land forms causes visual aesthetic loses. This implies that recreation areas may have to yield to extractive activities as well as electric generation plants and transmission lines, all of which could have a negative impact on the outdoor recreation experience. Development of a geothermal reservoir could therefore impose aesthetic damages upon the recreators of the region (Thayer, 1980; Hunt, 2001; Kristmannsdóttir, H. and Ármannsson, H., 2003; ESMAP/WB, 2012).

Mass withdrawal
Large-scale exploitation of liquid-dominated high temperature geothermal systems involves withdrawal of large volumes of geothermal fluid. This can lead to degradation, disappearance, shift or transformation of thermal and most common touristic and cultural features like hot springs, hot pools, mud pools, fumaroles and sinter terraces. Surface subsidence can also result from reduction in formation pore pressure due to compaction in rock formations that have high compressibility. Such subsidence can compromise the stability of pipelines, drains and well casings in a geothermal field, as well as buildings in residential areas (Hunt, 2001; Kristmannsdóttir, H. and Ármannsson, H., 2003).

Air pollution
Geothermal fluids (steam and hot water) usually contain gases like carbon dioxide (CO_2), hydrogen sulphide (H_2S), ammonia (NH_3) and methane (CH_4), which can contribute to global warming, acid rain and nuisance smells if released into the atmosphere. They also contain trace amounts of mercury (Hg) and boron (B). The emissions are mainly from the gas exhausters of power plants that are discharged through the cooling towers. The impacts of H_2S discharge depend on local topography, wind patterns and land use. The gas can be highly toxic, causing eye irritation and respiratory damage in humans and animals, and has an unpleasant odour. Ammonia can cause irritation of the eyes, nasal passages and respiratory tract at concentrations of 5 to 32 ppm. Ingesting or inhaling mercury can cause neurological disorders. Boron irritates the skin and mucus membranes, and is also phytotoxic at relatively low concentrations. The metals may be deposited on soils and if leached, they may cause groundwater contamination (Hunt, 2001; ESMAP/WB, 2012).

Disposal of waste fluids
Discharge of waste geothermal fluids is a potential source of chemical and thermal pollution. Waste water from cooling towers has a higher temperature than ambient water, therefore constituting a potential thermal pollutant when discharged to nearby streams or lakes. Untreated waste geothermal fluids lead to chemical poisoning of fish, birds and animals living near the water since toxic substances bio-accumulate through the food chain. Surface disposal of large volumes of waste geothermal fluids may cause soil erosion and contamination of groundwater sources (Hunt, 2001; ESMAP/WB, 2012).

Noise pollution
Noise pollution accompanies industrial development and has a potential impact of instigating a loss of natural silence and opportunity for solitude. The noise associated with operating geothermal electricity power plants could be a problem to humans and animals living nearby. High noise levels are normally generated from drilling and well testing activities (Thayer, 1980; Hunt, 2001; ESMAP/WB, 2012), as illustrated below:

- Air drilling – 120 dBa (85 dBa with appropriate muffling);
- Discharging wells – 120 dBa;
- Well testing – 70-110 dBa (with silencers);
- Earth moving machinery during construction – 90 dBa;
- Well bleeding – 85 dBa (65 dBa with rock muffler);

- Mud drilling – 80 dBa;
- Diesel engines – 45-55 dBa (with suitable muffling).

Landslides

Earth moving activities in areas of high relief and steep terrain could potentially cause landslide hazards. Landslides may also be triggered naturally by heavy rain or earthquakes. Landslides are dangerous in that they may place constraints on the placement of wells and other constructions (Ármannsson and Kristmannsdóttir 1992; Hunt, 2001).

3. OLKARIA GEOTHERMAL POWER DEVELOPMENT

3.1 Olkaria geothermal power project

The Kenya Electricity Generating Company Limited (KenGen) is a state corporation that supplies bulk power, about 80%, to the national electricity grid. The Company's power generation mix comprises hydro, thermal, geothermal and wind resources (KenGen, 2010). Currently, KenGen operates four power plants and nine wellhead units at Olkaria geothermal field, generating a total of 485.6 MW. The Olkaria I (commissioned between 1981 and 1985) and Olkaria II (commissioned in 2003 and 2010) power stations generate 45 and 105 MW of electricity, respectively. The Olkaria III geothermal power station, which generates 102 MW of electricity, belongs to an independent power producer (IPP), Orpower 4 Limited. In addition, the new Olkaria IV and Olkaria I Units 4 and 5 power plants were commissioned in 2014, with an installed capacity of 140 MW each. Olkaria I, II and III and three wellhead units are situated inside Hell's Gate National Park. Olkaria IV and the six wellhead units are located on KenGen's land that is about 15 km from the Olkaria I power station. This land constitutes an important dispersal area for wildlife from Hell's Gate National Park. Further, KenGen utilizes water for its drilling and domestic activities from the nearby Lake Naivasha, which is a wetland of international importance according to the Ramsar Convention on Wetlands. KenGen is implementing plans to increase geothermal power production within the Greater Olkaria Geothermal Area (GOGA) by optimizing the current potential of the Olkaria Domes and Olkaria East area. These plans will lead to the establishment of new power plants to be named Olkaria V and Olkaria I Unit 6 power stations, with an estimated capacity of 210 MW (KenGen, 2010).

FIGURE 5: Olkaria well-44 pad with three wells

3.2 Common environmental impacts of Olkaria geothermal project

The common environmental impacts which are associated with the development of Olkaria geothermal project and their respective mitigation measures are discussed below:

Impact on flora

Clearing of vegetation was inevitable to allow for construction of the required infrastructure to support Olkaria. This led to disturbance of the significant ecosystem that provides the habitat, feeding and breeding grounds for fauna within the park. To minimize the impact, clearing of vegetation was done selectively and strictly controlled and was limited to what was absolutely necessary. Disturbed areas were later re-vegetated with indigenous vegetation that include *Hyperrhenia, Digitaria*, *Themeda* grasses, *Tarchonanthus* shrubs, and *Acacia* trees. Further, directional drilling that provides for multiple wells on the same pad was implemented to reduce the surface area of cleared vegetation. Drilling multiple wells on a single pad significantly minimizes the total cleared surface area. One of the pads with multiple wells include OW-44, which has three wells comprising one vertical and two directional wells as shown in Figure 5.

Impact on fauna

The project lies within Hell's gate national park and Olkaria domes field. Both areas are environmentally significant for biodiversity conservation, the latter being an important wildlife dispersal area. The impact results from loss of habitat due to vegetation clearing and bush fires; loss of migratory corridors through installation of structures such as elevated steam pipes and power plants; use of fences to restrict animal movement; and potential drowning of animals in brine ponds. Consequently, the following mitigation

FIGURE 6: A giraffe pass loop

FIGURE 7: A buffalo and zebra pass loop

measures were implemented to reduce the stated impacts:

- Animal census and animal migratory route studies are conducted regularly by KenGen and Kenya Wildlife Service (KWS) to determine the wildlife population as well as map their respective movement routes. The studies generate information that is used in locating and designing animal friendly steam pipes to avoid interfering with the animals' routes in search of water and a habitat for breeding, feeding and hiding. Figure 6 and 7 show existing giraffe and buffalo/zebra pass loops, respectively;
- Clearing of vegetation is reduced to the absolutely necessary and rehabilitation is carried out immediately on the affected areas to restore the vegetation;
- Fences and other enclosures that reduce the grazing range and restrict the movement of wild animals have been installed to secure only critical operational areas such as power plants, offices, and temporary brine holding ponds, to avoid restricting the animals too much.

Exposure to high noise and vibration levels

Emission of uncontrolled noise is a danger to human health and might cause damage to the environment. The maximum permissible noise level for residential areas near such a construction site is 60 dB during the day (6a.m. – 6p.m.) and 35 dB at night (6p.m. – 6a.m.) NEMA, 2009. Noise modelling was conducted to assess the impacts of the proposed development on noise levels. The model considered the effect of noise from a combination of the existing Olkaria I & II, the proposed Olkaria IV & I Units 4 & 5 power stations, and OW 38 that was on discharge testing at the time (Gibb, 2010a). Discharge testing of wells takes about three months to determine the well flow characteristics and establish the power output at different wellhead pressures. The exercise is carried out all year round to test wells that are being drilled on a continuous basis. Monitoring of noise levels is carried out on all the working days and information is circulated immediately the noise levels exceed the recommended limit. Workers in and visitors to the relatively noisy areas are provided with personal protective equipment (PPEs) that comprise ear muffs and ear plugs. Further, staff working in the power plants and drilling sites operate in 12 hour shifts to prevent prolonged exposure periods to high noise levels. Informative and warning signs in the national and, in some instances, the local language are clearly displayed at the areas where it is mandatory for the PPEs to be worn. During discharge testing, noise levels at wells can reach a high of 125 dB, but decline to a low of 90 dB when fitted with temporary silencers. Figure 7 shows OW-909 that is discharging and is fitted with four silencers to reduce noise levels. The permanent separator stations at Olkaria IV and Olkaria I Units 4 and 5, illustrated in Figure 8, are made of concrete and rock mufflers that substantially reduce noise to negligible levels.

FIGURE 7: Discharging OW-909

FIGURE 8: Olkaria IV separator station

Exposure to hydrogen sulphide gas emissions

Geothermal wells and power plants emit substantial quantities of hydrogen sulphide (H_2S). Air dispersion modelling was conducted to assess the impacts of the proposed development on H_2S levels. The model considered the effect of H_2S emissions from a combination of the existing Olkaria I & II, the new Olkaria IV & I Units 4 & 5 power stations (Gibb, 2010a). Currently, the World Health Organization (WHO) 24-hour guidelines are being used to assess the impacts, since there are no ambient air quality criteria for H_2S in force in Kenya. The guidelines recommend an average exposure limit of 0.10 ppm concentrations for a period of 24 hours (WHO, 1987). Monitoring of H_2S levels is carried out on all the working days and information is circulated immediately the levels exceed the recommended limit. Informative and warning signs in the national and, where necessary, the local language are clearly displayed in areas where high emissions are recorded. The new power plants were fitted with cooling towers that are similar to those at the newer Olkaria II to provide greater plume rise and achieve better dispersion than in the older Olkaria I power plant. Workers operate in 12 hour shifts to prevent prolonged exposure to the H_2S gas emissions. They are also regularly trained on the dangers of exposure to hydrogen sulphide gas.

Water utilization and waste water for the geothermal wells

The Olkaria IV and Olkaria I Units 4 & 5 are utilising 5,000 m^3, respectively, of fresh water for cooling towers initially, for a duration of about three years. Thereafter, only a small quantity will be required for top up. More water is utilised for drilling of geothermal wells, for household use at KenGen staff housing quarters, and for supply to local communities for their domestic and livestock use. This water is abstracted from a single source, the nearby Lake Naivasha, which is a Ramsar Site. The total amount of lake water drawn by the existing and the proposed geothermal project development on its own does not impact significantly on the lake level. Nevertheless, historical data shows that Lake Naivasha water level fluctuates significantly, and is likely to continue to do so over the expected 30-year life span of the proposed power stations. This can significantly scale down geothermal project development operations. The fluctuation is mainly attributed to prolonged periodic droughts as experienced in 2009 and the beginning of 2010, and subsequent over-abstraction by competing users, such as the flourishing horticulture farming and domestic water use by an ever increasing population. The mitigation measures being implemented include continued monthly monitoring of the lake level; re-using of drilling water by containing it in temporary circulation ponds; rainwater harvesting facilities installed in the newer buildings; controlled water supply at the KenGen housing staff quarters; monitoring and immediate repair of accidental pipe leakages and bursts; and use of brine for drilling. Brine is the main waste water from geothermal wells and power plants. Substantial quantities of brine from production wells are separated from the steam that is used to drive the turbines that generate electricity in the power plants. Inappropriate disposal of the brine may cause soil erosion, as well as contamination of soils, water, and vegetation. The most appropriate brine disposal method is hot and cold re-injection from the wells and power plants respectively. Re-injection plays an important role of recharging the reservoir and minimizing land subsidence. Several wells are being used for re-injection, like OW-R5 and OW-901. In addition, brine is held temporarily in ponds that are lined with high density polyethylene (HDPE) to prevent percolation and surface flow that can cause contamination of soils, water and vegetation. Small rocks are laid on the HDPE layer to provide a grip to small crawling animals like lizards, snakes and rodents, against the slippery lining. Alternatively, brine is being used for drilling in order to supplement the fresh water from Lake Naivasha. A pumping station at the Olkaria I wetland supplies brine for drilling of wells that are connected to Olkaria I Units 4 & 5. An additional pumping station located at OW-903 supplies brine for drilling wells at Domes that provide steam to the new Olkaria IV power plant.

Impact on recreation and aesthetics

Construction of power plants and their associated infrastructure that comprises of the traversing steam gathering pipelines, transmission lines, and road network, affect the aesthetics. The existence of these diverse infrastructure has facilitated degradation of the surrounding environment through intrusion on the view of the natural landscape and the imposition of an image of economic and industrial nature within and in the vicinity of Hell's Gate National Park. In an attempt to reduce the impact of visual intrusion, the steam pipes were initially painted in a single beige or green colour so as to blend with the natural environment, as shown in Figures 6 and 7 above. Nevertheless, due to the increasing number of power plants, the associated infrastructure and the changing climatic conditions, the beige-painted pipes are now quite conspicuous during the wet season, which is dominated by a lot of green vegetation; in contrast, the green-painted pipes are highly visible during the dry season when the prevalent vegetation and soil cover is mainly grey and brown. In an attempt to address this problem, a new design of camouflaging the steam pipes with alternating patterns of beige and various shades of green so that the pipes are not as conspicuous during either season was adopted, as illustrated in Figure 9.

3.3 Economic valuation of common environmental impacts of Olkaria geothermal project

4. RESULTS

5. CONCLUSION

FIGURE 9: Camouflaged green and beige steam pipeline

ACKNOWLEDGEMENTS

NOMENCLATURE

°C	= Degrees centigrade
dB	= Decibels
≥	= Greater than or equal to
g	= Grams
kg/m^2/yr	= Kilograms per metre square per year
km^2	= Kilometre square
<	= Less than
≤	= Less than or equal to
l/s	= Litres per second
MW	= Megawatts
m^3	= Cubic metres
mg/kg	= milligrams per kilogram
%	= per cent
ppm	= parts per million

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