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PRELIMINARY ENVIRONMENTAL COST ACCOUNTING FOR OLKARIA IV GEOTHERMAL PROJECT

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ABSTRACT

Environmental impact is one of the most significant considerations in the evaluation of economic development projects, yet it is a difficult factor to measure and to monetize. Regularly, decisions are made by governments on new development proposals that have significant economic and environmental implications, yet the economics of environmental impacts are frequently ignored. Decision-making in the areas of energy and environment calls increasingly for a better evaluation of the possible impacts of any envisaged policy and measure. In such decision-making, the benefits of geothermal energy are made explicit, while the ensuing environmental impacts are merely identified and qualitatively described. This paper underscores the importance of valuing and monetizing environmental impacts that are associated with the development of geothermal energy. A preliminary economic accounting of the common environmental impacts of Olkaria IV geothermal project was conducted. The results of this study recommend that a comprehensive economic valuation study be carried out on all the environmental impacts that are associated with the development of the larger Olkaria geothermal project.

1. INTRODUCTION

Environmental impact is one of the most significant considerations in the evaluation of economic development projects, yet it is a difficult factor to measure and to monetize. The idea of sustainable development has led to a search for ways in which development projects can be assessed, accounting simultaneously for project outputs and environmental effects. This search recognizes the fact that there are trade-offs between economic development and the goods and services provided by the environment (Dixon and Hufschmidt, 1986). Nevertheless, many environmental cost assessments seriously understate the economic value of environmental impacts, a problem that has yet to be fully resolved (Callan and Thomas, 2013). In order to assess and ultimately determine if a project should proceed, and if so under what conditions, methods are required that allow comparisons of the direct project inputs and outputs and environmental effects (Dixon and Hufschmidt, 1986). 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 Lake Naivasha, which is a Ramsar site. Olkaria IV geothermal power plant was commissioned in October 2014 and it has an installed capacity of 140 MW.

It was selected for this study because of its relatively isolated location from the other power plants, making it ideal to identify, quantify and value its specific environmental impacts.

The aim of this study was to reveal the hidden costs of the environmental impacts that are associated with the development of Olkaria IV geothermal project, in order to broaden decision making in the application of the appropriate mitigation measures.

2. ECONOMIC VALUATION OF ENVIRONMENTAL IMPACTS

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. Changes in the flow of goods and services provided by the environment are occasionally triggered by natural events, e.g. tropical storms, and 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. Total economic value of ecosystem goods and services 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.

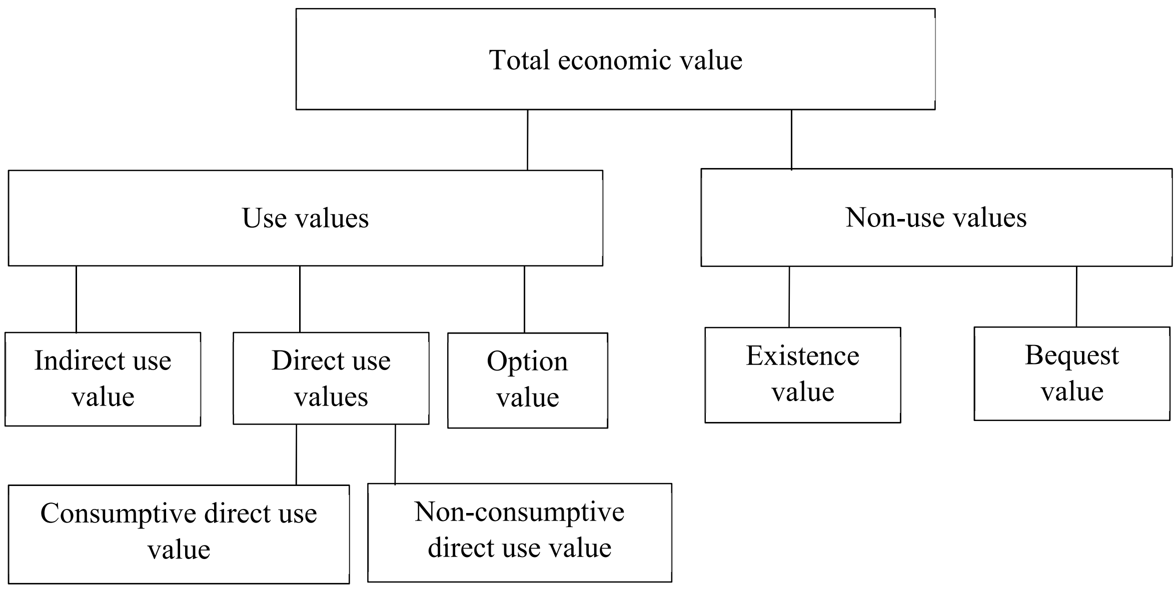

FIGURE 1: Total economic value and its components
(MNRE, 2008)

The distinction between use and non-use values is described below (MNRE, 2008; Goulder and Kennedy, 2009).

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;
- 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:

[Use value] = [Direct use value] + [Indirect use value] + [Option value]

FIGURE 2: Use value (MNRE, 2008)

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). These values are divided into what is called existence value and bequest value.

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:

Non-use value	=	Existence value	+	Bequest value

FIGURE 3: Non-use value (MNRE, 2008)

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

Total economic value	=	Use value	+	Non-use value

FIGURE 4: Total economic value (MNRE, 2008)

2.2 Economic valuation methods and techniques

Economic valuation of environmental goods and services or ecosystem services is quite difficult and fraught with uncertainties. Every day through the choices we make, we implicitly value environmental goods and services. However, as ecosystem goods and services are in most cases non-market goods that value is very low (Costanza et al., 1997, Field and Field, 2002). Traditional project appraisals consisted of economic evaluations accompanied by environmental impact statements, where the environmental impact was not monetized. 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, enabling a more comprehensive assessment of a project's net benefits (Dixon and Hufschmidt, 1986). Nevertheless, many environmental cost assessments seriously understate the value of environmental impacts, a problem that has yet to be fully resolved (Callan and Thomas, 2013). Since the impact of economic development on ecosystem services is, in many cases, affecting goods and services that are not traded in markets (Pearce et al. (2006), the economic assessment of ecosystem services necessitates creating hypothetical markets. To do so, economists try to identify people's willingness-to-pay (WTP) for those services or willingness-to-accept (WTA) compensation for losing these services in artificial markets (Munda, 1996).

Different economic valuation techniques are used to undertake the economic valuation of environmental impacts (EV, 2000; Pearce et al., 2006; MNRE, 2008). The following methodologies are presented and described below:

- 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 behaviour, 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 include: market price, productivity, hedonic pricing, travel cost, averting or defensive behaviour, cost of illness, as well as damage cost avoided/replacement cost/and substitute cost methods. The 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. The 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. The hedonic pricing method is used to estimate economic values for ecosystem or environmental services that are directly associated with specific 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 willingness to pay for that recreational site. Averting or defensive behaviour methods are based on the notion that individuals and households can defend themselves from a non-market bad, such as pollution or noise by selecting costlier types of behaviour 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 for, or amount of compensation they would be willing to accept to give up, 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). Choice modelling is a useful stated preference method where an environmental problem is complex or multidimensional, and proposed policy options are numerous and 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, such as 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, 2013). Many types of environmental impacts 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 as shown in Figure 5. 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 the identification and physical quantification of its resultant impacts on the environment (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). Shortall, et al. (2015) emphasize the need to monitor all the environmental, social and economic impacts of developing geothermal energy in order to ensure its sustainability. 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, it 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 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. A sustainable geothermal energy development is described as one that generates positive impacts to the society, is environmentally benign, demonstrates economic and financial viability, is

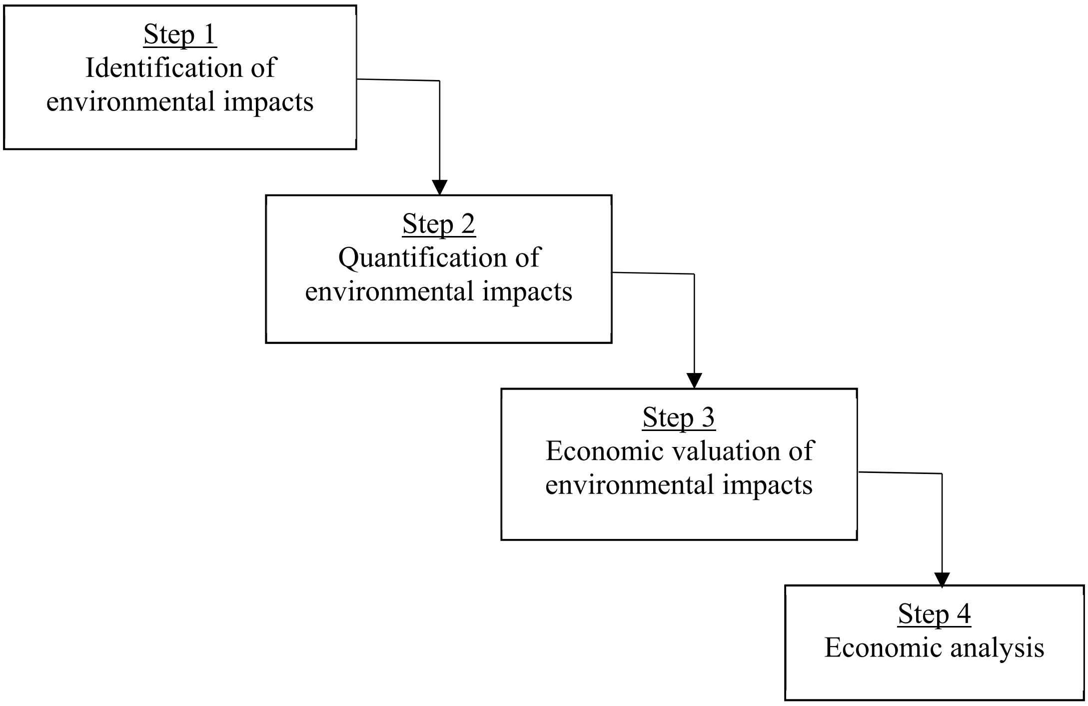

FIGURE 5: Steps of economic valuation of environmental impacts (modified from MNRE, 2008)

efficiently generated and utilised, as well as equitably distributed (Shortall, et al. 2015). The common environmental impacts that are associated with exploitation of geothermal energy are discussed below.

2.4.1 Landscape impacts

Power plants are built on the site of geothermal reservoirs, since long fluid transmission pipes would be expensive and result in pressure and temperature losses. Land is required for well pads, steam pipelines, power plants, cooling towers and electrical switchyards. 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 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 visitors to the region (Thayer, 1980; Hunt, 2001; Kristmannsdóttir and Ármannsson, 2003; ESMAP/WB, 2012, Mwangi-Gachau, 2012).

2.4.2 Mass withdrawal

Large-scale exploitation of liquid-dominated high temperature geothermal systems involves withdrawal of large volumes of geothermal fluids. This can lead to the degradation, disappearance, shift or transformation of thermal, and common touristic and cultural features like hot springs, hot pools, mud pools, fumaroles and sinter terraces. Surface subsidence can also result from the reduction in formation pore pressure due to a 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 residential buildings (Hunt, 2001; Kristmannsdóttir and Ármannsson, 2003).

2.4.3 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 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).

2.4.4 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 constitutes 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).

2.4.5 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).

2.4.6 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).

2.4.7 Induced seismicity/earthquakes

The majority of high-temperature geothermal systems lie in tectonically active regions with high stress levels in the upper parts of the crust, which are manifested by active faulting and numerous earthquakes. High wellhead reinjection pressures increase the pore pressure in deep existing fractures, allowing a sudden release of stress that results in an earthquake (Hunt, 2001). Enhanced geothermal system projects are perceived to induce some earthquakes through the "fracking" process, i.e. creation of an artificial underground reservoir by re-injecting highly pressured cold water (ESMAP/WB, 2012).

3. DEVELOPMENT OF OLKARIA GEOTHERMAL PROJECT

3.1 Olkaria geothermal power project

The Kenya Electricity Generating Company Limited (KenGen) is a state corporation that supplies the bulk of the 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. The park was gazetted in 1984, three years after the commissioning of Olkaria I power plant. The Park is known for its scenery and wide variety of wildlife, including the common zebra (*Equus burchelli*), Masai giraffe (*Giraffa camelopardalis*), Thomsons gazelle (*Gazella thomsonii*), leopard (*Panthera pardus*), Klipspringer (*Oreotragus oreotragus*), African buffalo (*Syncerus caffer*), common eland (*Taurotragus oryx*), various raptors i.e. Ruppell's vulture (*Gyps rueppellii*), white backed vulture (*Gyps africanus*), among other species of wildlife. The beautiful scenery includes the Fischer's Tower and Central Tower columns and Hell's Gate Gorge. The most common vegetation types include *Hyperrhenia, Digitaria, Themeda* grasses and *Tarchonanthus* and *Acacia* shrubs (Mwangi-Gachau, 2012).

Olkaria IV power plant is located on KenGen's land, about 7 km from the Olkaria I power station, Figure 6. This land constitutes an important dispersal area for wildlife from Hell's Gate National Park. Furthermore, 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 total installed capacity of 210 MW (KenGen, 2010).

FIGURE 6: Olkaria IV power plant

3.2 Common environmental impacts of Olkaria geothermal project

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

3.2.1 Impact on flora

Clearing of vegetation was inevitable to allow for construction of the required infrastructure to support the Olkaria IV power plant. This led to a 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 was strictly controlled and 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. Furthermore, 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-915, which has three wells comprising one vertical and two directional wells as shown in Figure 7.

FIGURE 7: Olkaria well-915 pad with three wells

3.2.2 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 environmental impact results from loss of habitat due to vegetation clearing and bush fires; loss of migratory corridors through the 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 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 to locate and design animal friendly steam pipes to avoid interfering with the animals' routes in search of water and a habitat for breeding, feeding and hiding. Figures 8 and 9 show existing giraffe and buffalo/zebra pass loops, respectively;
- Clearing of vegetation is reduced to what is 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.

FIGURE 8: A giraffe pass loop

FIGURE 9: A buffalo and zebra pass loop

3.2.3 Exposure to high noise and vibration levels

Emission of uncontrolled noise is a danger to human health and causes damage to the environment. The maximum permissible noise level for residential areas near such a construction site is 60 dBa during the day (6a.m. – 6p.m.) and 35 dBa 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 in order 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 working days, and information is circulated immediately if the noise level exceeds 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. Furthermore, staff working in the power plants and drilling sites operate in 12 hour shifts to prevent prolonged exposure periods to high noise levels. Information and warning signs are clearly displayed in the national, and in some instances the local, language, in areas where it is mandatory for the PPEs to be worn. During discharge testing, noise levels at wells can reach a high of 125 dBa, but decline to a low of 90 dBa when fitted with temporary silencers. Figure 10 shows OW-909 that is discharging and is fitted with four silencers to reduce noise levels. The permanent separator stations at Olkaria IV, as illustrated in Figure 11, are made of concrete and rock mufflers that substantially reduce noise to negligible levels.

FIGURE 10: Discharging OW-909

FIGURE 11: Olkaria IV steam venting station

3.2.4 Exposure to hydrogen sulphide gas emissions

Geothermal wells and power plants emit substantial quantities of hydrogen sulphide (H_2S) gas. Air dispersion modelling was conducted to assess the impact 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 and 2010b). 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 gas 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 gas levels is carried out on all working days and information is circulated immediately if the levels exceed the recommended limit. Information and warning signs are clearly displayed in the national, and in some instances the local, language, in areas where high gas emissions are recorded. The new power plant was fitted with cooling towers that are similar to those at the relatively new 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.

3.2.5 Water utilization and waste water disposal for the geothermal wells

The Olkaria IV power plant is currently utilising 2,500 m^3 of fresh water for the cooling towers initially, up to 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 to supply to local communities for their domestic and livestock use. This water is extracted 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 water level. Nevertheless, historical data shows that the Lake Naivasha water level fluctuates significantly, and is likely to continue to do so over the expected 30-year life span of the power plant. This can significantly scale down the power plant's operations. The fluctuation is mainly attributed to prolonged periodic droughts as experienced in 2009 and the beginning of 2010, and subsequent over-extraction by competing users, such as the flourishing horticulture farming and domestic water use by the increasing population in the area. The mitigation measures being implemented include: continued monthly monitoring of the lake level; re-use of drilling water by conserving it in temporary circulation ponds; rainwater harvesting facilities installed in the newer buildings; 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 plant. Inappropriate disposal of the brine may cause soil erosion, as well as the contamination of soils, water, and vegetation. The most appropriate brine disposal method is hot and cold re-injection from the wells and power plant, 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 as drilling fluid, in order to supplement the fresh water that is abstracted from Lake Naivasha. A pumping station that is located at OW-903 supplies brine for drilling wells that provide steam to Olkaria IV power plant.

3.2.6 Impact on recreation and aesthetics

Construction of power plants and their associated infrastructure, that is comprised of the traversing steam gathering pipelines, transmission lines, and road network, affects the aesthetics of the area. The existence of these diverse structures 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 8 and 9 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 method 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 12.

FIGURE 12: Camouflaged green and beige steam pipes

4. PRELIMINARY ENVIRONMENTAL COST ACCOUNTING FOR OLKARIA IV GEOTHERMAL PROJECT

The assessment below describes the economic costs associated with the environmental impacts of the Olkaria IV geothermal power project. The cost assessment reveals the WTP for environmental impacts as shown by the company's mitigation methods, but not the WTP as shown by societal actions. Consequently, this assessment accounts only for the environmental costs that are borne by the company.

Environmental costs arise at different points in time, some in the near future, and others in a more distant future. Consequently, time is a critical parameter in any calculation that involves monetary values (MENR, 2008). Since the overall cost of a particular mitigation measure is a combination of costs that occur at different points in time, discounting is therefore undertaken. Discounting is a mechanism whereby benefits and costs that occur at different points of time can be measured in a common unit (Dixon and Hufschmidt, 1986; MNRE, 2008). The monetary unit applied in the economic valuation is the US dollar ($) which is equivalent to 103 Kenya Shillings (KES). Equation 1 has been applied to calculate the levelized annual costs of mitigation measures of the respective environmental aspects and is applied to any capital cost that is incurred (Harris and Roach, 2002):

$$U = P\left[\frac{i}{1-(1+i)^{-n}}\right] \qquad (1)$$

where U = Uniform series amount
P = Present value
i = interest rate for the capital investment
n = number of time periods capturing the economic lifetime of the investment

The total levelized costs then consist of the sum of capital costs converted to annual costs of capital by Equation 1, and operation and maintenance costs that may include labour, transport and subsistence costs. The total levelized costs incurred by the company indicate its willingness-to-pay (WTP) for mitigating the environmental impacts of its activities.

Table 1 shows the five significant environmental aspects of Olkaria IV geothermal project, their respective associated effects and impacts, applied mitigation measures, as well as valuation methods and cost elements.

4.1 Economic valuation of the impact on flora

Economic valuation of the impact on flora was undertaken using replacement cost and defensive expenditure methodologies. Both methodologies rely on assessing the costs of undertaking activities aimed at offsetting changes in environmental quality. Replacement cost methodology applies when changes in environmental quality have an impact on productivity, while defensive expenditure methodology is applied when changes in environmental quality have an impact on the ecosystem or human health and actions have been taken to defend against that impact (Hufschmidt et al., 1983; MNRE, 2008). The replacement cost methodology was applied to assess the costs of restoring vegetation (rehabilitating) in ten well sites that supply steam to the Olkaria IV power plant. Defensive expenditure methodology was applied to assess the costs of controlling invasive species in the same well sites, as they have an impact on the health of the vegetation due to competition for nutrients. To calculate the levelized annual capital cost, Equation 1 was used with P = $174,194.20, n = 5, and i = 0.06 as shown in Table 2. Capital cost is the expenditure that was incurred to purchase tools and implements to undertake the rehabilitation activities. Capital cost of controlling invasive species is not included since the activity entails manual removal. Operational cost represents labour and subsistence expenditure. An average rate of 6% was applied for discounting for five years, the period that the restoration investment is estimated to last before being carried out again. The total levelized annual cost was then obtained from a sum of the levelized annual capital and operational costs.

TABLE 1: Valuation of common environmental impacts of Olkaria IV Geothermal Project

Environmental aspect	Environmental effects	Environmental impacts	Mitigation measures	Valuation technique and cost elements
1. Flora	i) Disturbance of vegetation by clearing ii) Growth of opportunistic and invasive species iii) Loss of biodiversity and habitat	i) Degraded Park ii) Reduced wildlife habitat	i) Rehabilitate disturbed areas with indigenous vegetation ii) Control growth of opportunistic and invasive species	Cost of replacement/ defensive expenditure i) Cost of rehabilitation ii) Cost of removing invasive species
2. Fauna	i) Loss of migratory corridors ii) Increased human activity iii) Loss of dispersal areas iv) Risk of drowning in brine ponds	i) Reduced wildlife habitat ii) Increased bush fires iii) Reduced wildlife population	i) Wildlife friendly steam pipe designs ii) Erect humps to reduce speed limits iii) Install firebreaks iv) Monitor wildlife population v) Fencing off well sites	Defensive expenditure i) Cost of wildlife accessible pipe design ii) Cost of installing speed humps iii) Cost of firebreaks iv) Cost of participation in wildlife census
3. Air quality	i) Dust emissions ii) H_2S gas emissions iii) Noise and vibrations	i) Discomfort and nuisance	i) Use of dust masks by the workers ii) Daily monitoring of H_2S gas concentrations iii) Daily monitoring of noise levels iv) Use of ear muffs by the workers v) Installation of concrete vent stations/silencers	Defensive expenditure i) Cost of dust masks for the workers ii) Cost of monitoring H_2S gas concentrations iii) Cost of monitoring noise levels iv) Cost of ear muffs for the workers v) Cost of concrete vent stations
4. H_2S gas and noise	i) H_2S gas emissions ii) Noise and vibrations	i) Discomfort and nuisance	i) Resettlement action plan	Contingent valuation/cost of replacement i) Cost of resettling project affected persons
5. Water	i) Water pollution ii) Water resources' depletion	i) Reduced water quality ii) Reduced water quantity	i) Re-injection of brine ii) Monitoring of Lake Naivasha levels iii) Rainwater harvesting iv) Use of brine for drilling	Defensive expenditure ii) Cost of re-injection wells iii) Cost of monitoring of Lake Naivasha water levels iv) Cost of rainwater harvesting reservoirs v) Cost of brine pumping station

TABLE 2: Valuation of annual cost of protecting flora

No.	Applied mitigation measures	Capital cost (USD)	Levelized annual capital cost (USD)	Operational cost (USD)	Total levelized annual cost (USD)
1.	Rehabilitate well sites (10)	174,194.20	41,353.08	2,158.25	43,511.33
2.	Control invasive species (10)	*n/a	n/a	29,667.50	29,667.50
				Total	**73,178.83**

*n/a – not applicable

4.2 Economic valuation of the impact on fauna

Defensive expenditure methodology was used to assess the costs of mitigation measures aimed at protecting the wildlife and its habitat. The mitigation measures include providing wildlife access loops, fencing around well sites, erecting speed bumps and firebreaks. The cost of carrying out semi-annual wildlife census to monitor the population was also included. Operational cost represents labour and subsistence expenditure. The total levelized annual cost was then obtained from a sum of the levelized annual capital and operational costs shown in Table 3.

TABLE 3: Valuation of annual cost of protecting fauna

No.	Applied mitigation measure	Capital cost (USD)	Levelized annual capital cost (USD)	Operational cost (USD)	Total levelized annual cost (USD)
1.	Wildlife access loops	29,126.21	2,278.45		2,278.45
2.	Fence well sites (10)	31,768.90	7,541.82	45,436.90	52,978.72
3.	Erect speed bumps (10)	8,427.20	3,152.70	2,528.20	5,680.90
4.	Establish firebreaks	*n/a	n/a	16,370.87	16,370.87
5.	Conduct wildlife census	n/a	n/a	3,200.00	3,200.00
				Total	**80,508.94**

*n/a – not applicable

Wildlife access loops
The levelized annual capital cost of wildlife access loops was derived from Equation (1) with P = \$ 29,126.21, n = 25, and i = 0.06. A period of twenty-five years was applied, being the economic life of the power plant.

Fencing around well sites
The levelized annual capital cost of fencing around ten well sites whose wells supply steam to Olkaria IV power plant was derived from Equation (1) with P = \$ 31,768.90, n = 5, and i = 0.06. The fencing materials are given a lifetime of five years before being replaced.

Erect speed bumps
The levelized annual capital cost of erecting ten speed bumps on roads leading to Olkaria IV power plant was derived from Equation (1) with P = \$ 8,427.20, n = 3, and i = 0.06. The speed bumps are given a duration of three years before being replaced for wearing out.

4.3 Economic valuation of noise control

The defensive expenditure methodology was used in an attempt to measure the cost of mitigation measures to avoid the impact of exposure to excessive noise and vibrations. Operational cost represents labour and subsistence expenditure, as well as the annual cost of purchasing ear muffs and ear plugs.

The operational costs of well test silencers and concrete separator stations are not included. The total levelized annual cost was obtained from a sum of the levelized annual capital and operational costs as shown in Table 4.

TABLE 4: Valuation of annual cost of noise control

No.	Applied mitigation measure	Capital cost (USD)	Levelized annual capital cost (USD)	Operational cost (USD)	Total levelized annual cost (USD)
1.	Monitor noise levels (2)	9,374.56	2,225.49	30,249.12	32,474.61
2.	Well test silencers (5)	242,718.45	43,479.37	missing data	43,479.37
3.	Concrete separator station	105,950.47	8,288.16	missing data	8,288.16
4.	Ear muffs and ear plugs	*n/a	n/a	7,893.20	7,893.20
				Total	**92,135.34**

*n/a – not applicable

Monitoring of noise levels
The levelized annual capital cost of monitoring noise levels using two integrated sound level meters was derived from Equation (1) with P = $ 9,374.56, $n = 5$, and $i = 0.06$. A life span of five years is assumed for the integrated sound level meters.

Well test silencers
The levelized annual capital cost of installing five twin well test silencers was derived from Equation (1) with P = $ 242,718.45, $n = 7$, and $i = 0.06$. A period of seven years was applied, being the economic life of the silencers.

Concrete separator station
The levelized annual capital cost of installing a concrete separator station was derived from Equation (1) with P = $ 105,950.47, $n = 25$, and $i = 0.06$. A period of twenty-five years was applied, being the economic life of the power plant...

4.4 Economic valuation of air quality

The defensive expenditure methodology was applied to obtain the mitigation measures applied to avoid exposure to the degraded ambient air quality resulting from the emission of hydrogen sulphide gas, particulate matter and dust. The mitigation measures include monitoring of hydrogen sulphide gas and particulate matter, as well as the procurement of dust masks. Operational cost represents labour and subsistence expenditure, as well as the annual cost of purchasing dust masks. The total levelized annual cost was obtained from a sum of the levelized annual capital and operational costs as shown in Table 5.

TABLE 5: Valuation of annual cost of improving air quality

No.	Applied mitigation measure	Capital cost (USD)	Levelized annual capital cost (USD)	Operational cost (USD)	Total levelized annual cost (USD)
1.	Monitor H_2S gas (2)	39,471.84	5,362.96	30,249.12	35,612.08
2.	Monitor particulate matter (2)	29,732.04	4,039.63	30,249.12	34,288.75
3.	Dust masks	*n/a	n/a	611.65	611.65
				Total	**70,512.48**

*n/a – not applicable

Monitor H_2S gas concentration levels
The levelized annual cost of monitoring H_2S gas concentration levels using two H_2S gas analysers was derived from Equation (1) with P = \$ 39,471.84, n = 5, and i = 0.06. A life span of five years is assumed for the integrated sound level meters.

Monitor particulate matter level
The levelized annual cost of monitoring particulate matter levels using two particulate matter level meters was derived from Equation (1) with P = \$ 29,732.04, n = 5, and i = 0.06. A life span of five years is assumed for the integrated sound level meters.

4.5 Economic valuation of H_2S gas and noise emissions' control

Defensive expenditure methodology was applied to measure the costs of resettling the seventy-five families that would have been affected by exposure to H_2S gas and noise emissions from the operations of the power plant. To calculate the levelized annual capital cost, Equation (1) was used with P = \$ 4,126,213.59, n = 25, and i = 0.06. The total levelized annual cost was obtained from a sum of the levelized annual capital and operational costs as shown in Table 6. A period of twenty-five years was applied, being the economic life of the power plant. Capital cost is the expenditure that was incurred to construct the project affected persons' residential houses and social amenities. The resettlement cost represents the company's willingness-to-pay to acquire the land for development of Olkaria IV power plant on one hand, and the project affected persons' willingness-to-accept compensation for the loss of their land and livelihoods, on the other hand.

TABLE 6: Valuation of annual cost of H_2S gas and noise emissions' control

No.	Applied mitigation measure	Capital cost (USD)	Levelized annual capital cost (USD)	Operational cost (USD)	Total levelized annual cost (USD)
	Resettlement	4,126,213.59	322,780.15	missing data	322,780.15

4.6 Economic valuation of water quality and quantity

The defensive expenditure methodology was used in an attempt to measure the cost of mitigation measures applied to avoid contamination of water sources by brine. The methodology was also used to assess the costs of preventing depletion of water from Lake Naivasha as shown in Table 7. Capital costs of monitoring activities are not included. Operational cost represents labour and subsistence expenditure to conduct the monitoring activities.

Brine re-injection
Brine from Olkaria IV power plant is re-injected into nine wells to prevent soil erosion, as well as contamination of soils, water, and vegetation. The nine comprise of seven hot and two cold re-injection wells, respectively. The levelized annual capital cost was derived from Equation 1 with P = \$ 49,500,000.00, n = 25, and i = 0.06. A period of twenty-five years was applied, being the economic life of the power plant.

Monitor soil, vegetation & brine
Monitoring of soil, vegetation, brine and rain chemistry is conducted four times a year to establish if there is any pollution associated with the geothermal development.

Brine sump pond
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. The levelized

annual cost of installing fifteen sump ponds that hold brine from Olkaria IV was derived from Equation (1) with P = \$ 48,543.70, n = 25, and i = 0.06. A period of twenty-five years was applied, being the economic life of the power plant.

Brine pump station

Brine is being utilised for drilling in order to supplement the fresh water that is abstracted from Lake Naivasha. The levelized annual capital cost of installing a brine pump station was derived from Equation (1) with P = \$ 93,203.88, n = 25, and i = 0.06. A period of twenty-five years was applied, being the economic life of the power plant.

Rainwater harvesting reservoir

Rainwater is harvested in order to supplement the fresh water that is abstracted from Lake Naivasha. The levelized annual capital cost of installing a rainwater harvesting reservoir was derived from Equation (1) with P = \$ 29,126.21, n = 25, and i = 0.06. A period of twenty-five years was applied, being the economic life of the power plant.

Monitor Lake Naivasha water level

Monitoring of Lake Naivasha water level is conducted on a monthly basis to establish if the water level changes are associated with extraction for the development of geothermal energy at Olkaria.

TABLE 7: Valuation of annual cost of conserving water quality and quantity

No.	Applied mitigation measure	Capital cost (USD)	Levelized annual capital cost (USD)	Operational cost ($)	Total levelized annual cost ($)
1.	Brine re-injection (9)	49,500,000.00	3,872,222.55	missing data	3,872,222.55
2.	Monitor rain chemistry	missing data	missing data	594.23	594.23
3.	Monitor soil, vegetation & brine	missing data	missing data	885.49	885.49
4.	Brine sump pond (15)	48,543.70	3,797.41	missing data	3,797.41
5.	Brine pump station	93,203.88	7,291.03	missing data	7,291.03
6.	Rainwater harvesting reservoir	29,126.21	2,278.45	missing data	2,278.45
7.	Monitor Lake Naivasha water level	missing data	missing data	1,151.07	1,151.07
				Total	**3,888,220.24**

5. DISCUSSION

Results of a preliminary economic valuation of the common environmental impacts of Olkaria IV geothermal project in separate categories of the key significant environmental aspects have been presented. A summary of the economic valuation that provides the total levelized annual cost of mitigating the common environmental impacts of Olkaria IV geothermal project is shown in Table 8. The estimated total levelized annual environmental cost is \$ 4,534,362.13, from a possible annual net revenue of \$ 52,545,108, amounting to 8.6% of the total annual revenue. A large proportion of this cost, 85.40%, is the expenditure on re-injection wells. As stated before, these costs reflect the company's WTP to mitigate against the adverse impacts of its development activities to the environment.

TABLE 8: Summary of economic valuation of environmental impacts of Olkaria IV geothermal project

Environmental aspect	Valuation technique and elements	Total levelized annual cost (USD)
1. Flora	**Cost of replacement & defensive expenditure**	
	i) Cost of rehabilitation	43,511.33
	ii) Cost of removal of invasive species	29,667.50
	Sum	**73,178.83**
2. Fauna	**Defensive expenditure**	
	i) Cost of wildlife accessible pipe design	2,278.45
	ii) Cost of installing speed bumps	52,978.72
	iii) Erection of speed bumps	5,680.90
	iv) Cost of firebreaks	16,370.87
	v) Cost of participation in wildlife census	3,200.00
	Sum	**80,508.94**
3. Noise	**Defensive expenditure**	
	i) Monitoring noise levels	32,474.61
	ii) Well test silencers	43,479.37
	iii) Concrete separator station	8,288.16
	iv) Ear muffs and ear plugs	7,893.20
	Sum	**92,135.34**
3. Air quality	**Defensive expenditure**	
	i) Monitoring H_2S gas	39,619.59
	ii) Monitoring particulate matter	37,307.40
	iii) Dust masks	611.65
	Sum	**77,538.64**
4. H_2S gas and noise	**Cost of replacement**	
	i) Cost of resettling project affected persons	322,780.15
	Sum	**322,780.15**
5. Water	**Defensive expenditure**	
	i) Cost of re-injection wells	3,872,222.55
	ii) Monitoring rain chemistry	594.23
	iii) Monitoring soil, vegetation & brine	885.49
	iv) Brine sump pond (15)	3,797.41
	v) Drilling brine pump station	7,291.03
	vi) Rainwater harvesting reservoir	2,278.45
	vii) Monitoring lake water level	1,151.07
	Sum	**3,888,220.24**
	Total	**4,534,362.13**

The main shortcomings in this study are threefold. First, the missing costs and associated uncertainties. For instance, by including the missing values of operational, maintenance and regulatory costs, as well as using different values of *p, n* and *i* in Equation 1 for the different mitigation measures could significantly affect the total levelized annual costs. Consequently, additional information is required to arrive at a more precise valuation. Secondly, the valuation focused only on the common environmental impacts. As a result, there is a need to value other environmental impacts, such as solid waste disposal, visual intrusion and lost aesthetics among others, in order to complete the economic valuation. Third, as the assessment only looked at WTP for environmental impact as shown by the company further economic valuation on societal WTP for ecosystem services is recommended for impacts on:

- Biodiversity in Hell's Gate National Park;
- Recreation activities in Hell's Gate National Park;
- Lost carbon sequestration due to cleared vegetation;

- Corrosion of structures and equipment by hydrogen sulphide gas;
- Extraction of water from Lake Naivasha.

Such assessment would illustrate the economic impact on society due to the environmental impact of economic development. The assessment would rely on economic valuation methods such as travel cost and contingent valuation to establish the society's WTP, e.g. to retain the services of recreation in Hell's Gate National Park, carbon sequestration or the existence of Lake Naivasha.

6. CONCLUSION

Despite the highlighted caveats, this report presents a practical example of how an economic valuation of environmental impacts of geothermal development can be conducted. Economic valuation as described in this report, helps to identify, quantify and monetise the environmental impacts that are associated with the development of geothermal projects, as borne by the company. By clearly identifying all possible environmental impacts and by placing monetary values on them where possible, a more realistic economic analysis of geothermal development projects can be achieved, by uncovering the usually hidden environmental costs that are associated with development activities. This provides significant opportunities for making informed decisions on minimising costs, through the application of economically efficient, environmentally friendly and socially acceptable mitigation measures, in order to achieve sustainable development.

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NOMENCLATURE

m^3	= Cubic metres
dB	= Decibels absolute
L	= Lake
MW	= Megawatts
%	= per cent
ppm	= parts per million
$/USD	= United States Dollar
WTA	= Willingness-to-accept
WTP	= Willingness-to-pay

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