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CDM Potential: Menengai and Olkaria Geothermal Power Projects in Kenya

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ABSTRACT

The current climate-energy concerns and effects have resulted in shifting developmental perspectives towards Clean Development Mechanisms (CDM). Kenya, with a current energy deficit of about 1191MWe per annum against an effective installed capacity of 1429MWe, is in the process of expanding existing energy resources with a focus on clean renewable energy. Hydropower yields most of the energy but has been unreliable due to unpromising hydrological conditions. Contributing about 14% of installed capacity, geothermal energy presents a potential in excess of 10,000 MWe along the Kenyan Rift Valley, and the thrust to develop 5000 MWe by the year 2030. Although a high initial capital investment is required, CDM could help unlock this potential. Two 140 MWe (Olkaria I and IV) and a 400MWe (Menengai I) geothermal power plant are envisaged between the years 2012 and 2016. This paper examines CDM potential for the three projects and the estimated emission reductions upon implementation of each project. The Approved Consolidated Methodology ACM0002 version 12 was used in the computation of the emission reductions. Upon registration under the CDM, about 3,044,129 tCO2-eq will be reduced annually at an expected generation capacity of 5,309,200MWh/year. The three projects could thus generate USD 213 million in the first 7 year crediting period accelerating the development process whilst sustaining environmental and social benefits. This achievement is anticipated to ensure both intra and inter-generational equity.

1. INTRODUCTION

The Clean Development Mechanism (CDM) is becoming a powerful incentive for geothermal projects. Matthíasdóttir et al. (2010) state that, CDM has the potential to produce incentives for promoting and accelerating the development of geothermal energy utilisation in developing countries. Bertani (2009) also reports that geothermal electricity production of about 1000 TWh/yr in 2050 would mitigate up to 1000 million tons CO2/yr (given the substituted fuel to be coal).

In Kenya, geothermal plants are situated in the greater Olkaria field (Rift valley) with a current installed capacity of 212 MWe and 18 MWt. The Updated Scaling-Up Renewable Energy Program (SREP) Kenya Investment program reports an exploitable geothermal potential exceeding 10,000 MWe which, if developed, would aid in meeting the current electric power demand of about 1191MWe (RoK, 2011). Thus, additional expansion is envisaged. The existing Olkaria power plants have generated base load power with an availability factor of more than 95% and have, thereby, saved the country on imported fuel costs and power outages during unreliable weather conditions; this is the foreseen capability of geothermal development. CDM could help unlock prospective geothermal development. According to the updated least cost power development plan (2011) for the years 2011 - 2031, Kenya anticipates an electricity expansion programme where about 50 geothermal power stations of about 100 MWe (1,100 wells) will be constructed by the year 2031 (Ministry of Energy, 2011). This massive capital (US$ 41.4 billion) undertaking can only be realised through a joint effort by both the public and private sectors (Ministry of Energy, 2011). Upon completion of these projects, significant annual tonnes of emission will be abated and the power plants will contribute to sustainable development. This report recapitulates CDM opportunities *inter alia*, and the sustainable development for Kenya´s anticipated large scale geothermal power projects aimed at the installation of 680 MWe between the years 2012 and 2014. Expected emission reductions and equivalent benefits over a seven year crediting period are evaluated and presented upon the construction of Menengai I (400 MWe), Olkaria I (140 MWe) and Olkaria IV domes (140 MWe) geothermal power plants.

2. GEOTHERMAL PROJECTS AND CDM POTENTIAL IN KENYA

2.1 Rationale and Location

CDM is herein assessed as a tool to help unlock the potential for Menengai I 400 MWe power plant, Olkaria I (East) fourth (70 MWe) and fifth (70 MWe) units, and Olkaria IV 140 MWe (Domes) power plant located along the Kenyan rift valley (Figure 1). The Menengai geothermal area is situated about 180 km northwest of Nairobi in Nakuru District, while Olkaria I and IV are located about 120 km northwest of Nairobi in Naivasha District. Non-condensable gases (NCGs) data from 15 wells which supply steam to the existing Olkaria II 70 MWe power station, and whose technology is expected to be similar to the new projects, are used to estimate project emissions and equivalent CERs for an assumed seven year crediting period. The Approved Consolidated Methodology ACM0002 version 12 'Consolidated baseline methodology for grid-connected electricity generation from renewable sources' published by the UNFCCC CDM-Executive Board (2010) is employed.

2.2 Description of Projects

The Government of Kenya plans to start construction of three large-scale geothermal power plants, Menengai I (400MWe) and Olkaria I (140MWe) and Olkaria IV (140MWe). Menengai is a new geothermal field; the proposed project upon implementation will mark the first geothermal power plant in the area. Olkaria geothermal field on the other hand is currently under expansion as it has been in production since 1981. Olkaria I 4th and 5th units will be a capacity addition to the existing 45 MWe (3×15 MW_e) power plant. Olkaria IV (Domes) is also a new power project, within the Olkaria area, foreseeing implementation of a 140 MWe power plant. All the fields have proven steam capability to yield about 680 MWe.

2.2.1 Project Objectives

The purpose of the three power plant projects is to abate the tight supply/demand balance and promote a stable power supply in the country. Through utilisation of geothermal energy, a positive contribution to sustainable development in Kenya is achieved. The projects will enhance environmental quality, positive health impacts and foster private sector participation, thus attracting investors to Kenya. This will contribute to economic development. Social development will accelerate as increased power availability will create more opportunities for expanded rural electrification with far reaching impacts on employment creation and improved livelihoods in the rural areas. The projects will also result in GHG emission reductions by displacing fossil fuel-based (thermal sources) electricity generation in the Kenyan grid with clean geothermal power.

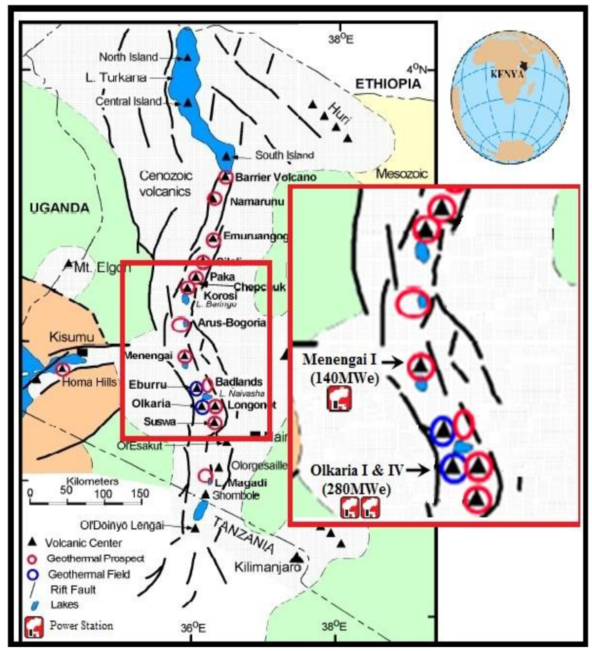

Figure 45: Simplified geological map of Kenya showing locations of Menengai I, Olkaria I (4th & 5th units) and Olkaria IV geothermal power plants in Kenya (modified from Simiyu, 2010)

2.2.2 Project Components and Process Activities

The main components of the projects that constitute the project boundaries are illustrated in Figure 2. Geothermal energy continuously flows from magma within the Earth's interior towards the surface. When this heat naturally produces hot water or steam, it can be piped to the surface and then used to turn a steam turbine to generate electricity.

Geothermal wells will be drilled to provide steam for electricity generation. Physical structures that will be constructed include new power stations, cooling tower blocks, steam gathering systems, switchyards and transmission lines. The process of generating geothermal electricity at Menengai I, Olkaria I and IV is purposed to be single-flash condensing type as that of the existing Olkaria II power plant. Olkaria I and IV power projects will be identical in power generation and configurations each yielding approximately 1097GWh/year (JICA, 2010). Menengai I having a different configuration is expected to yield about 3134 GWh/year. All projects will embrace optimal utilisation of the available geothermal resource to ensure 95% power availability.

The following steps will mark the process:

- Steam from the production wells will pass through a separator, where the liquid phase (brine) will be separated from the steam.
- The liquid phase consists mainly of brine and will be channelled through to a re-injection well.
- Steam (containing non-condensable gases (NCGs)) will be channelled through steam scrubbers and further to the turbine at the power station. The steam will then run a steam turbine/alternator for electricity generation.
- Upon transmission from the turbine, steam will be condensed; the hot condensate (containing NCGs) will be pumped to the cooling towers. NCGs will be expelled at this point through the cooling towers into the atmosphere. Cool condensate will then be re-circulated to the condenser.
- As the circulating condensate will be acidic, it will be dosed with soda ash (sodium carbonate) to prevent corrosion. In addition, the condensate will be dosed with biocide (hypochlorite) to prevent bacteria growing in the fins of the cooling tower.
- Any additional condensate will be pumped into different re-injection wells.
- The design steam pressure and temperature is expected to be 6 bar and 158.7°C (GIBB, 2009a, 2009b).

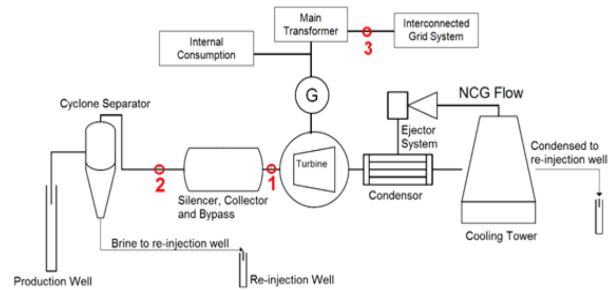

Figure 2: Simplified process flow (single flash) diagram showing sampling points 1 = Principal CO2, CH4 and steam sampling points; 2 = Secondary CO2, CH4 and steam sampling points in case of overhaul or outage (UNFCCC requirement); and 3 = Electricity measuring point (modified from CEC, 1980)

The main constituents of geothermal fluids are geothermal steam and a small quantity of geo gas (carbon dioxide (CO_2), hydrogen sulphide (H_2S), oxygen (O_2), nitrogen (N_2) and methane (CH_4). Geothermal steam will be used to drive the two 70 MWe turbines for each of the Olkaria projects and four 100MWe for the Menengai project. The main waste products expected will include:

- Brine, which is separated from the steam at the production wells;
- Condensate, produced when the steam passes over the turbine; and
- Non condensable gases, which will be released through the cooling towers.

Menengai I 400 MWe geothermal power project:

The mapped potential area (Figure 3) in Menengai is about 110 km^2 translating to over 1,650 MWe of electric power. GDC is currently in the initial development phase of drilling exploratory and appraisal wells. A total of about 120 production wells will be drilled. The 400 MWe power plant (Menengai I 4 units ×100 MWe) is expected to be functional by the year 2016. A decision has yet to be made on the power plant location.

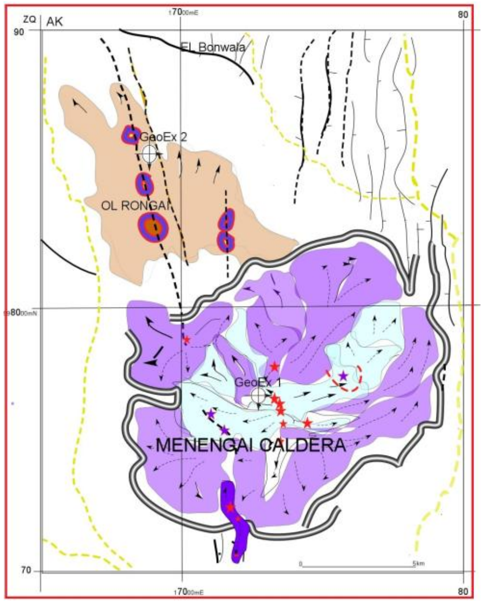

Figure 3: Proposed Menengai I geothermal power project.

Olkaria 1 units 4 and 5 140 MWe geothermal power project:
The proposed power plant site for units 4 and 5 is the wide flat area between wells OW-24 and OW-28 at Olkaria I (Figure 4). The 2 units × 70 MWe will be additional to the existing units 1, 2 and 3 (3×15 MWe) in the existing Olkaria I power plant. Olkaria East field, which supplies steam to Olkaria I power plant and has fifty four wells drilled (Kwambai, 2011). Currently, twenty six of them are in production for the 45MWe (Kwambai, 2011). An additional six wells are used for re-injection due to decline in productivity. Four others are in test for cold and hot re-injection while the remaining 18 will be used for the additional 140 MWe project. The 140 MWe power plant is expected to be commissioned in the years 2013 and 2014.

Olkaria IV (Domes field) 140 MWe geothermal power project:
Two 70 MWe power plants totalling 140 MWe will be constructed in Olkaria Domes (Figure 4), to be commissioned in the years 2013 and 2014, respectively. Power plant construction has been commissioned and about 23 of the drilled wells will supply steam to the 140 MWe power station. The proposed power plant location is expected to be close to the main production zone of the Olkaria Domes field.

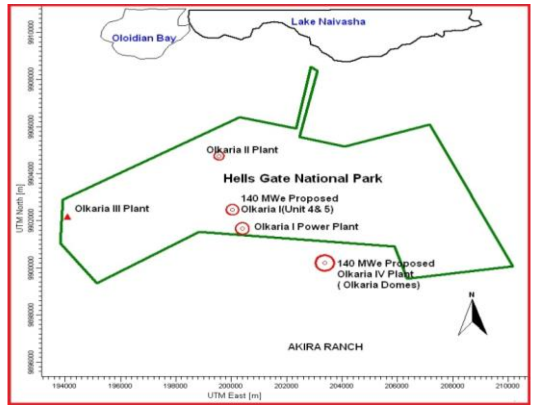

Figure 4: Proposed Olkaria I and IV geothermal power projects.

2.2.3 CDM Methodology
In order to qualify for CDM and generate Certified Emission Reductions (CERs), projects must follow approved methodologies for estimating and monitoring emission reductions. The UNFCCC CDM Executive Board (2010) methodology of Geothermal and CDM application used in this case is ACM0002 (Version 12), applicable for renewable electricity generation plants such as geothermal power projects which are connected to interconnected power grids.

Two case scenarios are used as required by the methodology in determining the baseline and project emissions:

- Project activities include the installation of 400 MWe in Menengai I and 140 MWe Olkaria IV as new geothermal power plants which will supply electricity to the grid, thus they are classified as the installation of new power plants.
- Project activities include the capacity addition of Olkaria I units 1, 2 and 3; (3×15 MWe) with the new Olkaria I (2×70 MWe) 4th and 5th Units, thus being classified as capacity addition by the installation of new power units beside the existing power units. The existing power plant/units continue to operate after the implementation of the project activity.
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3. ESTIMATION OF EMISSION REDUCTIONS
Baseline and project emissions are calculated to determine emission reductions in tCO2-eq/year. All calculated estimations are based on the ACM0002 version 12 UNFCCC CDM methodologies (UNFCCC CDM Executive Board, 2010).

3.1 Baseline Emissions

Baseline emissions include only CO_2 emissions from electricity generation in fossil fuel fired power plants that are displaced by project activity. Equation 6 of the methodology is used:

$$BE_y = EG_{PJ,y} \times EF_{grid\,CM,y} \quad (1)$$

Where

BE_y = Baseline emissions in year y (tCO_2/year);

$EG_{PJ,y}$ = Quantity of net electricity generation that is produced and fed into the grid as a result of the implementation of the CDM project activity in year y (MWh/year);

$EF_{grid,\,CM,\,y}$ = Combined margin CO2 emission factor for grid connected power generation in year y (tCO2/MWh).

Leakage:

The main emissions potentially giving rise to leakage in the context of electric sector projects are those arising due to activities such as power plant construction and upstream emissions from fossil fuel use (e.g. extraction, processing, and transport). Since the expected projects are geothermal, no leakage emissions are considered.

Combined grid emission factor:

Kenya is pursuing renewable energy and energy efficient grid connected projects such as hydropower, geothermal and wind, most of which are intended to be CDM. The Grid Emission Factor (GEF) is critical when considering the commissioning of new clean energy projects, as the baseline scenario keeps on changing with respect to the latest CDM projects incorporated. Many renewable and energy efficient grid connected projects translate to low emissions in the environment and thus low GEFs. Regular up-to-date databases of new grid connected projects in the electricity system are relevant for calculating the emission factor as per the approved methodology (ACM0002 version 12). This methodology includes the CDM tool for calculating the emission factor for an electricity system based on available data. The CERs generated are dependent on the GEF. The emission reductions are calculated over a seven year crediting period (renewable) and an average combined grid emission factor of 0.594 tCO2/MWh2 is used.

Calculating baseline emissions – Menengai I 400 MWe and Olkaria IV 140 MWe:

The project activities (Menengai I 400 MWe and Olkaria IV 140 MWe) entail the installation of new grid-connected renewable power plants at sites where no renewable power plants were operated. The quantity (EGPJ,y) of net electricity generation produced and fed into the grid is estimated at 1,097,000 MWh/yr for the 140 MWe; that for 400 MWe is estimated to be 3,134,000 MWh/yr.

The combined margin CO2 emission factor for grid connected power generation in year y (EFgrid, CM,y), 0.594 tCO2/MWh (KenGen, 2010) is used:

Olkaria IV 140MWe

BEy = 1,097,000 MWh/yr × 0.594 tCO2-eq/MWh

= 651,618 tCO2/year

Menengai I 400MWe

BEy = 3,134,000 MWh/yr × 0.594 tCO2-eq/MWh

= 1,861,596 tCO2/year.

Calculating baseline emissions - Olkaria I 4th and 5th units 140 MWe:

According to the UNFCCC, investment in Olkaria I 4th and 5th units entails capacity addition of 140 MWe besides the existing 45 MWe and is therefore not a new project. The average 5 year (2004-2009) historical electricity generation data for Olkaria I (3×15 MWe) units 1, 2 and 3 was used to determine the generation by the existing plant in the baseline scenario, the assumption being that the historical situation observed prior to implementation (operation of additional power units) of the project activity would continue. The statistical standard deviation of the historical electricity data was adjusted to check for errors and offset uncertainty; otherwise, the calculated emission reductions might depend primarily on the natural variability observed during the historical period rather than on the effects of the project activity.

The quantity of net electricity generation that is

[2] The GEF is computed using CDM tools (as given by ACM0002version 12) from the KenGen CDM database office.

produced and fed into the grid as a result of the implementation of the CDM project activity in year y (MWh/year), $EG_{PJ,y}$ was calculated using Equation 8 of the methodology ACM0002 version 12:

$$EG_{PJ,y} = EG_{facility,y} - (EG_{historical} + \sigma_{historical}); \text{ until } DATE_{BaselineRetrofit} \quad (2)$$

where:

$EG_{PJ,y}$ = Quantity of net electricity generation that is produced and fed into the grid as a result of the implementation of the CDM project activity in year *y* (MWh/year);

$EG_{facility,y}$ = Quantity of net electricity generation supplied by the project plant/unit to the grid in year *y* (MWh/year);

$EG_{historical}$ = Annual average historical net electricity generation delivered to the grid by the existing renewable energy plant that was operated at the project site prior to the implementation of the project activity (MWh/yr);

$\sigma_{historical}$ = Standard deviation of the annual average historical net electricity generation delivered to the grid by the existing renewable energy plant that was operated at the project site prior to the implementation of the project activity (MWh/yr); and

$DATE_{BaselineRetrofit}$ = Point in time when the existing equipment would need to be replaced in the absence of the project activity (date).

$EG_{historical}$ is estimated as the annual average electricity delivered by Olkaria I to the grid during the last five years, prior to the implementation of the project activity (Table 1). The standard deviation (σ) of the net electricity delivered to the grid in the past five years is estimated as follows:

Table 1: Recent net electricity generation to the grid for Olkaria I (45MWe) (KPLC,2009)

Year	Net electricity delivered to the grid (GWh)
2004/2005	371
2005/2006	324
2006/2007	360
2007/2008	359
2008/2009	368
Total	1782
Average/year	**356,4**

$$\sigma = \sqrt{\sum \frac{(X_i - \bar{X})^2}{n-1}} \quad (3)$$

Where:

σ = Standard deviation;
X_i = Represents an individual value;
$\bar{X}$ = Arithmetic mean; and
n = Number of values.

$\sigma historical$ = 18.8 GWh

$EG_{facility,y}$ is the net electricity delivered to the grid by the plant/unit. The average historical value over the last five years was used (356,400 MWh/yr) for the existing Units 1, 2 and 3 (Table 5). The value used for the new project is 140 MWe (1,097,000 MWh, Table 4). Hence, if both units 1, 2 and 3 and the new 140 MWe power plant were in production:

$EG_{facility,y}$ = 356,400 MWh/year + 1,097,000 MWh

= 1,453,400 MWh/year

The quantity of net electricity generation that is produced and fed into the grid as a result of the implementation of the CDM project activity (MWh/yr) is estimated as:

$EG_{PJ,y}$ = 1,453,400 MWh/yr - (356,400 MWh/year + 18,800 MWh/year)

= 1,078,200 MWh/yr

$DATE_{BaselineRetrofit}$ is the typical average technical lifetime of the existing turbines. With continuous routine maintenance practices, the plant life is given about 25 years from the commissioning date, assuming an average load factor of 93% (JICA, 2010); $EG_{PJ,y}$ is, therefore, estimated at 1,078,200 MWh/yr for a 25 year period.

The combined margin CO_2 emission factor for grid connected power generation in year y, $EF_{grid, CM, y}$ = 0.594 tCO_2/MWh (KenGen CDM office, 2010), was used to estimate the baseline emissions in tCO_2/yr:

BE_y = 1,078,200 MWh/yr × 0.594 tCO_2/MWh

= 640,451 tCO_2/year

Total baseline emissions
Summing up the three individual baseline emissions gives the overall baseline emissions for the projects:

2,513,214 tCO_2/year (sum; Menengai I and Olkaria IV) + 640,451 tCO_2/yr (Olkaria I)

= 3,153,665 tCO_2/year

3.2 Project Emissions

Fugitive emissions of carbon dioxide and methane, due to the release of NCGs from produced steam, will account for project emissions. NCGs in geothermal reservoirs consist mainly of CO_2 and H_2S, containing a small quantity of hydrocarbons, predominantly CH_4. In geothermal power projects, NCGs flow with the steam into the power plant. In the cooling water circuit, a small quantity of the CO_2 is converted to carbonate or bicarbonate with parts of the NCGs re-injected into the geothermal reservoir. As a conservative approach, however, the methodology assumes that all NCGs entering the power plant are discharged to the atmosphere through the cooling towers. Fugitive carbon dioxide and methane emissions due to well testing and well bleeding are not considered, as they are negligible (UNFCCC, 2012).

Calculating fugitive CO_2-eq/year:
Fugitive carbon dioxide and methane emissions due to the release of non-condensable gases from the produced steam ($PE_{GP, y}$) are estimated using Equation 1 of the methodology ACM0002 version 12;

$$PE_{GP, y} = (W_{steam, CO2, y} + W_{steam, CH4.y} \times GWP_{CH4}) \times M_{Steam,y} \quad (4)$$

where

$PE_{GP, y}$ = Project emissions from the operation of geothermal power plants due to the release of NCGs in year y (tCO_2-eq/year);

$W_{steam, CO2, y}$ = Average mass fraction of carbon dioxide in the produced steam in year y (tCO_2/tsteam);

$W_{steam, CH4, y}$ = Average mass fraction of methane gas in the produced steam in year y (tCH_4/tsteam);

GWP_{CH4} = Global warming potential of methane valid for the relevant commitment period (tCO_2/tCH_4); and

$M_{Steam, y}$ = Quantity of steam produced in year y (tsteam/year).

Data was obtained from a study conducted by KenGen during normal monitoring of 15 Olkaria II production wells (OW701, OW-705, OW-706, OW-709, OW-710, OW-713, OW-714, OW-715, OW-716, OW-720, OW-721, OW-725, OW-726, OW-727 and OW-728) to determine the NCG composition in the produced steam. Estimated project emissions were determined using average readings from the 15 wells, although the steam monitoring data from all producing wells were used ex-post. Project emissions from the operation of a 140 MWe geothermal power plant due to the release of NCGs (Appendix I) in year y (PEGP, y) were estimated. Project emission for the 400 MWe geothermal power plant were also estimated using CO_2 and CH_4 data from the Olkaria II wells. Tonnes of steam produced per year for the 400MWe project are computed based on the theoretical assumption; approximately 2 kg/s of steam is used to generate I MWe (Per comm, Stefan Arnosson, 2012). The annual quantity of steam produced for the 140MWe was also estimated using data from Olkaria II. It is assumed that steam flow from the wells for all the cases was the same. Table 2 presents the input values and estimated project emissions for the geothermal power plants.

140MWe
[(0.003269 tCO_2/tsteam) + (0.000000008213 tCH_4/tsteam × 21 tCO2 / tCH_4)] × 4,140,000 tsteam/year
= 13,533 tCO_2-eq/year

400MWe
[(0.003269 tCO_2/tsteam) + (0.000000008213 tCH_4/tsteam × 21 tCO_2 / tCH_4)] × 25,228,800 tsteam/year
= 82,470 tCO_2-eq/year

Total project emissions for the three geothermal projects were estimated at
(13,533 tCO_2-eq/year × 2) + 82,470 tCO_2-eq/year
109,536 tCO_2-eq/year

3.3 Emission Reductions

Emission reductions (ERs) for the projects were estimated for a 7 year (renewable) crediting period using Equation 11 of the methodology ACM0002 version 12:

$$ER_y = BE_y - PE_y \quad (5)$$

Where:

ER_y = Emission reductions in year y (tCO_2-eq/year);
BE_y = Baseline emissions in year y (tCO_2/year); and
PE_y = Project emissions in year y (tCO_2-eq/year).

The total baseline emissions for all the projects (680MWe) were estimated at 3,153,665 tCO2/year.
Estimated Emission Reductions for each project are computed below (See Appendix II for summary):

Menengai 400MWe ER_y

The baseline and project emissions were estimated as 1,861,596 tCO2/year (BE_y) and 82,470 tCO_2-eq/year (PE_y) respectively. The calculated reduction in emissions is therefore:

ER_y = 1,861,596 tCO_2/year - 82,470 tCO_2-eq/year

= 1,779,126 tCO_2-eq/year at an annual estimated generation of 3,134,000MWh/year

Olkaria IV 140MWe project ER_y

The baseline and project emissions were estimated as 651,618 tCO2/year (BE_y) and 13,533 tCO_2-eq/year (PE_y) respectively. The calculated reduction in emissions is therefore:
ER_y = 640,451 tCO_2/year - 13,533 tCO_2-eq/year

= 626,918 tCO_2-eq/year at an annual estimated generation capacity of 1,078,200MWh

Overall estimated emissions reduced in 7 years

Total baseline and project emissions were estimated at 3,153,665 tCO_2/year (*BEy*) and 109,536 tCO_2-eq/year (PE_y). The total emission reduction for Menengai I, Olkaria I and IV was therefore estimated as:

ER_y = BE_y - PE_y = (3,153,665 tCO_2/year – 109,536 tCO_2-eq/year)

= 3,044,129 tCO_2-eq/year at an approximate generation capacity of 5,309,200 MWh/year.

For the duration of the initial 7-year CDM crediting period, approximately 21,308,903 tCO_2-eq will be reduced.

3.4 Discussion

A key feature of the Clean Development Mechanism is *additionality*, the test of whether a project results in emission reductions in excess of those that would have been achieved in a "business-as-usual" scenario and determines whether a project should be awarded carbon credits that can be used by an Annex I country to meet its Kyoto commitments. Paragraph 43 of the protocol's Marrakech Accord establishes that a CDM project activity is additional if anthropogenic emissions of greenhouse gases by sources are reduced to levels below those that would have occurred in the absence of the registered CDM project activity (Escoto, 2007). Based on the Emission Reduction evaluations, electricity supplies from the three geothermal project activities would enhance economic sustainability. Presently, Kenya has to rely on fossil fuel based power when hydroelectric power supply is depressed by variations in the water columns during drought periods; implementation of the projects is foreseen to ease the instability in the electrical grid power. The Republic of Kenya is therefore committed to offset the current power supply deficit in the country through renewable and energy efficient technologies. Due to its high availability and reliable base load power (average of more than 95%), geothermal energy is currently the most promising indigenous resource for power development in Kenya, having an exploitable potential in excess of 10,000 MWe against a present installed capacity of only 212 MWe.

Upon implementation of Menengai I, Olkaria I and IV geothermal projects, the total project emissions of 109,536 tCO_2-eq/year are estimated at 0.0206 tCO_2-eq/MWh in one year. In total, about 3,044,129tCO_2-eq will be reduced annually and 21,308,903 tCO2-eq during the initial 7 year crediting period at an annual expected generation of 5,309,200 MWh. Carbon credits are measured in units of Certified Emission Reductions (CERs) where each CER is equivalent to one ton of carbon dioxide not emitted into the atmosphere when compared to "business as usual".

The World Bank (2011) reports that a ton of CO_2-eq reduced gains US$ 10, thus the three projects, if implemented under the CDM, could generate about US$ 213 million in the initial 7 year period, i.e about US$ 30 million per annum. Since initial geothermal projects have high upfront costs which require intensive loans that are difficult to access; by implementation of CDM projects, financial hurdles will be eased as they will provide revenue to the project income, improving cash flow. The foreign income will minimise considerable foreign exchange risks during the purchase of power plant equipment, overcoming the high development costs of geothermal plants and thus financial and investment barriers (Kollikho, 2007). Another barrier that CDM could help overcome includes electricity tariff barriers by the Energy Regulatory Commission (ERC) of Kenya to KPLC, caused by poor financial performance (Kollikho, 2007). These tariffs have led to high interest rates being charged by commercial banks *vis-a-vis* low rates of return. CDM can be considered an additional source of revenue and can help surpass the hurdle for the Internal Rate of Return. According to Rodriguez and Henriquez (2007), roughly 5-7% of the revenue streams can be accrued from a CDM certification of a geothermal project, having an impact of between 1 and 2% on the Internal Rate of Return (IRR).

CDM benefits will hasten the development of Kenya's earmarked geothermal potential, consequently enhancing sustainable economic development. With regard to economic development, the following positive outcomes are envisaged from the project:

- Decreased dependence on fossil fuels improving the hydrocarbon trade balance through the reduction of oil imports. This will reduce the use of thermal power generation plants and leave them only for stand-by power generation. By generating energy without GHG emissions, expensive heavy fuel, diesel, and gas-fired generation will be displaced, thus reducing CO_2 emissions to the atmosphere.
- Employment opportunities for local communities within the project vicinity, especially in construction and plant management.
- Contribution to Kenya's economic revenues through the payment of taxes.
- Participatory rural appraisal through corporate social responsibilities. A designated percentage of the revenue streams can be set aside for community and infrastructure development. Facilities such as health centres, clean water and education can be appraised as most communities near the project boundaries are marginalised with limited opportunities.

4. CONCLUSION

Stable, renewable and local supply of electricity from geothermal energy will permit the displacement of carbon-intensive power generation and thus contribute to sustainable development. Accelerated deployment of geothermal energy in Kenya will foster a reduction in CO_2 emissions which has global implications in terms of climate change mitigation. CDM will help offset key geothermal development hurdles and revenue returns will enhance economic development. Implementation of the proposed projects as CDM will derive great environmental, social and economic benefits for Kenya, becoming the cornerstone of sustainable development.

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Table 2: Project emission (tCO2-eq/year) input values

Input values	140 MWe	400MWe
Annual quantity of steam produced ($M_{steam,y}$); tsteam/year	4,140,000	25,228,800
Fraction of CO_2 in produced steam (W_{steam},$CO_{2,y}$); tCO_2/t steam	3.269E-03	3.269E-03
Fraction of CH_4 in produced steam (W_{steam},$CH_{4,y}$); tCH_4/t steam	8.213E-09	8.213E-09
GWP_{CH4} (tCO_2-eq/tCH_4)	21	21
$PE_{GP,y}$ (tCO_2-eq/yr)	13533	82470

APPENDIX I: WsteamCO2, y (tCO2/tsteam) and WsteamCH4, y (tCH4/tsteam) – Olkaria II production wells

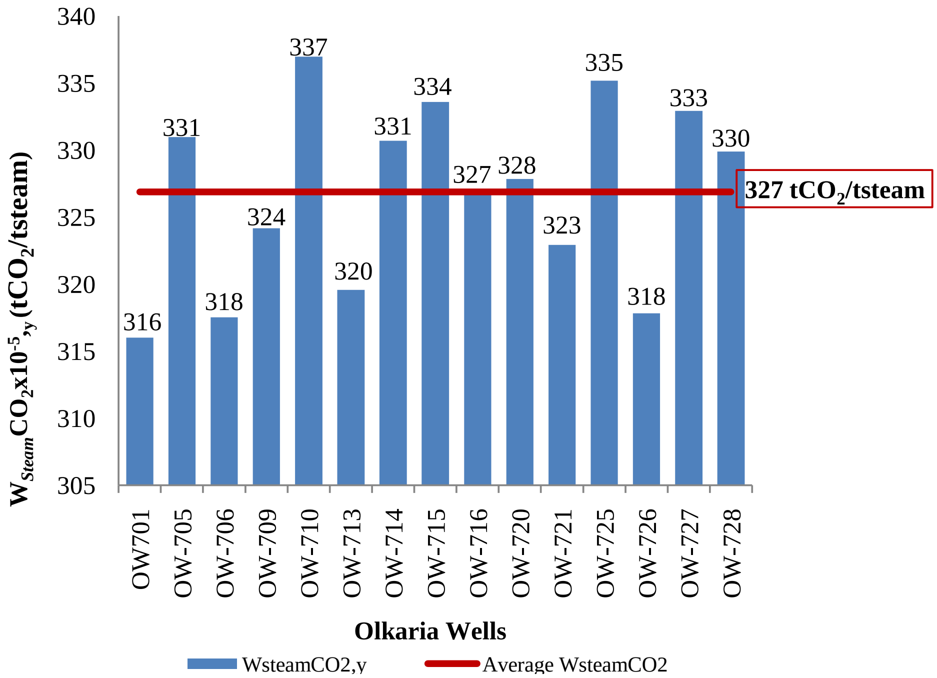

FIGURE 1: $W_{steamCO2}$, $_y$ (tCO_2/tsteam) – 15 Olkaria II production wells

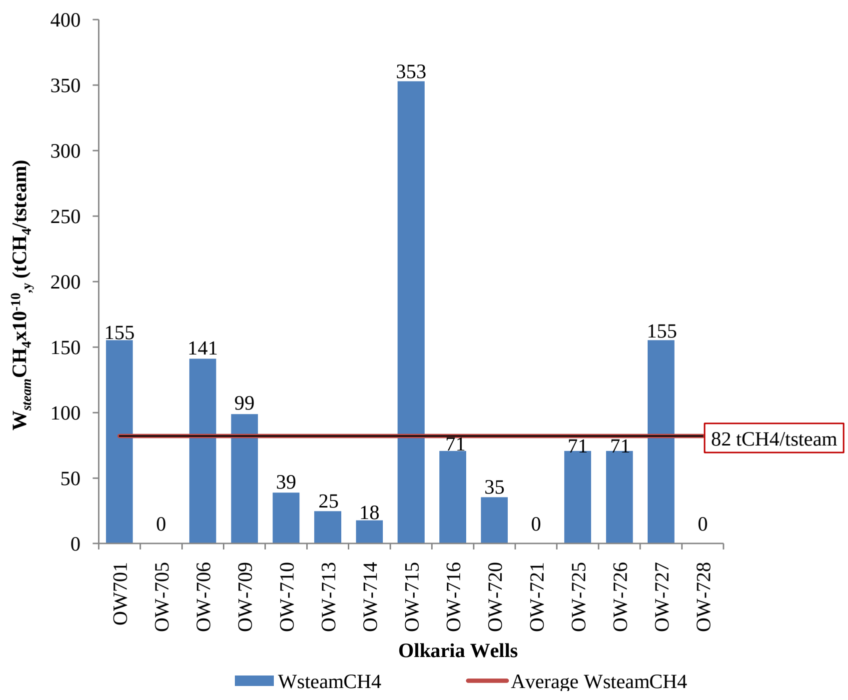

FIGURE 2: $W_{steam}CH_4$, $_y$ (tCH_4/tsteam) – 15 Olkaria II production wells

APPENDIX II: Summary of the ex-ante estimation of emission reductions

TABLE 1: Menengai I (400 MWe)

Year	Estimation of project activity emissions (tCO_2-eq/yr)	Estimation of baseline emissions (tCO_2-eq/yr)	Estimation of leakage (tCO_2-eq/yr)	Estimation of overall emissions reductions (tCO_2-eq/yr)
1	82,470	1,861,596	0	1,779,126
2	82,470	1,861,596	0	1,779,126
3	82,470	1,861,596	0	1,779,126
4	82,470	1,861,596	0	1,779,126
5	82,470	1,861,596	0	1,779,126
6	82,470	1,861,596	0	1,779,126
7	82,470	1,861,596	0	1,779,126
Total	**577,290**	**13,031,172**	**0**	**12,453,882**

TABLE 2: Olkaria IV (140 MWe)

Year	Estimation of project activity emissions (tCO_2-eq/yr)	Estimation of baseline emissions (tCO_2-eq/yr)	Estimation of leakage (tCO_2-eq/yr)	Estimation of overall emissions reductions (tCO_2-eq/yr)
1	13,533	651,618	0	638,085
2	13,533	651,618	0	638,085
3	13,533	651,618	0	638,085
4	13,533	651,618	0	638,085
5	13,533	651,618	0	638,085
6	13,533	651,618	0	638,085
7	13,533	651,618	0	638,085
Total	**94,731**	**4,561,326**	**0**	**4,466,595**

TABLE 3: Olkaria I Units 4 and 5 (140 MWe)

Year	Estimation of project activity emissions (tCO_2-eq/yr)	Estimation of baseline emissions (tCO_2-eq/yr)	Estimation of leakage (tCO_2-eq/yr)	Estimation of overall emissions reductions (tCO_2-eq/yr)
1	13,533	640,451	0	626,918
2	13,533	640,451	0	626,918
3	13,533	640,451	0	626,918
4	13,533	640,451	0	626,918
5	13,533	640,451	0	626,918
6	13,533	640,451	0	626,918
7	13,533	640,451	0	626,918
Total	**94,731**	**4,483,157**	**0**	**4,388,426**

TABLE 4: Total emissions from Menengai I, Olkaria IV, and Olkaria I Units 4 and 5 (420 MWe)

Year	Estimation of project activity emissions (tCO_2-eq/yr)	Estimation of baseline emissions (tCO_2-eq/yr)	Estimation of leakage (tCO_2-eq/yr)	Estimation of overall emissions reductions (tCO_2-eq/yr)
1	109,536	3,153,665	0	3,044,129
2	109,536	3,153,665	0	3,044,129
3	109,536	3,153,665	0	3,044,129
4	109,536	3,153,665	0	3,044,129
5	109,536	3,153,665	0	3,044,129
6	109,536	3,153,665	0	3,044,129
7	109,536	3,153,665	0	3,044,129
Total	**766,752**	**22,075,655**	**0**	**21,308,903**