United Nations Educational, Scientific and Cultural Organization
GRÓ GTP Geothermal Training Programme Under the auspices of UNESCO

GRÓ GTP, Grensásvegur 9,
IS-108 Reykjavík, Iceland

Reports 2021
Number 14

APPLICATION OF THE GEOTHERMAL SUSTAINABILITY ASSESSMENT PROTOCOL, SETTING A GREENHOUSE GAS ACCOUNTING, AND REPORTING FRAMEWORK: A CASE STUDY OF OLKARIA GEOTHERMAL POWER PLANTS

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ABSTRACT

Globally, emphasis on sustainability of projects is increasingly taking centre stage. In principle, for any organization to be successful, timely response to key external changes is paramount. Developing strategies to manage sustainability issues is an essential component for companies to adapt to the increasingly changing global business environment. Geothermal projects require sector specific tools to assess their overall contribution to sustainability. The aim of this study is to find out whether the Geothermal Sustainability Assessment Protocol (GSAP) is applicable to the Olkaria field, specifically to the geothermal power production phase of projects. The assessment of the power plants was based on selected topics due to time and data limitations. The study addresses three main objectives: 1) To determine if the company was sufficiently addressing specific sustainability topics, 2) to identify opportunities for improvement in the operation of the power plants, and 3) to set up a preliminary GHG emissions reporting framework to evaluate the projects' impact on climate change. To address these, the study made use of both primary and secondary data. Primary data was collected through personal interviews with KenGen key staff and a few stakeholders. Secondary data was obtained from KenGen inhouse publications, website ESIAs and monitoring reports. The study area is Olkaria geothermal field located in the southern part of the Kenyan rift. Presently, the field supports six geothermal power plants and ten well heads with a total installed capacity of 860 MWe, which is about 29% of the nationally installed capacity. The results demonstrate that the GSAP is a comprehensive tool and applicable in the Kenyan context and as such, it has the potential to support and enhance continuous sustainability performance of Olkaria power plants. The geothermal power plants sustainability management and performance was assessed on nine different topics. All the topics scored basic practice (score 3) or one evaluation step below best practice (score 4). None of the topics met proven best practice (score 5). This study concludes that the GSAP is a key management tool that provides assurance that the Olkaria power plants are operated in accordance with international standards and best practices. In addition, the GHG emissions preliminary assessment set the framework for commencing reporting on the impact of geothermal power plants on the climate. The study recommends commencing sustainability reporting using internationally, standardized frameworks GSAP and GHGP and later GRI for Olkaria geothermal projects since climate change is high on the global agenda.

1. INTRODUCTION

Energy plays a fundamental role in securing economic prosperity and welfare of nations, particularly for developing countries. The energy sector has also significant impacts on the environment, for example with the release of greenhouse gases from the use of fossil fuels, displacement of local communities and ecosystem degradation (Shortall et al., 2015). This calls for holistic assessment and management of all sustainability themes that are associated with energy development and use.

In recent years, the emphasis on renewable energy sources has gained prominence as a global pathway to meet energy demands using low-carbon energy. Globally, there is now a resolute international effort for the decarbonisation of energy systems as a key component of mitigating climate change. Possible renewable energy resources are widely documented in the literature including geothermal, hydro, wind, solar, biomass, tidal and wave energy. Geothermal energy is considered an important contributor due to its inherent stability compared to other renewable energy sources. However, just like any other energy development, geothermal energy development is associated with both positive and negative impacts across all sustainability themes. Positive impacts associated with geothermal development include increased employment, economic development, enhancement of health, sanitation, increased energy access, poverty reduction, higher standard of living and can assist in mitigating and adapting to climate change (Ogola et al., 2011; Cook et al., 2017). On the other hand, according to Shortall et al. (2015), possible adverse impacts include visual impact, impact on biodiversity, depletion of fresh water, land subsidence, potential for earthquakes, air and water pollution. However, with proper management of the various dimensions of sustainability, geothermal development can be consistent with the ideals of sustainable development since its proper use enables simultaneously environmental protection and social and economic development.

In line with the global effort to decarbonize energy systems, the Kenyan government has put policies, strategies and plans in place to facilitate the switch from conventional energy sources to renewable sources. According to The Kenya Vision 2030 strategy, which is the country's economic blueprint, the government aims to transform Kenya from a lower middle-income country into a newly industrialized middle-income country by the year 2030. The Vision recognizes energy as a key enabler for sustained economic growth and as a key foundation for Kenya's envisaged national transformation (Government of the Republic of Kenya, 2007). According to Vision 2030, the National Climate Change Action Plan (Government of the Republic of Kenya, 2018) and the Least Cost Power Generation Expansion Plan (Government of the Republic of Kenya, 2021), electric power consumption is expected to increase from 11,032 GWh in 2018 to 25,195 GWh and 65,733 GWh in 2030 and 2045, respectively (Musonye et al., 2021). Renewable energy is expected to contribute significantly to that increase. The continued shift from conventional to renewable sources is part of the country´s effort to increase long-term energy security, reduce the cost for consumers, decrease greenhouse gas emissions and thereby incorporate environmental concerns such as the Nationally Agreed Targets for Greenhouse gas (GHG) emissions. Presently, renewable energy sources account for 77.8% of the country's installed capacity including generation from geothermal, solar, wind and biogas. According to LCPDP (Government of the Republic of Kenya, 2021), renewable energy sources (geothermal, hydro, wind, solar and cogeneration) are envisaged to contribute approximately 79% of the installed capacity by 2030, indicating a significant increase in the development of geothermal resources. To ensure the potential multi-dimensional sustainability benefits of geothermal resources, sustainability issues including GHG emissions must be managed properly.

Sustainability assessment of energy systems is critical in evaluating the overall contribution of individual energy developments to sustainability. Though the adverse impacts of geothermal development are low compared to conventional systems, addressing negative impacts associated with its development is crucial to advancing the geothermal energy utilization narrative, particularly considering the scale at which renewable energy is envisaged to play a role in the supply of energy in

the future (Musonye et al., 2021). The Geothermal Sustainability Assessment Protocol (Orkustofnun et al., 2019a; Orkustofnun et al., 2019b) is a framework to support the management and sustainability performance of geothermal projects during the preparation and operation stage. It can assist in uncovering weak points in the system for purposes of continuous improvement.

This study aims to assess the applicability of the GSAP to the Olkaria field with specifical focus on the geothermal power production phase of the project (operation phase). The study seeks to understand the overall sustainability contribution of the project, to evaluate if the management of individual sustainability topics is according to best practices and to identify weak points in the operation of the power plants with respect to management of sustainability issues. In addition, it seeks to set up a preliminary GHG reporting framework to formally evaluate GHG emissions from the project using internationally standardized methodology. The results of this study intend to set the stage for sustainability management and reporting for KenGen power plants using globally recognized standardized systems for comparability with other systems. It also targets regulatory authorities whose focus is to provide advice to matters pertaining to energy production, environmental conservation, and management. Understanding the sustainability issues will pave the way for targeted licensing conditions.

2. HYDROPOWER SUSTAINABILITY ASSESSMENT PROTOCOL AND GEOTHERMAL SUSTAINABILITY ASSESSMENT PROTOCOL

The Hydropower Sustainability Assessment Protocol (HSAP) was developed by a wide range of stakeholders with diverse sustainability perspectives, ranging from governments to industry to NGOs. The International Hydropower Association (IHA) initiated the process in response to the World Commission on Dams' final report (World Commission on Dams, 2000) on the need for developers, governments, civil society to relook on social and environmental impacts of dams published in 2000 (International Hydropower Association, 2020).

The International Hydropower Association developed Sustainability Guidelines in 2004 and subsequently a Sustainability Assessment Protocol in 2006 as tools to assist the hydropower sector in evaluating performance against criteria in the IHA Sustainability Guidelines. In 2007, the Nature Conservancy (TNC) and the Worldwide Fund for Nature (WWF) approached IHA with the objective of refining the IHA Sustainability Assessment Protocol from 2006 to facilitate broad acceptance of the protocol. Out of this approach, the Hydropower Sustainability Assessment Forum (HSAF) was born. The HSAF is a multi-sector collaboration with representatives from the hydropower sector, the finance sector, several developing and developed countries, as well as international social and environmental NGOS. Reference groups to the forum members and two open consultation periods, which included trialling of a reworked draft, were built into the HSAF work programme to solicit views beyond the immediate forum membership. Throughout their two-year work programme, the HSAF members jointly reviewed, updated, and enhanced the IHA's Sustainability Assessment Protocol based on the views of the sectors represented in the forum. The objective was to develop a tool to measure, guide and improve the performance of the industry regarding the three dimensions of sustainability (social, economic, and environmental). The HSAP was first launched in November 2010. The protocol defines salient sustainability considerations for hydropower projects and allows for the generation of a sustainability profile through the assessment of management performance of key sustainability topics. Four separate documents were provided to reflect the different stages of hydropower development: Early stage, Preparation, Implementation and Operations. The HSAP is governed by the multistakeholder Hydropower Sustainability council and assessment is undertaken by accredited assessors. In September and October 2021 sustainability and certification standards were launched (International Hydropower Association, 2020).

2.1 Geothermal sustainability assessment protocol

The Geothermal Sustainability Assessment Protocol (GSAP) is modelled on the Hydropower Sustainability Assessment Protocol (HSAP). It is a framework to assess geothermal power projects management performance on key sustainability topics, comprising of technical, financial environmental and social issues (Orkustofnun et al., 2019a; Orkustofnun et al., 2019b). Iceland participated actively in the development of the HSAP and the protocol was applied to assess several hydro projects owned by Landsvirkjun. The assessments were considered a valuable tool for continuous improvement of sustainability issues management. Against this background and given that geothermal development in Iceland is advanced including electricity generation and a diverse array of direct use applications and has evolved over a long period, there was a felt need to adapt the HSAP to geothermal development. A working group for developing the GSAP was established that included representatives from Icelandic power companies and government agencies. The required adaption changes from HSAP to GSAP were kept minimal with the intent to preserve as much as possible of the international recognition and multistakeholder consensus obtained for the HSAP.

A draft GSAP for a geothermal power plant preparation stage was prepared in 2016 and a test assessment was carried out at Theistareykir 90 MWe power plant. The power plant in Northeast Iceland is owned by Landsvirkjun (National Power Company). According to Landsvirkjun (2017), the assessment was led by an experienced HSAP assessor from late 2016 to early 2017 and the final report was published in June 2017 (Landsvirkjun 2017).

Next, a draft GSAP for the operation stage was prepared in 2017 and a test assessment was conducted at Hellisheidi 330 MWe /130 MWth geothermal power plant in Southwest Iceland (Orkustofnun et al., 2019b). The power plant is owned by Orkuveita Reykjavikur (OR) and operated by its subsidiary Orka náttúrunnar (ON power). According to Orka náttúrunnar (2018), the assessment was undertaken with assistance of two experienced HSAP assessors and was undertaken from late 2017 to early 2018 with a final report published on the company webpage in June 2018 (ON Power, 2018). In 2019, the new topic "Climate Change Mitigation and Resilience" was incorporated into the protocol (Orkustofnun et al., 2019a; Orkustofnun et al., 2019b).

The two test assessments aptly demonstrated the applicability of the GSAP with no impediments experienced linked to the fact that the plants were geothermal and not hydropower plants. It was shown that the draft GSAP works well in Iceland but to date it is yet to be formally pilot tested in other countries. Further modifications, test piloting with test sites outside Iceland and streamlining are yet to be tackled. The two draft documents were handed over to the International Geothermal Association (IGA) in November 2021 for further development and for appropriate governance of the protocol.

2.1.1 An overview of HSAP and GSAP

The Geothermal Sustainability Assessment Protocol is an assessment framework for sustainability management of geothermal projects. The GSAP preparation and Operation phases documents encompasses 21 and 17 sustainability topics, respectively. Each sustainability topic is evaluated based on a predefined criteria and scored on a scale of 1-5. The results are shown in a spider graph. Table 1 summarizes the sustainability topics applied for the assessment of HSAP and GSAP.

TABLE 1: Sustainability topics and criteria within HSAP and GSAP

HSAP				GSAP		
Topics	Criteria	Preparation Assessment Tool	Operation Assessment Tool		Preparation Assessment Tool	Operation Assessment Tool
Communications & Consultation	Assessment	×	×		×	×
	Management	×	×		×	×

HSAP				GSAP		
Topics	Criteria	Preparation Assessment Tool	Operation Assessment Tool		Preparation Assessment Tool	Operation Assessment Tool
	Stakeholder Engagement	×	×		×	×
	Conformance	×	×		×	×
Governance	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Outcomes	×	×		×	×
	Conformance/ Compliance	×	×		×	×
Demonstrated Need & Strategic Fit	Assessment	NA	NA		×	N/A
	Stakeholder Engagement	NA	NA		×	N/A
	Outcomes	NA	NA		×	N/A
Siting & Design	Assessment	NA	NA		×	N/A
	Management	NA	NA		×	
	Stakeholder Engagement	NA	NA		×	
	Outcomes	NA	NA		×	
Environmental & Social Impact Assessment & Management	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Conformance/ Compliance	NA	×		N/A	×
	Outcomes	×	×		×	×
Integrated Project Management	N/A	NA	NA		N/A	N/A
	Management	x	NA		×	
	Outcomes	x	NA		×	
Hydrological Resource	Assessment	x	x	Geothermal Resource	x	×
	Management	x	x		x	×
	Conformance/ Compliance	N/A	N/A		N/A	×
Asset Reliability & Efficiency	Assessment	N/A	x		N/A	×
	Management	N/A	x		N/A	×
	Conformance/ Compliance	N/A	x		N/A	×
	Outcomes	N/A	x		N/A	×
Infrastructure Safety	Assessment	×	x	Public Health and Safety	×	×
	Management	×	x		×	×
	Conformance/ Compliance	NA	×		N/A	×
	Outcomes	x	×		×	×
Financial Viability	Assessment	×	×		×	×
	Management	×	×		×	×
	Conformance/ Compliance	NA	×		N/A	×
	Outcomes	x	x		×	×
Project Benefits	Assessment	×	×		x	×
	Management	×	×		x	×
	Stakeholder Engagement	×	N/A		x	N/A
	Conformance	NA	×		N/A	×
	Outcomes	×	×		×	×
Procurement	Assessment	×	N/A		×	N/A
	Management	×			×	
	Conformance/ Compliance	×			×	
	Outcomes	×			×	

HSAP				GSAP		
Topics	Criteria	Preparation Assessment Tool	Operation Assessment Tool		Preparation Assessment Tool	Operation Assessment Tool
Economic Viability	Assessment	×	N/A		×	N/A
	Stakeholder Engagement	N/A	N/A		×	
	Outcomes	×	N/A		×	
Project-Affected Communities & Livelihoods	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Stakeholder Support	×	N/A		×	N/A
	Outcomes	×	×		×	×
	Conformance/ Compliance	N/A	×		N/A	×
Resettlement	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Stakeholder Support	×	N/A		×	N/A
	Conformance/ Compliance	x	×		×	×
	Outcomes	x	×		N/A	×
Indigenous Peoples	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Stakeholder Support	×	N/A		×	N/A
	Outcomes	×	×		×	×
	Conformance/ Compliance	N/A	×		N/A	×
Labour& Working Conditions	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Conformance/ Compliance	N/A	×		×	×
	Outcomes	x	×		×	×
Cultural Heritage	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	N/A		×	N/A
	Stakeholder Support	×	×		×	N/A
	Outcomes	×	×		×	×
	Conformance	N/A	×		N/A	×
Public Health	Assessment	×	×		x	x
	Management	×	×		x	x
	Stakeholder Engagement	x	×		x	x
	Outcomes	×	×		x	x
	Conformance	N/A	×			
Biodiversity & Invasive Species	Assessment	×	×		×	×
	Management	×	×		×	×
	Conformance	N/A	×		N/A	×
	Outcomes	x	×		×	×
Erosion & Sedimentation	Assessment	×	×		N/A	N/A
	Management	×	×			

HSAP				GSAP		
Topics	Criteria	Preparation Assessment Tool	Operation Assessment Tool		Preparation Assessment Tool	Operation Assessment Tool
	Conformance/ Compliance	N/A	×			
	Outcomes	x	×			
Water Quality	Assessment	×	×	Air and Water Quality	×	×
	Management	×	×		×	×
	Conformance/ Compliance	N/A	×		N/A	×
	Outcomes	x	×		×	×
Reservoir Planning	Assessment	x	N/A		N/A	N/A
	Management	x				
Reservoir Management	Assessment	N/A	x		N/A	
	Management		x			
	Conformance/ Compliance		x			
Waste, Noise & Air Quality	Assessment	x	N/A			
	Management	x				
	Conformance/ Compliance	x				
	Outcomes	x				
Downstream Flow Regimes	Assessment	×	×			
	Management	×	×			
	Stakeholder Engagement	×	N/A			
	Conformance/ Compliance	N/A	×			
	Outcomes	×	×			
Reservoir Preparation & Filling	Assessment	x	N/A	N/A		
	Management	x				
	Conformance	x				
Induced Seismicity and Subsidence	Assessment				x	x
	Management				x	x
	Stakeholder Engagement				x	x
	Conformance				N/A	x
	Outcomes				x	x
Climate Change Mitigation and Resilience	Assessment	×	×		×	×
	Management	×	×		×	×
	Stakeholder Engagement	×	×		×	×
	Conformance	N/A	×		N/A	×
	Outcomes	×	×		×	×

2.1.2 Scoring criteria

Application of the protocol is an evidence-based performance assessment. The score provides an indication of the performance in relation to basic good practice and proven best practice for each criterion (International Hydropower Association, 2020).

The actual scoring system of GSAP is adapted from the HSAP scoring system (International Hydropower Association, 2020). Each topic is scored based on up to six criteria, that is assessment, management, stakeholder engagement, stakeholder support, conformation/compliance, and outcomes (Table 1). Appendix I illustrates the protocol´s gradational approach and the scoring statements for each of the criteria. As depicted in Appendix I, the scoring system is as follows: 5 points: meets proven best practice; 4 points: meets basic good practice with one significant gap compared to proven best practice; 3 points: meets basic good practice with more than one significant gap compared to proven best practice;

2 points: has one significant gap compared to basic good practice; and 1 point: more than one significant gap compared to basic good practice (International Hydropower Association, 2020; Muhammed, 2019).

2.1.3 Previous protocol assessments

The Theistareykir project assessment was carried out to test the draft Geothermal Sustainability Assessment Protocol for a power plant in Preparation stage. The aim was to assess applicability of the protocol, to gauge the performance of the project and to identify opportunities for improvement of the project and other geothermal projects in Iceland (Orkustofnun et al., 2019a). The assessment focused on the preparation stage of the project before key decisions such as the granting of licenses and the final investment decision were taken. The Theistareykir sustainability profile results shows that 18 topics were assessed, topics P-14 and P-15 were found to be irrelevant, and P-18 was not scored separately and later moved to P-8 (public health & safety). The findings demonstrated that the protocol was applicable to geothermal projects and the Theistareykir project received high scores throughout the assessment. The results are shown in Figure 1.

The Hellisheidi Geothermal project assessment was carried out to test the draft Geothermal Sustainability Assessment Protocol for the Operation stage (Orkustofnun et al., 2019b). The assessment was conducted in early 2018. The aim was to assess the applicability of the protocol whilst the objectives were to identify areas for improvement for the project and other OR/ON geothermal projects and to facilitate a discussion within OR/ON, with stakeholders, and with other working group members about sustainability in geothermal projects (Adalsteinsdóttir et al., 2020).

The Hellisheidi Geothermal project sustainability profile results show that fourteen (14) topics were assessed. Two topics, Resettlement, and Indigenous People were considered irrelevant for the project. The results confirmed that the protocol is applicable to geothermal projects and the Hellisheidi Geothermal project received high scores except for two topics which were Geothermal Resources Management and Project Affected Communities which scored 3 indicating that they met basic practice criteria (Adalsteinsdóttir et al., 2020). The results are depicted in Figure 2.

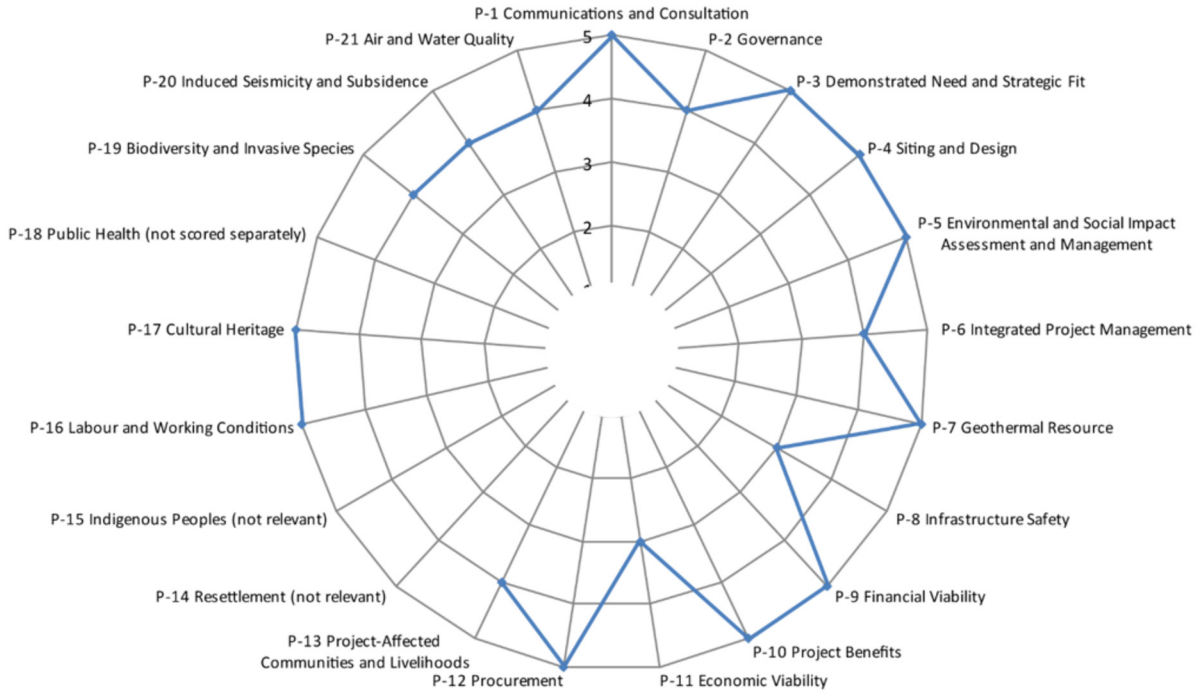

FIGURE 1: Theistareykir sustainability profile (Landsvirkjun, 2017)

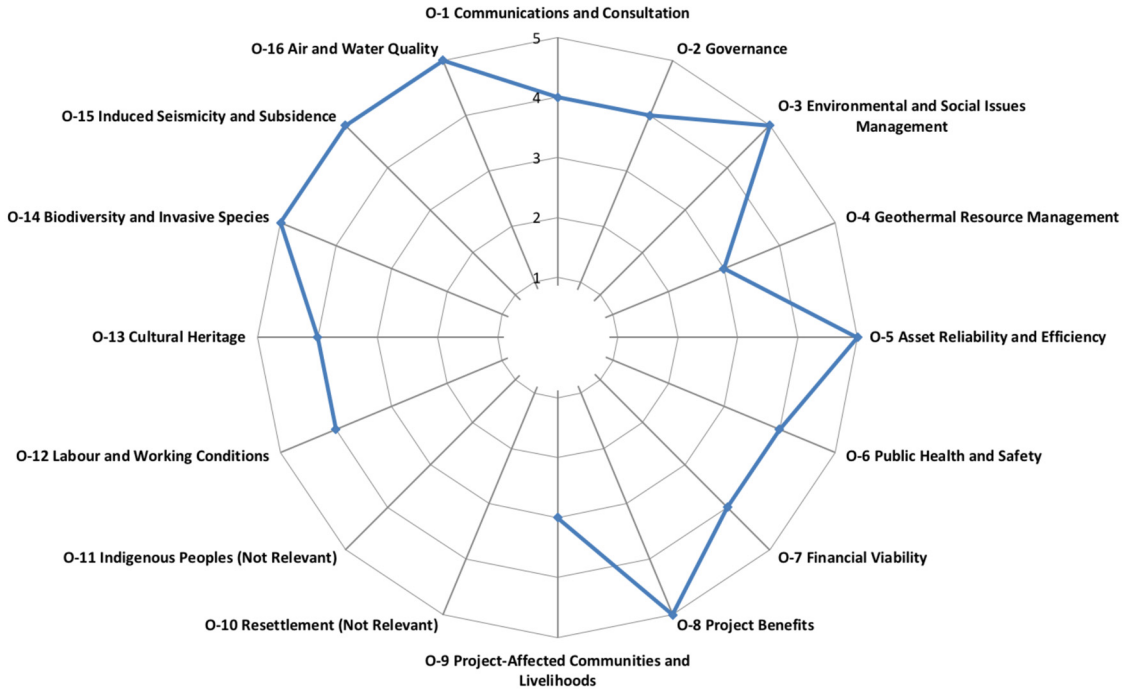

FIGURE 2: Hellisheidi Geothermal project sustainability profile Adopted from earlier (Adalsteindottir et al., 2020)

2.2 The greenhouse gas protocol- a corporate accounting and reporting standard

The Greenhouse Gas Protocol was set forth by WRI. It is used to support companies in calculating their GHG emissions (World Resources Institute, 2015) and focusses on the accounting and reporting of the six greenhouse gases regulated under the Kyoto Protocol, now the Paris Agreement, nitrous oxide (N_2O), methane (CH_4), carbon dioxide (CO_2), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). The protocol is broken up into three different scopes. Scope 1 controls direct emissions from operations, primarily caused by combustion of stationary and mobile sources owned or controlled by the company. Scope 2 controls emissions from energy use (purchased electricity and steam) and scope 3 is about emissions from different indirect activities (flights, commuting, waste, etc.). Under the GHG protocol, it is mandatory to account for Scope 1 and Scope 2 emissions while reporting Scope 3 emissions is optional. Figure 3 explains the different scopes by depicting the possible sources for emissions within each scope.

Developing a company's GHG emission inventory is the first step towards identifying risks and opportunities associated with GHG emissions. Further, setting GHG targets is a key tool that can drive GHG reductions in the long run. Just like any major business goal, an effective GHG emission management strategy requires setting targets and indicators, as well as tracking performance considering those targets. According to the Greenhouse Gas Protocol, setting a baseline for yearly emissions is the first step in monitoring GHG emissions. To maintain consistency over time, recalculations of historic emission data is undertaken whenever the company's structure is altered because of changes in the company through mergers, divestments or acquisitions. When using the protocol, the calculation of GHG emissions is based on various data sets availed in the GHG protocol such as emission factors and local data. The framework is useful as it provides an international standard for GHG estimation. The protocol has been applied worldwide in geothermal sector including Hellisheidi and Nesjavellir power plants. One of the most recent additions to the GSAP was the Climate Change Mitigation and Resilience theme, which require proper accounting of GHG emissions and management (Orkustofnun et al., 2019a; Orkustofnun et al., 2019b).

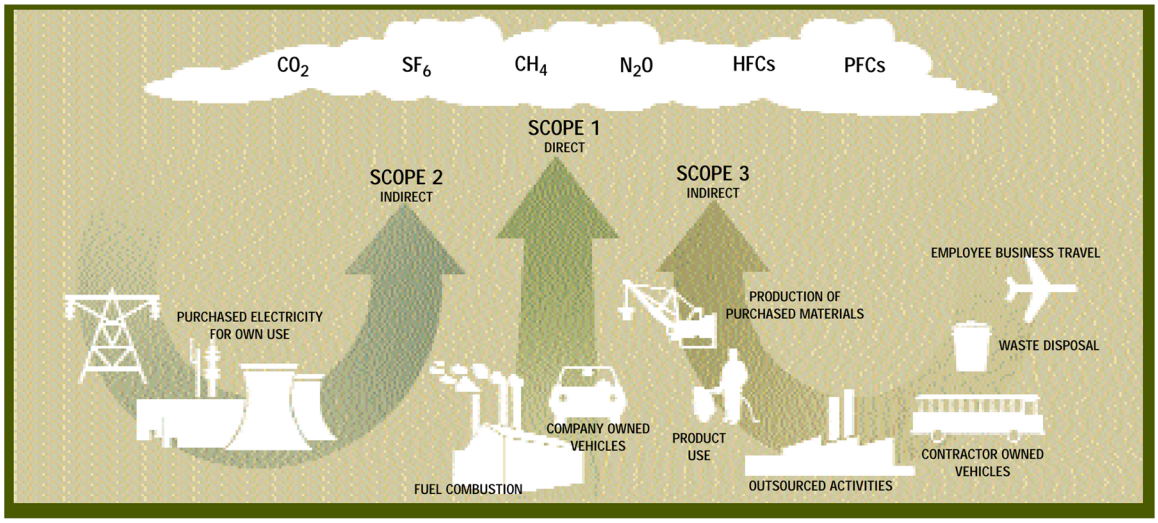

FIGURE 3: A schematic for possible sources for each one of the scope emissions. Adopted from GHG protocol

3. OLKARIA GEOTHERMAL FIELD CASE STUDY

3.1 Project description

The Kenya Electricity Generating Company PLC (KenGen) is a state corporation and is the main power generation entity accounting for 65% generation capacity in the country. The company's overall power generation mix encompasses geothermal, hydro, thermal, and wind resources. Currently, KenGen operates five power plants and 20 wellhead units at Olkaria geothermal field generating a total of 704.8 MWe (Mangi et al., 2020).

The Olkaria geothermal field is in the southern part of the Kenyan rift, within the Naivasha Sub County. It is located south of Lake Naivasha, approximately 120 km northwest of Nairobi city, the capital city of Kenya. It is bordered by other geothermal prospect areas namely Longonot, Suswa and Eburru (Figure 4). Presently, the field supports seven geothermal power plants (Olkaria I, Olkaria IAU, Olkaria II, Olkaria III, Olkaria IV, Oserian power plant, and Olkaria V) and 20 well heads (81MWe) with a total installed capacity of 860 Mwe which is about 29 % of the national installed capacity (Mangi et al., 2020).

Exploration of the Olkaria field commenced in 1956 (Mariita,2002) and development has been undertaken in phases since 1981. The Olkaria I (commissioned between 1981 and 1985) and Olkaria II (commissioned in 2003 and 2010) power stations generate 45 and 105 MWe of electricity, respectively, Olkaria IV and Olkaria I Units 4 and 5 power plants were commissioned in 2014 with an installed capacity of 140 MWe each, while Olkaria V was commissioned in 2019 and generates 140 MWe. The 20 well heads have a combined installed capacity of 80.58 MWe. The Olkaria III and Oserian geothermal power stations, which generate 155 MWe and 3.6 MWe of electricity, are owned by independent power producer (IPP) Orpower 4 Limited and Oserian Company LTD. Olkaria I, Olkaria IAU, II and III are situated inside Hell's Gate National Park while Olkaria IV and V are situated outside the park. This land constitutes an important dispersal area for wildlife in the Hell's Gate National Park. The park is known for its scenery and wide variety of wildlife. 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.

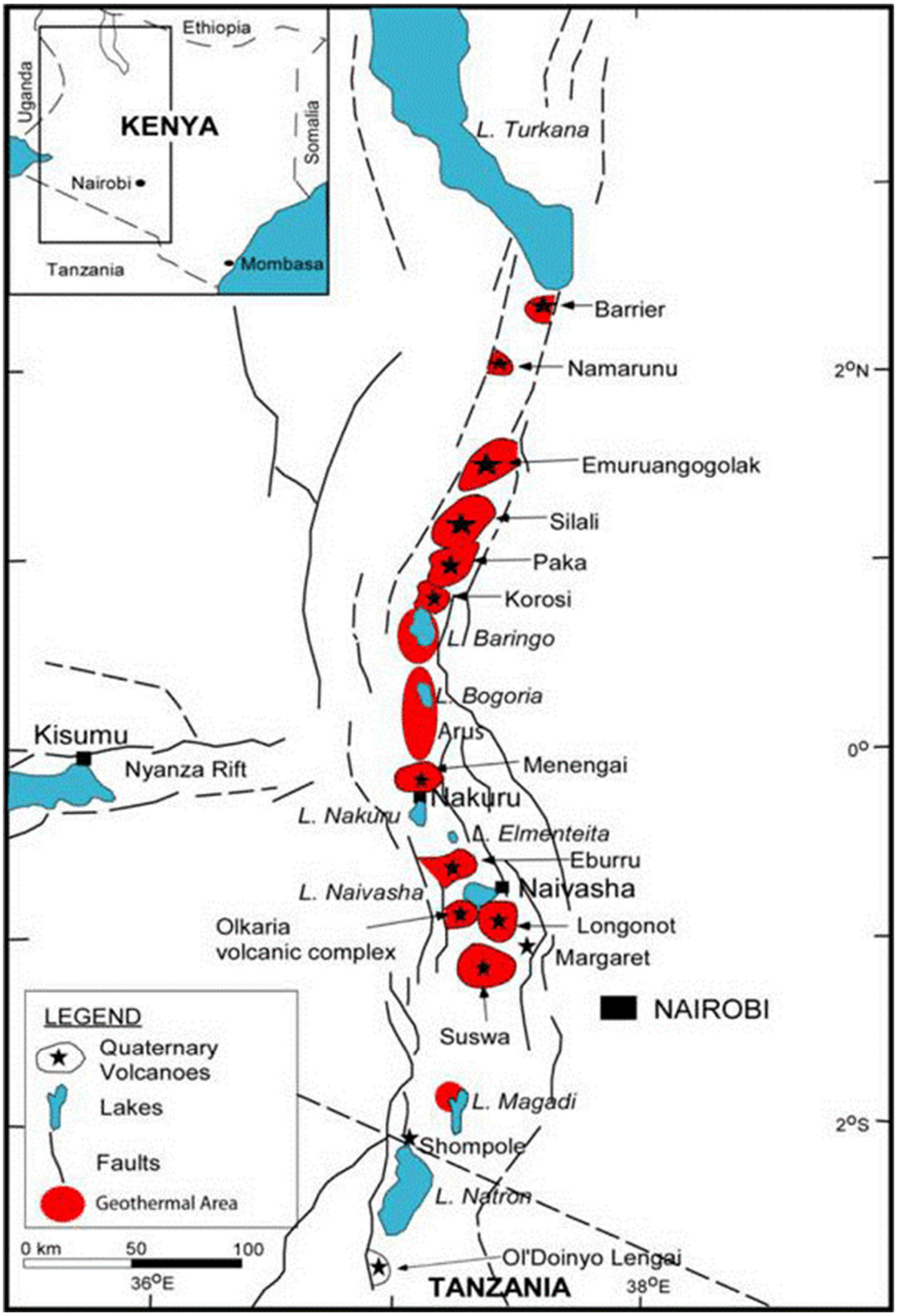

FIGURE 4: Location of Olkaria field within the Kenyan Rift from Adopted from (Lagat, 2004)

3.2 Objectives

This study was designed to:

i. Assess applicability of the GSAP framework in Olkaria field, specifically for the geothermal power production phase of the project (Operation phase).

ii. To identify areas of improvement on sustainability management

iii. To set a preliminary greenhouse gas emissions accounting framework for Olkaria with the aim to showcase how to apply international standard GHG protocol. This is a key step towards reporting the climate impact of Olkaria geothermal project.

The methodology involved a literature review on impacts of geothermal energy projects on sustainable development, HSAP, GSAP, GHGP, a review of internal documents (monitoring data) and interviews with selected KenGen departmental process owners and stakeholders.

3.3 Assessment process and methodologies

Due to limited time and data availability, 9 out of 17 sustainability topics were selected for this study (Table 1). All 17 sustainability topics under the GSAP operation phase, however, are applicable to the Olkaria field. The topics chosen to be included in the assessment were: Communications and Consultations (0-1), Environmental and Social Impact Assessment and Management (0-3), Geothermal Resource Management (0-4), Project Benefits (0-8), Project Affected Communities and Livelihood (0-9), Biodiversity and Invasive species (0-14), Induced Seismicity and Subsidence (0-15), Air and Water Quality (0-16) and Climate Change Mitigation and Resilience (0-17). Each topic was evaluated with respect to up to six criteria, as shown in Table 2, and scores were assigned according to the following process.

Step 1: Evaluates if the scoring statements for each of the criteria specified in Level 3 are met by the project.

Step 2: If there is one significant gap compared to the Level 3 statements (all or part of a criterion is not fulfilled), then a score of 2 is assigned to the topic.

Step 3: If there is more than one significant gap compared to the Level 3 statements, then a score of 1 is assigned to the topic.

Step 4: If all the Level 3 statements are met, then move to Level 5 to evaluate if the scoring statements for each of the criteria specified are met by the study project.

Step 5: If there is one significant gap compared to the Level 5 statements, then a score of 4 is assigned to the topic.

Step 6: If there is more than one significant gap compared to the Level 5 statements, then a score of 3 is assigned to the topic.

Step 7: If all the Level 5 statements are met, then a score of 5 is assigned to the topic (Muhammed, 2019).

Table 2 shows the assessment criteria for each selected topic. Note that not all elements of the criteria are fulfilled for each topic. For instance, stakeholder support is not relevant to any of the selected topics.

TABLE 2: Criteria applied for each selected sustainability topic

Criteria	Topics								
	0-1	0-3	0-4	0-8	0-9	0-14	0-15	0-16	0-17
Assessment	×	×	×	×	×	×	×	×	×
Management	×	×	×	×	×	×	×	×	×
Stakeholder Engagement	×	×		N/A	×	N/A	×	N/A	×
Stakeholder support	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Conformance / Compliance	×	×	×	×	×	×	×	×	×
Outcomes	N/A	×	N/A	×	×	×	×	×	×

3.4 Data sources

The scoring of each sustainability topic during the assessment is based on the review of objective evidence. In this study the written evidence was derived from:

- ESIA reports for Olkaria V, IV, IAU (Gibb, 2009: Gibb, 2013; Gibb, 2014)
- KenGen internal reports such as power plant monitoring, geothermal reservoir resource management, environmental monthly reports
- KenGen community engagement plan and integrated annual report
- KenGen EMS 1SO: 140001
- Kenya Vision 2030
- Kenya Least Cost Power Development plan 2021-2030

4. RESULTS

4.1. Summary

Figure 5 depicts the sustainability profile for Olkaria Power plants based on this assessment. As shown in the figure, all the topics scored basic practice (score 3) or one significant gap below best practice (score 4). None of the topics met proven best practice (score 5).

The sections below introduce each topic and criteria specific scoring statements used for the evaluation (in italics) followed by the rationale for each score and the scoring results for each topic.

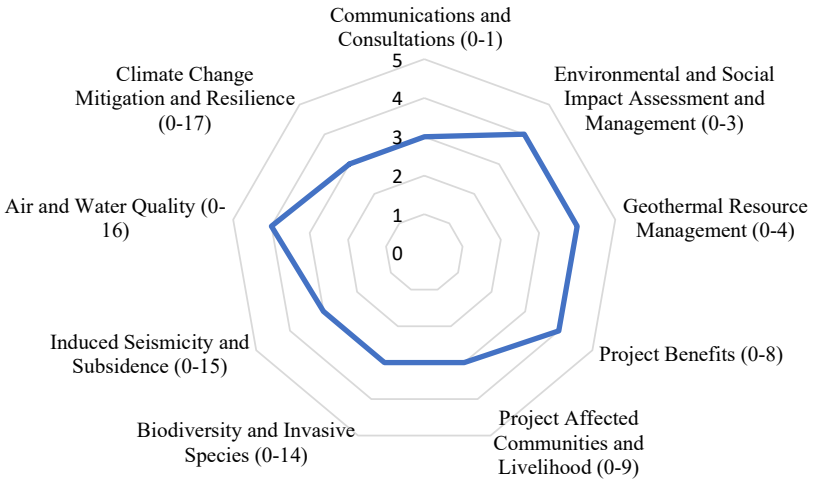

FIGURE 5: Olkaria Power Plants sustainability profile

4.2. Topic specific assessment

0-1 Communications and consultation

Introduction

This topic addresses ongoing engagement with project stakeholders, both within the company as well as between the company and external stakeholders (e.g., affected communities, governments, key institutions, partners, contractors, geothermal area residents, etc.). The intent is that stakeholders are identified and engaged in the issues of interest to them, and that communication and consultation processes maintain good stakeholder relations throughout the project life (Orkustofnun et al., 2019b).

The aim of stakeholder identification is to establish which individuals and organizations might be directly or indirectly affected or have interests in the project and/or the ability to influence its outcome either positively or negatively. Directly affected stakeholders are defined in the protocol as 'those with substantial rights, risks and responsibilities' in relation to the project or issues it affects. Stakeholder identification is a continuous process, necessitating regular review and updates. Stakeholder engagement is key to building strong, constructive, and responsive relationships that are vital for successful project management.

To date, a wide range of potentially affected, interested parties and those with ability to influence the project have been identified for Olkaria geothermal power plants. The directly affected stakeholders include KenGen employees, regulators (NEMA and EPPRA), the Government of Kenya, Nakuru County Government, international financial institutions (JICA, IFC, AfDB, EIB), KWS, project affected communities, landowners within the Olkaria Geothermal project license area, residents, local businesses, Kenya Power and Lighting Company and KETRACO. Indirectly affected stakeholders include Narok County, tourists, environmental NGOs, media (TV, newspaper, radio, TV) and other power generating companies.

Analysis

To assess the company's performance on communication and consultation 4 criteria were employed in line with the protocol namely assessment, management, stakeholder engagement and compliance.

Analysis against basic good practice – assessment

Scoring statement: *Ongoing or emerging issues relating to geothermal facility communications and consultation have been identified; requirements and approaches are determined through a periodically updated assessment process involving stakeholder mapping; and effectiveness is monitored (Orkustofnun et al., 2019b).*

Periodic stakeholder meetings and continuous presence of environment and liaison staff in the community and society form a mechanism for emerging issues identification. The stakeholders' map is in place and updated annually and on need-basis. The mapping exercise is based on the distance from the power plant, individual issues and project aspects. In addition, a stakeholders' matrix has been developed outlining their impact, influence, issues of interest, expectations as well as communication and consultation requirements. Further, the stakeholders' engagement strategy details a suit of engagement options based on the stakeholder category and the issue of concern. The key stakeholders in terms of communication needs are the Government, regulators, nearby communities, Nakuru county and the public in the vicinity of the geothermal area. Communication effectiveness is measured in periodic meetings and number of grievances raised. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, the stakeholder mapping takes broad considerations into account Orkustofnun et al., 2019b).*

Stakeholders' mapping is based on several aspects which include inter-relationships between stakeholders, geographical extent, risks, responsibilities, rights, and incorporating different professions to offer technical perspectives on issues. *Criteria met: Yes*

Analysis against basic good practice- management

Scoring statement: *Communications and consultation plans and processes, including an appropriate grievance mechanism, are in place to manage communications and engagement with stakeholders; these outline communication and consultation needs and approaches for various stakeholder groups and topics* (*Orkustofnun et al., 2019b)*

Communications and consultation strategy is an integral part of the EMS and encompasses a grievance handling mechanism and diverse engagement approaches, based on the stakeholder's category and issue of concern. The company employ diverse communication channels including meetings, maintaining presence through community liaison officers, emails, phone calls, releasing bulletins through the media and digital communication through facebook and twitter. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, communication and consultation plans and processes show a high level of sensitivity to communication and consultation needs and approaches for various stakeholder groups and topics; and processes are in place to anticipate and respond to emerging risks and opportunities* (*Orkustofnun et al., 2019b).*

The company employs diverse communication tools such as social media, media, email, phone calls, meetings, workshops, and awareness creation sessions depending on the stakeholder category. The company disseminates knowledge about geothermal energy to over 100,000 visitors per year visiting the power plants education institutions spread across the country. The risk and opportunity anticipation process entails risk assessment and holding stakeholder meetings. In addition, environment and liaison officers serve as a direct line of contact which helps to anticipate and respond to emerging risks and opportunities on an ongoing basis. *Criteria met: Yes*

Analysis against basic good practice- stakeholder engagement

Scoring statement: *The operation stage involves appropriately timed and scoped, and often two-way, engagement with directly affected stakeholders; engagement is undertaken in good faith; ongoing processes are in place for stakeholders to raise issues and get feedback* (*Orkustofnun et al., 2019b).*

Communication on issues of interest and relevance to stakeholders is undertaken in a timely manner to enable stakeholders to internalize, consult, and give feedback prior to decision making. The company has designated environment and liaison offices to connect to stakeholders and to maintain presence in the community. The office receives concerns and issues, it engages stakeholders, communicates feedback, and follows up on issues on an ongoing basis. In addition, periodic meetings are undertaken with various stakeholders on need-basis and form part of a public participation forum in decision making. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, engagement is inclusive and participatory; negotiations are undertaken in good faith; and feedback on how issues raised have been taken into consideration has been thorough and timely* (*Orkustofnun et al., 2019b).*

Engagement of a broad range of stakeholders on topics of relevance and interest is widely practiced. Stakeholder inputs form a mechanism for continuous process improvement. The company has undertaken several participatory studies with the community and relevant ministries on issues of concern to the community. In addition, the company has designed and deployed well discharge silencers with higher noise attenuation level for wells located close to sensitive receptors. This improvement was undertaken in response to a concern from the community regarding high noise levels during well discharge. However, communication to stakeholders on how issues are addressed is inconsistent and there is no effective mechanism to manage high expectations of communities. These are considered significant gaps. *Criteria met: No*

Analysis against basic good practice - conformance / compliance

Scoring statement: *Processes and objectives relating to communications and consultation have been and are on track to be met with no major non-compliances or non-conformances, and communications related commitments have been or are on track to be met* (*Orkustofnun et al., 2019b).*
Communications and consultation processes (targets) and objectives are on track without major non-compliances or non-conformances*. Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances* (*Orkustofnun et al., 2019b).*

There are no non-compliances or non-conformances. *Criteria met: Yes*

Evaluation of significant gaps
Analysis of Significant Gaps against basic good practice: There are no significant gaps against basic good practice. 0 significant gaps

Analysis of significant gaps against proven best practice: Communication with stakeholders on how issues are addressed is inconsistent and there is no effective system to manage high expectations from the community. 2 significant gaps

Scoring summary: There are two significant gaps on communication to stakeholders on how issues are addressed. In addition, there is no effective system to manage high expectations from the community, resulting in an overall score of 3.

0-3 Environmental & social issues management

This topic addresses the plans and processes for environmental and social issues management. The intent is that negative environmental and social impacts associated with the geothermal facility are managed; avoidance, minimization, mitigation, compensation, and enhancement measures are implemented; and environmental and social commitments are fulfilled (*Orkustofnun et al., 2019b)*.

Introduction

Environmental and social impacts associated with geothermal development in Olkaria include both positive and negative impacts. Positive impacts include promotion of economic growth, stabilization of

electricity supply, increased employment especially during construction phase, contribution to government revenue, improvement of roads and extension of Corporate Social Responsibilities (CSR). Negative impacts include air pollution, noise, vegetation clearance, visual impact from pipes and land clearance, disturbances of fauna, solid waste generation, increased water abstraction, occupational safety, and health.

All geothermal development projects implemented in Olkaria geothermal field are subjected to the Environmental Impact and Social Assessment (ESIA) commensurate with the risks and impacts of the project in accordance with the EMCA (CAP 387). The ESIAs are conducted by either consultants or internal teams and reports are submitted to the National Environmental Management Authority for purposes of licensing in accordance to the law. Public consultation and engagement are a mandatory part of the project as a mechanism to incorporate stakeholders concerns, interest, and values in the geothermal project in line with the constitution and laws of Kenya.

This topic overlaps with several other topics. The management aspects of the environmental management system are reviewed under this topic while all specific aspects are reviewed under the respective specialist topic such as O-1, O-4, O-8, O-9 O-12, and O-14 through O-17.

Analysis

To assess the company's performance of environmental and social issues management, 5 criteria were employed in line with the protocol namely assessment, management, stakeholder engagement, compliance, and outcomes.

Analysis against basic good practice- assessment

Scoring statement: *Systematic processes are in place to identify any ongoing or emerging environmental and social issues associated with the operating geothermal facility, utilizing appropriate expertise; and monitoring programs are in place for identified issues* (*Orkustofnun et al., 2019b).*
A comprehensive monitoring programme is in place at the power plant and close to sensitive receptors such as close residential areas (Olo Mayana Kubwa) and other key areas of impacts. The significant aspects are documented in individual power plant ESMPs. The significant impacts that are monitored include air quality and noise levels at the power plants and in Olo Mayana village, water abstraction from Lake Naivasha, water quality at a network of boreholes surrounding the field, solid waste generation, rehabilitation of disturbed land, stakeholders' engagement, Corporate Social Responsibilities (CSR) activities, awareness creation on HIV and other STDS and social afforestation. Significant aspects, objectives, targets, monitoring methodology, and monitoring frequency are documented and reported in accordance with the Environmental Management System ISO 14001: 2015. Periodic audit on the implementation of the system is undertaken internally and externally. Additionally, external monitoring is undertaken by consultants during initial environmental audits of power plants, and often ESIAs are conducted externally as requirements by financiers. Further, KWS also undertakes periodic external monitoring. On need-basis, participatory monitoring and research is undertaken with KWS, relevant ministries and neighboring communities. Continuous stakeholder engagement in ensured through consultation during annual audits, periodic meetings and through designated Environmental and Liaison offices. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, processes to identify ongoing and emerging environmental and social issues take broad considerations into account, and both risks and opportunities* (*Orkustofnun et al., 2019b)*.

The company has put in place a system to identify and consider both strategic and operational risks. The risk management is undertaken at different levels of the organization. The company board of directors

oversees risk management activities through the Audit and Risk Management committee of the board. In general, one of the major roles of the board is to consider the company's sustainability issues which include environmental and social sustainability issues.

Risk assessment at the operational level is configured as a "bottom-up" approach where process owners (supervisors) are responsible for all risks within their processes. Identification of risks and opportunities is generally managed through regular meetings at corporate level (including risk management meetings), holding annual innovation seminars where staff presents innovative ideas including risk management ideas, as well as through comprehensive monitoring programmes, stakeholder meetings and audit programmes undertaken internally and externally.

The company has a designated Environment and Liaison section to manage key institutional stakeholders and communities which operates on an "open door policy" to capture emerging risks and opportunities from stakeholders in addition to holding periodic meetings with key stakeholders and communities. Key stakeholders include the County Government of Nakuru, Public Health, Ministry of Agriculture and Livestock, KWS, neighbouring institutions and Central Government administrators. *Criteria met: Yes*

Analysis against basic good practice- management

Scoring statement: *An environmental and social management system is in place to manage measures to address identified environmental and social issues and is implemented utilising, which will set out measures and actions required for the project to achieve compliance with appropriate expertise (internal and external) (Orkustofnun et al., 2019b).*

The project has established an operational environmental and social framework for addressing social and environmental issues which entail EMP for each power plant as captured in the individual ESIA reports and updated based on the monitoring data. In addition, a comprehensive ISO 14001:2015 system is in place. The management system has a compliance register and actual compliance is reviewed as part of annual audits, internal audits as well as an inherent part of third-party audits of the EMS. All departments engage qualified/experienced staff, and new employees are given an introduction course to company policies, including those relevant to environmental and social issues.

KenGen submits power plants self-environmental audits reports annual (Latest 30th of January each year) to NEMA whose components include corporate social investment, natural resources utilization, significant aspects management, compliance to legal requirements and the environmental management plan. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, processes are in place to anticipate and respond to emerging risks and opportunities; and plans and processes are embedded within an internationally recognized environmental management system which is third party verified, such as ISO 14001* (Orkustofnun et al., 2019b).

The company has put in place a robust system to anticipate and respond to risks which include a comprehensive monitoring program, periodic stakeholder meetings and a designated Environment and Liaison office as a linkage to the society. The company ISO 14001: 2015 certification is valid throughout July 2024. Targets and indicators for identified significant aspects in line with the EMS system are embedded in monitoring programs. In addition, a risk management system is in place. However, integration of the EMS system into company processes is inconsistent.

The company has an Environmental Sustainability Policy and a Corporate Social Responsibility policy. In addition to the policy, other main management processes and documents include the KenGen /KWS

MOU, a service charter, a routine for management review, incident-management routines, key performance indicators, emergency-response procedures etc. Further, environment and social sustainability information forms part of the KenGen annual integrated report and the ESIA reports are available to the public.

In terms of responding to opportunities, the company has cascaded the use of the geothermal resource through the construction and operation of a recreational SPA that utilizes spent brine. Education trips (about 100,000 visits per year) to Olkaria to learn about geothermal energy have a positive impact on tourism in the park which translates to increased revenue for the KWS. In addition, a feasibility study on setting up an energy park in Olkaria field was undertaken in 2015. An update of the study to align the feasibility with the new EPZA laws was ongoing at the time of this study. The energy park is considered an opportunity to utilize geothermal waste resources. The aim is to enhance positive benefits by enabling cascading use of geothermal resources by setting up industries that can utilize geothermal waste products such as steam as inputs into their processes. Further, a geothermal training centre is planned to be established for technical trainings (drilling, geology, geochemistry, environment), the curriculum development was ongoing at the time of this study. *Criteria met: Yes*

Analysis against basic good practice- stakeholder engagement

Scoring statement: *Ongoing processes are in place for stakeholders to raise issues and get feedback (GSAP. 2019)*.

The systems in place are as detailed under topic 0-1. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, feedback on how issues raised have been taken into consideration has been thorough and timely* (Orkustofnun et al., 2019b).

Communication to stakeholders on how issues of interest have been considered in decision making is disseminated and communicated through various channels of communication such as letters and public meeting forums. *Criteria met: Yes*

Analysis against basic good practice - conformance / compliance

Scoring statement: *Processes and objectives in environmental and social management plans have been and are on track to be met with no major non-compliances or non-conformances, and environmental and social commitments and regulatory requirements have been or are on track to be me*t (Orkustofnun et al., 2019b).

All plans and commitments are either met or on track to be met. All reporting commitments are met. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances* (Orkustofnun et al., 2019b).

There are no non-compliances or non-conformances. *Criteria met: Yes*

Analysis against basic good practice – outcomes

Scoring statement: *Negative environmental and social impacts associated with geothermal facility operations are avoided, minimized, and mitigated with no significant gaps; and land disturbance*

associated with development of the geothermal project is rehabilitated or mitigated (Orkustofnun et al., 2019b).

Disturbed land is rehabilitated with endemic vegetation. Animal crossing loops allow for animal movement and are camouflaged to blend in with the environment to minimize visual impact. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, negative environmental and social impacts associated with geothermal facility operations are avoided, minimized, mitigated and compensated with no identified gaps (Orkustofnun et al., 2019b).*

The company pays an annual lease to support conservation measures according to a requirement for operating within a conservation area. Further, the company supports social afforestation as part of compensation for the project's footprint. *Criteria met: Yes*

Evaluation of significant gaps

Analysis of significant gaps against basic good practice There are no significant gaps against basic good practice. 0 significant gaps

Analysis of significant gaps against proven best practice There is one significant gap against proven best practice. 1 significant gap

Scoring Summary: There is one significant gap on integrating EMS to the company's processes, resulting in an overall score of 4.

0-4 Geothermal resource management
This topic addresses the level of understanding of the geothermal resource and the assessment of the geothermal production capacity together with the predicted and actual response to the planned production and generation efficiency based on the assessed geothermal conditions and utilization strategy. The intent is that energy generation planning and operations take into account the geothermal resource availability, renewability, and reliability in the short- and long-term, as well as efficient utilization of the geothermal resource (Orkustofnun et al., 2019b).

Introduction

Geothermal reservoirs store heat that is continuously replenished by the earth through conduction and convection processes. Sustainable utilization of a geothermal reservoir is hinged on not extracting more heat and not reducing the pressure by more than can be provided by the resource and through reinjection over the project lifetime. Generally, the reservoir yield may be reduced over time if used excessively. However, because of increased recharge following a period of excessive production, geothermal systems are generally able to recover, allowing for longer-term production cycles. A variety of disciplines and approaches contribute to understanding the amount of available resource and the limits of recharge and designing the most effective and efficient utilization, including geology, geophysics, geochemistry, reservoir modelling, and reservoir engineering.

Several modelling studies have been carried out since production commenced in Olkaria field in 1981.The first model was a simple two-dimensional, vertical model. Over the years, the model has become more complex with advancing knowledge about the geothermal system. Comprehensive modelling has guided the energy potential of geothermal resources within Olkaria concession (204 Km^2). The stepwise development strategy for Olkaria field is underpinned by the modelling results over the years.

Analysis

To assess the company's performance in Geothermal Resource Management, 3 criteria were employed in line with the protocol namely assessment, management, and compliance.

Analysis against basic good practice- assessment

Scoring statement: *Monitoring is being undertaken of geothermal resource production capacity and reliability, and ongoing or emerging issues have been identified; inputs include field measurements, testing of wells, appropriate statistical indicators and geothermal reservoir models, issues which may impact geothermal availability or reliability have been identified and factored into the geothermal models (Orkustofnun et al., 2019b).*

A comprehensive monitoring program is in place which encompasses multiple components that represent critical aspects of the reservoir. Currently, three main types of well measurements are undertaken, which include production mass flow data (tonnes per hour), enthalpy, well-head pressure data, and downhole logging of temperature and pressure to assess the status of reservoir over time. Production monitoring and tracer testing are undertaken biannually while downhole sampling is undertaken on need-basis. Tracer testing is undertaken biannually for tracing flow within the geothermal system to assess well connectivity and predict possible cooling effects from reinjection of colder water into several reinjection wells located in the field. Well monitoring data is trended to evaluate reservoir response to production over time as a mechanism to support decision making. Well monitoring data is incorporated into the model as part of the updating of model. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, issues that may impact on steam and fluid availability, renewability and reliability have been comprehensively identified; and scenarios, uncertainties and risks including reservoir drawdown, average well production decline and geothermal system response are routinely and extensively evaluated over the short- and long-term (Orkustofnun et al., 2019b).*

The monitoring program for critical aspects of the reservoir forms a robust risk and uncertainty evaluation system. Reservoir parameter data is assessed regularly to evaluate reservoir risks, mainly reservoir pressure draw down, production decline and cooling effects from the reinjection process. Data analysis results guide reservoir management decisions on an ongoing basis. *Criteria met: Yes*

Analysis against basic good practice – management

Scoring statement: *Measures are in place to guide generation operations that are based on analysis of the geothermal production capacity, a range of scientific and technical considerations, an understanding of power system opportunities and constraints, and social, environmental, and economic considerations* (Orkustofnun et al., 2019b).

Wells performance and effects of the reinjection strategy monitoring is undertaken on a continuous basis to guide power production. The reinjection strategy serves the dual purpose of maintaining reservoir pressure and reducing the environmental effects of surface disposal. Minimal steam venting is conducted to ensure optimal steam utilization. Geothermal resource utilization is subject to several licenses' conditions, including processes for resource monitoring, surface water disposal, annual technical and financial report to EPPRA and annual environmental audit reports to NEMA. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, generation operations planning has a long-term perspective; shows exemplary energy efficiency; and comprehensive monitoring of the effect of operation on the resource*

is performed and conceptual and numerical models are well maintained to ensure that geothermal fluid and energy balance can be achieved in the long run and goals of sustainable yield will be met, e.g., with reinjection as applicable. Predictions are presented with quantified and well supported uncertainty boundaries (Orkustofnun et al., 2019b).

A stepwise development strategy has been employed in the Olkaria field to take into consideration geothermal reservoir response to production over time. Modelling results have guided development since generation commenced in 1981. However, there are gaps in terms of data collection and storage though the issue is expected to be addressed through the ongoing internet of things project. *This is considered a significant gap.*

Analysis against basic good practice- conformance / compliance

Scoring statement: *Objectives for operating regulatory requirements for the geothermal resource have been and are on track to be met with no significant non-compliances or non-conformances (*Orkustofnun et al., 2019b*)*.

The regulatory requirements regarding geothermal resource management are spelt out in the utilization licenses from the Environment and Energy regulators. The company submits an annual environmental audit as well as technical and financial reports to NEMA and EPPRA, respectively. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances with operating regulatory requirements for the geothermal resource* (Orkustofnun et al., 2019b).

There are no improvement orders from the regulators regarding reservoir management. *Criteria met: Yes*

Evaluation of significant gaps

Analysis of significant gaps against basic good practice: There are no significant gaps against basic good practice. 0 significant gaps

Analysis of significant gaps against proven best practice: There is one significant gap against proven best practice. 1 significant gap on data collection and storage.

Scoring Summary: There is one significant gap on data collection and storage resulting in an overall score of 4*.*

0-8 Project benefits

This topic addresses the benefits that were committed to alongside the development of the geothermal facility and subsequent emerging opportunities for beneficial utilization. The intent is that commitments to additional benefits and benefit sharing strategies made during development of the geothermal facility are fulfilled, and that communities affected by the geothermal development have benefitted.

Introduction

The Olkaria geothermal project contributes to the national economy through payment of income tax and dividends to the government and shareholders. On a local scale, the project contributes to the economy mainly through construction of a local road network, construction of classrooms, offering education scholarship, provision of employment and economic opportunities for the locals through supply of goods and services. The project also supports community owned tourism businesses as most of the academic

institutions visiting the geothermal power plants tour the entire Olkaria tourism circuit. The circuit encompasses Ol njoruwa gorge where the local community offer guide services to tourists. In the gorge is a tourist walking trail which includes hot springs and a deep gorge. In addition to payment of conservation fees to KWS, water is provided to wildlife and the park roads are maintained on request of the KWS. The Geothermal Spa also boosts tourism activities in the area which translates into increased revenue for the KWS.

Analysis

To assess the company's performance on Project Benefits, 4 criteria were employed in line with the protocol namely assessment, management, compliance, and outcomes.

Analysis against basic good practice – assessment

Scoring statement: *Monitoring is being undertaken to assess if commitments to project benefits have been delivered and if management measures are effective; and ongoing or emerging issues relating to delivery of project benefits have been identified (*Orkustofnun et al., 2019b*)*.

The benefits to the central and local government, primarily in form of taxes and fees, are paid on a regular basis. There is no special monitoring or management beyond regular financial management in line with Kenyan Laws. Ongoing and emerging issues are mainly related to stakeholders' requests which are diverse in nature. Monitoring is undertaken to assess progress on implementation and effectiveness of the various projects. Depending on the project, different monitoring approaches are deployed including holding meetings, gathering information from the communities and from the central and county government administrators. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement*: In addition, identification of ongoing or emerging issues relating to project benefits considers both risks and opportunities (*Orkustofnun et al., 2019b*)*.

The project also offers opportunities for the youth through internships and attachment opportunities for university and college students and by promoting technical careers by supporting geothermal tourism visits by academic institutions. Every power plant dedicates a staff to disseminate power production process knowledge. Participation in site tours daily Monday through Friday is at no cost.

Processes for anticipating risks is as detailed in topic 0-1. *Criteria met: Yes*

Analysis against basic good practice – management

Scoring statement: *Measures are in place to deliver commitments to project benefits, and to manage any identified issues relating to these commitments; and commitments to project benefits are publicly disclosed (*Orkustofnun et al., 2019b*)*.

Systems are in place to deliver project benefits, including payment of required taxes. Annually, KenGen dedicated a certain percentage of income and revenue from the sale of CERs to CSR projects. The company operates a voluntary CSR program both at the project and company level, based on the program type and budget requirements. The area CSR committee receives and deliberates community requests based on the set criteria of benefit sharing. The Environment and community liaison office receives community request on an ongoing basis. Employment of local staff for contractual jobs is managed by the community Liaison office while attachment and internship opportunities for college and university students is managed by the Human Resource department. The company's focus in terms of project benefits is in the public domain and is primarily on education and environmental management. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, processes are in place to anticipate and respond to risks and opportunities (*Orkustofnun et al., 2019b*)*.

Periodic meetings with stakeholders and close contact with the County and Central government administrators serve as mechanisms to identify risks and opportunities. In addition, the Geothermal Resources Royalty Regulations were being developed at the time of this study, which upon becoming law is expected to guide payment of royalties to the communities and to the central and county government. *Criteria met: yes*

Analysis against basic good practice - conformance / compliance

Scoring statement: *Processes and objectives in place to manage project benefits have been and are on track to be met with no significant non-compliances or non-conformances, and commitments have been or are on track to be met (*Orkustofnun et al., 2019b*)*.

No non-conformances or non-compliances have been identified. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances (Orkustofnun et al., 2019b)*.

There are no non-conformances or non-compliances. *Criteria met: Yes.*

Analysis against basic good practice- outcomes

Scoring statement: *Communities directly affected by the development of the geothermal facility and any other identified beneficiary of the facility have received or are on track to receive benefits (*Orkustofnun et al., 2019b*)*.

The local communities have received and continue to receive benefits through employment, infrastructure development, construction of classrooms, education scholarships and support of a social afforestation program. Geothermal tourism, primarily by academic institutions, contributes to increased tourism in the wider area and to the education sector through dissemination of geothermal knowledge as part of the CSR. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement*: In addition, benefits are significant and sustained for communities affected by the project (*Orkustofnun et al., 2019b*)*.

Strategies are in place and certainly deliver socio-economic benefits to communities. Depending on the type of benefit, a suite of measures is in place to ensure benefits are sustained including hand over of projects to the relevant ministries and monitoring of the scholarship program. However, documentation of the social economic baseline and monitoring is inconsistent. In addition, there is a lack of studies on the impact of the projects and documentation*. Criteria met: No*

Evaluation of significant gaps

Analysis of significant gaps against basic good practice: There are no significant gaps against basic good practice. 0 significant gaps

Analysis of significant gaps against proven best practice There is one significant gap against proven best practice. 1 significant gap

Scoring Summary: There is one significant gap in the documentation of the social economic baseline. In addition, there is a lack of studies on project impacts and documentation resulting in an overall score of 4.

O-9 Project-affected communities and livelihoods

This topic addresses how impacts of development of the geothermal facility on project-affected communities have been attended to. The intent is that livelihoods and living standards impacted by the project have been improved relative to pre project conditions for project-affected communities with the aim of self-sufficiency in the long-term and that commitments to project-affected communities have been fully fulfilled (Orkustofnun et al., 2019b).

Introduction

This topic focusses on the potentially adverse impacts of the project on project-affected communities and their livelihoods and the efforts undertaken to avoid, minimize, mitigate, and compensate those impacts. Common adverse impacts of geothermal plants on project-affected communities include emissions, noise, geothermal wastewater discharge to groundwater, and impacts on local businesses and their employees. Economic activities around Olkaria encompasses farming, livestock keeping and tourism businesses. The adverse impacts enumerated under each power plant's EIA are mainly discharge of geothermal waste, H_2S emissions and noise pollution. Several other topics concern the impacts on project-affected communities. Potential positive impacts are covered in O-8, physical changes that can affect local communities are covered under O-15 (seismicity and subsidence) and impacts on air quality are addressed under O-16. The counties that are most affected by the project are Nakuru and Narok County.

Analysis

To assess the company's performance on Project-Affected Communities and Livelihoods, 5 criteria were employed in line with the protocol namely assessment, management, stakeholder engagement compliance and outcomes.

Assessment analysis against basic good practice – assessment

Scoring statement: *Monitoring is being undertaken to assess if commitments to project-affected communities have been delivered and if management measures are effective; and ongoing or emerging issues that affect project-affected communities have been identified (*Orkustofnun et al., 2019b*).*

Periodic meetings are held with an array of identified stakeholders including county government, regulators, KWS, and local communities and serve as a mechanism to identify various perspectives, to identify emerging issues and concerns, and to agree upon necessary management measures. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, identification of ongoing or emerging issues for project-affected communities takes into consideration both risks and opportunities, and interrelationships amongst issues (*Orkustofnun et al., 2019b*).*

Comprehensive monitoring of identified issues is undertaken for monitoring of air emissions (see O-16) and on Environment and Social Issues Management (see O-6) in addition to conducting participatory

research on identified issues. The company also improves processes based on stakeholders' inputs. In the recent past, the local community living in Olo Mayana Kubwa village and KWS had raised a concern regarding elevated noise levels during well discharge. The company designed and deployed improved silencers with a higher noise attenuation to address the concern. Monitoring of H_2S and noise levels is undertaken by sensitive receptors in the field including Olo Mayana Kubwa village and wastewater discharge is monitored in the geothermal field. *Criteria met: Yes*

Analysis against basic good practice- management

Scoring statement: *Measures are in place to deliver commitments to project-affected communities, and to manage any identified issues relating to these commitments; and if there are any formal agreements with project affected communities these are publicly disclosed (*Orkustofnun et al., 2019b*).*

The EMS system captures issues regarding project affected communities and livelihood. Monitoring and assessment on effectiveness of measures is undertaken according to the EMS requirement. Periodic meetings are held with different stakeholders to provide a platform to identify and manage issues. Further, the community liaison office manages community issues on a continuous basis. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, processes are in place to anticipate and respond to risks and opportunities (Orkustofnun et al., 2019b).*

The power plants have created an additional revenue source for the KWS through the geothermal tourism which is undertaken mainly by academic institutions from across the country. Risk management is detailed in topic 0-1. *Criteria met: Yes*

Analysis against basic good practice - stakeholder engagement

Scoring statement: *Ongoing processes are in place for project-affected communities to raise issues and get feedback (Orkustofnun et al., 2019b).*

The Environment and Liaison office serves as the principal contact point and deploy various systems to facilitate the communities to raise issues including holding meetings, phone calls, emails, and grievance handling mechanism as documented in the EMS system. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, feedback on how issues raised are taken into consideration is thorough and timely, and project-affected communities have been involved in decision-making around relevant issues and options (Orkustofnun et al., 2019b).*

Feedback delivery systems are in place and is mainly utilized by community representatives. However, there is evidence that the feedback often does not reach all of the intended recipients. *This is a significant gap.*

Analysis against basic good practice - conformance / compliance

Scoring statement: *Processes and objectives in place to manage delivery of commitments to project-affected communities have been and are on track to be met with no significant non-compliances or non-conformances, and commitments have been or are on track to be met (Orkustofnun et al., 2019b).*
There are no significant non-compliances or non-conformances identified. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances (Orkustofnun et al., 2019b).*

All commitments are met without non-compliances or non-conformances. *Criteria met: Yes*

Analysis against basic good practice – outcomes

Scoring statement*: Livelihoods and living standards impacted by the project have been or are on track to be improved; and economic displacement has been compensated, preferably through provision of comparable goods, property, or services (Orkustofnun et al., 2019b).*

Two of the geothermal projects resulted in resettlement of 155 households. The resettlement program was undertaken in line with the company's and community's MOU. Monitoring results of H_2S and noise levels during normal operation are within the legal requirements for sensitive receptors. Livelihoods and living standards of nearby communities have been improved by the project, mainly due to job opportunities for the locals, but this is not without controversies. *Criteria met: Yes*

A**nalysis against proven best practice**

Scoring statement: *In addition, the measures put in place to improve livelihoods and living standards are on track to become self-sustaining in the long-term (Orkustofnun et al., 2019b).*

The overall improvements of livelihoods and living standards in the local community created by the project are on track to be self-sustaining. However, the resettlement program carried out by the company in 2014 was one of its kind in the area, it created high expectations and dependency syndrome in the community which undermines the creation of collaborative partnerships with the locals. No effective systems has been put in place to drive the partnership model in line with the company's engagement strategy. This is a significant gap. *Criteria met: No*

Evaluation of significant gaps

Analysis of significant gaps against basic good practice

There are no significant gaps against basic good practice: *0 significant gaps*

Analysis of significant gaps against proven best practice

Criteria met: no, there are 2 significant gaps.

Scoring Summary: There is no effective process for disseminating the company's position to the wider community on relevant issues. In addition, there is no effective mechanism to drive the partnership model in line with the company's engagement strategy. There are two significant gaps to best practice resulting in an overall score of 4.

0-14 Biodiversity and invasive species

This topic addresses the ecosystem, habitat, species, and specific issues such as threatened species in the geothermal development areas and surroundings as well as potential impacts and invasive species associated with the operating geothermal facility. The intent is to preserve and facilitate healthy, functional, and viable aquatic and terrestrial ecosystems in the area that are sustainable over the long-term; that biodiversity impacts arising from the operating geothermal facility are managed responsibly;

that ongoing or emerging biodiversity issues are identified and addressed as required; and that those commitments to implement biodiversity and invasive species are fulfilled (Orkustofnun et al., 2019b).

Introduction

The Olkaria Geothermal Field partially lies within the Hell's Gate National Park while the rest of the area lies largely within the vicinity of the national park. Olkaria I, II and III power plants are located inside the park. The park is home to a diverse range of wildlife, comprising of the common zebra (*Equus burchelli*), gazelles (*Gazella thompsonii* and *Gazella grantii*), Impala (*Aecpyceros melamus*), Masai giraffe (*Giraffa camelopardis*), African buffalo (*Syncerus caffer*), Klipspringer (*Oreotragus oreotragus*), Thomsons, leopard (Panthera pardus), common eland (Taurotragus oryx), various raptors i.e. Ruppell's vulture (*Gyps rueppellii*), white backed vulture (*Gyps africanus*) and other species of wildlife. The most common vegetation types include Hyperrhenia, Digitaria, Themeda grasses, Tarchonanthus, and Acacia shrubs (Mwangi-Gachau, 2015). Moreover, the Olkaria field is situated ten kilometres west of Lake Naivasha which is a wetland of international importance protected under the Ramsar Convention on Wetlands.

Analysis

To assess the company's performance on Biodiversity and Invasive Species, 4 criteria were employed in line with the protocol namely assessment, management, compliance, and outcomes.

Analysis against basic good practice- assessment

Scoring statement: *Ongoing or emerging biodiversity issues have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective (Orkustofnun et al., 2019b).*

The biodiversity-related impacts predicted in the ESIAs are mainly loss of habitat through brine and condensate discharge, invasive species proliferation, vegetation clearance, fencing off of power plants and well heads, loss of habitat connectivity, direct impact on wildlife through animal kills and trapping in the steam lines infrastructure. A comprehensive monitoring programme is in place in line with individual power plant EMPs. External monitoring is undertaken annually by research institutions (KWS and Museum of Kenya) in collaboration with NGOs, particularly on mammals' counts in Hell's Gate and surrounding parks to assess changes over time. Additional monitoring systems are as captured under 0-6 on Environment and Social Issues Management. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, identification of ongoing or emerging biodiversity issues takes into account both risks and opportunities (Orkustofnun et al., 2019b).*

The routine monitoring and periodic meetings held with stakeholders are mechanisms to capture emerging risks and opportunities. The external monitoring undertaken by research institutions (KWS and Museum of Kenya) in collaboration with diverse stakeholders presents an additional window for identification of emerging risks and opportunities. However, there is no effective feedback systems for relaying external monitoring findings to the company to guide decision making. *Criteria met: No*

Analysis against basic good practice – management

Scoring statement: *Measures are in place to manage identified biodiversity issues (Orkustofnun et al., 2019b).*
Biodiversity monitoring forms an essential part of the individual power plants' EMPs and the company's EMS. Additionally, the MOU between the company and KWS guides conservation issues management.

Management measures are in place to react to identified significant biodiversity impacts which include revegetation of disturbed land, control of invasive species, incorporating animal crossing areas in the steam line design to avoid habitat fragmentation, minimizing fenced areas, and enforcing speed limit to minimize wildlife kills. The project applies the mitigation hierarchy in management of impacts. Criteria met: Yes

Analysis against proven best practice

Scoring statement: *In addition, processes are in place to anticipate and respond to emerging risks and opportunities (Orkustofnun et al., 2019b).*

Several systems are in place to anticipate and respond to emerging risks and opportunities as captured under Communication and Consultation (0-1), environment and social issues management (0-3), Geothermal Resource Management and Project Communities and Livelihood (0-9*). Criteria met: yes*

Analysis against basic good practice- conformance / compliance

Scoring statement: *Processes and objectives in place to manage biodiversity issues have been and are on track to be met with no significant non-compliances or non-conformances, and biodiversity related commitments have been or are on track to be met (Orkustofnun et al., 2019b).*

Monitoring programmes have been and are on track. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances (Orkustofnun et al., 2019b).*

Rehabilitation effectiveness is curtailed by loose soil that are prone to soil erosion. In addition, invasive species control is not executed in a timely manner. *Criteria met: No*

Analysis against basic good practice – outcomes

Scoring statement: *Negative biodiversity impacts arising from activities of the operating facility are avoided, minimized, mitigated, and compensated with no significant gaps (Orkustofnun et al., 2019b)*.

Designing of animal crossings has evolved through close collaboration with the KWS as well as designing silencers with higher noise attenuation factor for discharging wells. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are healthy, functional, and viable aquatic and terrestrial ecosystems in the area affected by the geothermal facility that are sustained over the long-term; or the facility has contributed or is on track to contribute to addressing biodiversity issues beyond those impacts caused by the operating geothermal facility* (Orkustofnun et al., 2019b).

The monitoring data does not demonstrate any significant impacts on biodiversity. However, the external monitoring data needs to be evaluated and engagement with external researchers (Kenya Museum of Kenya) is necessary to disseminate the findings of the study and to agree on an effective feedback system to guide decision making. *Criteria met: No*

Evaluation of Significant Gaps

Analysis of significant gaps against basic good practice
There are no significant gaps against basic good practice. *0 significant gaps*

Analysis of significant gaps against proven best practice

There are two significant gaps against proven best practice. *2 significant gaps*

Scoring Summary: There two significant gaps, the lack of an effective feedback system to disseminate external monitoring findings to guide decision making and that invasive species control is not executed in a timely manner, resulting in an overall score of 3.

0-15 Induced seismicity and subsidence

This topic addresses the management of induced seismicity and subsidence issues associated with the operating geothermal facility. The intent is that physical impacts such as induced seismicity and subsidence caused by the operating geothermal facility are recognized and managed responsibly, and do not present problems with respect to other social, environmental, and economic objectives; and those commitments to implement measures to address these impacts are fulfilled (Orkustofnun et al., 2019b).

Introduction

Generally, geothermal areas have higher seismicity in terms of intensity compared to background levels of seismicity. Mass extraction and injection of fluid into the wells cause stress in the underground which results in seismicity. Reinjection of geothermal water into the geothermal reservoir is required by license to protect the surrounding environment and maintain pressure in the reservoir. Land subsidence because of mass extraction has been documented in many geothermal fields across the world. In the Olkaria field, seismicity and land subsidence are identified as possible adverse impact associated with geothermal development.

Analysis

To assess the company's performance on Induced Seismicity and Subsidence, 5 criteria were employed in line with the protocol namely assessment, management, stakeholder engagement, compliance, and outcomes.

Analysis against basic good practice -assessment

Scoring statement: *Ongoing or emerging induced seismicity and subsidence issues have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective* (Orkustofnun et al., 2019b).

Microseismic and land subsidence monitoring is undertaken in the Olkaria field. A seismic network of 15 stations has been set up in the field, distributed mainly in Domes and the East field. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, identification of ongoing or emerging induced seismicity and subsidence issues takes into account both risks and opportunities* (Orkustofnun et al., 2019b).

The monitoring program, periodic meetings and maintaining presence in the community are tools deployed to identify risks and opportunities. *Criteria met: Yes*

Analysis against basic good practice – management

Scoring statement: *Measures are in place to manage identified induced seismicity and subsidence issues* (Orkustofnun et al., 2019b).

The power plant designs consider a vulnerability seismic threshold. A reinjection system is in place to manage subsidence risk. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, processes are in place to anticipate and respond to emerging risks and opportunities* (Orkustofnun et al., 2019b).

A monitoring program and two PHD research programs on seismic and land subsidence data processing that were ongoing at the time of this study offer an avenue for enhanced understanding of the geothermal reservoir and help to anticipate operational risks and opportunities. However, data analysis is not consistently undertaken. *Criteria met: No*

Analysis against basic good practice - conformance / compliance

Scoring statement*: Processes and objectives in place to manage induced seismicity and subsidence issues have been and are on track to be met with no significant non-compliances or non-conformances, and induced seismicity and subsidence related commitments have been or are on track to be met (*Orkustofnun et al., 2019b*).*

There are no indications for any non-compliances or non-conformances *Criteria met: Yes*

Analysis against proven best practice

Scoring statement*: In addition, there are no non-compliances or non-conformances* (Orkustofnun et al., 2019b).

Non-conformance was noted regarding inconsistent data analysis. Subsidence and microseismic monitoring of Olkaria field is documented in the literature reviewed for this study. However, there were no data analysis reports availed during the current study which is inconsistent with acceptable data analysis practices. This can lead to a gap in knowledge over time but is nevertheless considered under Management. *Criteria met: Yes*

Analysis against basic good practice – outcomes

Scoring statement: *Induced seismicity and subsidence issues are avoided, minimized, and mitigated with no significant gaps* (Orkustofnun et al., 2019b).

There have been no notable earthquakes which could be attributed to induced seismicity and no evidence of a significant land surface subsidence or uplift. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement*: In addition, induced seismicity and subsidence associated with operating facility do not present ongoing problems for environmental, social, and economic objectives of the facility or the project affected areas* (Orkustofnun et al., 2019b).

There has been no evidence of significant earthquakes and land subsidence in the Olkaria geothermal area. However, since data analysis is not consistently undertaken, it is difficult to conclude on presence or absence of induced seismicity and subsidence related to geothermal activities. But continuous data analysis is expected to be addressed by the ongoing PHD programs. *Criteria met: No*

Evaluation of significant gaps

Analysis of significant gaps against basic good practice There are no significant gaps against basic good practice. 0 significant gaps.

Analysis of significant gaps against proven best practice; There are 3 significant gaps against proven best practice.

Scoring Summary: There are two significant gaps regarding inconsistent data analysis and presence or absence of earthquakes attributable to geothermal activities due to lack of consistent data analysis, resulting in an overall score of 3.

O-**16 Air and water quality**

This topic addresses the management of air and water quality issues associated with the operating geothermal facility. The intent is that air and water quality in the vicinity of the operating geothermal facility is not adversely impacted by activities of the operator; that ongoing or emerging air and water quality issues are identified and addressed as required; and commitments to implement measures to address air and water quality are fulfilled (Orkustofnun et al., 2019b).

Introduction

Air quality impacts associated with geothermal power plants in Olkaria relate to gases and trace elements emissions and acids arising from the gases. Water quality issues are associated with disposal of solid and liquid waste and leakage of hazardous liquids or gases. In high-temperature geothermal reservoirs, hot fluid interacts with the surrounding rock resulting int dissolution of gases and various minerals from the rock to the geothermal fluid.

Geothermal steam contains a mixture of gases, notably carbon dioxide, hydrogen sulphide, methane, ammonia, and radon. Hot geothermal water can contain trace amounts of toxic chemicals in solution, such as boron, mercury, antimony, and arsenic. If discharged to the environment, these pollutants can contribute to global warming, acid rain, radiation, noxious smells, soil, and water pollution. Reinjection of geothermal water and condensate is undertaken to avoid pollution of ground water and to maintain reservoir pressure. Non-condensing gases have a negative effect on generation efficiency and are usually ejected from the condensers. In Olkaria, they have typically been released into the atmosphere with the updraft from the cooling towers to aid dispersal. The gas content of steam in Olkaria is relatively low compared to other geothermal areas. The National Environment Management Authority has set a public health standard for safe H_2S emissions of 150 $\mu g/m^3$ with an averaging time of 24 hours, which is the same as in WHO guidelines (WHO, 2000)

Analysis

To assess the company's performance on Air and Water Quality, 4 criteria were employed in line with the protocol namely assessment, management, compliance, and outcomes.

Analysis against basic good practice -Assessment

Scoring statement: *Ongoing or emerging air and water quality issues have been identified, and if management measures are required then monitoring is being undertaken to assess if management measures are effective* (Orkustofnun et al., 2019b).

Air quality related impacts during the operation phase, identified as part of the EIA, are mainly the emmission of H_2S gas and greenhouse gases. A comprehensive air quality monitoring program for H_2S concentrations is in place to assess impacts on sensitive receptors. The monitoring is undertaken by monitoring stations in the well heads, power plants and sensitive receptors including Olo Mayana Kubwa village. The GHG emissions are measured in the steam delivered to the power plants. In addition, modelling studies for H_2S were undertaken for the current ongoing accelerated development in Olkaria. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, identification of ongoing or emerging air and water quality issues takes into account both risks and opportunities* (Orkustofnun et al., 2019b).

Several systems are in place to anticipate and respond to emerging risks and opportunities as captured under 0-1, 0-3 and 0-9. *Criteria met: Yes*

Analysis against basic good practice – management

Scoring statement: *Measures are in place to manage identified air and water quality issues* (Orkustofnun et al., 2019b).

Management of air and water-quality issues is part of KenGen's overall EMS described under O-3. Geothermal wastewater is managed through reinjection as a license condition as well as a technical requirement to maintain reservoir pressure. A comprehensive monitoring program for H_2S, ground water, reinjection strategy and waste discharge to the environment is in place. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, processes are in place to anticipate and respond to emerging risks and opportunities* (Orkustofnun et al., 2019b).

The monitoring program which entails monitoring of H_2S in power stations and in sensitive receptors and ground water monitoring is a key component of risk analysis that focuses on identifying risks associated with air and water quality. Data of collected air and water quality parameters are evaluated on an ongoing basis to evaluate risks, primarily health risks, and for decision making.

Participatory research is a response tool deployed to address stakeholders' concerns about effects on agriculture. KenGen responded in a timely way to stakeholder complaints in relation to the effects of air quality on agriculture by undertaking comprehensive research on effects of H_2S on flower growing in Olkaria. In 2016, KenGen undertook participatory research in Eburru jointly with the Ministry of Agriculture, the local community, and research institutions (KEPHIS) in response to a complaint on the effects of geothermal fluid on agriculture in a different field. The results of the study informed a design change for the rock mufflers.

KenGen has been an active player in the CDM market for offsetting greenhouse gases by putting up geothermal plants to displace fossil power plants. As at the time of this study, the company had registered geothermal projects with 4,375,823tCO_2e. *Criteria met: Yes*

Analysis against basic good practice- conformance / compliance
Scoring statement: *Processes and objectives in place to manage air and water quality issues have been and are on track to be met with no significant non-compliances or non-conformances, and air and water quality related commitments have been or are on track to be met* (Orkustofnun et al., 2019b).

The H_2S monitoring results show very low concentrations in power plants and sensitive receptors. Criteria met: Yes

Analysis against proven best practice Scoring statement: *In addition, there are no non-compliances or non-conformances* (Orkustofnun et al., 2019b).

There are no detected water and air quality exceedances. Nevertheless, there could be intermittent exceedance periods depending on the wind direction. However, long term monitoring data shows that the air quality is within the required standard. *Criteria met: Yes*

Analysis against basic good practice – outcomes

Scoring statement: *Negative air and water quality impacts arising from activities of the operating geothermal facility are avoided, minimised, and mitigated with no significant gaps* (Orkustofnun et al., 2019b).

Geothermal wastewater is reinjected into the reservoir. The H_2S levels in sensitive receptors are within the required standards. No exceedance of water quality and air quality noted. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, air and water quality in the area affected by the operating geothermal facility is of a high quality; or the facility has contributed or is on track to contribute to addressing air and water quality issues beyond those impacts caused by the operating geothermal facility*. (Orkustofnun et al., 2019b).

Air quality in project-affected areas is reduced in terms of H_2S-related issues, such as odour in certain weather conditions. There are concerns from the community regarding odour and corrosion. The odour concern is expected as the threshold for odour is quite low. However, the monitoring data indicates that the levels in sensitive receptors are low. Lack of awareness creation in the community is a significant gap.

Evaluation of significant gaps

Analysis of significant gaps against basic good practice There are no significant gaps against basic good practice. 0 significant gaps

Analysis of significant gaps against proven best practice There is one significant gap against proven best practice. 1 significant gap

Scoring Summary. There is one significant gap comprising of lack of awareness creation regarding H_2S gas levels in sensitive receptors, resulting in an overall score of 4.

0-17 Climate change mitigation and resilience

This topic addresses the estimation and management of the project's greenhouse gas (GHG) emissions, analysis, and management of potential risks regarding climate change and the project's role in climate change adaptation. The intent is that the project's GHG emissions are consistent with low carbon power

and heat generation, that the project is resilient to the effects of climate change, and that the project contributes to wider adaptation to climate change (Orkustofnun et al., 2019b).

Introduction

Greenhouse gas impacts associated with geothermal power plants in Olkaria relate to carbon dioxide and methane gases in geothermal steam. Normally, in high-temperature geothermal reservoirs, hot fluid interacts with the surrounding rock resulting in dissolution of gases and various minerals from the rock into the geothermal fluid. The gases travel with the fluid to the plant at the surface and are released into the atmosphere in the case of the Olkaria field. Geothermal energy sources are known to emit GHGs, though on a lower scale compared to fossil-based energy resources. The contribution of GHGs to climate change is widely documented in the literature. Documentation of GHGs from geothermal resources is key for decision making regarding GHG management, assessing the contribution of geothermal power plants to climate change and as part of sustainability management and reporting for geothermal power plants.

Analysis

To assess the company's performance on Climate Change Mitigation and Resilience, 5 criteria were employed in line with the protocol namely assessment, management, stakeholder engagement, compliance, and outcomes.

Analysis against basic good practice – assessment

Scoring statement*: For climate mitigation: if estimates of net GHG emissions (gCO2e) of energy generation (electricity plus heat) are calculated and independently verified, and periodically updated; if estimated emissions are above 100 gCO2e/kWh, a site-specific assessment of GHG emissions is undertaken and periodically updated (Orkustofnun et al., 2019b)*

For climate resilience: an assessment of the project's resilience to climate change is undertaken and periodically updated; this assessment of project resilience incorporates an assessment of plausible climate change, identifies a range of resulting climatological conditions at the project site, and applies these conditions in a documented risk assessment or stress test, other infrastructural resilience, environmental and social risks, and power and heat generation availability (Orkustofnun et al., 2019b).

A monitoring program for GHG emissions for all power plants is in place with exception of the wellheads. The net GHG emissions are externally verified for projects under the Clean Development Mechanism projects (CDM). A total of three power plants are under the CDM program. The average GHG emissions are about 18 gCO2e/kWh which is far below 100 gCO2e/kWh. Further, KenGen supports a social afforestation program to enhance carbon sinks and improve both surface and ground water recharge systems. Regarding climate resilience, the monitoring program serves as a mechanism to monitor risks related to GHG emissions. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *For climate mitigation: in addition, if a site-specific assessment is required, it incorporates a broad range of scenarios, uncertainties, and risks* (Orkustofnun et al., 2019b).
Risk management and climate mitigation systems are in place which include the support of a social afforestation program which serves as a carbon sequestration program. In addition, the company actively participates in the Lake Naivasha Water Users Association with the twin objective of influencing conservation activities and to seek collaboration with the wider stakeholders' network within the basin. *Criteria met: Yes*

Analysis against basic good practice – management

Scoring statement: *For climate mitigation: if GHG emissions estimates assume management measures, these measures are in place* (Orkustofnun et al., 2019b).

For climate resilience: measures are in place to avoid or reduce identified climate risks (Orkustofnun et al., 2019b).

Monitoring measures are in place to establish GHG emissions baseline data for geothermal power production and related activities. The program entails establishing an inventory of scope 1, 2 and 3 emissions related to power generation as required under GHG protocol. Regarding climate resilience, investing in geothermal power generation contributes to reducing grid emissions by displacing fossil fuel generation. In addition, it improves grid reliability which allows for enhanced grid share of variable renewables such as solar and wind energy. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement:

For climate mitigation: management measures are in place to respond to risks and opportunities including offsetting emissions, for example by reinjecting the GHGs, use of GHGs for production of products; plans are in place to monitor parameters used in GHG emissions estimates or to monitor GHG stocks. For climate resilience: in addition, measures take account of a broad range of risks and interrelationships, and processes are in place to respond to unanticipated climate change; and plans are in place to provide adaptation services if necessary (Orkustofnun et al., 2019b).

Documentation of baseline data on scope 1, 2 and 3 emissions was ongoing as at the time of this study. The results of that study intend to set the stage for establishing the company's baseline year emissions and subsequent monitoring in addition to guiding the required GHG management processes for the different emissions in all three scopes. Regarding climate resilience, systems are in place to respond to risks. These risks are, firstly, rehabilitation of disturbed land during infrastructural development, secondly, power plant cooling systems are designed to utilize steam for cooling with the aim to minimize the need for fresh water top up, thirdly, reuse of brine for drilling to minimize freshwater intensity in drilling activities and lastly, drilling of multiple wells (vertical and directional) per well pad is undertaken to minimize the project's footprint. *Criteria met: No*

Analysis against basic good practice – stakeholders

Scoring statement: *For climate mitigation: estimated GHG emissions and / or the results of a site-specific assessment are publicly disclosed (Orkustofnun et al., 2019b).*

For climate resilience: ongoing processes are in place for stakeholders to raise issues and get feedback on the management of climate risks (Orkustofnun et al., 2019b).

Compilation of GHG emission baseline data for scope 1, 2 and 3 as required under GHG protocol was ongoing at the time of this study. That current study forms part of the company's effort to commence GHG emission reporting and public disclosure will form an essential part of the reporting. To enable stakeholders to raise issues, the company has a designated Environment and Liaison office as a company link to stakeholders and to maintain presence in the community. *Criteria met: Yes*

Analysis against best practice

Scoring statement: *In addition, the assessment of project resilience is publicly disclosed* (Orkustofnun et al., 2019b).

Investments into geothermal development form an integral part of the country's climate change mitigation strategy while also protecting the country's energy supply system from unpredictable weather patterns. Prioritizing geothermal development is a key part of the country's resilience program to creating resilience to climate change as per the National Climate Change Action Plan for the period 2018-2022(NCCAP, 2018). The resilience program has been widely communicated. *Criteria met: Yes*

Analysis against basic good practice - Conformance / Compliance

Scoring statement: *Processes and objectives relating to climate change mitigation and resilience have been and are on track to be met with no significant non-compliances or non-conformances, and any mitigation-related and resilience-related commitments have been or are on track to be met* (Orkustofnun et al., 2019b).

Rehabilitation of disturbed land and consistent support of a social afforestation program systems are in place. *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *In addition, there are no non-compliances or non-conformances* (Orkustofnun et al., 2019b).

The Olkaria geothermal project allows for low carbon power generation. However, given that the geothermal development acceleration program's momentum is expected to be maintained, accounting for GHG emissions of geothermal activities is crucial to establish geothermal power plants' actual carbon intensity and their contribution to climate change. *Criteria met: No*

Analysis against basic good practice – outcomes

Scoring statement: *For climate mitigation: the project's GHG emissions are demonstrated to be consistent with low carbon power and heat generation. For climate resilience: findings of the climate change assessment indicate that the project is resilient to climate change (Orkustofnun et al., 2019b).*

The Olkaria geothermal project allows for low carbon power generation with average GHG emissions of 18 gCO2e/kWh. In addition, prioritizing geothermal development is one of the country's resilience programs with the purpose of creating resilience to climate change according to the National Climate Change Action Plan for the period 2018-2022 (Government of the Republic of Kenya, 2018). *Criteria met: Yes*

Analysis against proven best practice

Scoring statement: *For climate mitigation: in addition, project net emissions are minimised, or project operations facilitate system emissions reductions (Orkustofnun et al., 2019b).*
For climate resilience: in addition, the project is resilient under a broad range of scenarios; and the project will contribute to climate change adaptation at a local, regional, or national level (Orkustofnun et al., 2019b).

The company's GHG inventory is currently being updated in line with international accepted frameworks (GHP). That current study will guide required GHG reduction measures for scope 1, 2 and 3 emissions related to power production.

Nationally, investing in geothermal power production contributes to wider climate change adaptation measures. This is achieved through the delivery of affordable and clean energy power which essentially displaces the use of kerosine for lighting, especially in rural areas. However, KenGen has not actively

promoted cascade use of geothermal resources to enhance diverse rural micro businesses and livelihoods that are resistant to drought. Direct use of geothermal energy provides an opportunity to enhance the community's adaptation capacity. *Criteria met: no*

Evaluation of significant gaps

Analysis of significant gaps against basic good practice There are no significant gaps against basic good practice. 0 significant gaps

Analysis of significant gaps against proven best practice There are two significant gaps against proven best practice.

Scoring Summary: There are two significant gaps which are the lack of a GHG emissions management system and the company's failure to actively promote direct use of geothermal resources which would form part of adaptation measures for the local community, resulting in an overall score of 3.

4.3 Olkaria geothermal project greenhouse gas accounting results

Compilation of GHG inventory for the Olkaria geothermal field commenced in January 2021. The objective was to assess impacts of geothermal production on climate change. According to this study, as depicted in Figure 6, the extrapolated carbon dioxide footprint for the Olkaria Geothermal field baseline year (2021) amounted to 376,487 total tonnes of CO_2 equivalent. In year 2021, scope 1 or direct emissions from Olkaria geothermal production core operations amounted to 247,176 tonnes of CO_2 equivalent. These emissions are traced to electricity production at Olkaria geothermal power plants, emergency diesel generators, drilling equipment, LPG consumption in clubs and conference centers, HFC systems in the power plants and the company vehicle fleet.

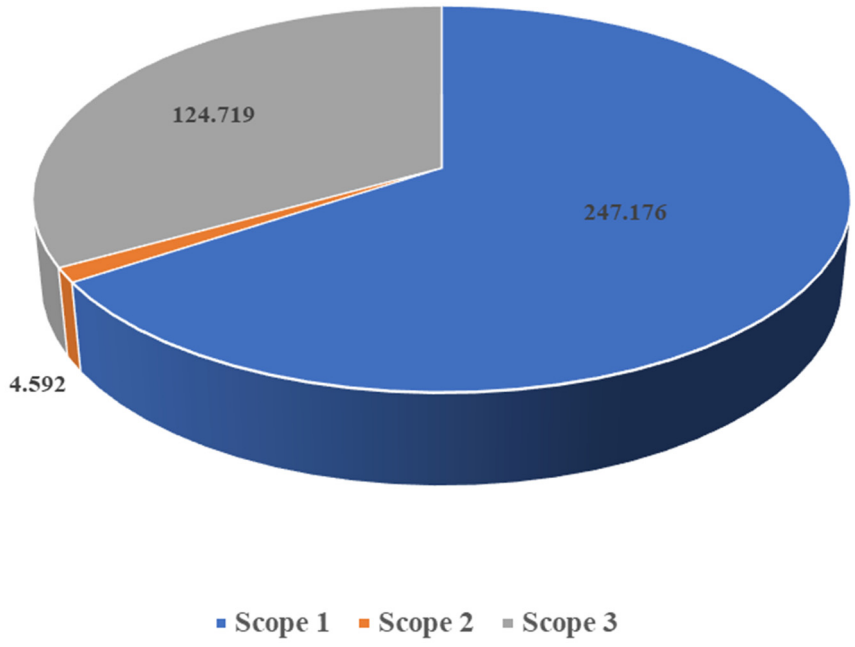

FIGURE 6: Olkaria Geothermal Project 2021 Net Carbon Footprint

Scope 2 or indirect emissions from purchased electricity amounted to 4,592 tonnes of CO_2 equivalent. Scope 3 or indirect emissions downstream of the business from the waste produced by the core operations of the company and employees' travels (excluding air travel) amounted to 124,719 tonnes of CO_2 equivalent.

The GHG emission inventory of the project is expected to form the basis for monitoring in coming years and for setting reduction targets.

5. DISCUSSION

Results of the GSAP evaluation for the nine selected topics (for operation phase) and greenhouse gas emissions for the Olkaria geothermal field have been presented. According to this study results, all topics met basic practice or were slightly above good practice with one significant gap below best practice. Developing an action plan for the identified weak areas can help the project to meet the criteria for level 5 and thereby achieve implementing best practices in the future and enhance the project's sustainability. The extrapolated carbon dioxide footprint baseline year (2021) of greenhouse gas emissions in the Olkaria geothermal field amounted to 376,487 total tonnes of CO2 equivalent.

The study results demonstrate that the protocol is a comprehensive framework to capture major sustainability impacts and is sensitive to local site settings. The tool is valuable and robust in terms of offering a holistic and up to date perspective of the project regarding sustainability management during the operational phase. Project affected communities and livelihoods inclusion in the GSAP assessment enhance stakeholders' engagement and communication which is key to capturing stakeholders' perspectives in decision making and to enhance social acceptance. Further, greenhouse gas accounting is a key tool for managing geothermal projects sustainably as it forms the basis for companies to understand and manage their climate change impacts. The study results show that scope 1, 2, and 3 emissions contributed 66 %, 1.2%, and 32.8 %, respectively. The results indicate that optimization of company fleet management provides a major reduction opportunity while applying the waste management hierarchy presents a window to minimize emissions associated with waste management. Further, since the company is the major renewable energy generator in the country, there is a need to identify its role in electrification of transport systems to enable the reduction of climate change impact from the country's transport system in the long run.

Based on the value of the tools applied in this study, KenGen needs to develop an action plan to improve the identified weak areas and commence sustainability management and reporting using international standardized frameworks such as GSAP, GHGP and later the Global Reporting Initiative. As a starting point, the company needs to commence reporting the climate impact of the Olkaria Geothermal Project since climate change is high on the global agenda.

The main shortcomings of this study on the applicability of GSAP is that the assessment was based on 9 selected out of 17 sustainability topics due to time limitation and data availability. In addition, the assessment was based on internal perspectives only as the study period was short and did not allow for the engagement of stakeholders to analyse external perspectives. Consequently, an assessment by an external person is recommended to incorporate stakeholders' input. This seems feasible in the short run as the draft GSAP was handed over to the International Geothermal Association (IGA) in October 2021 and there is a high chance that test piloting will be undertaken outside Iceland.

Regarding GHGP, the main limitation was that the study data was based on 9 months of data collection only and, therefore, extrapolation of the data was undertaken. Additionally, scope 3 emissions caused by staff travel were based on insured staff vehicles as listed in the transport section records. Due to the limited study period, a survey study was not undertaken.

Suggested GSAP improvements include the incorporation of water abstraction aspects as this is a major concern for stakeholders, particularly for geothermal fields located in water stress areas like the Olkaria geothermal field.

6. CONCLUSION

The purpose of this study was to assess the applicability of the GSAP in the Olkaria field (operation phase) and to set up a preliminary GHG reporting framework to evaluate the project impact on climate change.

Based on the results, the Geothermal Sustainability Assessment Protocol (GSAP) is a comprehensive sector-based management tool which is applicable in Kenya´s Olkaria geothermal field. It provides a holistic tool that can be applied during the operational phase of the project to guide compliance with best practices and result in positive impacts in all sustainability dimensions: environmental, social, and economic. Given that the tool is internationally recognized, this facilitates the comparison with other geothermal fields elsewhere in the world. The framework provides an opportunity for continuous improvement through the identification of weak areas across all sustainability themes. The study recommends KenGen to commence management and reporting on sustainability using standardized management, assessment and reporting frameworks like the GSAP and the Greenhouse gases Protocol framework for consistency in tracking and reporting on progress in addition to preparing for future national or regional climate policies and regulations. The study recommends the company to commence reporting on impact on the climate using the GHG framework developed in the study. Further, the company needs to identify its role in electrification of the transport system in the country, given that KenGen is the major green energy producer in Kenya. This would assist GHG mitigation in the transport sector and reduce its overall impact on climate change. Further work is recommended on the identification of targets and indicators that are context specific for the Olkaria field. This is crucial to facilitate monitoring and to assess progress of geothermal projects' sustainability performance regarding sustainability topics covered under the GSAP.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor, Prof. Brynhildur Davíðsdóttir, for guidance and unreserved support throughout the project period. I learned a lot from you, during the extra classes you organized and from the great people you referred me to; Sigurdur, Gisli Sveinsson and Kevin Dillman. Your guidance, suggestions, and criticism have contributed to the success of this research study. I am indebted to the Government of Iceland and the UNESCO GRÓ Geothermal Training Programme (GRÓ GTP) for awarding me the scholarship to study the Six Months Course and my employer Kenya Electricity Generating Company (KenGen) for granting me this opportunity to attend the training. To the GRÓ GTP fraternity, I am greatly indebted to Guðni Axelsson, the GRÓ GTP director, Mr. Ingimar G. Haraldson, Ms. Málfrídur Ómarsdóttir, Vigdís Harðardóttir and Mr. Markús A.G. Wilder for their invaluable support in different aspects throughout the training period. You made my stay in Iceland a lot easier and comfortable. To the 2021 fellows, we recreated our home away from home and shared great moments together that will remain etched in my mind. Special thanks go to my family for their unwavering support throughout my six months stay in Iceland.

NOMENCLATURE

Acronyms

CDM	Clean Development Mechanism
CH_4	Methane
CO_2	Carbon dioxide
EMP	Environmental management Plan
EMS	Environmental Management System
EPRA	Energy and Petroleum Regulatory Authority
ESIA	Environmental and Social Impact Assessment
EPZA	Export Processing Zone Authority
EMCA	Environmental Management and Coordination Act
GHG	Greenhouse gas
GHP	Greenhouse Gas protocol
GSAP	Geothermal Sustainability Assessment protocol
HSAP	Hydropower Sustainability Assessment Protocol
HSAF	Hydropower Sustainability Assessment Forum
hydrofluorocarbons	HFCs
IGA	International Geothermal Association
KenGen	Kenya Electricity Generating Company PLC
LCPDP	Least Cost Power Generation Expansion Plan
KWS	Kenya Wildlife Service
NEMA	National Environmental Management Authority
NGOS	Non-Governmental Organizations
N_2O	nitrous oxide
Orkuveita Reykjavikur	OR
PFCs	perfluorocarbons
SF6	Sulphur hexafluoride
TNC	The Nature Conservancy
WWF	Worldwide Fund for Nature

REFERENCES

Adalsteinsdóttir, H., Karlsdóttir, M.R., and Magnusdóttir. M., 2020: Testing the new geothermal sustainability assessment protocol on hellisheidi geothermal heat and power plant. *Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland*, 1-5.

Cook, D., Davíðsdóttir, B., Daði M., and Kristófersson, D.M., 2017: An ecosystem services perspective for classifying and valuing the environmental impacts of geothermal power projects. *Energy for Sustainable Development, 40*, 126-138.

Gibb, 2009: *Proposed Olkaria IV 140 MW project ESIA report*. Kenya Electricity Generating Company, Gibb Africa Ltd, October, report, 427pp.

Gibb, 2013: *Olkaria IAU 70 MW project ESIA report*. Kenya Electricity Generating Company, Gibb Africa Ltd, July, report, 129 pp

Gibb, 2014: *Proposed Olkaria V 140 MW project ESIA report.* Kenya Electricity Generating Company, Gibb Africa Ltd, February, report, 214pp.

Government of the Republic of Kenya, 2007: *The Kenya vision 2030*, website: *https://vision2030.go.ke/publication/kenya-vision-2030-popular-version.*

Government of the Republic of Kenya, 2018: *National climate change action plan 2018-2022*, website: *http://www.environment.go.ke/wp-content/uploads/2020/03/NCCAP_2018-2022_ExecutiveSummary-Compressed-1.pdf*

Government of the Republic of Kenya, 2021: *The least cost power development plan*, website: *https://communications.bowmanslaw.com/REACTION/emsdocuments/LCPD%202021.pdf*

International Hydropower Association, 2020: *Hydropower sustainability assessment protocol*, website: *https://www.hydrosustainability.org*

Lagat, J.K., 2004: *Geology, hydrothermal alteration and fluid inclusion studies of the Olkaria Domes geothermal field, Kenya.* University of Iceland, MSc thesis, UNU-GTP, Iceland, report 1, 79 pp.

Landsvirkjun, 2017: *Geothermal sustainability assessment protocol - Theistareykir power project, Iceland.* Landsvirkjun, National Power Company, project assessment report, 133 pp. website: *www.landsvirkjun.is/Media/gsap-theistareykir-assessment-reportfinal-3-may-2017-4.pdf*

Mangi, P., Ofwona, C., and Mwangi, M., 2020: Country update report for Kenya 2015-2019. *Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland,* 1-16.

Mariita, N.O., 2002: The impact of large-scale renewable energy development on the poor: environmental and socio-economic impact of a geothermal power plant on a poor rural community in Kenya. *Energy Policy, 30*, 1119–1128.

Muhammed, A., 2019: Preparation of the Abaya project for geothermal sustainability assessment protocol (Gsap) In Ethiopia. Report 7 in*: Geothermal training in Iceland 2019,* UNU-GTP, Iceland, 29-48.

Musonye, X.S., Davíðsdóttir, B., Kristjánssonc, R., Ásgeirssonc, E., and Stefánssonca H., 2021:

Environmental and techno-economic assessment of power system expansion for projected demand levels in Kenya using TIMES modeling framework. *Energy for Sustainable Development, 63*, 51-66.

Mwangi-Gachau, E., 2015: Preliminary economic valuation of environmental impacts of Olkaria geothermal project. Report 27 in*: Geothermal training in Iceland 2015,* UNU-GTP, Iceland, 585-606.

Ogola, P.F.A., Davíðsdóttir, B., and Fridleifsson I.B., 2011: Opportunities for adaptation-mitigation synergies in geothermal energy utilization – initial conceptual frameworks*. Mitig.Adapt. Strateg. Glob. Change, 17,* 507-536. Available at: https://link.springer.com/article/10.1007/s11027-011-9339-1

Orka Náttúrunnar, 2018: *Geothermal Sustainability Assessment Protocol - Hellisheidi geothermal project, Iceland.* ON - Orka Náttúrunnar, operation assessment report, 131 pp, website: *www.on.is/en/*

Orkustofnun, Landsvirkjun, Orkuveita Reykjavikur, HS Orka and Umhverfisstofnun, 2019a: *The draft GSAP preparation stage. geothermal sustainability assessment protocol,* website: *https://orkustofnun.is/gogn/Skyrslur/OS-2019/Draft-GSAP-1a-Prep-Stage-Sept-2019-Final-Handover-Protocol.pdf*

Orkustofnun, Landsvirkjun Orkuveita Reykjavikur, HS Orka and Umhverfisstofnun, 2019 b: *The draft GSAP operation stage. geothermal sustainability assessment protocol,* website:.*https://orkustofnun.is/gogn/Skyrslur/OS-2019/Draft-GSAP-2a-Op-Stage-Sept-2019-Final-Handove-Protocol.pdf*

Shortall, R., Davíðsdóttir, B., and Axelsson, G., 2015: Development of a sustainability assessment framework for geothermal energy projects. *Energy for Sustainable Development, 27*, 28-45.

WHO, 2000: *Air quality guidelines for Europe*. World Health Organization, Regional Office for Europe, European Series No. 91, Copenhagen, Denmark, 146 pp.

World Resources Institute, 2015: *Greenhouse Gas Protocol a Corporate Accounting and Reporting*, website: *https://ghgprotocol.org/corporate-standard*

APPENDIX I: Protocol Gradational Criteria and scoring statement (HSAP, 2019)

Level	Assessment	Management	Stakeholder Engagement
5	Suitable, adequate, and effective assessment with no significant opportunities for improvement. In addition to basic good practice (Level 3), the assessment is likely to take a relatively broad, external, or regional view or perspective; emphasise opportunities; and show a high-level examination of interrelationships amongst relevant sustainability issues.	Suitable, adequate, and effective management processes with no significant opportunities for improvement. In addition to basic good practice (Level 3), management plans and processes are likely to show excellent anticipation of, and response to, emerging issues or opportunities; senior management and/or executive decisions are likely to be timely, efficient, and effective in response to monitoring data, investigations and issues arising; and, in cases, commitments in plans are public, formal, and legally enforceable.	Suitable, adequate, and effective stakeholder engagement processes with no significant opportunities for improvement. In addition to basic good practice (Level 3), the engagement is likely to be inclusive and participatory with the directly affected stakeholders; thorough feedback is likely to be available on how directly affected stakeholder issues are taken in to consideration; in cases, there is likely to be directly affected stakeholder involvement in decision-making; and information identified through engagement processes to be of high interest to stakeholders is released publicly in a timely and easily accessible manner.
4	Suitable, adequate, and effective assessment with only a few minor gaps. In addition to basic good practice (Level 3), the assessment is likely to exhibit some recognition of broader, external, or regional issues; opportunities; and interrelationships amongst relevant sustainability issues	Suitable, adequate, and effective management processes with only a few minor gaps. In addition to basic good practice (Level 3), management plans and processes are likely to exhibit good anticipation of, and response to, emerging issues or opportunities; and, in cases, commitments in plans are public and formal.	Suitable, adequate, and effective stakeholder engagement processes with only a few minor gaps. In addition to basic good practice (Level 3), there is likely to be good feedback on how directly affected stakeholder issues have taken into consideration; and information on sustainability topics understood to be of high interest to stakeholders is voluntarily released publicly.

Level	Assessment	Management	Stakeholder Engagement
3	Suitable adequate and effective assessment with no significant gaps. This would typically encompass (as appropriate to the topic and life cycle stage) identification of the baseline condition including relevant issues, appropriate geographic coverage, and appropriate data collection and analytical methodologies; identification of relevant organizational roles and responsibilities, and legal, policy and other requirements; appropriate utilization of expertise and local knowledge; and appropriate budget and time span. At level 3 the assessment encompasses the considerations most relevant to that topic but tends to have a predominantly project focused view or perspective and to give stronger emphasis to impacts and risks than it does to opportunities.	Suitable, adequate, and effective management processes with no significant gaps. These would typically encompass (as appropriate to the topic and life cycle stage) development and implementation of plans that: integrate relevant assessment or monitoring findings; are underpinned by policies; describe measures that will be taken to address the considerations most relevant to that topic; establish objectives and targets; assign roles, responsibilities and accountabilities; utilize expertise appropriate to that topic; allocate finances to cover implementation requirements with some contingency; outline processes for monitoring, review and reporting; and are periodically reviewed and improved as required	Suitable, adequate, and effective stakeholder engagement processes with no significant gaps. These would typically encompass (as appropriate to the topic and life cycle stage): Identification of directly affected stakeholders; Appropriate forms, timing, frequency and locations of stakeholder engagement, often two-way; Freedom for affected stakeholders to participate; Attention to special stakeholder engagement considerations relating to gender, minorities, cultural sensitivities, level of literacy, and those who might require particular assistance; Mechanisms by which stakeholders can see that their issues are recognized and acknowledged, and how they have been or are being responded to; and disclosure of information on significant sustainability topics (in cases, this may be on request).
2	A significant gap in assessment processes relative to basic good practice (Level 3).	A significant gap in management processes relative to basic good practice (Level 3).	A significant gap in stakeholder engagement processes relative to basic good practice (Level 3).
1	Significant gaps in assessment processes relative to basic good practice (Level 3)	There are significant gaps in management processes relative to basic good practice (Level 3	There are significant gaps in stakeholder engagement processes relative to basic good practice (Level 3).

	Stakeholders Support	**Outcomes**	**Conformance/ Compliance**
5	There is support of nearly all directly affected stakeholder groups for the assessment, planning or implementation measures for that topic, or no opposition by these stakeholders. In cases formal agreements or consent with the directly affected stakeholder groups have been reached for management measures for that topic	In addition to basic good practice (Level 3), there may be exhibited enhancements to pre-project conditions; contributions to addressing issues beyond those impacts caused by the project; leveraging of opportunities; or significant contribution to capacity building.	No noncompliance or non-conformances.
4	There is support of a large majority of directly affected stakeholder groups for the assessment, planning or implementation measures for that topic, or only very low-level opposition by these stakeholders.	In addition to basic good practice (Level 3), there may be exhibited full compensation of negative impacts; some positive enhancements; or evidence of capacity building associated with the project	Very few minor non-compliances and non-conformances that can be readily remedied.
3	There is general support amongst directly affected stakeholder groups for the assessment, planning or implementation measures for that topic, or no significant ongoing opposition by these stakeholders.	As appropriate to the topic and the life cycle stage, there may be exhibited avoidance of harm, minimization, and mitigation of negative impacts; fair and just compensation; fulfilment of obligations; or effectiveness of implementation plans	No major noncompliance and non-conformances.
2	There is support amongst some directly affected stakeholder groups for the assessment, planning or implementation measures for that topic, with some opposition.	A significant gap relative to basic good practice (Level 3), for example, some deterioration in baseline condition.	A major non-compliance or non-conformance.
1	There is low support amongst directly affected stakeholder groups for the assessment, planning or implementation measures for that topic, or a majority oppose.	Significant gaps relative to basic good practice (Level 3), for example deterioration in baseline conditions with delay or difficulties in addressing negative impacts.	major non-compliance and non-conformances.