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A SUSTAINABILITY ASSESSMENT FRAMEWORK FOR GEOTHERMAL ENERGY PROJECTS

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ABSTRACT

With increasing global energy consumption, geothermal energy use is set to increase in the future as the potential of geothermal energy is largely untapped in numerous regions. Geothermal development may result in both positive and negative environmental and socio-economic impacts and thus have multi-dimensional sustainability implications. Sustainability assessment tools are useful to decision-makers in showing the expected impact of energy developments on sustainable development. This paper presents a framework, uniquely designed for geothermal resources, that captures sustainability implications of geothermal development.

1. INTRODUCTION

1.1 General

Sustainable development (SD) was defined by the Brundtland commission as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987). Energy is central to the three dimensions of sustainable development. On the one hand it is a driver for macroeconomic growth, and access to high quality energy is a prerequisite for being able to fulfil basic human needs (Modi et al., 2005). But on the other hand, energy development and use can have significant negative environmental impact. As a result, sustainable energy development, or the development of sustainable energy systems, has "*emerged as one of the priority issues in the move towards global sustainability*" (Davídsdóttir, 2012).

Development of geothermal energy resources has implications across all sustainability themes as defined by the United Nations. As a result, when assessing implications of geothermal development on sustainable development a multi-dimensional analysis is needed.

1.2 Sustainability assessment and energy development

Sustainable energy development (SED) was defined by the International Atomic Energy Agency (IAEA) in 1998 as "the provision of adequate energy services at affordable cost in a secure and

environmentally benign manner, in conformity with social and economic development needs" (IEA/IAEA, 2001).
A few years later, in 2001, the IEA defined SED as "development that lasts and that is supported by an economically profitable, socially responsive and environmentally responsible energy sector with a global, long-term vision" (IEA/OECD, 2001).

These two definitions clearly evoke multiple sustainability themes, and therefore to reveal whether an energy development is indeed contributing to sustainable development, sustainability assessment needs to be conducted. Sustainability assessments in general rely on multi-dimensional sustainability goals that tend to be broad and then more specific targets and indicators. The goals illustrate the broad aims, but the more specific quantifiable targets and indicators are used to reveal if the goals are likely to be attained or not. Goals and indicators should not be too rigid, but must take account of the local context both in terms of social and economic development needs as well as the local environment. In addition, they should be adaptive as for example it is likely that societal needs and opinions change over time (Lim and Yang, 2009). To capture such local specificities stakeholder engagement is an essential part of sustainability analysis (Fraser et al., 2006).

Several broad based indicator frameworks exist to measure sustainable development in the context of energy developments, such as the Energy indicators for sustainable development (IAEA, 2005), and the Energy Sustainability Index developed by the World Energy Council (WEC, 2011). In addition, a few renewable energy associations have developed sustainability assessment frameworks for energy developments. Although not based on indicators as such, the International Hydropower Association (IHA) published an assessment tool for hydropower projects in 2006 (IHA, 2006). The World Wind Energy Association (WWEA) has developed Sustainability and Due Diligence Guidelines (WWEA, 2005), for the assessment of new wind projects, similar to those developed by the IHA in their Sustainability Assessment Protocol. The WWF Sustainability Standards for Bioenergy (Fritsche et al., 2006) don't provide any indicators but highlight sustainability issues in bioenergy and offer recommendations for its sustainable use. UN-Energy has also published a report with a similar focus (UN-Energy, 2007). In addition, a standard for reporting on corporate social responsibility, the Global Reporting Initiative, has been developed that is widely used in sustainability reports for businesses all over the world (see www.globalreporting.org).

In this paper we present a sustainability assessment framework consisting of a set of sustainability goals and indicators that allow monitoring of geothermal projects during their entire life cycle and at different scales in the context of sustainability. The goals and indicators in this framework were developed using an iterative process for thematic indicator development (Davídsdóttir et al., 2007) in Iceland, New Zealand and Kenya (Shortall et al., 2014b and 2015).

2. SUSTAINABILITY ASSESSMENT FRAMEWORK FOR GEOTHERMAL POWER

2.1 Framework development process

The sustainability framework was developed using an iterative procedure in three countries (Iceland, New Zealand and Kenya), that resulted in a core set of sustainability goals, indicators and targets, as well as satellite indicators and targets (see section 2.3). Initially an extensive literature review of the impacts of geothermal energy projects on sustainable development was conducted (Shortall et al., 2015a and 2015b) to determine the boundaries of the system that the assessment framework was intended for, as well as to establish an initial set of potential sustainability indicators and goals. This set of goals and indicators provided a starting point for which stakeholder input was sought later in the process in an iterative process (Davídsdóttir et al., 2007). Following the literature review, stakeholders in three different countries were selected to participate in the development process via pre-engagement World Café workshops and online Delphi surveys. In the pre-engagement workshops and surveys, stakeholders rated and commented on a draft list of indicators with regard to their suitability to capture sustainability implications of geothermal development. Based on stakeholder input, certain goals and indicators were modified or even eliminated, and some new indicators were suggested. In the end, a greatly reduced set of goals and indicators remained that were deemed relevant by the stakeholders. The selected sustainability goals and indicators were then evaluated for suitability to their purpose using a set of criteria and assessed in several trial assessments, for example using data from the Nesjavellir geothermal power plant in Iceland (Shortall et al., 2015b and 2015c).

The final results yielded a final list of ten sustainability goals (Table 1) and a set of 21 common ("core") (Table 2) and 18 supplementary ("optional") sustainability indicators (Table 3) (Shortall et al., 2015b, 2015c and 2015d). The core indicators were rated important by stakeholders in all three countries, whereas the satellite or optional indicators were rated important in one or two countries.

2.2 Sustainability goals

Table 1 illustrates the 10 sustainability goals chosen, which capture multiple sustainability themes and dimensions.

TABLE 1: The sustainability goals chosen (Shortall et al., 2015c and 2015d)

GOAL 1 – Renewability In order to ensure that a geothermal resource remains replenishable, sustainable production should be the goal in all geothermal projects.
GOAL 2 – Water resource usage Water usage of a power plant must not reduce supply of cold fresh water to communities nearby.
GOAL 3 – Environmental management A geothermal resource should be managed in such a way as to avoid, remedy or mitigate adverse environmental effects.
GOAL 4 – Efficiency Geothermal utilization shall be managed in such a way as to maximize the utilization of exergy available where practical at sustainable production levels. The desired maximum efficiency for electricity generation should be based on the theoretical maximum efficiency for converting heat to electrical energy (Carnot efficiency).
GOAL 5 – Economic management and profitability Energy use from geothermal power and heat plants must be competitive, cost effective and financially viable. The financial risk of the project shall be minimized. The project should carry positive net national and community economic benefits.
GOAL 6 – Energy equity The energy supplied by the geothermal resource is readily available, accessible and affordable to the public.
GOAL 7 – Energy security and reliability The operation of geothermal power and heat plants shall be reliable and prioritize the security of supply.
GOAL 8 – Community responsibility The power companies should be responsible toward the community and the effect of the utilization of the geothermal resource shall be as positive for the community as possible and yield net positive social impact.
GOAL 9 – Research and innovation Power companies shall encourage research that improves the knowledge of the geothermal resource as well as technical developments that improve efficiency, increase profitability and reduce environmental effects.
GOAL 10 – Dissemination of knowledge Information and experience gained through geothermal utilization shall be accessible and transparent to the public and the academic community alike while respecting confidential intellectual property rights.

2.3 Sustainability indicators

Table 2 illustrates the 21 core sustainability indicators and Table 3 the 18 optional indicators, as well as the appropriate metrics for each indicator. Applicable optional indicators need to be chosen for each location as well as targets and benchmarks for each indicator for each location. Normally this would be done using expert opinion and stakeholder analysis.

TABLE 2: Core sustainability indicators (Shortall et al., 2015d)

Indicator
Air quality in the surrounds of the geothermal power plant (metric: Concentrations (μg/m3) of potentially toxic gases (hydrogen sulphide, mercury, sulphur dioxide, carbon dioxide, etc.)
Tons of greenhouse gas emissions resulting from geothermal operations (metric: Tons of CO2 equivalents per kilowatt hour per annum)
Water quality of water bodies impacted by geothermal power plant operations (metric: Status of water bodies impacted by geothermal power plant operations, based on national water directive ratings)
Noise levels in working, recreation and residential areas in the surrounds of the geothermal power plant (metric: dB)
Impact on important or vulnerable geothermal features (metric: Value of predefined impact parameters)
Rate of subsidence in the geothermal field (metric: Millimeters (mm) per year)
Number of accidents leading to work absence in the energy company per year (metric: Count)
Duration of plant power outages per year (metric: Use hours of unplanned interrupted service)
Level of induced seismicity per year (metric: Peak ground velocity levels (PGV) during the year)
Estimated productive lifetime of geothermal resource (metric: Years)
Resource reserve capacity ratio of the geothermal resource (metric: Ratio)
Utilization efficiency for the geothermal power plant (metric: %)
Project internal rate of return (IRR) (metric: rate)
Average income levels in project-affected communities (metric: Dollars per annum)
Direct and indirect local job creation over lifetime of project (metric: Mo. full-time employees per year)
Expenditure on heat and electricity as a percentage of household income (metric: %)
Imported energy as a percentage of total (national level) (metric: %)
Income-to-expenditure ratio for project-affected municipalities (metric: ratio)
Percentage of community residents that must be relocated due to energy project (metric %)
Percentage of energy company expenditure given to R&D per year (metric %)
Percentage of renewables in total energy supply nationally (metric %)

TABLE 3: Optional sustainability indicators (Shortall et al., 2015d)

Indicator
EBIDTA ratio per project (metric: ratio)
Percentage of protected area removed/affected due to geothermal project (metric: %)
Number of threatened species that may be affected by the geothermal project. (metric: count)
Rate of literacy of existing population in project-affected areas (metric: %)
Cost per MW of power produced compared to price per MW from other sources (metric: ratio)
Income Equity in Project-Affected Communities (metric: gini coefficient)
Infant mortality rates in the project-affected area (metric:
Life expectancy at birth in project-affected area (metric: year)
Percentage of mass of fluid reinjected and/or cascaded compared to total extracted fluid mass (metric: %)
Percentage of satisfied workers in the energy company per year (metric: %)

TABLE 3 cont'd: Optional sustainability indicators (Shortall et al., 2015d)

Indicator
Ratio of average male income to female income for similar jobs for the project staff (metric: ratio)
Percentage of population with access to commercial energy in project-affected area (metric: %)
Amount of freshwater used during geothermal development (exploration, construction or operation activities) as a percentage of available freshwater in the project area (metric: %)
Monetary value of socially beneficial initiatives in project-affected communities as a percentage of total project expenditure (metric %)
Percentage of community residents that have agreed to potential culture-changing activities relating to the energy project (metric: %)
Unemployment rate in project-affected communities (metric: %)
Percentage of population below poverty line in project-affected area (metric: %)
Economic diversity of project-impacted areas (metric: Adjusted Shannon-Wiener Index (%))

3. IMPLEMENTING THE INDICATOR FRAMEWORK

Based on the results we suggest an assessment framework structure (Figure 1) of the ten sustainability goals measured by the core and optional indicators as applicable in each case. The optional indicators may or may not have relevance, depending on the circumstances such as state of economic and social development (Shortall et al., 2015c).

For each location, therefore, the implementation of the indicator framework takes the following steps:

1. The sustainability goals are reviewed by experts;
2. The core indicators are reviewed by experts;
3. The optional indicators are reviewed and applicable ones identified by experts and stakeholder using stakeholder engagement;
4. Benchmarks and targets for each chosen indicator are established by experts;
5. Each indicator is measured, compared to a benchmark or a target; and
6. Final results are displayed using e.g. a spider graph revealing where improvements need to be made to ensure a positive impact on sustainable development.

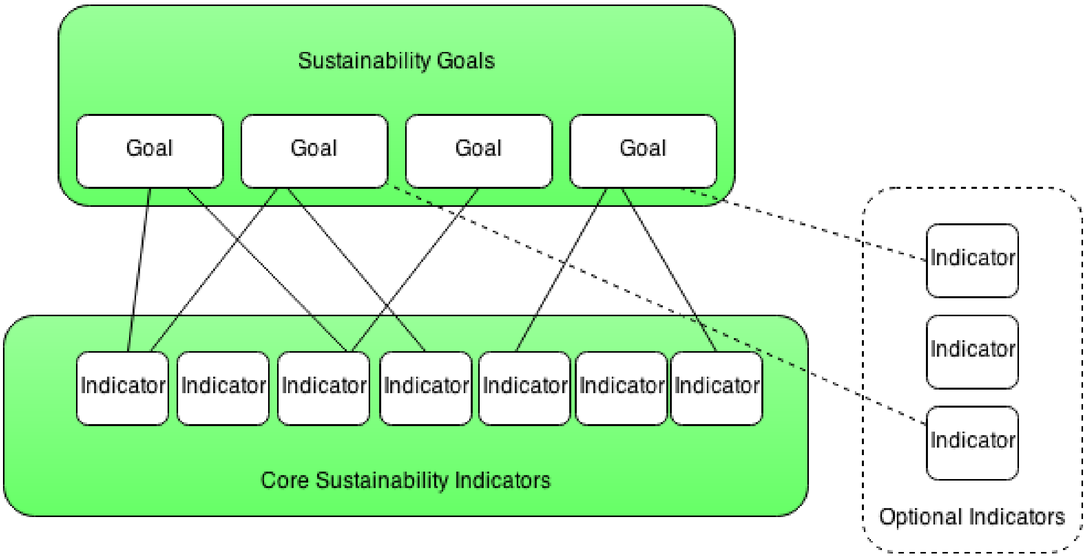

FIGURE 1: Optional Sustainability Indicators (Shortall et al., 2015d)

4. CONCLUSIONS

This paper has illustrated how the development and utilization of geothermal resources can be assessed in the context of broader sustainability assessments. The sustainability goals and indicators presented enable comprehensive sustainability assessment of geothermal utilization. They are quite general and can be applied to geothermal development projects and geothermal energy production operations the world over, such as in the countries represented at this short course.

Careful use of geothermal resources can contribute to sustainable energy development in all sustainability dimensions and as a result the development of geothermal energy is intimately related to the movement towards global sustainability. The application of sustainability assessment frameworks, e.g. as the one presented here, should be an integral part of their careful utilization.

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