A Sustainability Assessment Protocol for Geothermal Utilization

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2010

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A 60 credit units Master´s thesis

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Reykjavik, January 2010

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60 ECTS thesis submitted in partial fulfillment of a *Magister Scientiarum* degree in Environment & Natural Resources

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Bibliographic information:
Ruth Shortall, 2010, *A Sustainability Assessment Protocol for Geothermal Utilization*, Master's thesis, Faculty of Environmental & Life Sciences, University of Iceland

Printing: University of Iceland
Reykjavik, Iceland, January 2010

ABSTRACT

Sustainable development calls for the use of sustainable energy systems. However, the way in which a geothermal resource is utilized will ultimately determine whether or not it is sustainable. Sustainable utilization of geothermal energy means that it is produced and used in such a way that is compatible with the well-being of future generations and the environment (UNDP, 2000).

A measurement and assessment framework is needed for a sustainable energy development strategy, as it can provide an integrated understanding of current socio-economic and ecological conditions. The objective of this project is to develop a Geothermal Sustainability Assessment Protocol (GSAP) tailored especially for geothermal energy development projects, and based on a methodology recommended by the International Institute of Sustainable Development (IISD). This protocol will be pilot tested on the Krafla geothermal project in Iceland in association with Landsvirkjun Power.

The protocol is intended to aid policy- and decision-making regarding geothermal energy developments, equipping decision-makers at all levels with a tool to aid the choice of sound national sustainable development policies (UN, 1992), for monitoring progress of past policies, plans or projects, and for facilitating strategy formulation and comparison of different energy project options.

ÚTDRÁTTUR

Sjálfbær þróun hefur verið skilgreind svo að þörfum okkar á líðandi stund eigi að fullnægja þannig að ekki verði gengið á möguleika komandi kynslóða til að uppfylla sínar þarfir. Sjálfbær þróun samfélagsins vísar því til þróunar þar sem horfið er frá áherslu á skammtímaefnahagslegum ávinningi og í staðinn litið til lengri tíma. Orkunotkun er mikilvægur þáttur í slíkri þróun og því hefur mikilvægi sjálfbærrar nýtingar auðlinda jarðarinnar orðið stöðugt ljósara. Jarðhitakerfi teljast til endunýjanlegra orkulinda sem hægt

er að nýta á sjálfbæran hátt ef vel er haldið á spöðunum. Nýting jarðhita getur því haft jákvæð áhrif á efnahagslega og þjóðfélagslega þróun samfélagsins en þó einnig neikvæð áhrif á náttúruna.

Í þessari rannsókn verður þróuð aðferð til mats á sjálfbærri nýtingu jarðhita með gerð sjálfbærnivísa. Til þess verður notuð matsaðferð sem byggir á lögmálum sjálfbærrar þróunar og stuðst var við svokölluð Bellagio lögmál ásamt aðferðafræði sem þróuð hefur verið af International Institute for Sustainable Development. Matsaðferðinni var beitt á Kröfluvirkjun í samvinnu við Landsvirkjun.

PREFACE

This thesis is submitted to the School of Engineering and Natural Sciences at the University of Iceland as a 60 ETCS project in the Environment and Natural Resources program. I want to extend a very big thank you to my supervisors, Dr. Brynhildur Davíðsdóttir of University of Iceland and Jónas Ketilsson of Orkustofnun for their continued encouragement and outstanding guidance and support.

A special thank you is also due to the sustainability working group at Orkustofnun for their input into the process and guidance. I would also like to thank the people at Landsvirkjun for their support of this project and their help with finding data and people, in particular Ragnheiður Ólafsdóttir, Bjarni Pálsson and Ragnheiður Vigfúsdóttir. Also I would like to to acknowledge the help all the other people that kindly assisted me during the course of the project.

I am extremely grateful to my classmate Rut Bjarnadóttir, Masters student at Reyst, for her valuable contribution to the project with her masters thesis, *Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland 2010.* The ultimate success of this project depended upon her hard work, dedication and expertise.

Without their generous grants, this project would not have been possible and so I wish to express my gratitude to Orkustofnun, Landsvirkjun and Rannis for making this research possible.

Last of all I would like to thank my husband, Árni, for his incredible support and patience during the past year and for his valuable help with translating from Icelandic.

Dedication

To my parents, with thanks for their love and support

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1. INTRODUCTION

1.1 Motivation

Sustainable development calls for the development of sustainable energy systems. Geothermal energy is classified as renewable by the International Energy Agency and is relatively environmentally friendly when compared with fossil fuel energy (IEA, 2003). However, these characteristics alone do not guarantee its sustainability.

The way in which a geothermal resource is used will ultimately determine whether or not it is sustainable. Sustainable usage of geothermal energy means that it is produced and used in such a way that is compatible with the well-being of current and future generations. (UNDP, 2000) Therefore, a measurement and assessment framework is needed for a sustainable energy development strategy, as it can provide an integrated understanding of current socio-economic and ecological conditions. By developing the appropriate indicators, best practices for the sustainable use of the geothermal resource are highlighted and measurement of the project objectives against the goal of sustainability is possible. A sustainability assessment protocol equips decision-makers at all levels with a tool to aid the choice of sound national sustainable development policies, (UN, 1992) for monitoring progress of past policies, plans or projects, and for facilitating strategy formulation and comparison of different energy project options.

1.2 Objective

The objectives of this study were to

- Demonstrate the need for assessing sustainability in the geothermal energy sector
- Develop a pilot sustainability assessment protocol for geothermal utilization for electricity generation for international use and compare it to current sustainability assessment protocols available for the energy industry.

- Perform a pilot study using the sustainability assessment protocol to assess a geothermal energy project at the operation phase. This pilot study constitutes the first iteration of the indicator development process for GSAP.
- Identify potential improvements that could be made to the assessment protocol and gather information necessary before performing further iterations of the indicator development process. Further work for this project is expected to be carried out in the author´s doctoral thesis.

1.3 General Methodology

This project was carried out for The National Energy Authority, in consultation with a working group of experts in the geothermal industry in Iceland as well as other stakeholders including government bodies, NGOs and corporate representatives.

To perform this study the general research methodology involved a review of the literature pertaining to sustainable energy, sustainability assessments and the development of indicators of sustainable development for energy. The geothermal lifecycle was also studied as well as the impacts of geothermal development. The appropriate indicator development frameworks were then chosen and a definition of sustainable geothermal energy was developed.

The development of the Geothermal Sustainability Assessment Protocol (GSAP) was achieved using a systemic approach to indicator development. A thematic approach was also explored for comparative purposes. The Bellagio Principles, a set of guiding principles developed by the International Institute for Sustainable Development for the assessment process were used as overarching guidelines throughout the development process.

The International Hydropower Association has developed their own sustainability assessment protocol for hydropower projects (IHA-SAP). It was considered appropriate to carry out a comparison between this protocol and GSAP. The comparison evaluates the thematic and systemic differences between the two protocols and attempts to assess their strengths and weaknesses.

The Geothermal Sustainability Assessment Protocol (GSAP) was implemented for the Krafla geothermal energy project in northern Iceland. There is currently an operating 60 MW power station at Krafla, and there are plans to build a second 150 MW power station in the same geothermal system.

As part of the GSAP project, Rut Bjarnadóttir carried out a project for the development of indicators for the geothermal resource only. These indicators are described in her masters thesis and the results of her project (Bjarnadottir, 2010) are incorporated into this project.

2. BACKGROUND

This section provides a summary of the important points that emerged during the literature review. It describes the state of the art of sustainability assessment and indicator development and summarizes the strengths and weaknesses of the different frameworks. The meaning of sustainable energy is also defined and this definition is later used to aid the identification of critical sustainability issues in geothermal energy utilization. This study of critical sustainability issues was required to provide a rough understanding of the relevant systems for which indicators of sustainable development were eventually chosen.

2.1 Sustainability assessments

In Iceland, strategic environmental impact assessment (SEA) is now required by law to be carried out during the preparation of plans and programs likely to have a significant effect on the environment (The Strategic Environmental Assessment Act, 2006). This includes energy matters. This law came into force in 2006. Before this, only environmental impact assessments (EIAs) were required.

SEA can be defined as a systematic process for evaluating the environmental consequences of a proposed policy, plan or program initiatives in order to ascertain that they are fully included and appropriately addressed at the earliest appropriate stage of decision making on par with economic and social considerations. (Sadler & Verheem, 1996)

SEA allows a more systematic approach to environmental protection than EIA. While EIA reacts to development proposals and aims to minimize impacts, SEA anticipates them and aims to prevent impact and so requires a more pro-active approach. SEA deals mainly with the environmental aspect of plans or programs and could therefore be used alongside a Sustainability Appraisal (SA). SA can be defined as a framework that promotes sustainable development by the integration of social, environmental and economic considerations into the preparation of plans and programs.

Sustainability appraisals (SAs) are now carried out in many countries, sometimes incorporating the requirements of strategic impact assessment (SEA). In the United Kingdom, SAs are mandatory under the Planning and Compulsory Purchase Act 2004 (Planning and Compulsory Purchase Act, 2004) in addition to SEAs, and the two are often integrated. SAs must incorporate the requirements of SEA such as those found in the Strategic Environmental Assessment Directive (EU Directive 2001/42/EC). For regional and local development project plans, including renewable energy projects in the U.K., it is required that sustainability indicators be developed during the baseline information collection stage of SA. An “SA framework” is created, consisting of sustainability objectives which, where practicable, may be expressed in the form of targets, the achievement of which is measurable using indicators. (Office of the Deputy Prime Minister, 2005)

2.2 Indicator development Frameworks and Methodologies

2.2.1 General Overview

While there are many examples of sustainability indicator development for renewable energy to be found in the literature, to date there are precious few examples of the development of sustainability indicators specifically for geothermal energy projects. Although there is no international protocol for measuring the sustainability of geothermal energy projects, sustainability indicators for energy have been developed by international organizations and various other guidelines and methodologies are available to facilitate indicator development.

During indicator development there are a number of methods that may be applied.
These consist of:

1. The use of general overarching guiding principles
2. The use of indicator development frameworks
3. The use of specialised sets of indicators that can be tailored to a country´s needs

2.2.2 General Guiding Principles for Indicator Development

2.2.2.1 The Bellagio Principles

The International Institute of Sustainable Development's Bellagio Principles (Box 1) are a set of guiding principles designed to be applied when improving sustainability assessment systems and have been widely adopted. (IISD, 1997) The Bellagio Principles were developed in an attempt to provide a common framework for indicators of sustainable development worldwide, due to the shortcomings of indicator schemes recognized by the research community (Bossel, 1999). They were developed by an international group of measurement practitioners and researchers in 1996, with the aim of harmonizing indicator sets internationally and improving co-ordination among measurement and assessment processes (IISD, 1997). The principles are intended to serve as guidelines for the entire assessment process including the choice and design of indicators, their interpretation and communication of the result. While the Bellagio Principles identify desirable common patterns in sustainable development-related assessments, they do not offer a detailed methodological approach required for the development of an indicator set.

Box 1: The Bellagio Principles

The Bellagio Principles

1. Guiding Vision and Goals

Assessment of progress toward sustainable development should be guided by a clear vision of sustainable development and goals that define that vision

2. Holistic Perspective

Assessment of progress toward sustainable development should:

- include review of the whole system as well as its parts
- consider the well-being of social, ecological, and economic sub-systems, their state as well as the direction and rate of change of that state, of their component parts, and the interaction between parts
- consider both positive and negative consequences of human activity, in a way that reflects the costs and benefits for human and ecological systems, in monetary and non-monetary terms

3. Essential Elements

Assessment of progress toward sustainable development should:

- consider equity and disparity within the current population and between present and future generations, dealing with such concerns as resource use, over-consumption and poverty, human rights, and access to services, as appropriate
- consider the ecological conditions on which life depends
- consider economic development and other, non-market activities that contribute to human/social well-being

4. Adequate Scope

Assessment of progress toward sustainable development should:

- adopt a time horizon long enough to capture both human and ecosystem time scales thus responding to needs of future generations as well as those current to short term decision-making
- define the space of study large enough to include not only local but also long distance impacts on people and ecosystems
- build on historic and current conditions to anticipate future conditions - where we want to go, where we could go

5. Practical Focus

Assessment of progress toward sustainable development should be based on:

- an explicit set of categories or an organizing framework that links vision and goals to indicators and assessment criteria
- a limited number of key issues for analysis
- a limited number of indicators or indicator combinations to provide a clearer signal of progress
- standardizing measurement wherever possible to permit comparison
- comparing indicator values to targets, reference values, ranges, thresholds, or direction of trends, as appropriate

6. Openness

Assessment of progress toward sustainable development should:

- make the methods and data that are used accessible to all
- make explicit all judgments, assumptions, and uncertainties in data and interpretations

7. Effective Communication

Assessment of progress toward sustainable development should:

- be designed to address the needs of the audience and set of users
- draw from indicators and other tools that are stimulating and serve to engage decision-makers
- aim, from the outset, for simplicity in structure and use of clear and plain language

8. Broad Participation

Assessment of progress toward sustainable development should:

- obtain broad representation of key grass-roots, professional, technical and social groups, including youth, women, and indigenous people - to ensure recognition of diverse and changing values
- ensure the participation of decision-makers to secure a firm link to adopted policies and resulting action

9. Ongoing Assessment

Assessment of progress toward sustainable development should:

- develop a capacity for repeated measurement to determine trends
- be iterative, adaptive, and responsive to change and uncertainty because systems are complex and change frequently
- adjust goals, frameworks, and indicators as new insights are gained

- promote development of collective learning and feedback to decision-making

10. Institutional Capacity

Continuity of assessing progress toward sustainable development should be assured by:

- clearly assigning responsibility and providing ongoing support in the decision-making process
- providing institutional capacity for data collection, maintenance, and documentation
- supporting development of local assessment capacity

2.2.2.2 Guidelines from Other Organisations

The Commission for Sustainable Development (CSD) has produced guidelines for the creation of sustainability indicators for energy at the national level (UN, 2007). In the EU, these indicators have been used in creating an indicator framework to monitor implementation of the main EU directives and other policy documents targeting sustainable energy development.

Other renewable energy associations have attempted to improve sustainability assessment for energy projects. The World Wind Energy Association (WWEA) have developed Sustainability and Due Diligence Guidelines (WWEA, 2005), for the assessment of new wind projects, similar to those developed by the International Hydropower Association in Section A of their Sustainability Assessment Protocol. These guidelines do not cover the operation stage of a wind energy project and do not provide a set of comprehensive indicators. The WWF Sustainability Standards for Bioenergy (WWF, 2006) does not provide any indicators but does highlight sustainability issues in bioenergy and offer recommendations for its sustainable use. UN Energy has also published a report with a similar focus entitled Sustainable Bioenergy: A Framework for Decision-Makers (UN, 2007).

2.2.3 Indicator Development Frameworks and Approaches

2.2.3.1 Pressure-State-Response Framework

Two well-known frameworks for the creation of sustainability indicators are the Pressure-State-Response (PSR) or Driving Force -State-Response (DSR) models. The PSR framework was initially developed for environmental statistics in Canada, then further developed and adopted internationally for use in methodological handbooks and country studies (Pinter et al., 2005). These frameworks have been used in the past for indicator development by the OECD and Commission for Sustainable Development (CSD) (UN, 2007) and are used in particular when defining environmental indicators.

According to the CSD's guidelines and methodologies for indicator development, when using the DSR framework, indicators are categorised as driving force, state or response indicators. Driving force indicators describe processes or activities that have a positive or a negative impact on sustainable development. State indicators describe the current situation, whereas response indicators reflect societal actions aimed at moving towards sustainable development (UN, 2007). The DSR framework is a modified version of the PSR framework, the difference being that while the pressure indicators point directly to the causes of problems, driving-force indicators describe underlying factors influencing a variety of relevant variables, i.e. basic sectoral trends that are not very responsive to policy action. The OECD cautions that while the PSR framework has the advantage of highlighting the links between pressures, states and responses, it tends to suggest linear relationships in human -environment interactions. More complex relationships exist in ecosystems and in environment-economy interactions, and this should be kept in mind (OECD, 1993). The OECD states, however, that more socio-economic and environmental information could be included in the framework, with a view to fostering sustainable develo[1]pment strategies (OECD, 1993).

Hartmut Bossel, in his report to the Balaton Group, offers a critique of the PSR or DSR models, claiming that even though these models attempt a more systemic approach than others, they neglect the systemic and dynamic nature of processes for environmental problems, and their embedding in a larger system that has many feedback loops. He argues that impacts in one causal chain may be pressures or states in another and multiple pressures or impacts are not considered, and non-linear relationships cannot be accounted for (Bossel 1999). As stated in the discussion paper of the IISD, this is also the main reason why the DSR framework was abandoned in the UN (2001) indicator report. (Pinter et al., 2005), The OECD also point out (OECD, 1992) the difficulties associated with using the PSR indicator framework. They warn that for societal response indicators, it must be taken into account that such indicators are in the early stage of development conceptually and terms of data availability, and sometimes they may not be suited to quantitative measurement, such as policy areas. They also warn that the distinction between pressure and response indicators can easily become blurred. They therefore recommend that indicators be supplemented by other qualitative and scientific information, to avoid the danger of misinterpretation if indicators are presented without appropriate supplementary information. They recommend that indicators must be reported and interpreted in the appropriate context, taking into account the ecological, geographical, social, economic and structural features of the area. Key information on methodology for indicator derivation should also accompany the use of indicators in performance reviews (OECD, 1993).

Janne Hukkinen offers further advice when using the PSR framework, arguing that while we do not need to throw it out completely, we should be aware of certain issues when using it. He argues that indicator systems tend to assume the existence of just one sustainability scenario, a scenario being a plausible causal description of future trends and events. It may be that indicators are included in a set just because they are easy to measure or easily available, not really related to the scenario of sustainability. There may in fact be several stable states (scenarios) possible for a system, no one sustainability scenario being correct or optimal. The question of temporal and spatial scale must be dealt with carefully, i.e. having alternative scenarios is advisable to show contradictions between the scales (Hukkinen, 2006). This is similar to what Bossel advises in the Balaton Report (Bossel, 1999).

2.2.3.2 Systemic Approach

Although the analysis of sustainability issues based on the thematic approach is still deemed useful by the CSD (Pinter et al., 2005), the systems approach is believed to offer a more structured, holistic view of the sustainability of systems, taking account of systemic interactions and system dynamics and by ensuring that the sub-systems critical for full system sustainability are considered (Bossel, 1999).

In the Balaton Report, Bossel outlines a systems theory approach to developing indicators of sustainability, where he equates sustainability to the viability of the human, support and natural systems. The viability is measured by indicators of various orientors of viability within the systems. He offers a method of choosing the most important indicators and a guideline of the whole development process, arguing that this process is bound to create a more holistic balanced set of indicators than other frameworks such as PSR. However he warns that subjective ethical choice is unavoidable by the practitioner. The method considers the coevolutionary nature of the interconnected systems, the hierarchies of subsystems within systems, as well as the horizons of attention and responsibility.

2.2.3.3 Theme-Based Approach

The Commission for Sustainable Development (UN, 2007) used a theme-based approach in its most recent set of indicators for sustainable development. Theme-based approaches are more common for national energy indicator sets, and dividing the indicators into themes and sub-themes allows for more emphasis on the systematic cross-linkages between the indicators.

The International Atomic Energy Agency (IAEA) developed their set of EISDs using the DSR framework, and then later classified the indicators using themes and sub-themes, similar to the Commission for Sustainable Development indicator set (IAEA, 2005). The DSR (Driving force –State- Response) framework was abandoned after national testing, as themes or policy issues were seen to better serve the purposes of national policymaking and performance measurements (UNDESA, 2001).

2.2.4 Specialised Indicator Sets

2.2.4.1 International Atomic Energy Agency Energy Indicators of Sustainable Development

In 2005 the International Atomic Energy Agency (IAEA) in collaboration with several other bodies published guidelines and methodologies for a set of energy indicators for sustainable development (EISDs), emphasising national self-examination (IAEA, 2005).

Their interpretation depends on the state of development of each country, the nature of its economy, its geography and the availability of indigenous energy resources (IAEA, 2005).

The EISDs were created to provide policy-makers with information about their country´s energy sustainability. They are intended to provide an overall picture of the effects of energy use on human health, society and the environment and thus help in making decisions relating to choices of energy sources, fuels and energy policies and plans. Collecting the indicator data over time is intended to provide a picture of the longterm implications of current decisions and behaviours related to the production and use of energy.

The EISD indicators consist of a core set of 30 indicators classified into three dimensions (social, economic and environmental). These are further classified into 7 themes and 19 sub-themes. The social indicators cover aspects of energy equity and health. The economic indicators cover energy use and production patterns such as efficiency and end use and security aspects such as dependency on fuel imports. The environmental indicators cover impacts on atmosphere, water and land as well as waste issues.

Some indicators are clear measures of progress such as the rate of environmental degradation whilst others simply give information about certain aspects of energy use such as the fuel mix in a country.

The set of Energy Indicators for Sustainable Development (EISD) was developed using the DSR framework, and then later the indicators were classified using themes and sub-themes. (IAEA, 2005). The IAEA indicators are designed to be used at a national level, however they provide some valuable insight into what constitutes the sustainable development of energy resources.

2.2.4.1 International Hydropower Association Sustainability Assessment Protocol

The International Hydropower Association published a set of indicators for hydropower projects in 2006 (IHA, 2006). Three levels of indicators were developed. The first level deals with any new energy project. The second level deals with new hydropower projects**.**

The third level deals with the operation of a hydropower project. These levels are represented by Section A, B and C of the protocol.

The IHA SAP was applied to a hydropower project in Seti, Nepal and in Iceland to Blanda hydropower project in 2008 by Pravin Karki. Karki makes several recommendations to improve the protocol, after assessing it according to two protocol assessment frameworks. (Karki, 2008) These recommendations will be taken into account when developing the sustainability indicator set for geothermal energy. Included in the recommendations was that:

1. A whole systems approach to energy projects should be emphasized.
2. System level planning using tools such as SEA and LCA should be addressed
3. Section B should contain some items that are in section A, such as demonstrated need and direct benefits for local community part strengthened – in case section B is undertaken apart from section A
4. Ethical questions such as corruption and transparency be addressed
5. Holistic financial accounting be assessed
6. More guidance on assessment procedures be provided
7. Quality of auditors required i.e. sensitive to language and culture, experience of sector, broad experience, multidisciplinary
8. A knowledge base of past reports stored online in a database – to keep track of lessons learnt, final reports and guidance to future assessors.
9. A universal reporting format be developed for assessing projects so that reports can be compared.
10. National capacity building be assessed, especially for developing countries

The IHA-SAP is currently being reviewed and the new format will have four sections. Section I will assess the strategic basis for a proposed hydropower project including demonstrated need, options assessment and conformity with regional and national policies and plans, Section II will assess the preparation stage of a new hydropower project during which investigations, planning and design are undertaken, Section III will assess the implementation stage of the new hydropower project during which preparations, construction, and other management plans and commitments are implemented Section IV will assess the operation of a hydropower facility with focus on continuous improvement.

(IHA, 2008) A document has been produced to allow stakeholder input on the IHA-SAP and outlines the current aspects dealt with by the protocol. (IHA, 2009)

2.2.4.2 Gold Standard Foundation Indicators for Carbon Projects and Credits

The Gold Standard Foundation provide a sustainability assessment framework for new renewable energy or end-use efficiency improvement projects. Projects must go through a number of steps, including a sustainability assessment, to become accredited with the Gold Standard. These steps include a Stakeholder Consultation Process and development of a Sustainability Monitoring Plan, which uses indicators of sustainable development relevant to the project. The aim of the Gold Standard is to promote investments in energy technologies and energy management techniques that mitigate climate change, promote (local) sustainable development and are directed towards a transition to non-fossil energy systems. (Ecofys et al., 2009)

The Gold Standard accredits greenhouse gas reduction projects that generate credible greenhouse gas emission reductions, show environmental integrity and contribute to local sustainable development. Project eligibility is defined by several aspects, including the scale of the project and project location. Only reductions in carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are eligible under the Gold Standard (Ecofys et al., 2009).

2.3 Sustainable Geothermal Energy

After carrying out a review of the literature (Prindle & Eldridge, 2007; American Council for an Energy Efficient Economy, 2007; UN, 1992; UNDP, 2000; UNDP, 2004) a few common threads are apparent regarding what constitutes sustainable energy. Sustainable energy should therefore have the following characteristics:

1. Renewable
2. Efficiently produced and used
3. Economically and financially viable

4. Secure (contributes to energy independence and diversity)
5. Equitable (readily accessible, available and affordable)
6. Avoid or minimise environmental impacts
7. Positive social impacts

Based on the characteristics that were identified for sustainable energy, a number of critical sustainability issues were identified for geothermal energy utilization.

The first steps in developing an indicator set require that a good understanding of the systems involved is gained (Bossel, 1999). This can be achieved by examining the human activity in question and its possible environmental, social and economic effects. Therefore, a summary of the main issues pertinent to the sustainable utilization of geothermal energy is presented in this section.

2.3.1 Renewability or Sustainable Utilization

Renewability is seen as a necessary characteristic of sustainable energy, as the resource in question must remain available for future generations. The degree to which a geothermal resource is renewable will depend on several factors. These include the type of technology used and the characteristics of the resource itself, e.g. natural recharge rates (Axelsson et al., 2004), the utilization and recovery times, the management strategies for production and water supply issues.

2.3.1.1 Utilization Time

Whilst the usual lifespan for geothermal power plants to date is 30-50 years, a recent definition for sustainable utilization has been given as utilization that can be maintained for 100-300 years, for any mode of production (Axelsson et al., 2004).

Constant production below a certain limit to guarantee sustainable utilization is possible, but more often than not this is not an attractive option for economic reasons. Therefore other production options that prolong the production period may be useful such as stepwise production up to the sustainable limit or periods of intense or excessive production followed by breaks in production of comparable length or greatly reduced production following a short period of intense production.[2] This kind of cyclical production can be just as economically viable as intensive unsustainable production aimed at achieving quick economic payback. Even at lower extraction rates, the lifespan of the resource can be prolonged and as much energy generated as that following excessive production, e.g. using cycle durations to meet seasonal demand cycles (Bromley et al., 2006) .

2.3.1.2 Recovery Time

Sustainable utilization of geothermal systems has also been recently defined to be such that the timescale for energy replacement for the resource is acceptable to technological or societal systems, say 30-300 years (Axelsson, 2005). For instance, when geothermal resources are used for electricity generation, the time taken for rest or recovery periods should be socio-economically acceptable, which means between 30 and 300 years. Furthermore, if a system is utilized in an excessive manner during a period, other systems will need to be available in the same area while the first system is being rested. Hence, geothermal sustainability considerations may well need to take account of a larger area including several geothermal systems, as well as possible interference between the various systems (Axelsson, 2008).

2.3.1.3 Utilization Modes and Management Strategies

For each type of utilization mode, sustainable utilization will have its own management requirements.

In hydrothermal aquifers used in a doublet space-heating systems, a thermal steady state may occur after some time, leading to a constant production temperature. In these cases the rate of production may be sustained (Rybach & Mongillo, 2006) .

Sustainable production in low enthalpy systems may be possible, even without reinjection. This type of use is common in Iceland. An example of this is the Laugarnes geothermal field, where increased production caused a pressure drop and enhanced recharge leading to the maintenance of a sustainable production level (Rybach & Mogillo, 2006).

For high enthalphy resources this is not usually the case, as high enthalpy resources used for electricity generation are often subject to extensive reductions in pressure, eventually rendering them uneconomic. Reinjection schemes may mitigate this effect but there is a risk that reinjected fluids may cause cooling of reservoir temperatures. This implies that high enthalpy resources will often have short lifespans of just a few decades (Rybach & Mogillo, 2006).

Flexibility and adaptive reinjection management are key components of successful and sustainable field developments (Bromley et at., 2006). This includes flexibility in locating and utilizing future injection wells (Bromley et al. 2006).

Due to the limited knowledge that may be gained about the resource characteristics and generating capacity before production commences, it is important that adequate monitoring and management be put in place for a single resource to avoid overexploitation and subsequent possible drastic drops in production (Axelsson, 2004). Careful monitoring is necessary for several years prior to development in order to ensure the most viable field in terms of sustainable energy production (Kristmannsdottir, 2003).

Modelling using monitoring data can also be used to provide vital information about the conditions of the resource, to calculate response predictions and to estimate production. potential and to predict outcomes of different management strategies (Axelsson et al., 2005). However, due to difficulties with the modelling and prediction of the behaviour of geothermal resources, further research is called for to aid the sustainable utilization of geothermal resources (Rybach & Mongillo, 2006).

2.3.1.4 Water Supply

A further challenge is presented by the effects of water scarcity on both geothermal renewability and sustainability. The water required for the underground recharge of a geothermal reservoir may come into competition with water required for agricultural and other uses. In the case of water scarce countries such as Kenya, fluid or steam loss and water consumption are potential long-term issues for geothermal expansion in the country (Hiller 2008). As two thirds of the worlds geothermal resources are found in developing countries (Friedleifsson, 2008), water scarcity may become an important issue with further impacts on the health and livelihoods of poor rural communities. Land-use such as irrigation in the catchment area of the geothermal system may affect the maintenance of the flow of water into the system. Studies on the hydrological catchments of the geothermal system should be carried out to enable estimation of impact of geothermal development on groundwater levels. (White, 2008).

2.3.2 Economic and Financial Viability

Sustainable energy development requires that an energy project must be economically viable and carry minimal financial risk.

The financial risk associated with geothermal developments is high in the initial stages due to the high costs and uncertainty associated with exploration and drilling to determine the viability and renewability of the resources. Drilling can account for 30–50% of a geothermal project's total cost, and a geothermal field may consist of 10–100 wells (Shibacki & Beck, 2003). Technological difficulties or lack of institutional efficiency may contribute to financial risk for geothermal projects (Hiller 2008).

Geothermal developments should be economically viable compared to other types of energy developments. To be economically viable, the project must produce a net positive result, after all social and environmental costs have been taken into account (e.g. through a cost-benefit analysis).

Economic benefits should be considered at the macro and micro levels. At the project level, aspects such as energy efficiency and health costs should be taken into account, whereas at the macro level, benefits in the form of employment creation, economic developments or the effects on other economic activities such as tourism and farming should be considered.

In developing countries, previously underdeveloped sectors could benefit from geothermal utilization. India´s food production and processing industries could benefit from geothermal energy through a reduction of up to 80% in fuel costs compared to fossil fuel sources. About 75-80% of vegetables and fruits in India perish due to their high water content and the lack of essential infrastructure like cold storage and dehydration facilities (Chandrasekharam, 2003).

Local infrastructure development and employment can be extremely beneficial economic impacts of geothermal energy development. Direct and indirect job creation associated with geothermal energy production is a further potential economic benefit, with possible jobs being created in exploration, drilling and power plant construction as well as power generation and plant operation phases (Shibacki & Beck, 2003).

2.3.3 Energy Security

Energy security is seen as an integral part of sustainable development. Energy security generally involves aiming for energy independence for a nation i.e. reducing geopolitical security risks as well as diversifying the nation´s energy portfolio (UNDP, 2004). In electricity generation, introducing a broad porfolio of renewables into a nation´s energy system, including decentralised power generation, can improve security. Whilst a nation´s diversified energy portfolio may include fossil fuels, domestic renewable technologies can enhance energy security in electricity generation, heat supply, and transportation as their risks are different than fossil fuel supply risks. For example, as the cost of renewables such as geothermal energy does not fluctuate like the price of gas and oil, this can further contribute to a nation´s energy security (IEA, 2007).
Geothermal energy, an indigenous resource can be utilized in remote areas for small decentralised energy generation. It may also reduce a nation's trade deficit. In the US, Nevada's geothermal plants save the equivalent of 3 million barrels of oil each year, as well as generating tax revenue for government (US Dept. of Energy, 1997). In the Philippines, dependence on imported oil was reduced by 95% with the introduction of an energy plan comprising mostly of renewable energy source use. (IAEE, 2008).

Official development assistance, however, as opposed to foreign direct investment is encouraged as a more sustainable strategy for energy projects (UNDP, 2004).

2.3.4 Efficiency

Increasing energy efficiency is one recommended way of addressing the need for more energy services whilst pursuing sustainable development (UNDP, 2004). Energy efficiency may need to be compromised in geothermal plants due to the high cost of more efficient turbines. For low temperatures and pressures the efficiency of conversion from heat to electricity may be lower than fossil-fuel plants.

Whilst direct uses of geothermal energy are the most efficient, efficiency from generation varies depending on the temperature of the geothermal resource and the type of plant technology used. Overall efficient use of the available energy that is extracted from geothermal systems is required for sustainable development.

Transport and distribution efficiency inadequacies may result from inadequate investment into infrastructure or from poor management practices.

In the case of India, it is estimated that efficiency improvements alone for the economy as a whole could save up to 23% of current power generation, with maximum potential in industrial and agricultural sectors (Ministry for Power, 2008).

Energy efficiency for geothermal projects should be considered at the project level, where efficient plant, reinjection or multiple uses of the extracted heat may raise overall efficiency. Efficiency should also be examined at the regional or national level where transport and distribution networks may need to be examined.

2.3.5 Social Impacts

Geothermal developments have intended and unintended social consequences, both positive and negative. Social impacts can be seen as changes to people´s way of life, culture, community structure, stability, services and facilities and their level of participation in decision-making. Environmental changes also create social impacts such as changes in food quality or the creation of health concerns including noise, sanitation, safety, access and control over resources such as water. People´s physical, mental and spiritual health and wellbeing may also be affected by geothermal energy developments. Perceptions of safety, fears about the future of the community or their aspirations for their own or their children´s future may be affected. Personal or property rights may be impacted as people may be economically affected, or experience personal disadvantage which may include a violation of their civil liberties (IAIA, 2003).

National and local social impacts may arise from geothermal project developments such as social security contributions, energy taxes, direct or indirect education, training employment, skill develpment, income increases, and improved life expectancy. Project developments may affect access to food, water and shelter or cultural sites as well as worker health and income levels. This has been observed in Kenya where geothermal development has created much enterprise and employment for locals in areas such as horticulture (Hiller, 2008).

In the Philippines, 40 percent of the PNOC-EDC profits net of tax are given to the municipalities or regions that host the company´s geothermal resources as well as a development fund which is used for missionary electrification, livelihood development and reforestation, watershed management, health and environment enhancement. Other community relations projects provide educational support in the form of scholarships, infrastructure development and skills and training assistance. Rural electrification is also a priority of the PNOC-EDC (Prosini et al., 2008).

The electrification of communities without previous access to electricity may bring with it undesirable cultural impacts, which must also be considered. Developments in American Indian settlements have required community involvement and discussion to gain acceptance (Farhar & Dunlevy, 2003). The use of land for geothermal development that is culturally or historically significant to certain communities may also pose problems (Becker and Vanclay, 2003).

2.3.6 Energy Equity

Sustainable development is generally accepted to incorporate raising the living standards of the world´s poor. For energy to be equitable, it must be affordable, accessible and available to all income groups (IAEA, 2005).

2.3.6.1 Availability

Geothermal energy resources are widely available worldwide, but high temperature areas, most suitable for electricity production are mostly located close to tectonic boundaries. Low temperature geothermal fields are located worldwide. Geothermal energy is not heavily climate-dependent and it is thus possible to produce energy from geothermal sources more constantly than other variable renewable sources such as wind or solar energy. Geothermal plants also have a high capacity factor. They typically run between 90 % to 97% of the time (Shibaki, 2003), whereas wind plants average between 25 -40% (AWEA, 2009) and coal plants between 65- 75% of the time (Shibaki, 2003).

2.3.6.2 Accessibility

Geothermal resources are often located in rural areas where direct-use applications could allow economic development or raise living standards. Utilizing geothermal resources for electricity generation could allow previously unconnected areas to become electrified. Small geothermal plants could be used to improve living standards of rural populations living in remote areas where supplying power is uneconomical due to transmission losses and long transmission line costs. Rural populations in developing countries typically have low per-capita energy demands, so many small generating units rather than fewer larger ones could serve this market. In developing countries such as Latin America, the Caribbean and Philippines, estimates show that with demands of 100 watts per house hold for lighting, a 1 MW plant can serve about 10,000 households (Chandrasekharam, 2003).

2.3.6.3 Affordability

The generation of electricity from geothermal energy does not require fuel so it is not subject to fluctuations in fuel prices. Levelized cost analyses for geothermal power generation show that it is competitive with fossil fuel generation (RETI, 2008), and this may be made more competitive with tax incentives, as firms gain experience with installing geothermal plants and as technology, improvements in drilling technology. For energy to be affordable, it should be within the means of all income groups to provide themselves with the necessary energy to ensure a good standard of living. Inforse-Europe, part of The International Network for Sustainable Energy, has defined energy poverty as when a household must spend more than 10% of its disposable income on energy bills.(Inforse-Europe, 2009). Energy affordability therefore means that a household spends 10% or less of its disposble income on energy bills.

2.3.7 Environmental Impacts

Geothermal energy projects have a number of associated potential environmental impacts and / or benefits associated with them.

2.3.7.1 Environmental Benefits

Geothermal energy is generally regarded as climate-friendly, as the greenhouse gas emissions per kWh are on average lower than other types of energy. Geothermal emits on average less CO_2, SO_2 and NOx than coal, oil and natural gas. A study of CO_2 emissions from geothermal plants by the International Geothermal Association shows that the emissions from geothermal plants range from 4-740 g/kWh, with a weighted average of 122g/kWh (IGA, 2002). This figure is significantly lower than the CO_2 emissions of fossil fuel power plants (natural gas, coal and oil), which range from approximately 450 g/kWh to 1300 g/kWh (Armansson, 2003). A study of air pollutants emitted by geothermal power plants in the United States shows that on average, geothermal plants emit very small amounts of nitrous oxides or none at all. Hydrogen sulphide (H_2S) emissions from geothermal plants may be oxidized to sulphur dioxide (SO_2) and the average emissions in the United States were small at 0.16 g/kWh. It should be taken into account however that in most states, hydrogen sulphide abatement systems are required by law. Particulate matter emissions are also reported to be zero on average for geothermal plants in the United States (Kagel & Gawell, 2005).

Increasing the use of climate-friendly energies such as geothermal could help to reduce the greenhouse gas emissions in countries currently depending on fossil fuels, for instance in

India where over 50% of India's power production is based on coal. Current government expenditure in India on adaptation to climate change already exceeds 2% of the GDP, on issues related to agriculture, water resources, health and sanitation, forests, coastal-zone infrastructure and extreme weather events (Ministry of Environment & Forests et al., 2007).

Geothermal projects, in some cases may incorporate beneficial environmental strategies. In the Philippines, geothermal projects have involved integrated total communitiy development and forest protection. The government owned Philippine National Oil Company – Energy Development Corporation (PNOC-EDC) has instituted schemes that, along with optimized and sustained operation, adopts the integrated social forestry (ISF) approach (Prosini et al., 2005).

As geothermal is a water-based energy resource, it inherently depends on the health of the forest, therefore the PNOC-EDC was aware of its responsibility to protect the forests around its development sites. This involved finding solutions to socioeconomic problems which were leading to destruction of the forests, using watershed management, ecological enhancement and community development. The socio-economic circumstances of people living near the geothermal developments was enhanced through a system of community engagement, education, training and capacity building. Similar programs were successfully run in around 80 other forests (Prosini et al., 2005).

2.3.7.2 Environmental Impacts

Environmental impacts associated with geothermal projects include land and water use, air pollution, water pollution, visual pollution, noise pollution, induced seismicity and impacts on rare species.

2.3.7.2.1. Land and Water Use

Geothermal energy development requires relatively little land compared to other types of power plant such as fossil fuel or nuclear energy (Shibaki, 2003).

Land for geothermal energy development may be valued as natural environment or may have other proposed uses. The amount of land used can be reduced by the use of directional drilling techniques, as advocated by the Sierra Club (Heath, 2002). A drill site usually covers 200–2500 m^2 and can be kept at a minimum by directional drilling of several wells from one site (Kristmannsdottir & Armansson, 2003).

Geothermal plants, which harness underground reservoirs of clean water, may face the issue of water scarcity. However, geothermal plants may use closed cycle systems that reinject water back into the earth, allowing for water conservation. New technology, as well as direct-use technology that uses the earth's heat directly and not the hot water itself, will need to be developed, in order to keep geothermal energy production competitive and viable for water-scarce regions.

Surface disturbances are possible due to drilling, excavation, construction and the creation of new roads and long pipelines may need to be built for space heating purposes (Kristmannsdottir & Armansson, 2003).

Fluid withdrawal can cause lowering of the groundwater table, leading to mixing of fluids between aquifers and an inflow of corrosive water, or the formation of a steam pillow and subsequent boiling and degassing of the field. This may cause large explosions and these have caused deaths in the past (Kristmannsdottir & Armansson, 2003).

2.3.7.2.2 Air Pollution and Gaseous Emissions

CO_2, H_2S, NH_3, volatile metals, minerals, silicates, carbonates, metal sulphides and sulfates may be emitted from geothermal plants, depending on site characteristics. These gases may have an impact on the environmental conditions of an area. Technologies to separate and isolate and control concentrations to acceptable levels can be used. Also the reinjection of spent brines can limit emissions (Heath, 2002).

Geothermal energy on average produces less CO_2, SO_2 and NO_X than conventional fossil fuels (Kagel & Gawell, 2005). However, the emission of hydrogen sulphide is also important. H_2S is usually considered to be an odour nuisance but is also toxic to humans at concentrations above a certain level. Exposure is limited to levels of 5 ppm in the UK and 20 ppm in the US for 8-hour periods (IVHHN, 2009). The removal of H_2S is mandatory in some countries, such as the US (REPP-CREST, 2009). Absorption and stripping techniques are available for the removal of H_2S gas and there are no emissions at all if binary plant technology is used (Heath, 2002).

Although H_2S does not directly cause acid rain, it may be oxidized to sulphur dioxide (SO_2) which reacts with oxygen and water to form sulphuric acid, a component of acid rain.

Furthermore, carbon dioxide and hydrogen sulfide are heavy gases and tend to concentrate in pits and lows, careful monitoring is required to ensure that hazardous conditions do not develop locally (Kristmannsdottir & Armansson, 2003).

Traces of ammonia, hydrogen, nitrogen, methane, radon and the volatile species of boron, arsenic and mercury, may be present as emissions though generally in very low concentrations. Silica may also be a problem, as at Wairakei in New Zealand, where forest damage has been attributed to silica deposition (Heath, 2002).

There are also emissions associated with the plant's construction and transport of materials for components. Emissions values for geothermal energy calculated from life cycle analysis for the geothermal plant construction and machinery are higher than for other energy sources because geothermal sources are more dispersed and require more work to extract that other sources such as fossil fuels (Heath, 2002). Dust can be associated with the construction of the plant, drilling and the clearance of the land for site development.

2.3.7.2.3 Water Pollution

Surface and ground waters can be affected by geothermal energy projects. Geothermal brines and waste waters may be disposed of so that they do not contaminate ground waters or surface waters, for example when waste waters are stored in holding ponds.

Some geothermal fluids are brines, whose excessive salt concentrations can cause direct damage to the environment (Kristmannsdottir & Armansson, 2003). Chloride brines of Na and Ca can have very high concentrations of metals such as iron (Fe), manganese (Mn), lead (Pb), zinc (Zn) and boron (B). Other contaminants can include iodine (I), aluminium (Al), lithium (Li), hydrogen sulphide (H_2S), cadmium (Cd), arsenic (As), mercury (Hg), bicarbonate, fluoride, silicate and ammonia (NH_3). As and Hg may accumulate in organisms (Heath, 2002; Kristmannsdottir & Armansson, 2003).

Contamination of shallow groundwater reservoirs can occur from drilling fluids and as a result of well casing failure, which may also affect groundwater levels (Heath, 2002). High metal concentrations in brines exceeding maximum admissible concentrations for drinking water represent a potentially significant environmental hazard. Geothermal brines can also affect soils, and this has implications for agriculture; phytotoxic boron is particularly important in this respect (Heath, 2002).

Water pollution can be mitigated through effluent treatment, the careful storage of waste water and its reinjection into deep wells and through careful monitoring of the condition of holding ponds and well casing (Heath, 2002).

2.3.7.2.4 Thermal Pollution

Thermal pollution of air and, particularly, water can represent a significant environmental impact as well as being energy inefficient. The discharge of hot water to rivers can damage aquatic wildlife, an example of this being the Waikato River in Wairakei (Heath, 2002), and lead to undesirable vegetation growth. Heat emitted in the form of steam can affect cloud formation and affect local weather conditions. By cooling waste water in ponds, thermal pollution of ecosystems can be avoided but care must be taken that this does not also cause chemical pollution. Reinjection of fluids or making use of the spent fluid for multiple purposes can also prevent thermal pollution (Kristmannsdottir & Armansson, 2003).

2.3.7.2.5 Visual or Aesthetic impacts

Many geothermal energy resources are located in regions that are considered to be of great natural beauty, in national parks or in aesthetically or historically valuable areas. The geothermal station may have an impact on the aesthetic quality of the landscape, as may pipes and plumes of steam. This may affect tourism in the area. This can be reduced by assessing public reactions to proposed structures, as well as the careful design of the site and buildings (Kristmannsdottir & Armansson, 2003).

Phenomena such at geysers and hot springs are valued as important environmental assets with both cultural value and economic value for tourism. Although discharge from such features is naturally variable, a fall in a geothermal reservoir's pressure can result in a reduction or change in the activity of geysers and other geothermal phenomena, affecting their touristic value (Kristmannsdottir & Armansson, 2003; Heath 2002).

Geothermal resource management practices can influence future discharges from active or dormant thermal features. It may be an appropriate policy to attempt to balance induced increases against decreases across a region (Bromley et al., 2006).

2.3.7.2.7 Noise

Unwanted noise can be a nuisance or a health concern. Exposure for more than 8 hours a day to sound in excess of 85 dB is potentially hazardous. The WHO guidelines for community noise state that levels should not exceed 55 dB for outdoor living areas and 70 dB for industrial areas (WHO, 2001). Noise pollution may be possible during drilling period as well as from plant operation. Drilling can take place over a period of several months. Noise pollution is a nuisance to local residents and can also have a negative impact on tourism. In Kenya, anecdotal accounts state that drilling noises have been reported to scare away wild animals and pipelines pylons have reportedly affected migration of certain species.

If drilling or operation takes place near a populated area, noise abatement measures such as those used by the oil-industry for town-site drilling should be considered. Silencers may be used to mitigate plant noises during operation. Noise levels in and around plant areas should conform to regulations regarding employee and visitor health and safety as well as recommended noise levels for the area.

2.3.7.2.8 Induced Seismicity

Instability may occur in seismically active areas, in the natural landscape and in association with geothermal energy utilization (DiPippo, 1991). Fluid reinjection can enhance the seismic activity of the area, though this can be minimized by keeping reinjection pressures to a minimum. Hazards may also be present in geothermal regions with steep slopes at risk from landslides, perhaps leading to damaged pipes or equipment, resulting in the release of steam and hot fluids. Volcanic rocks such as pumice and the soil and upper basements in geothermal fields are often thermally altered and can become increasingly so during utilization (Kristmannsdottir & Armansson, 2003). Slopes prone to landslides may be stabilized to prevent this occurring (Kristmannsdottir & Armansson, 2003).

2.3.7.2.9 Subsidence

The removal of geothermal fluid from underground reservoirs, may cause the rock formations about it to compact, leading to subsidence on the land surface. While this is rare in vapour-dominated fields, it can happen in liquid dominated fields if reinjection is not practised to maintain reservoir pressures (Heath, 2002).

Factors which may lead to subsidence include pressure dropping in the reservoir as a result of fluid withdrawal, the presence of a highly compressible geological rock formation above or in the upper part of a shallow reservoir, the presence of high-permeability paths between the reservoir and the formation, and between the reservoir and the ground surface (Shibaki, 2003).

Ground subsidence can affect the stability of pipelines, drains, and well casings. It can also cause the formation of ponds and cracks in the ground and, if the site is close to a populated area, it can lead to instability of buildings (Shibaki, 2003). For enhanced geothermal systems, (HDR), a closed loop arrangement with total reinjection can minimize subsidence and induced seismicity risks (Heath, 2002).

2.3.7.2.10 Rare Species and Biodiversity

Disturbances of special thermophilic vegetation such as algal mats, thermophilic plants and bacteria may occur if the natural state of an area is changed (Kristmannsdottir & Armansson, 2003).

Potential geothermal resources may intersect important native forest and endangered species habitat. Changes in vegetation, such as medicinal plants, have also been reported (Anon, 2008).

As many geothermal resources are located near the world's biodiversity hotspots, such as those found in the Carribean and the Philippines, particular care would be required when deciding on a site for geothermal energy production. Locating a power plant within or near a biodiversity hotspot may be problematic due to the senstivity and importance of these ecosystems.

2.3.7.3 Overarching Concerns

Some issues critical for sustainable development are overarching issues concerned with general aspects of the behaviour of organisations involved in geothermal energy projects.

2.3.7.3.1 Corporate Social Responsibility

Corporate Social Responsibility (CSR) is a mechanism whereby business monitors and ensures its adherence to law, ethical standards, and international norms. Businesses practicing CSR take responsibility for the impact of their activities on the environment, consumers, employees, communities, stakeholders and all other members of the public sphere. Furthermore, business proactively promote the public interest by encouraging community growth and development, and voluntarily eliminating practices that harm the public sphere, regardless of legality (Wood, 1991).

For sustainable energy development, it is desirable that the developer company and its suppliers and contractors practice corporate social responsibility, as this will lead to better company performance in all dimensions, economic, social and environmental.

2.3.7.3.2 Institutional Concerns

Institutions provide the underlying enabling mechanisms for carrying out actions and changes for sustainability. For sustainable energy development, institutions must have the capacity and resources necessary for the successful implementation or support of sustainable energy projects. The governance, regulatory and research and development functions of institutions should operate in such a way as to enable sustainable development for the nation and therefore increase the likelihood of the sustainability of energy developments in that nation.

2.4 Context for the Sustainability Assessment

2.4.1 Overview of Geothermal Energy Development and Use in Iceland

Currently, Iceland obtains around 82% of its energy from renewable sources. Over 67% of the primary energy used in Iceland comes from geothermal sources. In 2008, 24.5% of electricity generation in Iceland came from geothermal energy, 75.4% from hydro power, and 0.1% from fossil fuels (Landsvirkjun, 2008). Energy consumption is predicted to expand by 61% from a current consumption of 11.976 TWh (Iceland Statistics, 2007) to 19.304 TWh by 2030 (Energy Authority, 2008).

Geothermal energy is mainly used for space heating in Iceland but is also used for electricity production, and for example in swimming pools, for heating greenhouses, and for snow melting. District heating from geothermal sources is provided to most of the Icelandic population. In 2005 geothermal space heating accounted for 89% of all space heating supplied. The remainder of buildings is heated by electricity, 10%, and oil, 1% (Energy Authority, 2005). The main district heating companies are Orkuveita Reykjavikur, Hitaveita Sudurnesja, Nordurorka, Skagafjardarveitur and Sellfossveitur.

As well as providing space heating, some of these companies also produce electricity from geothermal energy.

Hitaveita Sudurnesja is owned by a private shareholder, Orkuveita Reykajvikur and a number of municipalities in the south of Iceland. It operates the Svartsengi and Reykjanes geothermal power plants.

The Svartsengi power plant, situated in the south-west of the country, near the International Airport at Keflavík on the Reykjanes peninsula. It produces approximately 75

MW of electricity. Part of this electrical energy produced, around 27,6 MW, goes to Norðurál aluminium smelter in Hvalfjöður. The plant also produces about 475 litres/second of 90 °C hot water. Surplus mineral rich water from the plant is used for the popular tourist bathing resort Blue Lagoon (Hitaveita Sudurnesja, 2009).

The Reykjanes power plant, situated to the west of Svartsengi produces100 MW. Further expansion is planned in the near future. Almost all of the production of the plant is sold to Norðurál aluminium smelter in Hvalfirði (Hitaveita Sudurnesja, 2009).

Orkuveita Reykjavikur (Reykjavik Energy) is owned by the City of Reykjavik and the Akranes and Borgarbyggð municipalities. It provides hot water for space heating, cold water for consumption and fire fighting as well as operating a data-utility network and waste-treatment facilities. Orkuveita Reykjavíkur owns and operates the Nesjavellir and Hellisheidi Geothermal Power Plants. The plants provide electricity and hot water to industries and households in the Reykjavik capital area. 99% of housing in this area is heated with hot water provided by geothermal sources. Both plants are situated in the Hengill region; an active volcanic ridge (Randburg, 2009).

The Nesjavellir power plant is situated in the south of the country, near the lake Þingvallavatn and Hengill volcano. It currently produces 120 MW of electricity, and about 1800 litres/second of heating water. The Hellisheiði Power-Plant has a current production of 213 MW and further expansion is in progress (Orkuveita Reykjavikur, 2009).

The Landsvirkjun power company was founded on 1 July 1965, and is currently run as a State-owned partnership. In 2005, following the deregulation of the Icelandic electricity sector, the company´s transmission division became an independent limited company and subsidiary of Landsvirkjun, now known as Landsnet. Landsvirkjun currently produces approximately 74% of Iceland´s power from electricity generation. Over 93.9% of electricity produced by Landsvirkjun comes from hydropower, while geothermal power contributes approximately 6.1% (Landsvirkjun, 2007).

Landsvirkjun operates the Krafla and Bjarnaflag geothermal power plants. These plants are situated in the north-east of Iceland near lake Mývatn. The Bjarnaflag plant produces 3 MW of electricity whereas the Krafla power plant produces 60 MW of electricity.

3. METHOD

3.1 Rationale for Choice of Methodology

3.1.1 Guiding Principles

While using any approach to develop a sustainability assessment protocol, it is also necessary to adhere to a set of guiding principles. The Bellagio Principles are described in Section 2.2.2.1. This set of principles (Box 1) were used as overarching guidelines for this project, as they have been recommended by the International Institute of Sustainable Development (Bossel, 1999).

A holistic perspective, as outlined in Bellagio Principle 2, was gained by examining the whole system and its subsystems that would be affected by geothermal development. Section 2.3 outlines the main issues that need to be considered for the systems involved.

3.1.2 Indicator Development Approaches Used

As the Bellagio Principles do not offer a detailed methodological approach required for the development of an indicator set, another framework was required for this purpose.

The indicators in the geothermal sustainability assessment protocol were developed using the systemic approach to indicator development. However, the thematic approach was also explored. This was done as an academic exercise in order to compare indicator themes produced from both the thematic and systemic approaches.

A comparison was also undertaken between the results of each approach used and the indicators of the International Hydropower Association´s Sustainability Asseement Protocol (IHA-SAP) (IHA, 2009).

3.1.2.1 Overview of Theme-Based Approach

The first method of indicator development used involved developing thematic indicators, similar to the approach used in the development of the IHA-SAP. This method was chosen as the theme-based approach was used by the Commission for Sustainable Development (UN, 2007) in its most recent set of indicators. It was also used to create the Atomic Energy Agency´s Energy Indicators of Sustainable Development (IAEA, 2005).

The theme-based approach consists of ten steps as outlined in Figure 1.

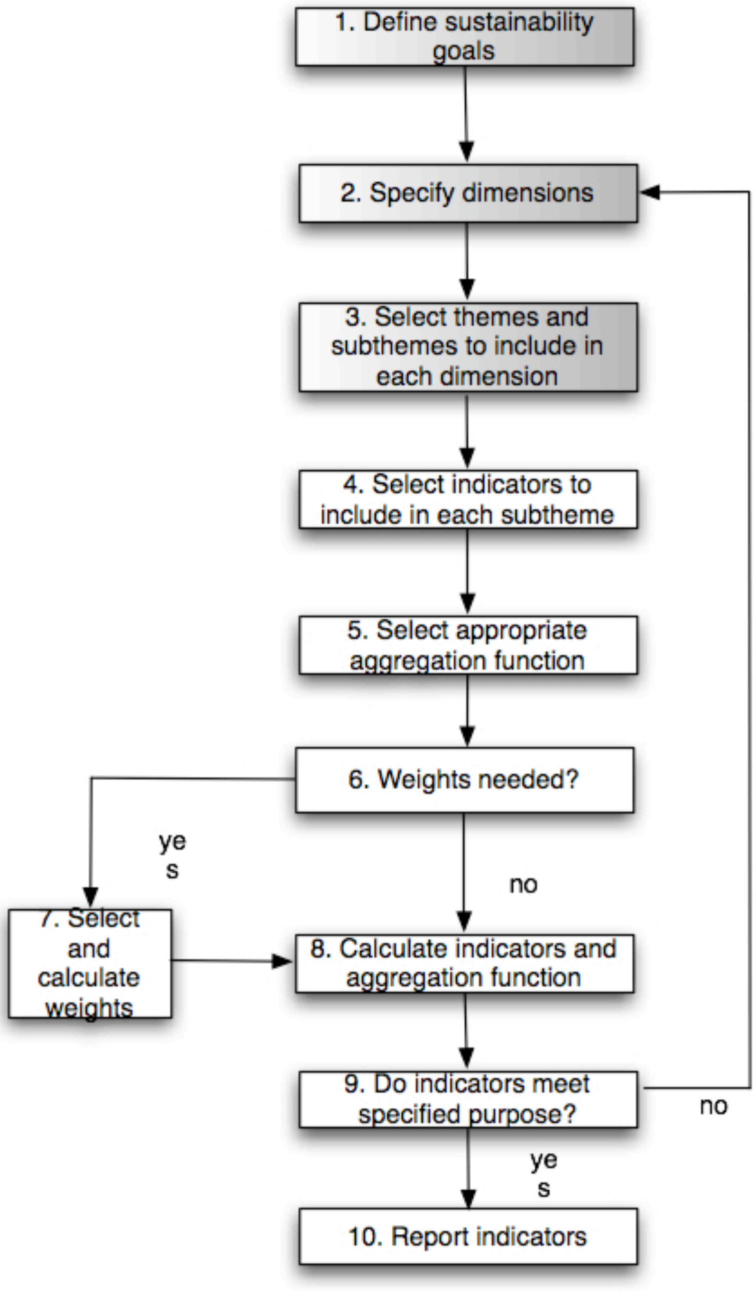

Figure 1: Thematic Approach to Indicator Development (Adapted from Davidsdottir et al., 2007)

The thematic approach was used mainly as an academic exercise to compare the sustainability themes that were produced as a result of applying a thematic approach and a systemic approach. For this reason, only steps 1 to 3 (grey boxes) in the thematic process were performed.

3.2.1.2 Overview of Systemic Approach

The second method involved a systemic approach – a method set out by Hartmut Bossel (International Institute of Sustainable Development) in the Balaton Report (Bossel, 1999). This approach was used in full because, like the Bellagio Principles, it has been advocated by the International Institute for Sustainable Development and is considered to offer a more object, holistic view of sustainable development.

The approach requires that three major systems be analysed – i.e. Human, natural and support systems. The three main systems may be broken up into sub-systems if desired.

The approach is based on the theory that any system will survive in its environment if the essential characteristics of the system´s environment are favourable to its survival. Orientors of viability represent a systems´ interests, values, criteria or objectives in relation to survival in its environment. In other words, orientors of viability represent the major general themes or issues that are important for the sustainability of any system. This is somewhat the same idea of the thematic approach to indicator development, except for the fact that whilst themes are chosen by the analyst in the thematic approach, orientors in the systemic approach must always be the same for any system. Different systems may have the same orientors, but would have different corresponding indicators.

Like the thematic approach, the systemic approach follows a ten-step process, shown in Figure 2 below.

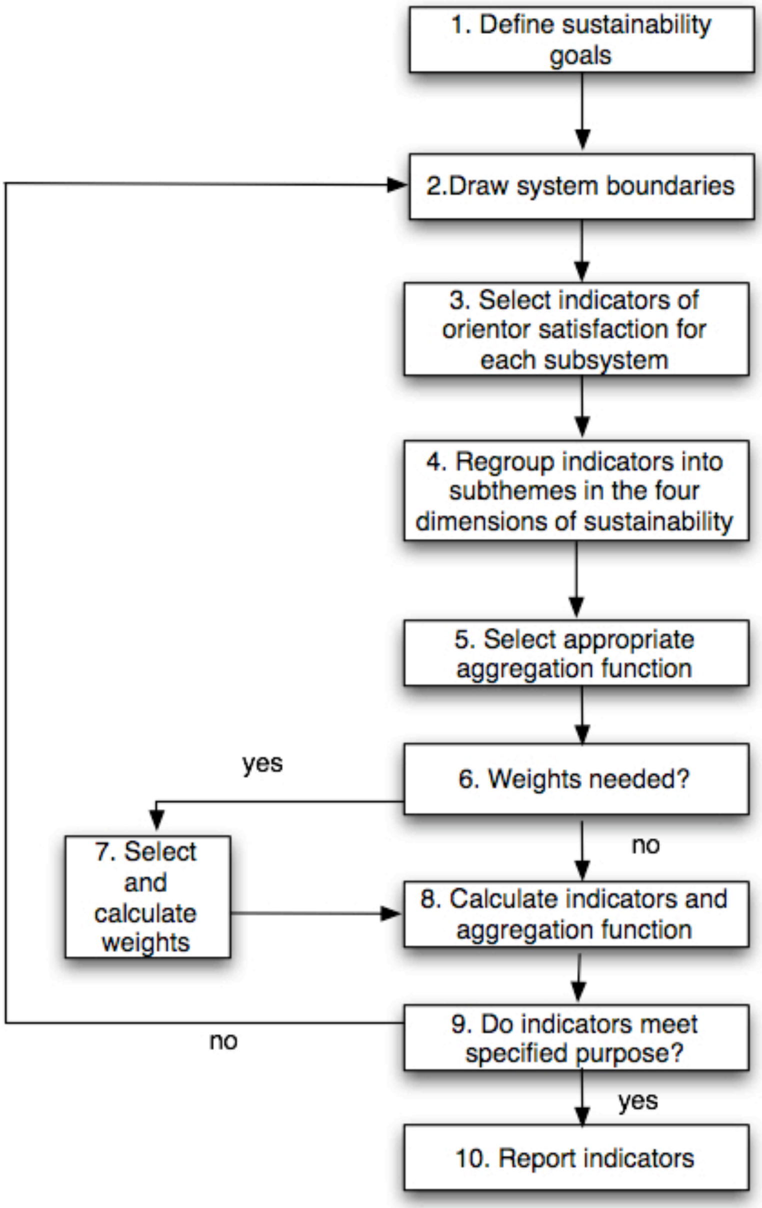

Figure 2: Systemic Approach to Indicator Development (Adapted from Davidsdottir et al., 2007)

3.1.3 Influence of Existing Specialised Indicator Sets

The IAEA indicator set provides some valuable insight into what constitutes the sustainable development of national energy systems (IAEA, 2005). The EISD indicators were therefore incorporated into the Geothermal Sustainability Assessment Protocol where possible.

The Gold Standard Foundation´s sustainability assessment criteria for Clean Development Mechanism (CDM), Joint Implementation (JI) and Voluntary Emission Reduction (VER) projects were also taken into account during the indicator development process. As well as this, the International Hydropower Association´s Sustainability Asseement Protocol (IHA-SAP) was used as a guideline to the indicator development process as hydropower and geothermal energy projects have similar impacts in some cases and share procedural characteristics.

3.2 Indicator Development Process

Figure 3 describes the indicator development process for both the thematic and systemic approaches and shows the differences between them as well as the points at which the processes merge. Step 1, Goal Definition, is common to both approaches, whereas Steps 2 to 4 differ for each. Steps 5 and 6 are dealt with in Section 3.2.4 Development of an Aggregation Function, which describes the choice of aggregation function and scoring mechanisms. Steps 7 to 10 describe the calculation and checking process. A detailed account of steps 7 to 10 as they were implemented for the Krafla power project is given in Section 4.

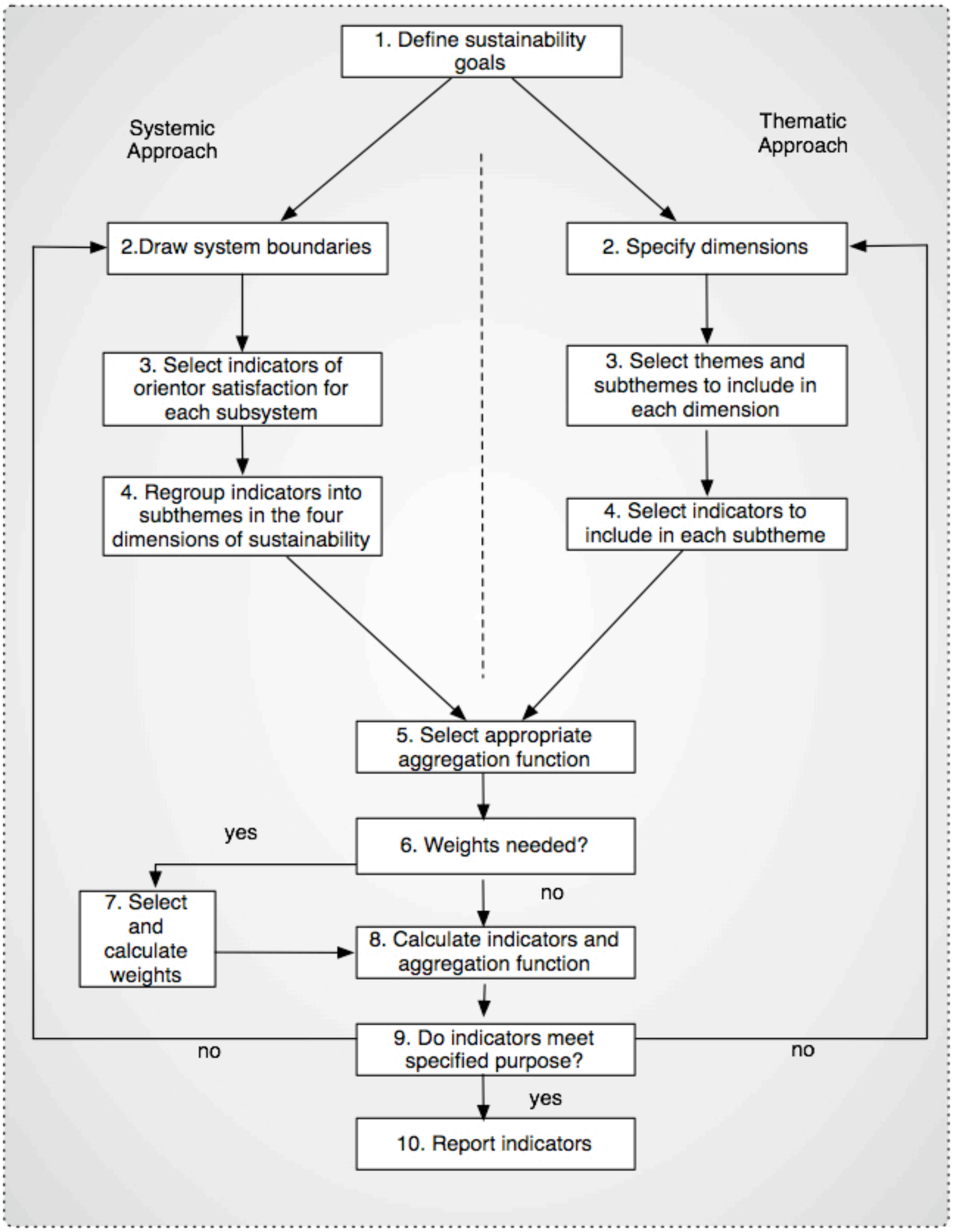

Figure 3: The iterative process of indicator development for both thematic and systemic approaches (Adapted from Davidsdottir et al., 2007).

3.2.1 Goal Definition

The first step of goal definition is common to both approaches. According to the Bellagio Principles (Box 1), this step is essential to provide a clear vision of sustainable development. The goals were chosen based on the critical issues for sustainable geothermal energy identified in Section 2.3. The goals are intended to reflect these critical issues and comply with Bellagio Principles 2-4 (Box 1) and offer a holistic perspective, cover essential elements and have adequate scope.

The goals that were defined at the first step in the process are shown in the box below (Box 2). In keeping with Bellagio Principle 8 (Box 1), these goals were reviewed by a working group of geothermal, engineering and environmental experts. Stakeholders from the business community, government agencies and NGOs were consulted through a series of stakeholder meetings. A set of ten goals were agreed upon.

Box 2: Sustainability Goals for Geothermal Utilization

Sustainability Goals for Geothermal Utilization

Resource Management / Renewability

1. For each geothermal system and each mode of production there exists a certain level of energy production below which it will be possible to maintain constant energy production from the system for at least 100 years. Production of energy at this level is termed sustainable production, whereas production above this level is termed excessive production.

   If possible, sustainable production should be the goal during geothermal utilization. However, in cases where excessive production is necessary (e.g. for electricity generation), a geothermal reservoir must be afforded a recovery period. Such recovery periods should be on a timescale acceptable to society and the use of other geothermal reservoirs should be possible in the meantime. Resource management strategies should therefore consider a number of geothermal systems based around a central volcanic system.

2. Water usage for the power plant is compatible with other water usage needs in the hydrological catchment area of the geothermal resource.

Efficiency

3. The geothermal resource is managed to obtain the maximum use of all heat and energy produced and to minimise the waste of energy, by adequate forward planning and design of plants, the use of efficient technologies, reinjection where appropriate and cascaded energy uses.

Research and Innovation

4. New technologies for the exploitation of previously untapped geothermal, or other, energy resources are actively researched or supported either directly or through links with university programmes or other research and development groups.

Environmental Impacts

5. The geothermal resource is managed so as to minimize local and global environmental impacts through thorough resource and enviromental impact assessment before development, appropriate reinjection management, usage of mitigation technologies and environmental management strategies during all phases of development

Social Aspects

6. The use of the geothermal resource generates net positive social impacts.

Energy Equity & Security

7. The energy supplied by the geothermal resource is readily and equally available, accessible and affordable.

8. The geothermal energy source is reliable and contributes to energy security for a nation or region.

Economic and Financial Viability

9. The geothermal energy project is cost-effective and financially viable. The project should carry positive net national economic benefits.

10. The enterprise managing the geothermal resource practises corporate social responsibility.

An additional goal was added (Goal 11) later in the development process by the sustainability working group:

Knowledge Sharing

11. Knowledge and experience gained during the development of geothermal utilization projects should be accessible and transparent to the public and other interested groups

This goal was added later on in the indicator development process as it was considered important to make explicit the need for knowledge sharing in sustainable energy development. The fulfillment of this goal is a pre-requisite for the fulfillment of all of the other sustainability goals, as a lack of access to data or knowledge about geothermal utilization projects would mean it is not possible to carry out sustainability assessments of these projects.

3.2.2 Selection of Indicator Themes with the Thematic Approach

Step 1: Define Sustainability Goals The first step of this approach was to define sustainability goals for geothermal utilization (Box 1).

Step 2: Specify Dimensions In the second step of the thematic approach, the dimensions of sustainable development to be used for the indicator set were chosen. These dimensions were social, economic, environmental and institutional. An institutional dimension was introduced in order to highlight issues that involve major institutions or organizations such as government and business, which are central for managing sustainable energy systems. Although sometimes institutional indicators are merged into the social dimension (Hák et al., 2007), in this case it was felt that institutions have such an important role in sustainable geothermal development that this dimension deserved separate attention. An institutional dimension has also been used historically, in the development of indicators of sustainable development by the UN (UNDPCSD, 1996). This can be seen as a movement of the thematic approach towards a more systemic view of the interacting systems. Similarly, in development economics, institutional capacity and quality administration are seen as an important element of sustainable development and refers to any type of organization: state, private or civil (Hák et al., 2007).

Step 3: Select Themes and Subthemes to Include in Each Dimension In the third step of the thematic approach, indicator themes were chosen to reflect the set of sustainability goals (Box 2) chosen in step 1. shows the themes that were chosen as a result of this step. These themes were chosen by carefully examining the most important issues for sustainable geothermal utilization, which are summarized in *Section 2.3 Sustainable Geothermal Energy*. In the fourth step of the thematic approach, a preliminary set of indicators is chosen for each theme for each lifecycle stage of a geothermal energy project, however this step was not performed, as it was decided that the systemic approach to indicator development was more effective in its fulfillment of the Bellagio Principles (Box 1). The sustainability themes that resulted from the thematic approach were later compared to the themes that materialized during step 4 of the systemic approach (*Section 3.2.3 Selection of Indicators and Themes with the Systemic Approach).*

Table 1: Themes derived from the theme-based approach

Environmental	Social	Economic	Institutional
Greenhouse gases	Employment	Energy efficiency of generation, distribution, transmission	Political Risk / Corruption
Acidification	Availability (capacity factor)	Econmic viability: (including externalities and economic benefits - Trade deficit reduction, tourism)	
Land use	Energy access	Infrastructure	
Water use	Income levels or Income Generation	Financial Risk	
Chemicals in Brine	Worker H& S	Energy security	
Thermal pollution	Community H & S (including life expectancy, infant mortality)	Power mix diversity	
Thermophilic bacteria or rare species	Training		
Biodiversity	Housing		
Siesmicity	Cultural heritage		
Subsidence			
Resource Renewability			
Regional exploitation of resource			

3.2.3 Selection of Indicators and Themes with the Systemic Approach

Step 1: Define Sustainability Goals The first step (Figure 3) of this approach was to define sustainability goals for geothermal utilization (Box 1).

Step 2: Draw System Boundaries The second step (Figure 3) in the systemic approach involves drawing the system boundaries for the indicator set in time and space.

Temporal Boundaries: The GSAP indicator framework is designed to be used at all phases of the geothermal project lifecycle which includes the strategic, preparation, constrution and operation phases. This is done to allow reporting of indicators that show both short and long term effects of geothermal development and hence serve short-term and long-term decision making needs.

The indicators presented in this report have been chosen to aid assessment of progress toward sustainable development by allowing for building up of time series data during the project operation phase. A different set of indicators for the other phases (strategic, preparation and construction) would need to be produced using the same indicator development process. Developing such indicators is planned in future iterations of the development process.

Spatial Boundaries: The system that the indicator set is concerned with is the national system or the Icelandic anthroposphere, that is, the sphere that is affected by and affects human society in Iceland. The national system includes sub-systems that constitute society as well as the sub-systems upon which human society depends (Bossel, 1999). The indicator set must examine how the geothermal energy project contributes to the sustainable development of the national system. The systems approach involves finding indicators for subsystems in the three main systems relevant to sustainable development: human, natural and support (Bossel, 1999) (Table 2). Each of the three systems was further divided into subsystems:

Table 2: Systems and sub-systems used in systems analysis for indicator development

Human	**Natural**	**Support**
Government & Organizations (Owner/Developer/ Contractors)	Geothermal Resource (Individual & National/Regional)	Economy (Local & National)
Individual Development System (Local & National)	Environmental System (Local & National)	Infrastructure (Local & National)
Social System (Local & National)		

The human, natural and support systems are defined so as to allow the aggregation of the subsystems within them to allow the number of indicators to be kept at a manageable level.

Indicators for each of the three systems can be chosen from any of the subsystems they contain. For example, the indicators for the human system may comprise of any of the indicators within the government and organisations subsystem, the individual development subsystem or the social subsystem. This is how the indicators are presented in the results section (Section 5) of this document.

The systems boundaries were drawn so as to focus the indicator set on the goals of sustainable geothermal utilization (Box 2), as a subset of sustainable energy utilization in general. Depending on the system involved, geothermal development may have direct or indirect effects. For instance spin-off effects for the local economy may occur indirectly due to new industries establishing in the area rather than resulting in a direct increase in salary for residents. While drawing the system boundaries, it was necessary to consider the possible direct and indirect effects of geothermal energy projects. These possible direct and indirect effects were found by conducting a review of the literature on all known positive and negative impacts of geothermal energy projects and by interviews with experts in the geothermal industry and other stakeholders. A further means of capturing direct and indirect effects was to consider the total national system as a hierarchical set of systems from the local to the national level. For the purposes of this project, it was decided to focus only on the local and national level, but not the levels in between such as regions, as this would have become too time consuming. By defining system boundaries for different levels, indicators for each level would then have to be chosen to allow a more detailed examination of the sustainability of the entire system.

While a holistic view of the contribution of geothermal energy developments to the entire national system was sought, it was chosen to focus as much as possible on sub-systems that are directly involved in the geothermal development process and to choose indicators that bring out the contribution of geothermal developments to sustainable development for a nation, its regions and localities. For example, only the geothermal resource sub-system is included as a resource and for the infrastructure system, the energy infrastructure was mainly considered. For the organization system, it was chosen to focus on the developer company and the government, as these are the main organizations involved in geothermal energy projects.

The spatial scope of the indicators encompasses the nation in which the energy development will take place, including indicators for local and national concerns and, where necessary, global concerns, for example greenhouse gas emissions.

Step 3: Select Indicators of Orientor Satisfaction In this step, indicators for the operation phase of geothermal development projects were chosen. For each subsystem, indicators of orientor satisfaction were chosen. Indicators were chosen to represent the local and national level effects of geothermal energy projects. The indicators for a nation, provided in the Balaton Report (Bossel, 1999), as well the IAEA´s Energy Indicators of Sustainable Development (IAEA, 2005), were used as a guideline. In addition, when choosing the indicators for the corporate entities such as the owner company, indicators from the Global Reporting Initiative's (GRI) Sustainability Reporting Guidelines & Electric Utility Sector Supplement were used or modified to suit the purposes of the geothermal assessment protocol.

It should be noted that for each indicator, many alternatives exist in the form of different metrics. However it was not possible to include all of these possible alternatives, as only a limited number of indicators could ultimately be used. Therefore the final list of indicators produced in this report should by no means be considered as covering all possible sustainability issues associated with geothermal development projects. It does however attempt to provide a simplified yet holistic view of the impact of geothermal energy projects on the entire national system. Further development of the indicator set would allow for increased flexibility of coverage, depending on the location and type of project being assessed. Also it should be noted that indicators produced in further iterations for the strategic, preparation or construction phases could differ significantly from indicators in the operation phase.

Orientors of viability represent a systems' interests, values, criteria or objectives in relation to survival in its environment. In other words, orientors of viability represent the major general themes or issues that are import for the sustainability of any system. As orientors are general terms like existence, freedom or security, they cannot be measured directly and therefore we require indicators to determine their state of fulfillment.

For each sub-system, indicators within seven orientors of viability must perform satisfactorily in order for the sub-system to be viable, meaning they are sustainable. Six of these orientors are: existence, effectiveness, freedom of action, security, adaptability and coexistence. These orientors represent the basic interests of any system, necessary for its survival and health (Bossel, 1999).

For some systems, orientors of viability are determined by the system itself. In the case of human beings, consciousness implies that a human system will also require that psychological needs are fulfilled. Psychological needs may therefore be added as a seventh orientor of viability.

Table 3: Orientors of Viability with Examples (Adapted from the Balaton Report, (Bossel, 1999))

Orientor	**Description**	**Example**
Existence	The system must be compatible with and able to exist in the *normal environmental state*. The information, energy and material inputs necessary to sustain the system must be available	*Resource System:* The reclamation time of the geothermal resource indicates whether or not the resource is reclaimable after production. If over-exploitation occurs, the geothermal resource may not be reclaimable for several centuries, and effectively would cease to exist.
Effectiveness	The system should on balance (over the long term) be effective (not necessarily efficient) in its efforts to secure *scarce resources* (information, matter, energy) and to exert influence on its environment	*Infrastructure System*: Efficiency of energy generation, transmission and distribution (ECO-ECD1) indicates whether energy resources are utilized effectively in the infrastructure system.
Freedom of Action	The system must have the ability to cope in various ways with the challenges posed by *environmental variety*.	*Individual Development system:* Economic diversity (SOC-QS2) indicates whether the local and national economic systems are diverse, as this leads to more stable economies less likely to be affected by shocks and this contributes to the capacity for individual development.
Security	The system must be able to protect itself from the detrimental effects of *environmental variability*, i.e., variable, fluctuating and unpredictable conditions	*Environment System:* Air & Water Pollution (ENV-AW1) indicates the ability of the ecosystems to withstand

	outside the normal environmental state.	environmental impacts due to energy projects such as the release of gases and thermal pollution in effluent.
Adaptability	The system should be able to learn, adapt and self-organize to generate more appropriate responses to challenges posed by *environmental change*.	*Economic System:* Support of energy R&D capacity (INST-R&D2) indicates that the economic system is investing in ways to learn and adapt to changes in energy supply and climate change.
Coexistence	The system must be able to modify its behaviour to account for behaviour and interests (orientors) of *other* (actor) *systems* in its environment	*Owner / Developer System:* Employee Origin (SOC-EMP2) indicates the consideration of the owner company for the interests of the local community by showing how many project employees are locally or nationally based.
Psychological Needs	Sentient beings have psychological needs that must be satisfied.	*Environmental System:* Landscape Esthetics (ENV-LSC1) indicates the impacts on landscape as changes in landscape may affect local or national communities who have a need of them for their psychological well-being.

For each sub-system, two indicators must be chosen for each orientor of viability. One indicator represents satisfaction of the orientor for the subsystem and the other indicator represents satisfaction of the orientor for the entire national system, due to a contribution of the sub-system. This gives a total of fourteen indicators for each sub-system. The three sub-systems, human, natural and support should always be represented, meaning a minimum of 42 indicators should be chosen to indicate viability for the entire national system.

The metrics used for each indicator are explained in the Appendix A. The indicators chosen for each of the subsystems are listed in tables 6-13 below. The elements and processes each system represents are explained above each table. These are the general elements that should be taken into account and are taken from the Balaton Report (Bossel, 1999). When choosing indicators for GSAP, indicators were chosen to represent these elements whilst maintaining a focus on issues that relate as much as possible to the impacts that would be brought about directly or indirectly by geothermal energy projects.

3.2.3.1 Human System

3.2.3.1.1 Government System

The government system is a sub-system in the human system. It represents government organizations and their functions such as government and administration, public finances and taxes, political participation and democracy, conflict resolution (national, international), human rights policy, population and immigration policy, legal system, crime control, international assistance policy and technology policy (Bossel, 1999). Indicators in this system are considered as both national and local level indicators.

Table 4: Indicators of orientor viability for the Government subsystem

Orientor	Sub System Performance	Contribution to Total System
Existence	Government debt	Government agency capacity
Effectiveness	Government agency capacity	Government agency operational effectiveness
Freedom of Action	Government debt	Democracy
Security	National security	National security
Adaptability	Government agency capacity	Government support of energy R&D
Coexistence	Social and environmental protection	Social and environmental protection
Psychological Needs	Government Corruption	Political Alienation

Example - Existence Orientor: The system must be compatible with and able to exist in the normal environmental state. The information, energy and material inputs necessary to sustain the system must be available.

Government Debt indicates whether the government system has adequate resources to sustain itself financially and continue to exist. Government agency capacity indicates the capacity of its personnel and institutions to carry out government functions, without whose effective performance, the total national system could not continue to exist.

3.2.3.1.2 Organisations

The organisations system is a subsystem in the human system. It represents businesses and other organizations and their functions and processes such as management systems, community relations, financial performance, standards and performance management and resource use (Bossel, 1999). Indicators in this system are taken to represent the developer company and are considered as both local and national level indicators.

Table 5: Indicators of orientor viability for the Organisations subsystem

Orientor	**Sub System Performance Indicator**	**Contribution to Total System Indicator**
Existence	Company profitability	Ability of energy project to fulfill stated needs
Effectiveness	Company design and operational efficiency	Company competence
Freedom of Action	Company debt status	Availability of further geothermal energy resources in the region Estimated productive lifetime of geothermal resource
Security	Level of financial risk associated with the project	Energy security
Adaptability	Company management system quality	Economic diversity
Coexistence	Employee Origin	Perceptions of project at home and abroad
Psychological Needs	Employee satisfaction or health and safety	Company support of energy R&D

Example - Effectiveness Orientor: The system should on balance (over the long term) be effective (not necessarily efficient) in its efforts to secure *scarce resources* (information, matter, energy) and to exert influence on its environment.

Company design and operational efficiency indicates the effectiveness of the company itself in its operation, or in securing scarce resources, such as energy and utilizing them effectively. Company competence indicates the success of the company in fulfilling its specified purpose (completing successful energy projects), which contributes to the effectiveness of the total national system through the efficient use of scarce energy resources used for supplying the nation with power.

3.2.3.1.3 Social System

The social system is a sub-system in the human system. It represents social processes such as population development, ethnic composition, income distribution and class structure, social groups and organizations, social security, medical care and old age provisions (Bossel, 1999). Indicators in this system are considered as both local and national level indicators.

Table 6: Indicators of orientor viability for the Social subsystem

Orientor	Sub System Performance	Contribution to Total System
Existence	Contribution to social services	Income Equity
Effectiveness	Health effects of energy project	Poverty
Freedom of Action	Unemployment	Contribution to surplus uncommitted funds for social services by development project
Security	Security of Support Services	Social and Environmental Protection
Adaptability	Education and skills	Education of least educated groups
Coexistence	Education Equity	Education Equity
Psychological Needs	Cultural or recreational areas	Perceived fairness of project

Example - Freedom of Action Orientor: The system must have the ability to cope in various ways with the challenges posed by *environmental variety*.

Unemployment indicates how well the social system is coping with the challenges of a changing economic environment. The contribution of the project to surplus uncommitted social service funds indicates the ability of the social system to cope with unexpected changes by having backup emergency funding to ensure flexibility or freedom of action for government expenditure decisions and thus contributing to the freedom of action for the total system.

3.2.3.1.4 Individual Development System

The individual development system is a subsystem in the human system. It represents processes that contribute to development of the individual such as civil liberties and human rights, equity, individual autonomy and self-determination, health, right to work, social integration and participation, gender and class-specific role, material standard of living, qualification, specialization, adult education, family and life planning horizon, leisure and recreation and the arts (Bossel, 1999). Indicators in this system are considered as both national and local level indicators.

Table 7: Indicators of orientor viability for the Individual Development subsystem

Orientor	Sub System Performance	Contribution to Total System
Existence	Standard of health care	Income inequity
Effectiveness	Public participation	Organizational and management skills
Freedom of Action	Standard of living	Economic diversity
Security	Income or savings	Access to shelter or nutrition
Adaptability	Economic diversity	Economic diversity
Coexistence	Land area affected by of energy project	Level of deforestation attributed to energy project
Psychological Needs	Education Opportunities	Adverse effects on communities

Example - Security Orientor: The system must be able to protect itself from the detrimental effects of *environmental variability*, i.e., variable, fluctuating and unpredictable conditions outside the normal environmental state.

Income or savings levels indicate how the individual has succeeded in securing herself from unpredictable conditions brought about by changes in economic or social conditions. Access to shelter or nutrition indicates how the individual development system is succeeding in supporting basic individual living needs and therefore contributing to the security of the entire national system.

3.2.3.2 Support System

3.2.3.2.1 Economic System

The Economic system is a subsystem in the support system. It represents processes such as production and consumption, money, commerce and trade, labour and employment, income, markets and interregional trade (Bossel, 1999). Indicators in this system are considered as both local and national level indicators.

Table 8: Indicators of orientor viability for the Economic subsystem

Orientor	Sub System Performance	Contribution to Total System
Existence	Energy Security	Hotspots of biodiversity
Effectiveness	Poverty Levels	Renewable energy share in energy and electricity
Freedom of Action	Reserve Capacity	Ability of geothermal resources to meet consumption patterns
Security	Income Equity	Poverty Levels
Adaptability	Government support of energy R&D capacity Owner support of energy R&D capacity	Employee Origin
Coexistence	Project costs vs. benefits Impact on hydrological features or hot springs Impact on other water uses – drinking water, water for irrigation etc	Perceptions of project at home and abroad
Psychological Needs	Corporate Corruption	Perceived levels of fairness of project

Example - Adaptability Orientor: The system should be able to learn, adapt and self-organize to generate more appropriate responses to challenges posed by *environmental change*.

The government support of energy R&D capacity indicates that the economic system is investing in ways to learn and adapt to changes in energy supply and the challenge of climate change, by training R&D staff in the area of geothermal development. The employee origin indicates whether or not the Economic system is contributing to the adaptability of the nation, as ensuring that jobs are provided to locals and nationals ensures that the nations workforce learns and adapts to the new demands of the energy project and the available expertise for the energy project are kept within the project's host country.

3.2.3.2.2 Infrastructure System

The infrastructure subsystem is a subsystem in the support system. It represents elements, services and processes such as settlements and cities, transportation and distribution, supply system (energy, water, food, goods, services), waste disposal, health services, communication and media, facilities for education and training, science and research and development (Bossel, 1999). Indicators in this system are considered as both local and national level indicators.

Table 9: Indicators of orientor viability for the Infrastructure subsystem

Orientor	**Sub System Performance**	**Contribution to Total System**
Existence	Reliability of Infrastructure	Energy Access
Effectiveness	Efficiency of energy utilization, conversion and distribution	Energy Affordability
Freedom of Action	Energy diversity	Energy diversity
Security	Safety in energy projects	Safety in energy projects
Adaptability	Skills and Qualifications	Energy Access

Coexistence	Hotspots of biodiversity	Ecosystem Disturbance
Psychological Needs	Energy Use Disparities	Cultural and Recreational Areas

Example - Coexistence Orientor: The system must be able to modify its behaviour to account for behaviour and interests (orientors) of *other* (actor) *systems* in its environment

Hotspots of biodiversity indicates whether or not there would be an impact on hotspots of biodiversity by the power project and associated infrastructure. This indicates the ability of the infrastructure system to coexist with the natural system. The ecosystems disturbance indicator shows how the infrastructure system contribute to the coexistence of the entire national system with other systems by showing how much ecosystems will be disturbed by the energy project. Ecosystem disturbance can affect the coexistence of the entire national system with other nations as some ecosystems may be important internationally as they provide biodiversity, be a tourist attraction or are culturally important.

3.2.3.3 Natural System

3.2.3.3.1 Environmental System

The environmental system is a subsystem in the natural system. It represents elements and processes such as natural environment, atmosphere and hydrosphere, natural resources, ecosystems, species, pollution, degradation, carrying capacity and waste absorption (Bossel, 1999). Indicators in this system are considered as both local and national level indicators.

Table 10: Indicators of orientor viability for the Environment subsystem

Orientor	Sub System Performance	Contribution to Total System
Existence	Threatened species	Deforestation
Effectiveness	Global environmental impacts	Global environmental impacts
Freedom of Action	Land area used by the project	Environmental Toxicity
Security	Air & Water Pollution	Level of ecosystem disturbance
Adaptability	Environmental Toxicity	Air and Water Pollution
Coexistence	Hotspots of biodiversity	Land area used by the project
Psychological Needs	Landscape Esthetics	Noise

Example - Psychological Needs Orientor: Sentient beings have psychological needs that must be satisfied.

Impacts on landscape esthetics may have an impact on the psychological well-being of local or national residents. Subsidence may also impact landscape esthetics at a local level. The contribution of the environment system to the coexistence of the entire national system with other systems is indicated by the amount of noise pollution as noise pollution can have a psychological affect. Noise pollution can cause habitat disturbance for certain animals as well as causing distress to humans. National or international tourism may be affected by noise impacts in the region due to geothermal operation.

3.2.3.3.1 Resource System

The resource system is a subsystem in the natural system. It represents processes such as the depletion of nonrenewable resources, regeneration of renewable resources, material recycling and resource use efficiency (Bossel, 1999). Indicators in this system are considered as both local and national level indicators.

Table 11: Indicators of orientor viability for the Resource subsystem

Orientor	Sub System Performance	Contribution to Total System
Existence	Reclamation Time	Reserve Capacity
Effectiveness	Utilization Efficiency	Encouragement of efficient energy use
Freedom of Action	Ability of geothermal resources to meet consumption patterns	Reserve Capacity
Security	Productive Lifetime of geothermal resource	Energy Import Dependency
Adaptability	Changes in Dissolved Chemicals	Ability of geothermal resources to meet consumption patterns
Coexistence	Micor-seismic activity	Air & Water Pollution
Psychological Needs	Subsidence (Landscape Esthetics)	Odour

Example - Existence Orientor: The reclamation time of the geothermal resource indicates whether or not the resource is reclaimable after production. If over-exploitation occurs, the geothermal resource may not be reclaimable for several centuries, and effectively would cease to exist. The reserve capacity of the geothermal system in which the utilized resource is found indicates whether or not there will be enough energy in the region to allowed continued power production. The supply of this energy is essential for the existence of the total system as the economic and social systems are dependent upon it.

Step 4: Regroup Indicators According to Sustainability Themes. The organization of the indicators using the systemic approach is quite complex and may not be easily understood by a wide range of users or audiences. For this reason, it was decided to organize the indicators chosen in this method according to sustainability themes (Table 3), a similar organization to that shown in Table 1. Organising the indicators thematically makes them more convenient to use in policy or decision-making and shows clearly how they fit into each of the four dimensions of sustainability.

The sustainability themes that emerged in this reorganization closely matched the themes produced in the thematic approach, although it can be seen that several more themes were identified, particularly within the institutional dimension.

Table 12: Themes used when regrouping indicators derived in systemic approach

Environmental	Social	Economic	Institutional
Land	Social Welfare Benefits	Economic Viability	Capacity
Air & Water	Cultural Heritage	Financial Viability	Regulation
Noise & Odour	Energy Equity	Supply Efficiency	Governance
Landscape	Social Equity	Energy Security	Political Risk
Ecosystems	Health & Safety	Infrastructure	Research & Development
Global Impacts	Public Participation		
Resource			

The tables 13-16 below show a detailed list of the themes and sub-themes within each dimension, along with the corresponding indicators

ENVIRONMENTAL DIMENSION

The Environmental Dimension contains the themes, sub-themes and indicators related to environmental sustainability. Environmental themes for geothermal energy projects include land use, air and water pollution, noise, odour, visual pollution and ecosystems. Indicators relating to the physical state of the geothermal resource are included in this dimension.

Table 13: Themes, Sub-themes and Indicators in the Environmental Dimension

LAND THEME		
Sub Theme	Indicator Code	General Description
Area	ENV-LU1	Land area used

Forests	ENV- FOR1	Deforestation
Esthetics	ENV-LSC1-N	Landscape esthetics
Ground Subsidence	ENV-LSC1-L	Ground subsidence
AIR & WATER THEME		
Sub Theme	Indicator Code	General Description
Toxicity	ENV-TOX1a ENV-TOX1b ENV-TOX1c	Environmental Toxicity
Key physio-chemical air and water parameters	ENV-AW 1a ENV-AW1b ENV-AW1c ENV-AW1d	Performance of key physio-chemical air and water parameters
NOISE & ODOUR THEME		
Sub Theme	Indicator Code	General Description
Noise	ENV-NSE1	Noise
Odour	ENV-NSE2	Odour
ECOSYSTEMS & HABITATS THEME		
Sub Theme	Indicator Code	General Description
Biological Diversity	ENV-ECO1	Hotspots of Biodiversity
Threatened Species	ENV-ECO2	Threatened species
Disturbance	ENV-ECO3	Ecosystem Disturbance
GLOBAL ENVIRONMENTAL IMPACTS THEME		
Sub Theme	Indicator Code	General Description
Global Environmental Impacts	ENV-GLB1	Global Environmental Impacts
RESOURCE THEME		
Sub Theme	Indicator Code	General Description
Lifetime	ENV-RES1	Productive Lifetime of geothermal resource
Key resource parameters	ENV-RES2	Performance of key chemical resource parameters
Productivity	ENV-RES3	Utilization Efficiency
Seismic	ENV-RES4	Seismic activity
Reclaimability	ENV-RES5.	Reclaimability of resource

SOCIAL DIMENSION

The Social Dimension contains the themes, sub-themes and indicators related to social sustainability. Social themes for geothermal energy projects include social welfare, equity, employment, education, culture, health and participation.

Table 14: Themes, Sub-themes and Indicators in the Social Dimension

SOCIAL WELFARE BENEFITS THEME		
Sub Theme	Indicator Code	General Description
Social security and support	SOC-SW1	Contribution to social service processes
	SOC-SW2	Security of support service processes
	SOC-SW3	Contribution to surplus uncommitted funds for social services by development project
Employment	SOC-EMP1	Unemployment
	SOC-EMP2	Employee origin
Income	SOC-INC1	Income levels
	SOC-INC2	Access to shelter (or nutrition)
	SOC-INC3	Poverty
Qualifications, Skills	SOC-QS1	Organizational and management skills
	SOC-QS2	Economic diversity
	SOC-QS3	Education and skills
	SOC-QS4	Education of least educated groups
CULTURAL HERITAGE THEME		
Sub Theme	Indicator Code	General Description
	SOC-CH1	Recreational and cultural areas
ENERGY EQUITY THEME		
Sub Theme	Indicator Code	General Description
Energy Access	SOC-ACC1	Energy access

Energy Affordability	SOC-AFF1	Energy affordability
Energy Disparity	SOC-DIS1a	Disparity of energy use
	SOC-DIS1b	Disparity of energy use by gender
	SOC-DIS1c	Disparity of energy use by ethnicity
SOCIAL EQUITY THEME		
Sub Theme	Indicator Code	General Description
Income Equity	SOC-IE1a	Income equity
	SOC-IE1b	Income equity between genders
	SOC-IE1c	Income equity between ethnicities
Opportunities Equity	SOC-OE1a	Education equity between income groups
	SOC-OE1b	Education equity between genders
	SOC-OE1c	Education equity between ethnicities
HEALTH & SAFETY THEME		
Sub Theme	Indicator Code	General Description
Employee H&S	SOC-EHS1	Worker safety or satisfaction
Social H&S	SOC-SHS1	Standard of health care
	SOC-SHS2	Standard of living
	SOC-SHS3	Adverse effects on communities
	SOC-SHS4	Health cost of environmental pollution
	SOC-SHS5	Family contact levels for population
	SOC-SHS6	Perceived levels of fairness of energy project
	SOC-SHS7	Safety of energy projects
PUBLIC PARTICIPATION THEME		
Sub Theme	Indicator Code	General Description
Level of participation	SOC-PP1	Public participation
Protest	SOC-PP2	Perception of energy project at home and abroad

	SOC-PP3	Perception of energy infrastructure related projects at home and abroad

ECONOMIC DIMENSION

The Economic Dimension contains the themes, sub-themes and indicators related to economic sustainability. Economic themes for geothermal energy projects include economic viability, supply efficiency, energy security, infrastructure and financial viability.

Table 15: Themes, Sub-themes and Indicators in the Economic Dimension

ECONOMIC VIABILITY THEME		
Sub Theme	Indicator Code	General Description
Costs vs Benefits	ECO-CB1	Government Debt
	ECO-CB2	Energy needs fulfilled
	ECO-CB3a ECO-CB3b ECO-CB3c	Project costs vs. benefits Impact on hydrological features or hot springs Impact on other water uses – drinking water, water for irrigation etc
SUPPLY EFFICIENCY THEME		
Sub Theme	Indicator Code	General Description
Generation Transmission & Distribution	ECO-ECD1	Efficiency of energy generation of utilization, transmission and distribution
Use	ECO-EU1	Encouragement of efficient energy use
ENERGY SECURITY THEME		
Sub Theme	Indicator Code	General Description
Imported Energy	ECO-IE1	Net Energy Import Dependency
Resources & Reserves	ECO-RR1	Renewable energy share in energy and electricity
	ECO-RR2	Ability of geothermal resources to meet consumption patterns
	ECO-RR3	Reserve Capacity
Energy	ECO-DIV1	Energy diversity

Diversity		
INFRASTRUCTURE THEME		
Sub Theme	Indicator Code	General Description
Reliability	ECO-IMT1	Reliability of Energy Infrastructure
FINANCIAL VIABILITY THEME		
Sub Theme	Indicator Code	General Description
Profitability	ECO-PRF1	Performance of profitability metric for owner company
Debt	ECO-DBT1a ECO-DBT1b ECO-DBT1c	Performance of key debt metrics for owner company
Risk	ECO-RSK1a ECO-RSK1b ECO-RSK1c	Performance of key financial risk metrics for owner company

INSTITUTIONAL DIMENSION

The Institutional Dimension contains the themes, sub-themes and indicators related to institutional sustainability. Institutional themes for geothermal energy projects include capacity, regulation, governance, political risk and energy R&D.

Table 16: Themes, Sub-themes and Indicators in the Institutional Dimension

CAPACITY THEME		
Sub Theme	Indicator Code	General Description
Government Capacity	INST-CAP1	Government agency capacity
	INST-CAP2.	Government agency operational effectiveness
Owner Capacity	INST-OCP1	Company design and operational efficiency
	INST-OCP2a	Company competence
	INST-OCP2b	Company management system quality
General Capacity	INST-GCP1	Skills and qualifications
REGULATION THEME		
Sub Theme	Indicator Code	General Description
Government	INST-REG1	Social and /or Environmental Protection

GOVERNANCE THEME		
Sub Theme	Indicator Code	General Description
Government	INST-GOV1	National corruption
Owner	INST-GOV2	Corporate corruption
POLITICAL RISK THEME		
Sub Theme	Indicator Code	General Description
	INST-POL1	Democracy level
	INST-POL2	National Security
	INST-POL3	Political alienation
	INST-POL4	Perceptions of project at home and abroad
RESEARCH & DEVELOPMENT THEME		
Sub Theme	Indicator Code	General Description
	INST-R&D1	Owner support of R&D
	INST-R&D2a	Government contribution to amount organizational capacity dedicated to energy R&D
	INST-R&D2b	Owner contribution to amount of organizational capacity dedicated to energy R&D
	INST-R&D3	Government support of R&D related to energy

3.2.4 Development of an Aggregation Function

Step 5: **Select Aggregation Function.** involves the choice of an agreggation function for the indicator set. Bellagio Principle 5 (Box 1) requires that standardized measurement be used to permit comparison and that indicator data is compared indicator values to targets, reference values, ranges, thresholds, or direction of trends, as appropriate.

Performance is therefore measured by comparing the data described by the indicator to a reference value. This reference value may be a national or international standard or agreement, best available technologies, a threshold value, a benchmark or a baseline figure. In some cases, it may be necessary to use comparisons to highest or lowest indicator values for the decade because other benchmarks such as national standards do not exist.

3.2.4.1 GSAP Scoring Method

Scores must show whether an indicator is moving toward or away from sustainability. There is no such score to indicate that an indicator is "sustainable", as we are considering sustainability to be a dynamic state due to the coevolution of the systems in question.

Assessment functions (Bossel, 1999) must be defined first, to allow scoring to take place. Where possible, these should be based on national or international standards or agreements. For instance, environmental indicators most often have clearcut benchmarks defined by science. However, if there are no existing national or international standards for a particular indicator, the creation of an assessment function may involve some subjective judgment on the part of the author.

Assessment functions should ideally be defined by individual nations, so as to avoid forcing a particular set of values on the nation that is implementing the indicators, particularly economic and social indicators. This is because countries at differing stages of development will have different priorities concerning sustainable development. In this way individual countries may define sustainable development for themselves and measure progress against flexible national policy targets (Dahl, 1995).

Over time, the scores of all the indicators should show the movement of the entire system towards or away from sustainability, regardless of changes in policy or benchmarks.

3.2.4.2 Assessment Functions

The assessment functions used for scoring the indicators are found in Appendix A. The assessment functions for the indicators were chosen to be suitable for indicators for the operation phase of a geothermal energy project. Assessment functions were constructed by finding a reference value for each indicator and coming up with a scoring system based on the distance of the indicator value from the reference value. Benchmarks and therefore assessment functions can be expected to differ for the different lifecycle phases of a geothermal energy project. For example in the strategic or preparation phase, it could be more desirable for the region to have high unemployment rates, as the region would be more likely to benefit from hosting the energy project. Strategic phase indicators could rely more on values from predictive studies such as surveys to guage community reception of the energy project or predictive socio-economic models, therefore requiring different scoring methods or benchmarking to suit such values.

The assessment functions produced in this study are only suitable for use in the operation phase. Where possible, regional and national reference values were used. If there was no regional and national reference value, an internationally accepted reference value was used. Where neither international nor national reference values existed, a comparison was made between indicator values during the decade or the indicator score was based on a yes or no answer. Examples of each type of reference value are given in the table below.

Table 17: Types of reference values used to define assessment functions

Reference Value Type	**Examples**
International	• Transparency International Corruptions Perceptions Index • Freedom House Democracy Level
Regional or National	• Regulation about toxicity of metals in groundwater • Regulation on public participation during environmental impact assessments • Kyoto protocol greenhouse gas emissions targets • Municipal unemployment rates compared to regional or national unemployment rates • Company level of education compared to regional or national level of education • National classification of protected areas
Comparison to past decade	• Number of supreme court cases against developer

	• Government expenditure on environmental protection • Company contribution to expenditure on energy R&D
Yes or No Answer	• Presence of Environmental Management system

3.2.4.3 Weighting

Step 6: Weights Needed? While it is possible to using weightings in certain approaches to indicator development, the systemic approach does not lend itself to the weighting of individual indicators. As each of the orientors of satisfaction for each system or sub-system must be satisfied to attain system viability or sustainability, no indicator is therefore deemed more important than another, in other words, they are all weighted equally. This is in keeping with the notion of strong sustainability, which maintains that stocks of man-made and natural capital are not substitutes for each other (Hanley et al., 2005).

Step 7: Calculate Weights. As no weights were required in this instance, Step 7 was not performed.

3.2.5 Implementation of the Indicators

Implementation involves using the indicators in the sustainability assessment protocol to assess the performance of a given geothermal energy project in relation to its sustainability goals. The results of the assessment also allow evaluation of the suitability of the indicators for the given context.

Step 8: Calculation of Indicators and Aggregation Function. The relevant data is collected and transformed into meaningful information regarding the project´s progress toward or away from sustainability.

Step 9: Do Indicators meet Specified Purpose? In order to assess their suitability to represent the sustainability goals chosen in Step 1 of the development process, each indicator was checked against a list of criteria. These criteria are based on OECD (OECD,

1993) and UN indicator development guidelines (OECD, 2007) and are listed in Box 3 below.

Criteria to Assess Suitability of Indicators

1. **Clear and unambiguous** and able to show trends over time;
2. **Responsive** to changes in the environment and related human activities;
3. **Relevant** to assessing sustainable development progress;
4. Provide a basis for international comparisons;
5. Have a **threshold** or **reference value** against which to compare it so that users are able to assess the significance of the values associated with it.
6. **Theoretically well founded** in technical and scientific terms
7. Based on international standards and international consensus about its validity to the extent possible
8. Lend itself to being linked to economic models, forecasting and information systems
9. **Use data which is readily available** or made available at a reasonable cost/benefit ratio;
10. **Use data which is updated regularly** or adequately documented and of known quality

Box 3: Criteria for Assessing the Suitability of Indicators in Meeting their Specified Purpose

Step 10: Report indicators. The indicators should be presented in an understandable and meaningful format.

4. Implementation for Krafla Power Project

The implementation or assessment process for the Krafla I power project is covered by steps 8-10 in Figure 3, that is, the calculation of the indicators and aggregation functions and checking of indicator suitability. The results of the assessment for Krafla I also allowed evaluation of the suitability of the indicators for the given context.

The indicators of the GSAP framework are intended for use at all phases of the energy project life cycle i.e. the strategic, preparation, construction and operation. Indicators for each phase will differ due to differences in the availability of data, the focus of sustainability issues for the particular phase and the benchmarks and assessment functions that are used at each phase. For projects in the operation phase, assessments can be performed at regular intervals in order to build up time series data. The assessment of the Krafla I power project involved assessing the project in the operation phase. This is the first sustainability assessment to be carried out in Krafla and as such is a pilot study for the GSAP indicators for the operation phase. A study of a project in any other phase would require that the assessment process (Step 8-10) be carried out again to assess the suitability of the indicators for that purpose and modify them accordingly.

The system boundaries for the case study were drawn to correspond with the systems given in Table 18, which lays out the systems that were analysed.

Table 18: System boundaries for the Krafla I case study

System	Case Study Equivalent
Government	The Icelandic Government in general and agencies involved in energy projects such as the Planning Agency (Skipulagstofnun)
Organisations	Owner / Developer company, i.e. Landsvirkjun.
Social	The Icelandic Social system (national and local). The local social development system refers to the social development system in the municipality of Skútustaðahreppur.
Individual Development	The Icelandic Individual Development system (national and local). The local individual development system refers to the individual development system in the municipality of Skútustaðahreppur.
Economic	The Icelandic Economy (national and local). The local economy refers to the municipality of Skútustaðahreppur.
Infrastructure	The Icelandic energy Infrastructure system (national and local). The infrastructure system refers to the systems used to transmit and distribute energy produced from the power project.
Environment	The local and national Environment system. The local environmental system refers to the environment in the area of the power plant that is likely to be affected by its operations.
Resource	The geothermal Resource system used by the Krafla power project and the regional or national geothermal Resource system of which it is part.

Indicators that were chosen as a result of steps 2-6 (Figure 3) of the indicator development process were used for the case study. These indicators are listed in Tables 6-13. The initial indicators for the Resource system were chosen in Steps 1-4 of the indicator development process as part of this project. These indicators were then developed further and implemented in a separate project by Rut Bjarnadóttir (Bjarnadottir, 2010). The results were then taken into account in this report when calculating the final scores for the GSAP indicators.

4.1 Geothermal Power Development at Krafla, Northern Iceland

The Krafla I power project began operation in 1977. Today it operates with an installed capacity of 60 MW.

The Krafla II project is a second power station planned in the same area, with a planned capacity of 150 MW. Several other geothermal fields are being explored in the region. Power lines will run from Krafla II to the planned exploration of Þeistareykir and Bakki to supply power to potential future industrial users in Bakki, near Húsavík.

At the time of writing, the environmental impact assessment for Krafla II is underway and the report due in Spring 2010. No reports on environmental or social impacts, design documents or financial plans are permitted to be released for inspection in this thesis for the new Krafla power plant at this time.

The Krafla I power project is located in the municipality of Skútustaðahreppur, which has a population of 380 (Iceland Statistics, 2009). There are several tourist areas and hiking trails in the Krafla region, including Víti crater, geothermal features in Leirhnjúkur and the Krafla fissure swarm. The area has a history of volcanic activity. The last series of eruptions known as the "Krafla-fires" took place in Krafla from 1975 to 1984, after an intermission of about 250 years. During the years of activity, nine eruptions occurred.

4.3 Assessment Process

The assessment process corresponds to steps 8-10 in the indicator development process (Figure 3). These steps involve the calculation of indicators (Step 8), checking the indicators for suitability (Step 9) and reporting the indicators (Step 10).

4.2.1 Preparation for Assessments

If possible, baseline data should be gathered for indicators that require baseline data. This may not be possible in some cases, e.g. if a project is already underway but baseline figures may be available historically or may be estimated in some cases. (Figure 3, Step 8) .

4.2.2 Indicator Data Collection

Indicator data relating to the Krafla projects was obtained from the following sources:

- Landsvirkjun Power: Library publications, interviews with staff and contractors
- Iceland Statistics: statistical data and reports available online
- The Icelandic Property Registry
- The Icelandic Police Force
- The Icelandic Power Agency (Orkustofnun)
- The Association of Local Authorities in Iceland (Samband)
- The Icelandic Planning Agency (Skipulagstofnun)
- The Environmental Agency (Umhverfistofnun)
- Námsmatsstofnun

4.2.3 Indicator Calculation

Following the collection of the relevant local and national data, the indicators were calculated by transforming the data into meaningful information regarding the energy project´s contribution to the entire national systems´s progress toward or away from sustainability as well as impacts of the system on the energy project. This was achieved by comparing the indicator data to a reference value that was assigned in Step 5 (Figure 3) and assigning the indicator a score for the year based on the assessment function. Where data was available, it was also possible to interpret past data and determine trends for some of the indicators. This provided additional contextual information for the indicators, even though it may not have affected the actual scoring. The reference values and scoring mechanisms that were used for the indicators are given in Appendix A.

4.2.4 Checking If Indicators Meet Specified Purpose

In order to assess their suitability to represent the sustainability goals chosen in Step 1 of the development process, each indicator was checked against a list of criteria. (Box 3) This was undertaken in collaboration with the sustainability working group at the Icelandic National Power Agency. Various stakeholders from the power industry, academia, NGOs and government gave their input on the suitability of the indicators. The results of the assessment for suitability for each indicator are given in Appendix B. The resource indicators were assessed as part of another project and their evaluation for suitability is found in Appendix C, a modifcation of the results from Rut Bjarnadóttir´s thesis (Bjarnadottir, 2010).

Where indicators were not deemed suitable to represent the sustainability goals developed in Step 1 and no suitable substitute could be found, it was necessary to return to Step 2 of the indicator development process and repeat steps 2-9 until all indicators met the specified purpose of representing the sustainability goals.

A total of 53 indicators out of a possible 77 were deemed suitable for use in this study. Of these, 42 had to be chosen for the systems framework assessment of Krafla II. As only certain indicators could be used to represent certain orientors of viability and as some indicators were used more than once for different orientors, a total of 35 respective indicators was actually used for the systems framework assessment.

It was also decided to present the results of all 53 indicators by grouping them according to four sustainability dimensions Environment, Social, Economic and Institutional. The following table shows the indicators that were deemed suitable for use.

Table 19: Indicators deemed suitable for use

Code	Indicator Name
ECO-CB1	Government Debt
ECO-CB2	Energy Needs Fulfilled
ECO-ECD1	Efficiency of generation, transmission, distribution
ECO-DIV1	Energy Diversity
ECO-IE1	Energy Import Dependency
ECO-IMT1	Reliability of Infrastructure
ECO-RR1	Renewable Energy Production
ECO-RR3	Reserve Capacity
ENV-AW1	Air & Water Pollution
ENV-ECO1	Hotspots of Biodiversity
ENV-ECO2	Presence of Threatened Species

ENV-ECO3	Ecosystem Disturbance
ENV-FOR1	Deforestation
ENV-GLB1	Global Environmental Impacts
ENV-LSC1	Landscape Esthetics (including Subsidence)
ENV-LU1	Land Area Used
ENV-NSE1	Noise Pollution
ENV-NSE2	Odour
ENV-TOX1	Environmental Toxicity
ENV-RES1	Productive Lifetime of geothermal resource
ENV-RES2	Dissolved Chemicals
ENV-RES3	Reserve Capacity
ENV-RES4	Seismic Activity
ENV-RES5	Reclamation Time
INST-GOV1	Government Corruption
INST-GOV2	Corporate Corruption
INST-OCP2	Company Managemet Systems
INST-POL1	Democracy
INST-POL3	Political Alienation
INST-R&D1	Owner company financial contribution to energy R&D
INST-R&D2	Institutional Support of Geothermal Energy R&D Capacity
INST-R&D3	Institutional Support of Geothermal Energy R&D Expenditure
INST-REG2	Social and Environmental Protection
SOC-ACC1	Accessibility of Energy
SOC-AFF1	Affordability of Energy
SOC-CH1	Cultural or Recreational Areas
SOC-EHS1	Employee Satisfaction or Safety
SOC-EMP1	Unemployment
SOC-EMP2	Employeee Origin
SOC-IE1	Income Equity
SOC-OE1	Opportunity Equity
SOC-INC1	Income Levels
SOC-INC2	Access to Shelter or Nutrition
SOC-INC3	Poverty
SOC-PP1	Public Participation
SOC-QS2	Economic Diversity
SOC-QS3	Education and Skilll Level
SOC-QS4	Education of Least Educated Groups
SOC-SHS1	Standard of Healthcare
SOC-SHS2	Standard of living
SOC-SHS3	Adverse Effects on communities
SOC-SW1	Contribution to Social Security Processes
SOC-SW2	Security of Support Service Processes

4.2.5 Reporting the Indicators

The final step of the development proecess (Step 10), the reporting of the indicators, involved presenting the indicator in an understandable format. It was decided to present the indicators graphically, showing trends over time where data was available for several years and also using radar plots for a single year, to show a snapshot of the performance of the indicators in the three main systems involved: human, support and natural in 2008.

For comparative purposes and to make use of indicators that had been calculated but not reported as part of the systems framework assessment, the indicators were also grouped into sustainability dimensions, Environmental, Social, Economic and Institutional and radar plots produced for each dimension. The results of the assessment are described in Section 5.

4.2.6 Building Time Series

Ideally, assessments are to be done at each life cycle stage and then at regular intervals during the operation phase e.g. every three years. The protocol may, however, be used to assess any of the life cycle stages on their own. For the purposes of monitoring progress toward sustainability regular sustainability assessments should be carried out during the operation of the project. This study is a pilot study and the first sustainability assessment to be carried out on the Krafla power project. Further assessments would be necessary in later years to allow the build up of time-series data.

5. RESULTS

5.1 General Overview

The results for individual indicators are found in Appendix A.

Fourteen indicators were chosen for each of the three main systems: human, support and natural. Seven indicators were for sub-system performance and seven indicators were for the contribution of that system to the total system. This gave a total of forty-two indicators to be used in the assessment.

Indicators were selected from the eight sub-systems given in on the basis of the suitability of the indicators. The criteria used to determine indicator suitability are outlined in *Box 3: Criteria for Assessing the Suitability of Indicators in Meeting their Specified Purpose.*

Each indicator is awarded a percentage score between 0 and 100. The assessment functions in Appendix A explain the scoring set-up for each indicator. A score of 100 % means the indicator value is completely consistent with its sustainability target. A score of between 50 and 100% indicates that the indicator has not reached its sustainability target but is moving in the direction of sustainability. A score of less than 50% indicates that the indicator is far from its sustainability target and is not performing to an acceptable level.

Tables 20-25 show the scores for each system, human, support and natural. The system with the best performance is the human system, with overall best sustainability, whilst the support system had the worst overall performance.

The system that performs best in the sub-system indicators is the natural system and the system with the highest contribution to the total system was the human system.

Due to the lack of local data, many of the local and national indicators have the same score, as the local level score was assumed to be the same as the national level score for the purposes of this assessment. Where this is the case, it is stated in the individual indicator result sheet found in Appendix A.

The same indicators may appear several times, as it is permissible to use the same indicator to represent different orientors of satisfaction if appropriate (Bossel, 1999). An example of this is the indicator ENV-LU1 (Land Area Used). This indicator is used in three places, in the human system for the coexistence orientor, in the natural system for the freedom of action orientor and also for the total system coexistence orientor. This is done because the land area used is an indication of how well the human system can coexists with other systems, such as the natural system and also indicates how much freedom of action the natural system will have, as more available land area will allow the natural system to deal better with a variety of environmental processes and patterns. It also indicates how well the natural system contributes to the coexistence of the total system with other systems in that the nation is not unnecessarily using land that may be valuable for other nations for esthetic or biodiversity reasons.

5.1.2 Human System Indicators

The human system comprises the individual development, social and organizational sub-systems. The human system and its sub-systems must be maintained in good state to ensure that it contributes to the development of the total system. This implies maintaining the potential for competent individual action and possibilities for individual development, the ability to deal constructively with social processes and employ them for the benefit of the total system and the know-how and performance standards of governments and businesses (Bossel, 1999).

The results of the human system indicators for the assessment of Krafla power project are given in Table 20 and 21 below for the national and local level.

Table 20: Human System National Level Indicators

	Subsystem Indicator	**Score**	**Total System Indicator**	**Score**
Existence	Government Debt (ECO-CB1)	0	Income Equity (SOC-IE1)	86
Effectiveness	Efficiency of Generation /Transmission / Distribution (ECO-ECD1N)	100	Poverty (SOC-INC3)	100
Freedom of Action	Unemployment (SOC-EMP1)	0	Economic Diversity (SOC-QS2)	100
Security	Security of Support Service Processes (SOC-SW2)	0	Environmental or Social Protection (INST-REG1)	0
Adaptability	Economic Diversity (SOC-QS2)	100	Education of Least Educated Groups (SOC-QS4)	100
Coexistence	Land Area Used (ENV-LU1)	100	Deforestation (ENV-FOR1)	100
Psychological needs	Employee Satisfaction or Safety (SOC-EHS1)	87	Adverse Effects on Communities (SOC-SHS3)	100

Table 21: Human System Local Level Indicators

	Subsystem Indicator	**Score**	**Total System Indicator**	**Score**
Existence	Government Debt (ECO-CB1)	0	Income Equity (SOC-IE1)	86
Effectiveness	Efficiency of Generation /Transmission / Distribution (ECO-ECD1L)	50	Poverty (SOC-INC3)	100
Freedom of Action	Unemployment (SOC-EMP1)	0	Economic Diversity (SOC-QS2)	100
Security	Security of Support Service Processes (SOC-SW2)	0	Environmental or Social Protection (INST-REG1)	0

Adaptability	Economic Diversity (SOC-QS2)	100	Education of Least Educated Groups (SOC-QS4)	100
Coexistence	Land Area Used (ENV-LU1)	100	Deforestation (ENV-FOR1)	100
Psychological needs	Employee Satisfaction or Safety (SOC-EHS1)	87	Adverse Effects on Communities (SOC-SHS3)	100

5.1.3 Support System Indicators

The support system comprises the infrastructure and economic sub-systems. The support system and its sub-systems must be maintained in good state to ensure that it contributes to the development of the total system. This implies maintaining the stock of built structures like cities, roads, water supply systems, schools and universities as they are the backbone of economic and social activities as well as maintaining production potential, distribution and marketing facilities as these are the means for all economic activity (Bossel, 1999).

The results of the support system indicators are given in Tables 22 and 23 for the assessment of Krafla power project are given in the table below for the national and local level.

Table 22: Support System National Level Indicators

	Subsystem Indicator	**Score**	**Total System Indicator**	**Score**
Existence	Reliability of Infrastructure (ECO-IMT1)	0	Hotspots of Biodiversity (ENV-ECO1)	100
Effectiveness	Efficiency of utilization /transmission /distribution (ECO-ECD1-N)	100	Affordability of Energy (SOC-AFF1)	100
Freedom of Action	Reserve Capacity (ECO-RR3)	100	Energy Diversity (ECO-DIV1)	67
Security	Income Equity (SOC-IE1)	82	Poverty (SOC-INC3)	100

Adaptability	Institutional Support of Geothermal Energy R&D Capacity (INST-R&D2)	100	Accessibility of Energy (SOC-ACC1)	100
Coexistence	Hotspots of Biodiversity (ENV-ECO1)	100	Ecosystem Disturbance (ENV-ECO3)	25
Psychological needs	Corporate Corruption (INST-GOV2)	0	Cultural or Recreational Areas (SOC-CH1)	100

Table 23: Support System Local Level Indicators

	Subsystem Indicator	**Score**	**Total System Indicator**	**Score**
Existence	Reliability of Infrastructure (ECO-IMT1)	0	Hotspots of Biodiversity (ENV-ECO1)	100
Effectiveness	Efficiency of utilization /transmission /distribution (ECO-ECD1-L)	50	Affordability of Energy (SOC-AFF1)	100
Freedom of Action	Reserve Capacity (ECO-RR3)	75	Energy Diversity (ECO-DIV1)	67
Security	Income Equity (SOC-IE1)	82	Poverty (SOC-INC3)	100
Adaptability	Institutional Support of Geothermal Energy R&D Capacity (INST-R&D2)	100	Accessibility of Energy (SOC-ACC1)	100
Coexistence	Hotspots of Biodiversity (ENV-ECO1)	100	Ecosystem Disturbance (ENV-ECO3)	25
Psychological needs	Corporate Corruption (INST-GOV2)	0	Cultural or Recreational Areas (SOC-CH1)	100

5.1.3 Natural System Indicators

The natural subsystem comprises the environment and resource sub-systems. The natural system and its sub-systems must be maintained in good state to ensure that it contributes to the development of the total system. This implies maintaining the stock of renewable and nonrenewable resources of materials, energy and bio-systems, including the capacity for waste absorption and regeneration (Bossel, 1999).

The results of the natural system indicators for the assessment of Krafla power project are given in the Tables 24 and 25 below for the national and local level.

Table 24: Natural System National Level Indicators

	Subsystem Indicator	**Score**	**Total System Indicator**	**Score**
Existence	Threatened Species (ENV-ECO2)	100	Reserve Capacity (ECO-RR3)	100
Effectiveness	Global Environmental Impacts (ENV-GLB1)	0	Global Environmental Impacts (ENV-GLB1)	0
Freedom of Action	Land Area Used (ENV-LU1)	100	Environmental Toxicity (ENV-TOX)	58.33
Security	Air & Water Pollution (ENV-AW1)	12.5	Ecosystem Disturbance (ENV-ECO3)	25
Adaptability	Environmental Toxicity (ENV-TOX1)	58.33	Air & Water Pollution (ENV-AW1)	12.5
Coexistence	Hotspots of Biodiversity (ENV-ECO1)	100	Land Area Used (ENV-LU1)	100
Psychological needs	Landscape Esthetics (ENV-LSC1-N)	100	Noise (ENV-NSE1)	0

Table 25: Natural System Local Level Indicators

	Subsystem Indicator	Score	Total System Indicator	Score
Existence	Reclamation Time (ENV-RES5)	75	Reserve Capacity (ECO-RR3)	75
Effectiveness	Utilization Efficiency (ENV-RES3)	50	Global Environmental Impacts (ENV-GLB1)	0
Freedom of Action	Land Area Used (ENV-LU1)	100	Environmental Toxicity (ENV-TOX1)	58.33
Security	Productive Lifetime of Resource (ENV-RES1)	75	Ecosystem Disturbance (ENV-ECO3)	25
Adaptability	Changes in Dissolved Chemicals (ENV-RES2)	75	Air & Water Pollution (ENV-AW1)	12.5
Coexistence	Micro-siesmic Activity (ENV-RES4)	75	Land Area Used (ENV-LU1)	100
Psychological needs	Subsidence (ENV-LSC1-L)	75	Noise (ENV-NSE1)	0

5.2 Graphical Representation of Results

5.2.1 Results for the Human, Support and Natural systems

The results of the sustainability assessment on the Krafla I power project are presented below in figures 4-23. Scoring for the year 2008 is presented in radar plots for three systems, human, support and natural as well as for the four sustainability dimensions.

There are four graphs show for each system. Two graphs show national level indicators and two graphs show local level indicators. The national level indicators are used to show impacts of the energy project on sustainability at the national level whereas the local level indicators are used to show impacts of the energy project on sustainability at the local level.

5.2.1.1 Human Sub-system

The human system indicators were chosen from the government, owner, social and individual development sub-systems.

5.2.1.1.1 Human Sub-system National Level Indicators

The following graphs show the human system indicators at the national level. The national level indicators deal with the contribution of the energy project to national sustainability. The first graph, Figure 4 shows the scores for the human system itself. These scores show how well the human system can survive in its environment, that is, how sustainable it is in and of itself. The second graph, Figure 5 shows the scores for the contribution of the human system to the entire national system. These scores show how the human system is helping the national system to survive in its environment, that is, how well the human system contributes to national sustainability.

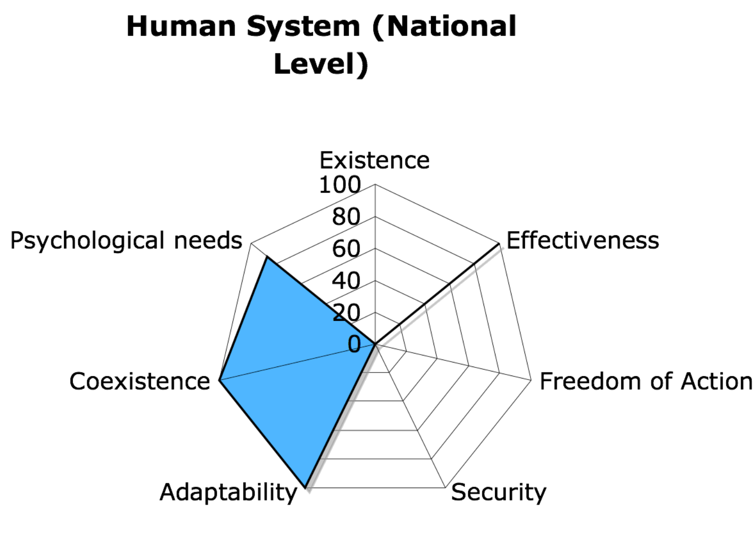

Figure 4: Human System Scoring National Level (Sub-system)

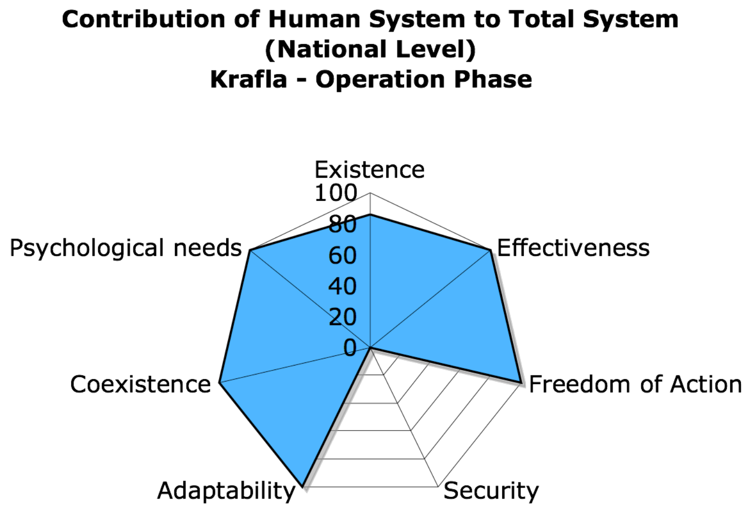

Figure 5:Human System Scoring National Level (Total System)

5.2.1.1.2 Human Sub-system Local Level Indicators

The following graphs show the human system indicators at the local level. The local level indicators deal with the contribution of the energy project to local or municipality sustainability. The first graph, Figure 6 shows the scores for the human system itself. These scores show how well the human system can survive in its environment, that is, how sustainable it is in and of itself. The second graph, Figure 7 shows the scores for the contribution of the human system to the entire local system or municipality. These scores show how the human system is helping the local system to survive in its environment, that is, how well the human system contributes to local or municipality sustainability.

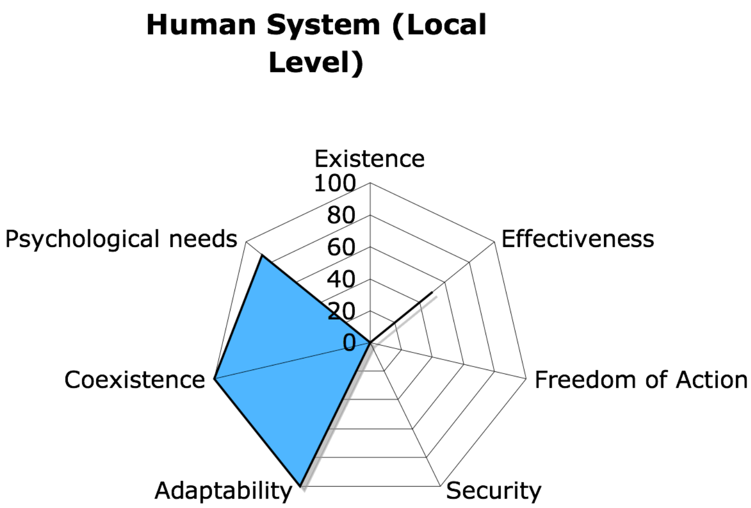

Figure 6: Human System Scoring Local Level (Sub-System)

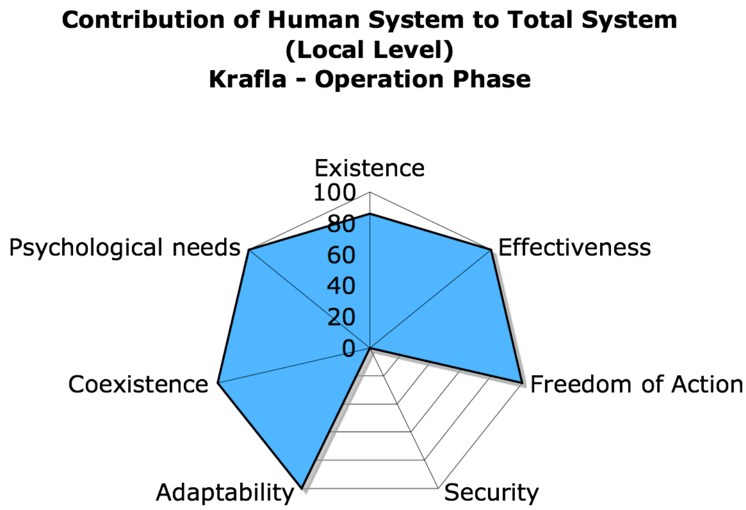

Figure 7: Human System Scoring Local Level (Total System)

Scores were lowest for the existence, freedom of action and security orientors of the human subsystem.

The low scoring indicators were Government Debt (ECO-CB1), Unemployment (SOC-EMP1) , Social and Environmental Protection (INST-REG1) and Security of Support Service Processes (SOC-SW2).

Government Debt (ECO-CB1) – From 2005 onwards, Icelandic foreign debt to revenue ratios are well above 290%, the level recommended by the IMF. This is due to the economic conditions of the country itself.

Unemployment (SOC-EMP1) – Unemployment rates in the North East of Iceland are greater than the national average and regional average in 2008, suggesting that the power project at Krafla has not been instrumental in creating employment in the region.

Security of Support Service Processes (SOC-SW2) – The percentage of unlicensed teachers in the North East has remained above the national average for the last ten years, although the percentage has moved closer to the national average in recent years, showing an improvement. This would indicate that the quality of schools and possibly other social support services has not improved despite the presence of the Krafla power project in the region.

Social and Environmental Protection (INST-REG1)- The level of government expenditure on environmental protection was below the average for the past decade indicating that environmental protection is becoming less of a priority for government which may leave the energy project at risk of reputational risk.

5.2.1.2 Support Sub-system

The support system indicators were chosen from the economic and infrastructure sub-systems.

5.2.1.2.1 Support Sub-system National Level Indicators

The following graphs show the support system indicators at the local level. The national level indicators deal with the contribution of the energy project to national sustainability.

The first graph, Figure 8 shows the scores for the support system itself. These scores show how well the support system can survive in its environment, that is, how sustainable it is in and of itself. The second graph, Figure 9 shows the scores for the contribution of the support system to the entire national system. These scores show how the support system is helping the national system to survive in its environment, that is, how well the support system contributes to national sustainability.

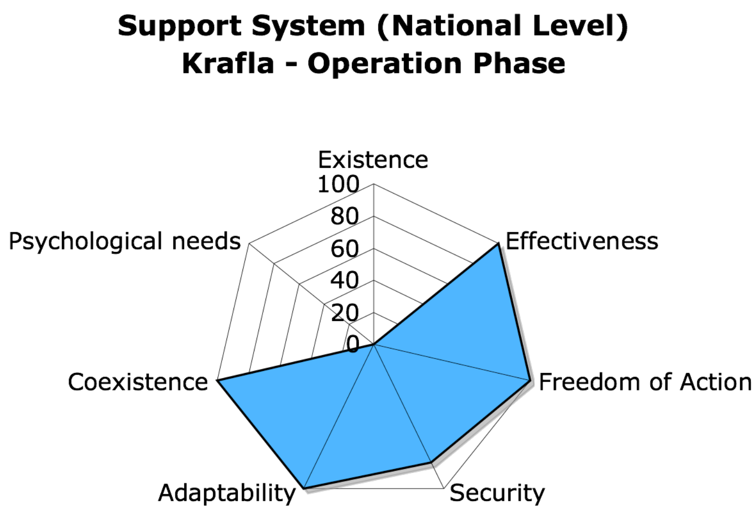

Figure 8: Support System Scoring National Level (Sub-System)

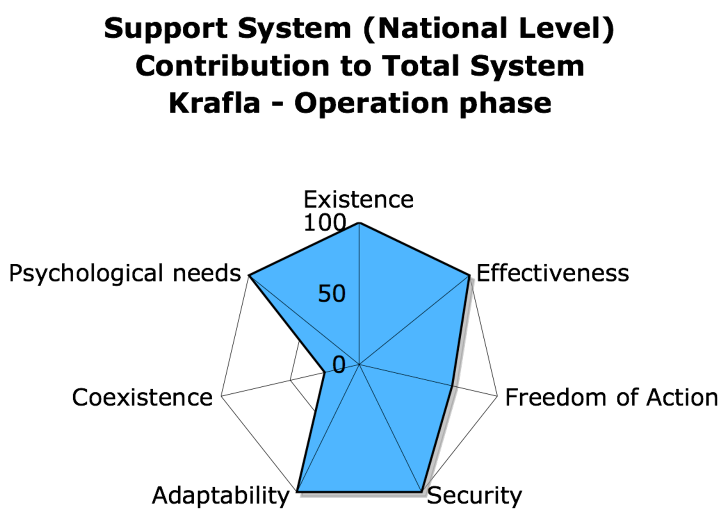

Figure 9: Support System Scoring National Level (Total System)

5.2.1.2.2 Support Sub-system Local Level Indicators

The following graphs show the support system indicators at the local level. The local level indicators deal with the contribution of the energy project to local or municipality sustainability. The first graph, Figure 10, shows the scores for the support system itself. These scores show how well the support system can survive in its environment, that is, how sustainable it is in and of itself. The second graph, Figure 11, shows the scores for the contribution of the support system to the entire local system or municipality. These scores show how the support system is helping the local system to survive in its environment, that is, how well the support system contributes to local or municipality sustainability.

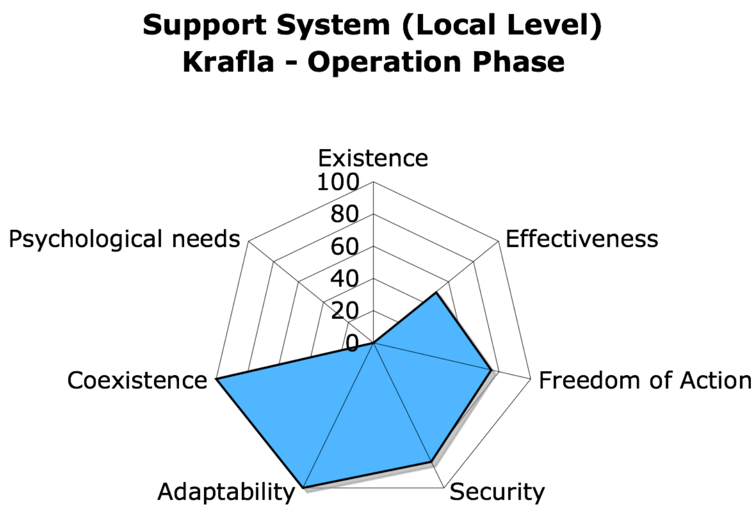

Figure 10:Support System Scoring Local Level (Sub-System)

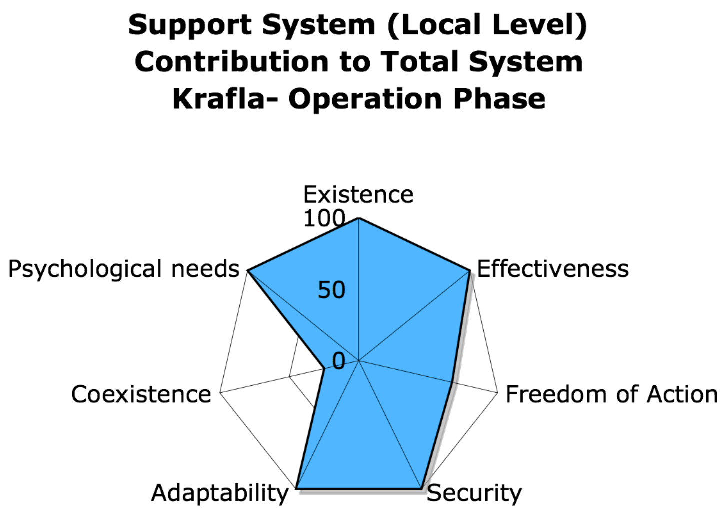

Figure 11: Support System Scoring Local Level (Total System)

Scores were lowest for the existence and psychological needs orientors of the support subsystem and for the effectiveness, freedom of action and coexistence orientors for the contribution of the support system to the total system.

The low scoring indicators were Reliability of Infrastructure (ECO-IMT1), Energy Diversity (ECO-DIV1), Corporate Corruption (INST-GOV2) and Ecosystem Disturbance (ENV-ECO3) .

Reliability of Infrastructure (ECO-IMT1) - In 2008 Landsnet did not fulfil their own target regarding the amount of yearly power outages. Landsnet´s own target was chosen as a benchmark here as there are no current nationally recommended levels of power outages. As of the end of 2008 Landsnet is owned by Landsvirkjun (64.73%), RARIK (22.51%). Orkuveita Reykjavíkur (6.78%) and Orkubú Vestfjarða (5.98%).

Energy Diversity (ECO-DIV1)– The adjusted Shannon-Weiner index for diversity of energy sources in Iceland indicates that complete (100%) diversity is not achieved due to the increasing use of geothermal energy nationally. Geothermal energy accounted for 69% of all energy sources for Iceland in 2007. Hydropower accounted for 15% and oil for

16%. Although it is a domestic renewable energy source, heavy dependence on geothermal energy leaves the national energy system more open to risks associated with geothermal production alone.

Corporate Corruption (INST-GOV2) –Cases against Landsvirkjun in the supreme court were no lower than last year, remained the same between 2007 and 2008. Scoring is based on whether this years score is higher or lower than the average of the past decade. In 2008, the number of cases was higher than the average for the past decade.

Ecosystem Disturbance (ENV-ECO3) – The waters in the rivers and lakes around the Krafla power plant into which waste water or effluent is released, show evidence of major alterations to the values of the biological quality elements for the surface water body type and the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions. This is due to changes in temperature and chemical composition resulting from the discharge of effluent from the power plant into the water bodies. The only report on the state of aquatic ecosystems in the Krafla area available in the Landsvirkjun library is a report that is part of environmental impact assessment done in 2001 for a planned expansion of the power plant. Since this study, there does not appear to have been any further regular monitoring of the state of terrestrial or aquatic ecosystems around the power plant, or such data was not accessible.

5.2.1.3 Natural Sub-system

The natural system indicators were chosen from the environment and resource sub-systems.

5.2.1.3.1 Natural Sub-system National Level Indicators

The following graphs show the natural system indicators at the local level. The national level indicators deal with the contribution of the energy project to national sustainability. The first graph, Figure 12, shows the scores for the natural system itself. These scores show how well the natural system can survive in its environment, that is, how sustainable it is in and of itself. The second graph, Figure 13, shows the scores for the contribution of the natural system to the entire national system. These scores show how the support system is helping the national system to survive in its environment, that is, how well the natural system contributes to national sustainability.

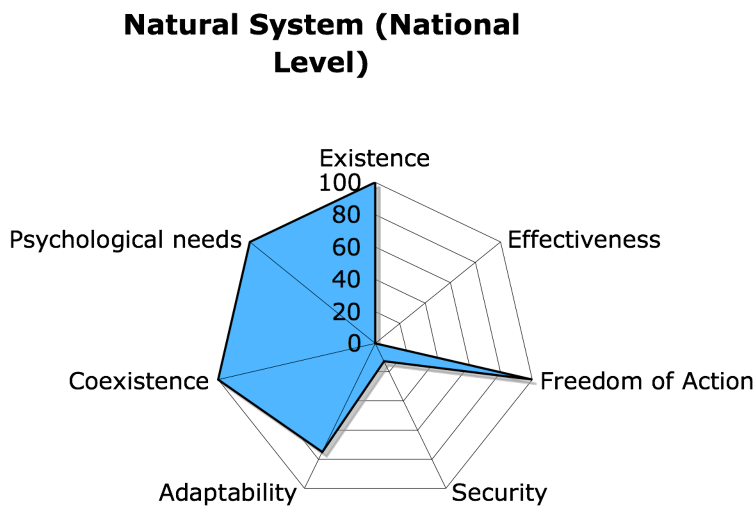

Figure 12: Natural System Scoring National Level (Sub-System)

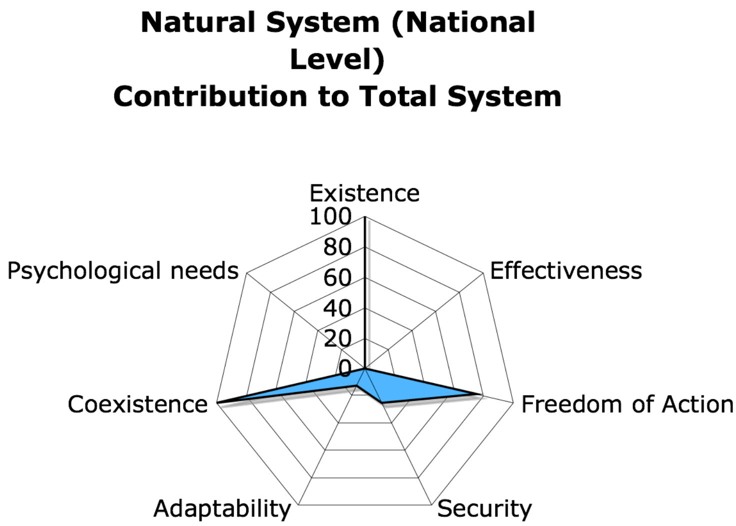

Figure 13: Natural System Scoring National Level (Total System)

5.2.1.3.2 Natural Sub-system Local Level Indicators

The following graphs show the natural system indicators at the local level. The local level indicators deal with the contribution of the energy project to local or municipality sustainability. The first graph, Figure 14, shows the scores for the natural system itself. These scores show how well the natural system can survive in its environment, that is, how sustainable it is in and of itself. The second graph, Figure 15, shows the scores for the contribution of the natural system to the entire local system or municipality. These scores show how the natural system is helping the local system to survive in its environment, that is, how well the natural system contributes to local or municipality sustainability.

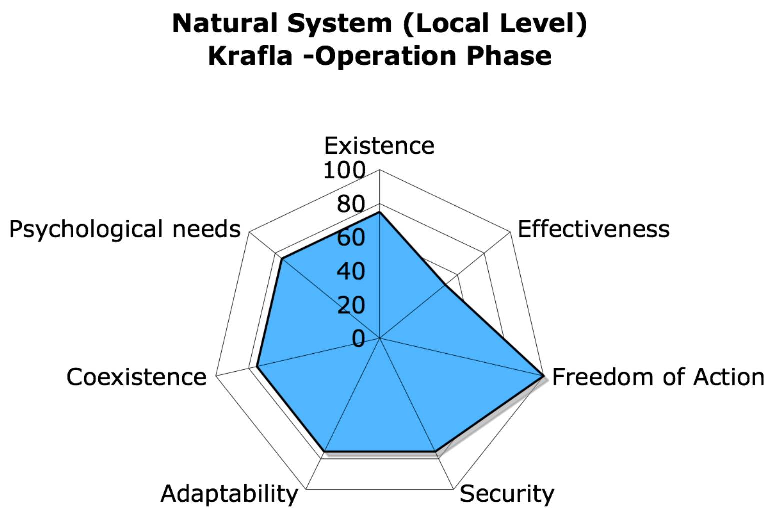

Figure 14:Natural System Scoring Local Level (Sub-System)

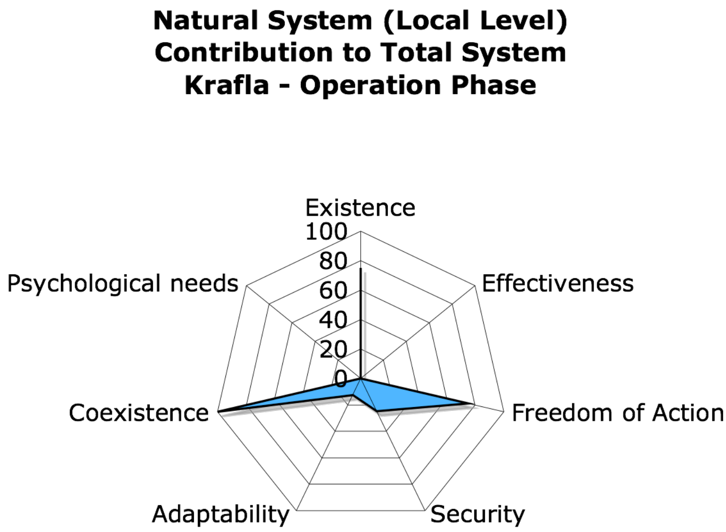

Figure 15: Natural System Scoring Local Level (Total System)

Scores were lowest for the effectiveness, security and adaptability orientors of the natural subsystem and for the effectiveness, freedom of action, security, adaptability and psychological needs orientors for the contribution of the natural system to the total system.

The lowest scoring indicators were Global Environmental Impacts (ENV-GLB1), Air & Water Pollution (ENV-AW1), Environmental Toxicity (ENV-TOX1), Ecosystem Disturbance (ENV-ECO3), Utilization Efficiency (ENV-RES3) and Noise (ENV-NSE1).

Global Environmental Impacts (ENV-GLB1) - The Kyoto target agreed for Iceland in 2009 was that GHG emissions would be 30% below 1990 levels by the year 2020. This target was used as a benchmark for GHG emissions from geothermal energy and for individual geothermal projects. In 2007, GHG emissions for the geothermal sector were well above this target.

Air & Water Pollution (ENV-AW1)

(a) H_2S emissions for the Krafla plant increased in 2008 compared to 2007. As there is no national ceiling for H_2S emissions from geothermal power plants in Iceland, scoring was based on the amount of yearly H_2S emissions compared to the average for the previous decade. H_2S gas can be removed by the use of the appropriate mitigation technologies.

(d) The waters in the rivers and lakes around the Krafla power plant into which waste water or effluent is released, show evidence of major alterations to the values of the biological quality elements for the surface water body type and the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions. This is due to changes in temperature and chemical composition resulting from the discharge of effluent from the power plant into the water bodies. The only report on the state of aquatic ecosystems in the Krafla area available in the Landsvirkjun library is a report that is part of environmental impact assessment done in 2001 for a planned expansion of the power plant. Since this study, data on further regular monitoring of the state of terrestrial or aquatic ecosystems around the power plant was not accessible.

Environmental Toxicity (ENV-TOX1)

(a) A 1993 model of H_2S concentration shows that levels are more than zero in certain tourist areas e.g. Viti, Mt. Krafla and around the power plant itself. Levels do not exceed the 100 ppb limit (0.15 mg m^{-3}). No inhabited areas are affected by the H_2S gas that is released from the power plant. The last available report on H_2S concentrations in the Krafla area is a study from 1993, which was included in an environmental report carried out for an expansion to the Krafla plant in 2001. Further data on H_2S concentrations in the Krafla area was not accessible. According to the Icelandic Environmental Agency (Umhverfistofnun) there is no air quality monitoring done today in the Krafla region.

(b) A 1993 report on mercury levels in the Krafla area shows Hg to be 2,0 ng m^{-3} in all areas. This is below the WHO reference value of 1 µg m^{-3} for mercury vapour. The last available report on mercury gas concentrations in the Krafla area is a study from 1993, which was included in an environmental report carried out for an expansion to the Krafla plant in 2001. Further data on Hg concentrations in the Krafla area was not accessible. According to the Icelandic Environmental Agency (Umhverfistofnun) there is no air quality monitoring done today in the Krafla region.

(c) Arsenic was present in effluent at concentrations that posed high risk of impact on living organisms in ground water. Further data on arsenic concentrations in groundwater in the Krafla area was not accessible.

Ecosystem Disturbance (ENV-ECO3) – The waters in the rivers and lakes around the Krafla power plant into which waste water or effluent is released, show evidence of major alterations to the values of the biological quality elements for the surface water body type and the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions. This is due to changes in temperature and chemical composition resulting from the discharge of effluent from the power plant into the water bodies. The only report on the state of aquatic ecosystems in the Krafla area available in the Landsvirkjun library is a report that is part of environmental impact assessment done in 2001 for a planned expansion of the power plant. Further data on regular monitoring of the state of terrestrial or aquatic ecosystems around the power plant was not accessible.

Utilization Efficiency (ENV-RES3) – The Krafla power plant is not a cogeneration plant so the heat energy extracted is only used for electrical generation.

Noise (ENV-NSE1) – According to a survey of noise levels performed for an environmental impact assessment for the Krafla power plant in 2008, noise levels exceed acceptable levels for industrial areas (79 dB).

5.2.2 Results for Dimensions of Sustainability

The results of the sustainability assessment may also be presented so as to show indicator performance according to the dimensions of sustainability: Environmental, Economic, Social and Institutional. This is the way indicators have been traditionally presented by bodies such as the UN Commission for Sustainable Development (UN, 2007), OECD (OECD, 1993). The indicators shown in the following graphs, figures 16-23 were chosen using the systems framework and have been grouped into their dimensions. As only forty-two indicators could be used in the systems framework analysis, some indicators were not used in the systems framework analysis and are not shown in the previous section. Indicators that were left out of the systems framework analysis are now included here. Graphs are shown for indicators at the local and national level. All of the indicators represent the contribution of the energy project to the sustainable development of the entire national system.

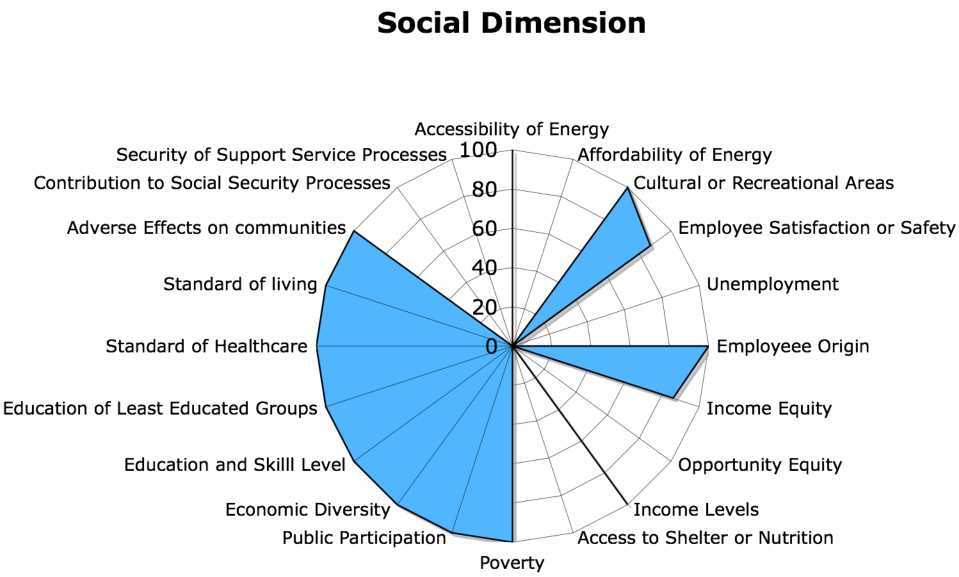

Figure 16: Scoring for Indicators in the Social Dimension at National Level

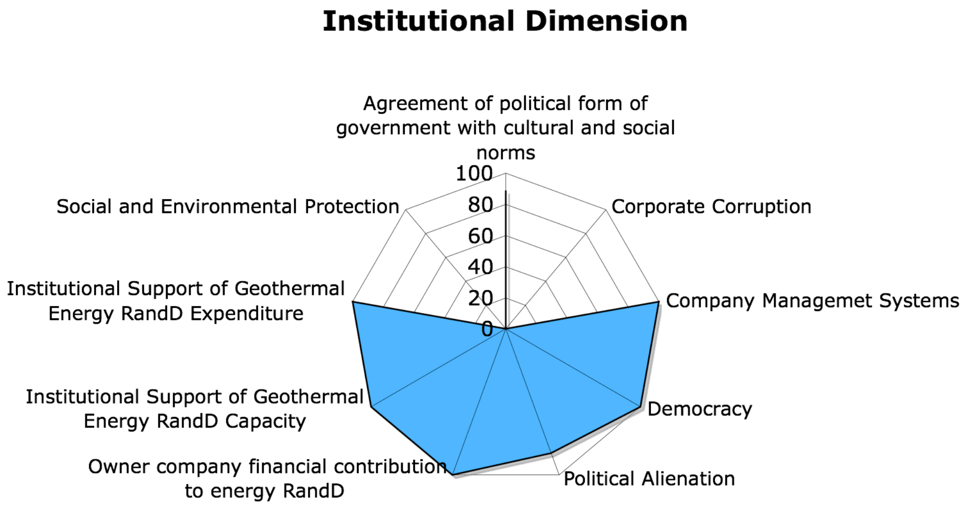

Figure 17: Scoring for Indicators in the Institutional Dimension at National Level

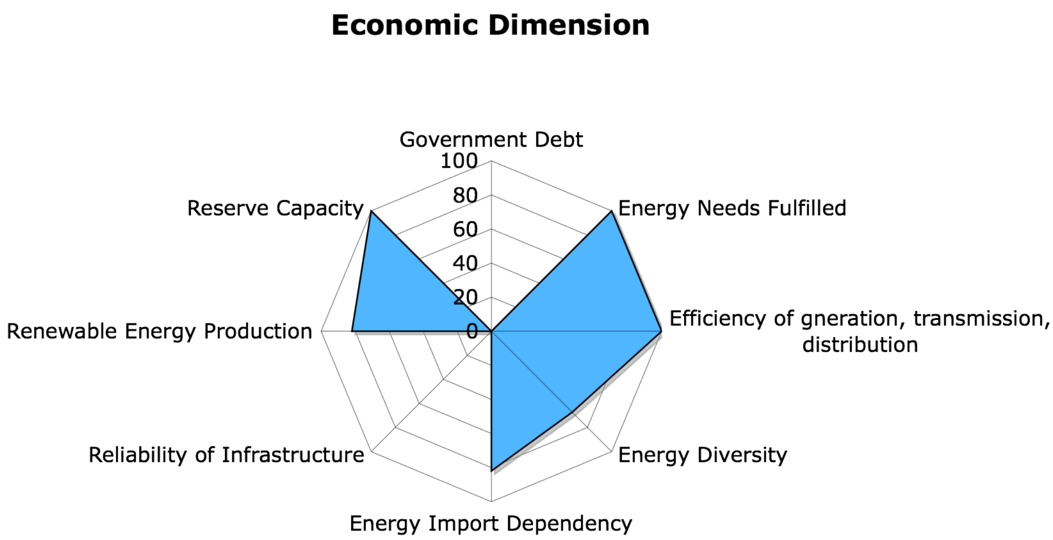

Figure 18: Scoring for Indicators in the Economic Dimension at National Level

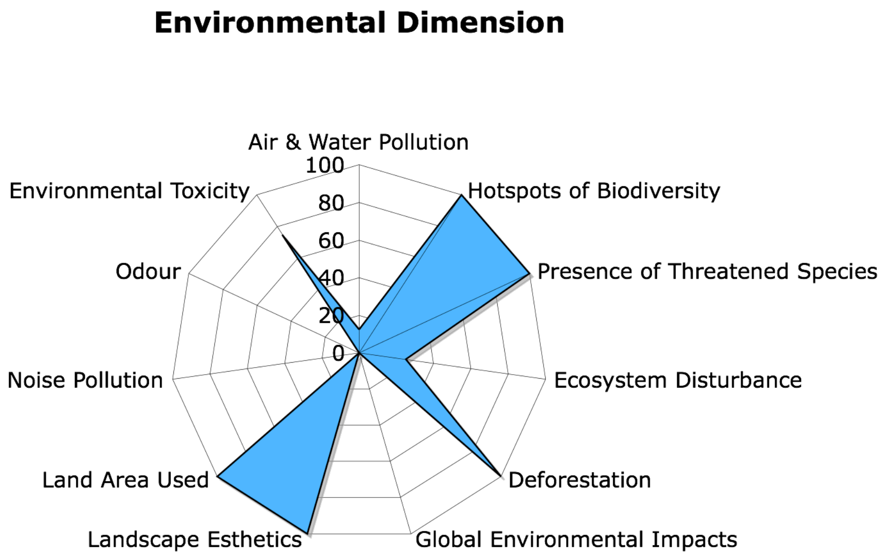

Figure 19: Scoring for Indicators in the Environmental at National Level

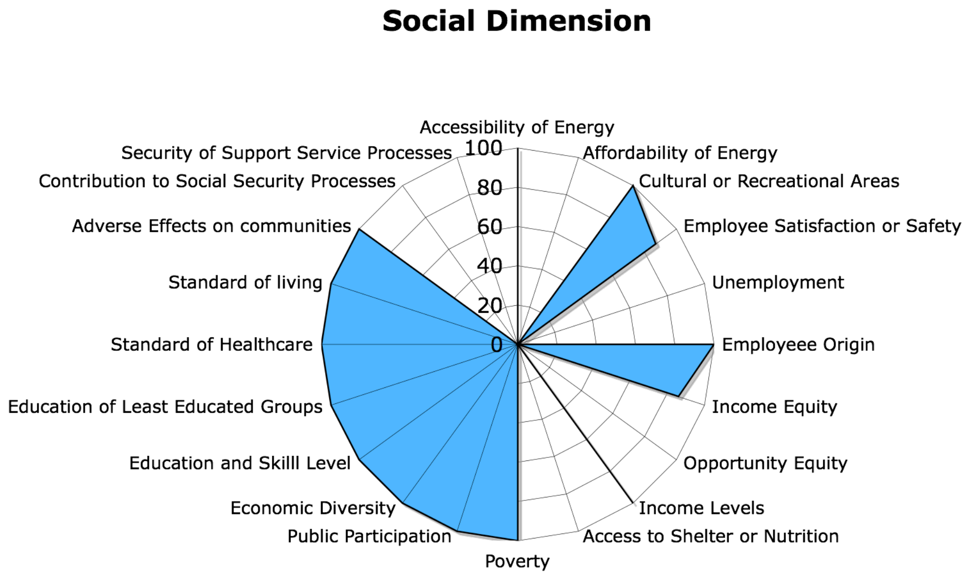

Figure 20: Scoring for Indicators in the Social Dimension at Local Level

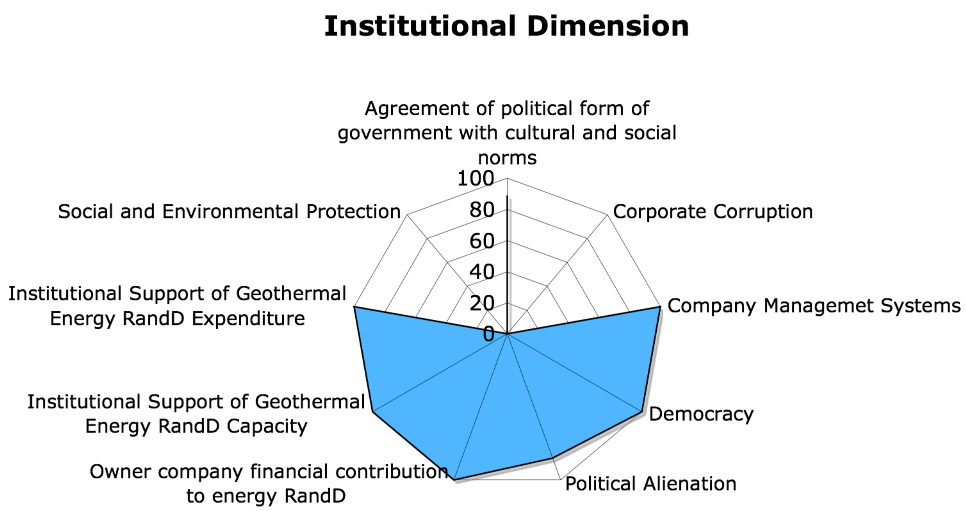

Figure 21:Scoring for Indicators in the Institutional Dimension at Local Level

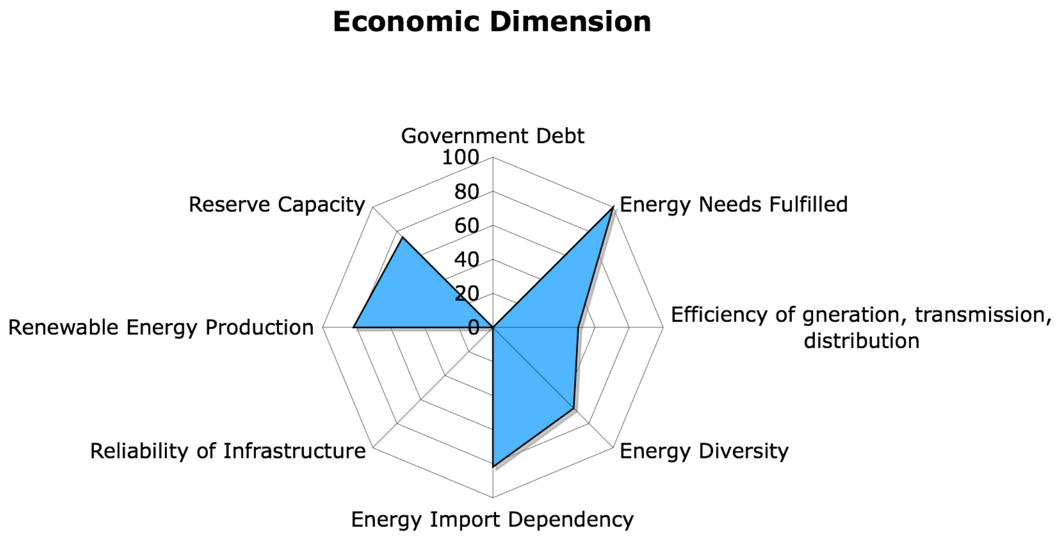

Figure 22:Scoring for Indicators in the Economic Dimension at Local Level

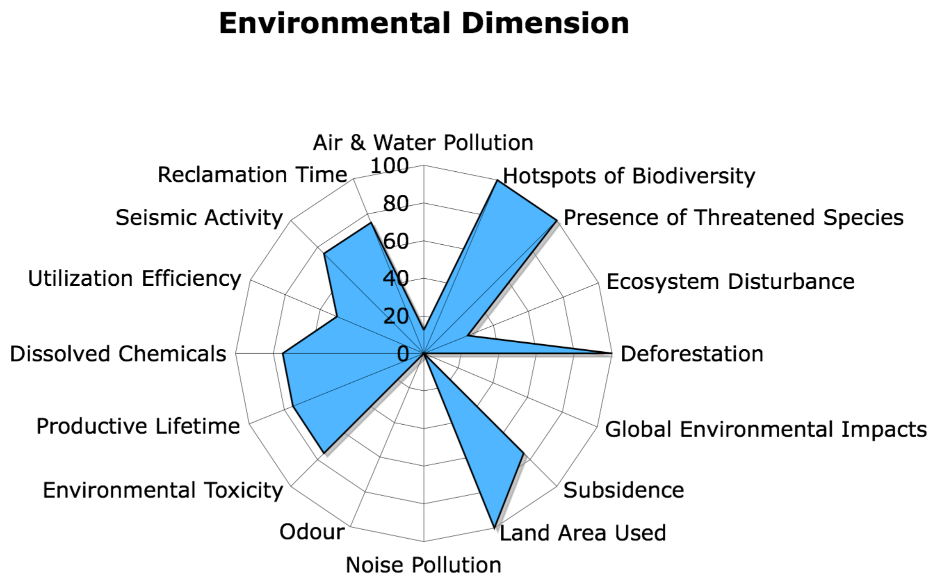

Figure 23:Scoring for Indicators in the Environmental Dimension at Local Level

6. DISCUSSION

6. 1 Strengths of the Indicator Set

6.1.1 Potential as Common Assessment Tool

The indicators in GSAP were produced as a result of a development process in consultation with various Icelandic stakeholders, in order to provide information of progress toward a set of sustainability goals (Box 2). As a results of this sustainability assessment, the indicators chosen have been proven as suitable indicators for the purpose of providing information on progress toward the sustainability goals. Each individual indicator was subjected to assessment of its suitability by evaluating it against a number of criteria and it was found that the final set of indicators was suitable to its purpose.

Although the sustainability goals were chosen by an Icelandic stakeholder group, the indicators in the geothermal sustainability assessment protocol have the potential to provide a common language allowing for comparison and benchmarking between countries, regions or localities. They are a powerful tool for communicating sustainable development issues to policymakers and decisionmakers regarding geothermal energy development projects.

6.1.2 Early Warning System and Time Series

The indicators of the GSAP framework are intended for use at different stages of the geothermal project lifecycle, meaning they can be used to guide decision-making by highlighting pressures and predicting impacts at the early stages of development as well as providing a means of monitoring policy decisions during the implementation and operation of a project. Indicators for the strategic, preparation and construction phases of geothermal energy projects will be developed at a later stage as part of a doctoral thesis. Indicators for these phases would serve as an early-warning system and allow identification of unsustainable energy projects. The indicators produced in this study are indicators suitable for assessing sustainability at the operation phase of geothermal energy projects and are therefore intended to be used for monitoring purposes. Monitoring implies building up time-series data to show progress toward or away from sustainability over time for the entire system.

6.2 Weaknesses of the Indicator Set

6.2.1 Simplification Necessary

The indicators may be used to measure performance against some target value, such as national or international standards or benchmarks. However, while many of the links between human-environmental interactions are well understood, many other complex issues remain to be studied. The indicators are chosen based only on our assumptions of the connection between cause and effect. They do not replace actual statistical analyses of data or the results of testing of hypotheses (Hák et al, 2007). Therefore, performing an assessment using these indicators is never guaranteed to provide a fully integrated view of the entire system we wish to assess.

The indicators provide a simplified view of a vast number of complex systems, interactions and processes, which can be useful in showing progress and guiding decision-making. However this simplification is also problematic as it means we must capture as much information about tradeoffs between the various dimensions or systems in an extremely condensed format. Developer companies, for instance, may find that there are relatively few indicators relating to company performance. For the Krafla power project, certain effects, such as community benefits may not have been captured in the indicators due to the restricition on the number of indicators, or simply due to the fact that the benefits in question were simply not considered during the indicator development process. Some benefits, such as increases in tourism as a result of thermal pollution, are not typical impacts associated with geothermal developments, yet such benefits or negative effects doubtlessly exist.

The list of indicators produced by this report is not prescriptive, in that it is entirely possible to find alternative metrics for any of the indicators presented in this report, some of which may be more suited to certain types of geothermal development projects than others. For example, the social benefits of geothermal energy projects may differ signifcantly from country to country. Further iterations of the indicator development process should result in increased flexibility of coverage of all sustainability issues concerned with geothermal development projects, metrics for which could be introduced at a later stage, after further study reveals issues that may have been neglected or that arise in certain situations.

6.3 Issues Faced During the Indicator Development Process

6.3.1 Stakeholder Involvement

During the indicator development process an inter-disciplinary group of stakeholders was invited to contribute to and review the indicators of GSAP. This group consisted of representatives from the energy industry, government, academia and NGOs. At this stage, banking and community representatives were not invited into the process, which, in the author's opinion, was a serious oversight. According to the Balaton report, the process of finding an indicator set must be participatory to ensure that the set encompasses the visions of the community or region for which it is developed and represents the interests and views of different stakeholders (Bossel, 1999).

It is strongly recommended that the indicators produced by this study be subject to further review by the relevant stakeholders in Iceland before proceeding with their use in any form. If necessary, modifications would be made according to stakeholder input.

Community groups from areas that are likely to be affected by geothermal developments in Iceland in the future should be invited into the process. A list of potential geothermal development areas will be produced by the Icelandic Master Plan for Hydro and Geothermal Energy Resources 1999-2009 (Iceland National Energy Framework Plan, 2009).

Ideally, the indicators would be implemented and reviewed by diverse stakeholders in a number of different countries at different stages of development in order to obtain a more balanced input into the development. This is a process that would take a number of years and as such would be covered by the author's doctoral thesis.

Stakeholder involvement is also possible during the operation phase of geothermal power projects, but this topic is beyond the scope of this thesis.

6.4 Issues Faced During the Implementation of the Indicators

6.4.1 Selection of Suitable Indicators

While selecting the GSAP indicators inevitable tradeoffs had to be made between useability, measurability in practice, availability of data and relevance to the sub-system in question. Having evaluted all indicators using the criteria in Box 3, some indicators had to be discarded and the selection process repeated.

Proxies or substitutes were chosen when it appeared that existing data or methods would prevent adequate calculation of the indicator. Also, if direct indicators were not possible, indirect indicators were chosen instead. For example, based on scientific research the connection between increased access to energy and a reduction of infant mortality is known, thus an indicator of infant mortality rate was chosen. However infant mortality may not reduce directly due to or immediately following a geothermal energy project development.

Due to the time available for this test run, it was decided to focus on indicators for the local and national level only. In a future revised version of the indicator set, a more comprehensive and holistic view would be gained by having indicators at all levels in the hierarchy. More detailed local and company indicators could feed data into the next level of regional indicators, which in turn would feed into indicators at the national level.

6.4.1.1 General Data Availability

The presence of relevant and reliable data is a major issue affecting the use of any indicators of sustainable development. Ideal indicators may suffer from lack of data forcing us to use less appropriate indicators instead. There may be considerable time delays in the calculation of indicators as many organisations only collect and analyse data every few years. Data also tends to be much more readily available in developed countries

Some of the first indicators selected had to be discarded because local or national data was not available. In many cases, local data was simply not collected. The monitoring of social impacts was especially uncommon, as social impacts, unlike environmental impacts are not usually incorporated into a monitoring system. A full economic cost-benefit analyses for the energy project had not been carried out at any stage in the past. Such an analysis would be an important pre-requisite for sustainability assessments in the future as they assess whether project benefits exceed costs, and should be carried out for any energy projects under consideration to allow economic comparisons between energy projects. The results of these analyses would then be fed into the GSAP indicators where appropriate.

The table below summarise the data availability issues faced during the assessment of the Krafla power project.

Table 26: Indicators for which no data was available

Indicator	**Reason**
ENV-LU1 Land area affected by energy project and associated infrastructure	No available studies on land area taken by energy project and infrastructure
All environmental indicators (ENV-XXX)	For all environmental indicators, the responsiveness of national level indicators could be improved by gathering data on all geothermal plants in Iceland and using this as a benchmark for the performance of individual plants for each indicator.
ECO-CB3a Project costs vs. benefits	CBA analysis had not been done for project
ECO-CB3b Impact on hydrological features or hot springs of touristic or aesthetic value	No baseline or monitoring data available
ECO-CB3c Impact on other water uses – drinking water, water for irrigation etc	No studies available on impact of water for other uses
ECO-EU1 Encouragement of efficient energy use	No data on tax from energy use collected at local or national level
ECO-RR3 Ability of geothermal resources to meet consumption patterns	No models of resource productivity available or models not updated
INST-CAP1 Government agency capacity (time taken to complete cases)	No data on Skipulagstofnun (Icelandic Planning Agency) capacity for task completion
INST-OCP1a - Owner effectiveness in energy	Release of results of customer satisfcation

projects	statistics not permitted by Landsvirkjun
INST-OCP1b Owner effectiveness in energy projects	Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with laws and regulations by owner – data not available from Landsvirkjun
INST-GCP1 Average skills and qualifications per person	Average qualification levels of government employees – data was not available from Skipulagstofnun (Icelandic Planning Agency)
INST-POL2 Internal and external security	Statistics on deaths due to crime or war not available from Statiscis Iceland
INST-POL4 Perceptions of project at home and abroad	No data available for numbers of national or international protests related to the project
SOC-SW3 Contribution to surplus uncommitted funds for social services by development project	No data was available from local municipalities in this regard
SOC-EMP2 Employment	Data released only for Landsvirkjun employees, none for contractors
SOC-INC1 Income Levels	Debt-to-income ratio for households not available in Iceland
SOC-QS1 Organizational and management skills	Data not available on hours of training for workers in municipality compared to hours of training for workers nationally.
SOC-DIS1a Disparity of energy use between income groups	Data not available from Iceland Statistics
SOC-DIS1b Disparity of energy use between genders	Data not available from Iceland Statistics
SOC-DIS1c Disparity of energy use between ethnicities	Data not available from Iceland Statistics
SOC-IE1c income inequity between ethnicities	Data not available from Iceland Statistics
SOC-OE1a Levels of overall education inequity between income groups	Data not available from Iceland Statistics
SOC-OE1c Education inequity between ethnicities	Data not available from Iceland Statistics
SOC-EHS1 Worker safety or satisfaction	Data available for Landsvirkjun employees only, not from contractors
SOC-SHS4 Health effects of geothermal energy project	No studies undertaken to calculate external cost of environmental pollution from energy project.
SOC-SHS5 Predicted family contact levels for population	No data available from Landsvirkjun or other sources.
SOC-SHS6 Perceived Levels of Fairness of Project	No data available on percentage of budge spent on local suppliers from Landsvikrjun.
SOC-SHS7 Safety of geothermal projects	No data available on the number of accident

	fatalities in geothermal energy available from Administration of Occupational Safety and Health in Iceland (Vinnueftirlitid).

6.4.1.2 Lack of Local Data

Whilst data was available for many of the indicators for the national level, it was often not collected or available in a meaningful format that would allow the analysis of trends in the municipalities. Local (municipal) data was not available for the following indicators:

Table 27: Indicators for which there was a lack of local data

Indicator	Reason
ENV-GLB1 Global Environmental impacts	Emissions data not collected for municipalities by environmental agency
ECO-CB1 Government Debt	Debt of individual municipalities not published by central bank
ECO-CB2 Ability of energy project to fulfill energy needs	Energy needs for individual municipalities not published by Landsnet
ECO-ECD1b Efficiency of energy transmission	Energy transmission performance not recorded for individual municipalities by Landsnet
ECO-IE1 Energy Import Dependency	Energy import dependencies of individual municipalities not published by Energy Authority
ECO-RR1 Renewable energy share in energy	Renewable energy share of individual municipalities not published by Energy Authority
ECO-DIV1 Energy diversity	Statisics for energy use not available at municipal level from Energy Authority
INST-REG2 Environmental and Social Protection	Expenditure on environmental policies by municipalities not published by Statistics Iceland
INST-GOV1 Government Corruption	Transparency International does not pubish corruption perceptions index at municipalitiy level
INST-POL1 Democracy	Freedom house does not publish democracy levels for municipalities.
INST-POL3 Political alienation	Voter turnout in individual municipalities not recorded by Statistics Iceland
INST-R&D1 Company support of energy R&D	Rannis data on company support of energy R&D is not broken down by municipality
INST-R&D2a Government contribution to amount of organizational capacity dedicated to energy R&D	Rannis data on government contribution to amount of organizational capacity dedicated to energy R&D is not broken down by locality
INST-R&D3 level of government support of energy R&D	Rannis data on government support of energy R&D is not broken down by locality
SOC-EMP1 Unemployment	Only regional data on unemployment is available from

	Statistics Iceland
SOC-INC1 Income Levels	Debt-to-income ratio for households is not available at municipality level from Statistics Iceland
SOC-INC2 Access to shelter (or nutrition)	Only regional data is available for housing prices and income levels from Statistics Iceland
SOC-INC3 Poverty	Poverty levels at the municipality level are not measured by Statistics Iceland
SOC-QS2 Economic diversity	Data on economic sector employment is not measured at the municipal level by statistics Iceland.
SOC-QS3 Level of education and skills	Average education levels are only measured at the national or regional level by Statistics Iceland
SOC-QS4 Level of education of least educated groups	Average education levels are only measured at the national or regional level by Statistics Iceland
SOC-ACC1 Energy access	Energy access levels only measured on national level by Statistics Iceland
SOC-AFF1 Energy affordability	Energy prices only measured at national and regional level by Statistics Iceland
SOC-IE1a Income Inequity	Income inequity (gini coefficient) only measured at national level in Iceland
SOC-IE1b Income inequity between genders	Data on income inequity between genders is only kept at national and regional level by statistics Iceland
SOC-OE1b Education inequity between genders	Data on education inequity between genders is only kept at national and regional level by statistics Iceland
SOC-SHS1 Standard of health care	Infant mortality rates are only recorded at national level by Statistics Iceland
SOC-SHS2 Standard of Living	Life expectancies are only recorded at national level by Statistics Iceland

6.4.1.3 Lack of Adequate Benchmarking

Benchmarks or reference values were unavailable or not yet agreed for the following indicators:

Table 28: Indicators for which no benchmarks or reference values existed

Indicator	Reason
ENV-AW 1a Emissions of acidifying air pollutants	No Icelandic or EU ceiling on H_2S gas
ENV-AW 1b Level of acidity/alkalinity of discharge	No baseline data for pH of water bodies available from Landsvirkjun or Environmental Agency
ENV-AW 1d Thermal Pollution	No baseline or ambient data for temperature of water bodies available from Landsvirkjun or Environmental Agency
ECO-CB3c Impact on other water uses – drinking water, water for irrigation etc	National benchmarks for ideal water usage by power plants not available

ECO-EU1 Encouragement of efficient energy use	No national benchmarks for amount of taxes that should be received from energy
ECO-PRF1 Owner company profitability	No known benchmarks set for ideal levels
ECO-DBT1a Owner company debt status	No known benchmarks set for ideal levels
ECO-DBT1b Owner company debt status - leverage	No known benchmarks set for ideal levels
ECO-DBT1c Owner company debt status – exchange rate	No known benchmarks set for ideal levels
ECO-RSK1a Owner Company Financial Risk	No known benchmarks set for ideal levels
ECO-RSK1b Financial soundness of owner company	No known benchmarks set for ideal levels
ECO-RSK1c Owner company foreign currency exposure	No known benchmarks set for ideal levels
INST-CAP1 Government agency capacity	No benchmarks on ideal times for case completion or other capacity metrics set
INST-CAP2 Government competent authority effectiveness	No benchmarks for ideal education levels within government agencies
INST-GOV2 Corporate corruption	No benchmarks for number of supreme court cases against the developer company (Landsvirkjun)
INST-OCP1b Owner effectiveness in energy projects	No benchmark for ideal levels of non-compliance with regulation etc.
INST-OCP2b Standard of Company Management Systems	No well-defined benchmark for level of EMS quality, no harmonization of EMS standards internationally
INST-R&D1 Owner Contribution to Geothermal Energy R&D Expenditure	No standards exists for the ideal amount of company support for energy R&D expenditure.
INST-R&D2 Owner Support of Geothermal Energy R&D Capacity	No standards exists for the ideal amount of developer company support for energy R&D capacity.
INST-R&D3 Institutional Support of Geothermal Energy R&D Capacity	No standards exists for the ideal amount of government support for energy R&D capacity.
INST-REG2 Social & Environmental Protection	No benchmark exists for the ideal level of government expenditure on environmental protection
INST-POL3 Political alienation	Voter turnout is difficult to interpret without other contextual information
SOC-SHS3 Adverse effects on communities	No internationally / nationally agreed benchmarks for recommended levels of human / economic displacement due to energy project

6.4.1.4 Lack of Up-to-Date Data

The following indicators suffered from a lack of up-to-date data:

Table 29: Indicators for which data was not up-to-date

Indicator	Reason
ENV-TOX1a Toxicity of H_2S	Most recent report on H_2S gas concentrations in the Krafla area is from 1993.
ENV-TOX1b Toxicity of Hg	Most recent report on Hg gas concentrations in the Krafla area is from 1993.
ENV-NSE2 Odour Nuisance	Most recent report on H_2S gas concentrations in the Krafla area is from 1993.
ENV-ECO3 Level of disturbance of ecosystems	Most recent report on ecosystem disturbance in the Krafla area is from environmental impact assessment from 2001. No regular monitoring reports appear to be done for ecosystem state in the area.
ENV-RES1 Productive Lifetime	Numerical models of the Krafla geothermal system are outdated, new models are currently in development.
ENV-RES5 Reclamation Time	Numerical models of the Krafla geothermal system are outdated, new models are currently in development.
INST-R&D2b Owner contribution to organizational capacity dedicated to geothermal energy R&D	Data on business sector support of geothermal power R&D capacity only available up to 2005 from Rannis.
SOC-SHS1 Standard of health care (infant mortality rates)	Data on infant mortality rates only available up to 2005 from Statistics Iceland.
SOC-QS3 – Level of Education & Skills	Data only available up to 2002 for regional and national education levels from Statistics Iceland.
SOC-QS4 – Education level of least affected groups	Data only available up to 2002 for regional and national education levels from Statistics Iceland..
INST-R&D2b – Owner support of geothermal energy R&D capacity	Data on business sector support of geothermal power R&D capacity only available up to 2005 from Rannis.
INST-R&D1 Owner company contribution to energy R&D expenditure	Data on business sector support of geothermal power R&D expenditure only available up to 2005 from Rannis.

6.4.2 Interpretation of Assessment Results

The indicator development process for GSAP has highlighted a number of areas in which data collection could be improved in Iceland. It is however to be expected that data will not be readily available if there has never previously been a need to collect it before for indicators of sustainable development or any other purposes.

Certain data was not accessible for this study from the developer company. Although social and economic monitoring are not required by Icelandic law, environmental monitoring is generally required for operations such as the Krafla power plant. Landsvirkjun has implemented ISO14001 for its power operations and has received certification and put in place an environmental monitoring system, yet certain environmental data needed for the GSAP assessment was nevertheless either not available or not accessible. Measurements for concentrations of H_2S and Hg gases, odour levels or the state aquatic ecosystems do not appear to be carried out on a regular basis or were not available from the library. Data on ambient environmental conditions, such as air and water quality in the Krafla area was not available from the Environmental Agency. The availability of data on water quality may however improve if Iceland decides to implement the EU Water Framework Directive in the future.

For the environment and resource indicators, further work will need to be done to obtain data for and calculate national level indicators. For the resource indicators, this would require studying geothermal production on a national level and calculating or defining national level indicators for utilization efficiency, productive lifetimes, reserve capacity, reclamation time, subsidence, changes in dissolved chemicals and seismic activity. In some cases it may be necessary to draw comparisons to other geothermal plants worldwide. For the environmental indicators, data on all environmental indicators could be collected for all Icelandic geothermal plants and the contribution of individual energy projects to national trends assessed.

As this was a pilot study, the results of the sustainability assessment of the Krafla energy project are less reliable than they would be if further iterations of the indicator development process had been carried out with more stakeholder involvement in the process. As such it is therefore not possible to state with accuracy in exactly which areas the contribution of the energy project to local and national sustainability could improve. Nor would it be entirely fair to prescribe measures that the developer company should take to improve data collection and accessibility. It is possible however to identify some general trends in the data.

The figures presented in Section 5 show that the contribution of the natural system to the total system is the poorest for all systems for both local and national levels, with the national level performing slightly better. The support and human systems contribute the most to the total system for both local and national levels. The natural system is the best performing of all sub-systems, with the support sub-system in second place and human sub-system in last place for both local and national levels.

Trends are similar at both local and national levels in the support and human systems. However, it should be noted that local data was missing in many cases and national or regional data may have been used as a substitute. Local performance was poorer than national performance in the support and human systems, but slightly better for the natural system.

Overall, there seems to be significant room for improvement for the Krafla energy project for fulfilling the sustainability goals for geothermal utilization as set out in this document. The contribution of the energy project to national sustainability could be improved by addressing problem areas in all systems. These problem areas can be identified by investigating the lowest scoring indicators in each system, and from this it can be seen where the responsibility lies for the improvements.

In the human system, it can be seen that government debt, unemployment, security of support services, corporate corruption and energy efficiency have all attained poor scores. Of these, the first four can be seen as indirect impacts of the project, or indirect impacts on the project by the system in the case of government environmental protection and government debt. Utilization efficiency is a direct impact of the energy project and is under the direct control of the developer company. The indirect impacts are not under the direct control of the developer, so improvements in these areas may require studies into how certain actions could improve performance, and which actors would be required to carry them out.

In the support system, poorly performing indicators include corporate corruption, infrastructure reliability, energy efficiency and ecosystem disturbance. The impacts of each of these indicators are under the control of the developer company or the transmission and distribution companies.

In the natural system, air and water pollution, global environmental impacts, ecosystem disturbance and noise receive low scores. All of these impacts are under the control of the developer company.

When the indicators are grouped into four dimensions of sustainability, the best performance appears to be in the Social and Institutional themes, whereas the Environment and Economic themes perform less well. This is the case on both local and national levels, but as already mentioned, local data was lacking so this may not present an accurate picture of the differences between levels.

6.4.3 Country Specific Application and Issues

Given that an Icelandic Framework Plan for Energy (Rammaáætlun) (Thorhallsdottir, 2007) has been carried out and has identified potential desirable hydropower and geothermal energy projects for the nation based on a number of sustainability criteria, the use of GSAP in Iceland could serve as a further step in assessing energy projects for sustainability, alongside strategic environmental assessments or on its own. Also, due to a lack of available baseline data for potential geothermal development areas, the use of GSAP would be more suited for this stage in Iceland. This would then allow input of baseline data produced in SEA or EIA processes to be used for baseline data in GSAP. Projections for socio-economic impacts carried out in the EIA or SEA study would also then be available for GSAP strategic phase assessments.

Potentially GSAP could be used alongside the SEA or EIA process for geothermal developments in the strategic phase in order to guide the investigation into issues relevant for the sustainable utilization of goethermal energy resources where such issues may not have been covered otherwise. For instance, social impact assessments may not be included in the normative frameworks for SEA or EIA in certain countries. The investigation of environmental and socio-economic impacts for previous EIA studies of Krafla power plant were found to be lacking in many of the areas that is covered by the GSAP indicators such as employment effects, noise levels and certain pollutanting substances (Landsvirjun 2001). Such information would be required to supply data for GSAP strategic phase indicators. In this way, using GSAP strategic phase indicators would be akin to carrying out an independent audit of current SEA or EIA studies, using indicators and benchmarks that have been previously agreed upon by all the relevant stakeholders. Such an audit or monitoring process could be carried out by government bodies and independent organisations and could allow for the certification of geothermal energy projects.

A further potential use of GSAP would be the use of the strategic phase indicators as a means of assessing different geothermal energy options, for instance in energy masterplanning. Depending on the type and scope of indicators used, GSAP could be a useful tool to assess potential projects against a set of sustainability criteria, before beginning the SEA or EIA process and thus allowing for cost-savings to be gained by ruling out unsustainable projects early on, aswell as prompting various studies of potential environmental or socio-economic impacts, the results of which could cascade down through the decision-making tiers into the SEA or EIA processes.

Due to the lack of baseline data or the lack of up-to-date data, the author attempted to obtain baseline data from an ongoing EIA study for another power plant in the same area, known as the Krafla II project. Data was not available from environmental impact studies done for the Krafla II power project at the time of the assessment, due to proprietary issues. Such data would need to be made available at the strategic phase of energy projects, to enable sustainability assessments to be carried out at this stage.

In countries where there is little or weak legislation regarding SEA or EIA studies, GSAP could be beneficial in prompting studies to gather the relevant baseline and monitoring data for certain indicators. However, if GSAP is to be used in different countries, it is necessary that flexibility is built into the assessment tool so that there are a considerable number of options for the indicators that would be used. The indicators that are to be used would also depend at which stage in the decision-making process GSAP is to be used.

6.5 Comparison of GSAP and IHA-SAP

This section provides a comparison between the Geothermal Sustainability Assessment Protocol (GSAP) developed in this masters thesis and the International Hydropower Association's Sustainability Assessment Protocol (IHA-SAP).

6.5.1 Purpose

Both the IHA-SAP and GSAP have been developed in order to highlight best practices for energy developments and to provide an assessment framework for the sustainability of energy projects.

At the outset of the development of GSAP, a set of sustainability goals were defined for geothermal utlization. These goals guided the choice of sustainability indicators during the indicator development process.

The IHA-SAP does not outline specific sustainability goals for hydropower developments, but does list a number of guiding principles that are used (IHA, 2009).

6.5.2 Structure

6.5.2.1 GSAP Structure

GSAP uses a systems framework to group its indicators, where indicators are chosen for the human, support and natural system. These indicators are chosen with a specific purpose in mind – to indicate whether an orientor of system viability has been fulfilled. Each individual indicator is given a percentage score. Using several indicators to represent the same issue is not permitted except in situations where several aspects of one issue are important, in which case an aggregate score is calculated for the aspects.

6.5.2.2 IHA-SAP Structure

The IHA-SAP examines the sustainability of energy projects across a number of Perspectives – Development, Government, Technical, Financial & Economic, Social, Environmental, Geographical / Spatial. Each Perspective in turn contains a number of aspects relevant to the sustainability of hydropower projects. The aspects each have seven attributes, which are graded on a scale of 1-5. In some cases these attributes are not relevant, depending on the stage of the project, or depending on who is performing the assessment, but generally the seven attributes are assessed for each aspect.

Attributes are divided into Process Attributes (3) and Performance Attributes (4):

Process Attributes

Quality of the Assessment Process

For each aspect, the quality of the developer/owner/operator company´s assessment process is assessed, taking account of:

1. Identification of baseline condition.
2. Clarity of definition of the role and responsibility of the proponent and accountability of other parties
3. Identification of legal and other requirements.
4. Identification of potential positive and negative impacts related to project implementation and operations.
5. Risk assessment of potential impacts occurring, and addressing of uncertainties for example by extending data sets, forecasting/modeling, and parallel studies.
6. Opportunity assessment to determine if improvements could be made to the existing condition.
7. Evaluation of scenarios, including alternative project siting and design options, and alternative management and mitigation measures.
8. Allocation of resources to the assessment process. This includes qualifications/expertise of those involved, utilization of local knowledge as appropriate, scale of resource commitment, and continuity (IHA, 2009).

Quality of the Management Process

For each aspect, the quality of the developer/owner/operator company´s management process is assessed, taking account of:

1. Integration of the assessment process as the basis for development of planned arrangements.
2. Formulation of plans or planned arrangements. Plans outline measures to manage (avoid, minimise, mitigate, compensate) risks and enhance opportunities, including the establishment of achievable objectives and targets.
3. Implementation of the planned arrangements. This includes utilising appropriate and effective methodologies.
4. Allocation of resources. This includes qualifications/expertise of those involved; utilization of local capacity as appropriate; scale of resource commitment; continuity of resources through project preparation, implementation and operation; and contingency planning.
5. Clarity of roles, responsibilities and accountabilities.
6. Effective strategies for identifying and managing change.
7. Checking and evaluation, including monitoring, auditing, and management review.
8. Continual improvement and adaptive management, including management of nonconformities, corrective and preventive actions, and any necessary plan revision. (IHA, 2009)

Quality of the Consultation Process

For each aspect, the quality of the developer/owner/operator company´s consultation process is assessed, taking account of:

1. Identification of issues and associated affected stakeholders. This includes stakeholder mapping and engagement guided by the consideration of rights, risks and responsibilities.

2. Formulation of the consultation plan. This includes consultation objectives and targets over an appropriate time period.
3. Appropriateness and transparency of the engagement processes. This includes freedom to participate, assistance to stakeholders, timing, location, accessibility of information, and feedback procedures,
4. Allocation of resources for consultation. This includes appropriateness, scale, continuity and capability.
5. Consultation developed with informed participation of affected peoples, respectful of rights, culturally sensitive, and gives appropriate attention to gender, minorities, level of literacy, and others who might require particular assistance.
6. Integration of the consultation plan, processes and outcomes with other relevant plans and arrangements.
7. Issues raised in the consultation considered in the decision-making.
8. Grievance and dispute resolution processes. This includes grievance mechanisms in appropriate languages, and evaluating if they were developed with affected stakeholder participation.
9. Monitoring, evaluation, review, and continual improvement of the consultation plan (IHA, 2009).

Performance Attributes

Level of Stakeholder Support

For each aspect, the level of stakeholder support is assessed, taking account of :

1. The level of support of stakeholder groups directly affected by that issue for the assessment, management and consultation processes for the issue, and associated review and improvement.
2. The level of support of stakeholder groups directly affected by that issue for the outcomes.
3. The level of success in resolving disputes. (IHA, 2009)

Level of Compliance

For each aspect, the level of compliance with relevant legal requirements and other publicly stated commitments on the part of the developer / owner / operator is assessed, taking account of:

1. Compliance with relevant legal requirements and other public commitments made by the developer/owner/operator.
2. Number, level, significance, persistence and ease of remedy of non-compliances. (IHA, 2009)

Level of Conformance with Plans

For each aspect the level of conformance with the developers own plans is assessed. conformance with plans measures the degree to and quality with which the developer / owner / operator is implementing its plans and planned arrangements. This differs from level of compliance in that it is not restricted to legal requirements and public commitments of the developer / owner / operator, but is looking at the quality of internal business systems and plans. Considerations relevant to this attribute include:

1. Level of conformance with relevant management plans and other associated documents.
2. Number, level, significance, persistence and ease of remedy of non-conformances. (IHA, 2009)

Level of Effectiveness

This attribute deals with the performance of the project in relation to objectives for each aspect. The auditor must assess whether or not the developer has been effective in minimizing, mitigating or compensating negative impacts, maximizing positive impacts, enhancing baseline conditions. The auditor must take account of the developer/owner/operator´s influence and responsibility on a case-by-case basis

This attribute covers important performance issues for each aspect, outside of the level of stakeholder, compliance and conformance attributes.

6.5.3 Assessment Method and Benchmarks

As such, it appears that the IHA-SAP does not set specific requirements for evidence that should be produced to demonstrate the sustainability of energy projects, but suggests instead a number of possible options for the type of evidence that may be acceptable.

Whilst this allows for flexibility in assessing projects in different regulatory environments or with different resources available to them, it means that it is ultimately up to the auditor to decide if the evidence is indeed proof of sustainable performance for a particular aspect of sustainability.

The auditor must deem what is “suitable”, “adequate” or “effective” in the assessment of each attribute. The IHA states that no precise requirements should be necessary to ensure that expectations are appropriate to the needs at hand (IHA, 2009). It is assumed that it is the auditor´s responsibility to determine what are the needs at hand in each case.

The IHA does state however in the same document that the IHA-SAP could be developed in a number of different ways, including identification of acceptable levels of performance for the different sustainability issues addressed in the protocol and that the acceptable levels of performance could be applied for sustainability and performance standards, awards and recognition schemes, industry benchmarking, etc. (IHA, 2009).

The GSAP protocol on the other hand, sets out specified values of each indicator that must be attained, meaning that the auditor must only check if the indicator meets that target or not. The disadvantage of this approach is that targets must be set for all indicators before the assessment takes place, meaning that stakeholder consensus must be sought on indicator values across a range of different project types. This is a task that would be undertaken if the GSAP project is to be continued for the author´s doctoral thesis.

6.5.3 Analysis Using a Systems Framework

With three out of seven aspect attributes dealing with quality of process, this means approximately 42% of the assessment is dedicated to quality of company processes alone. With quality of process, the focus is on the quality of the developers/owner/operator company´s assessment, management and consultation processes.

Within the systems framework, the three quality of process attributes would be covered by one indicator within the owner company subsystem, associated with the effectiveness orientor.

In GSAP, only one indicator out of a possible forty two deals with effectiveness within the owner subsystem. Approximate coverage of the owner subsystem by the IHA-SAP quality of process attributes and GSAP indicators is shown in the table below.

Table 30: Comparing owner effectiveness indicator coverage for owner system

System / Sub-system:	Human / Organisations / Owner
Percentage of IHA-SAP assessment covered by this indicator:	42
Percentage of GSAP assessment covered by this indicator:	2.38

With one out of seven aspect attributes dealing with the level of stakeholder support this means approximately 14% of the assessment is dedicated to assessing the level of stakeholder support for various project aspects.

Within the systems framework, the level of stakeholder support attribute would be covered by one indicator within the individual development subsystem associated with the effectiveness orientor or within the owner company subsystem, associated with the coexistence orientor.

In GSAP, only one indicator out of a possible forty two deals with effectiveness within the individual development subsystem or coexistence in the owner subsystem. Approximate coverage of the owner subsystem by the IHA-SAP stakeholder support attribute and GSAP is shown in the table below.

Table 31: Comparing effectiveness or coexistence indicator coverage for individual development or owner system

System / Sub-system:	Human / Individual Development OR Human / Organisations / Owner
Percentage of IHA-SAP assessment covered by this indicator:	14
Percentage of GSAP assessment covered by this indicator:	2.38

With one out of seven aspect attributes dealing with the level of compliance this means approximately 14% of the assessment is dedicated to assessing the level of compliance for various project aspects.

Within the systems framework, the level of compliance attribute would be covered by one indicator within the owner company subsystem, associated with the coexistence orientor.

In GSAP, only one indicator out of a possible forty two deals with coexistence within the owner subsystem. Approximate coverage of the owner subsystem by the IHA-SAP level of compliance attribute and GSAP is shown in the table below.

Table 32: Comparing coexistence indicator coverage for owner system

System / Sub-system:	Human / Organisations / Owner
Percentage of IHA-SAP assessment covered by this indicator:	14
Percentage of GSAP assessment covered by this indicator:	2.38

With one out of seven aspect attributes dealing with the level of conformance this means approximately 14% of the assessment is dedicated to assessing the level of compliance for various project aspects.

Within the systems framework, the level of conformance attribute would be covered by one indicator within the owner company subsystem, associated with the effectiveness orientor.

In GSAP, only one indicator out of a possible forty two deals with effectiveness within the owner subsystem. Approximate coverage of the owner subsystem by the IHA-SAP level of conformance attribute and GSAP is shown in the table below.

Table 33: Comparing effectiveness indicator coverage for owner system

System / Sub-system:	Human / Organisations / Owner
Percentage of IHA-SAP assessment covered by this indicator:	14
Percentage of GSAP assessment covered by this indicator:	2.38

With one out of seven aspect attributes dealing with the level of effectiveness this means approximately 14% of the assessment is dedicated to assessing the level of effectiveness of performance in relation to objectives for the various project aspects.

Within the systems framework, the level of effectiveness attribute would be covered by a number of different indicators within a number of different subsystems. This corresponds to all remaining indicators in GSAP.

In GSAP, all remaining 40 indicators deal with the level of effectiveness of the project´s performance relating to all remaining issues apart from company processes, stakeholder support, compliance or conformance. Approximate coverage of the owner subsystem by the IHA-SAP level of effectiveness attributes and GSAP indicators is shown in the table below.

Table 34: Comparing remaining indicator coverage for all systems

System / Sub-system:	All other systems
Percentage of IHA-SAP assessment:	14
Percentage of GSAP assessment:	95.24

When the issues covered by the IHA-SAP and GSAP attributes and indicators are placed within the systems framework, the proportional representation of the three main systems - human, natural and support – become apparent. As can be observed in Figure 24 and Figure 25 below, the IHA-SAP places a much higher focus on the human system. This is due to the large percentage of indicators/attributes that are related to the quality of the owner/developer/operator company processes and levels of stakeholder support, compliance and conformance. As a result, most of the IHA-SAP indicators relate to company or social concerns.

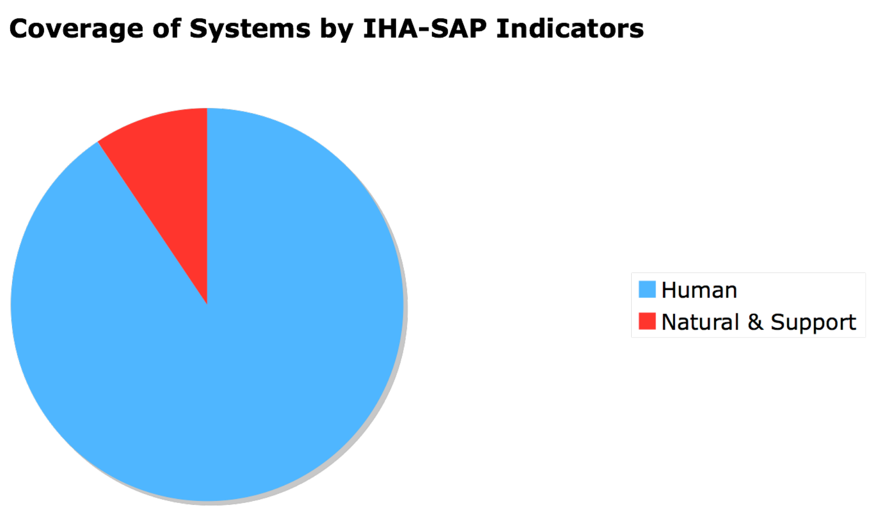

Figure 24: Coverage of Systems by IHA-SAP Indicators

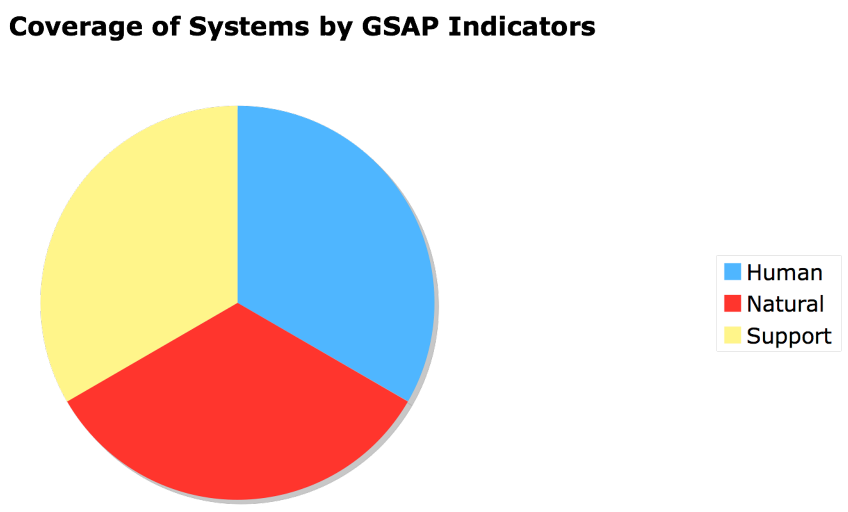

Figure 25: Coverage of Systems by GSAP Indicators

Notes:

1. Percentages are approximate, due to the fact that for some aspects, not all attributes will be relevant.
2. The scoring system for the IHA-SAP has not yet been finalized, therefore the assumption is made that each of the seven attributes are awarded one seventh of the total "score" for each aspect.
3. In the IHA-SAP, 14% of the attributes deal with the effectiveness of the project with regard to specified goals. It is assumed that this 14% is divided equally among the human, natural and support systems.

In conclusion, having assessed the IHA-SAP using a systems framework, it seems that it is insufficient as a tool for assessing sustainable development, due to its uneven coverage of all the systems involved. According to this framework, a tool for sustainable development must cover the human, natural and support systems equally.

7. CONCLUSIONS

7.1 Summary Evaluation

The indicators presented in this document are the result of a first iteration of the indicator development process (Figure 3) produced as a result of a pilot study on the Krafla power plant. The indicators that have been produced are suitable to their purpose in that they deal with all the sustainability goals that were agreed upon by the sustainability working group in Iceland. As such, they are suitable for use in the environment in which they were developed. Iceland is a developed country with specific data-availability and institutional characteristics. However, as the sustainability goals were intended as high level, general guiding principles for the sustainable utilization of geothermal resources, many possible indicator combinations could be said to cover the goals. It is only through involving all stakeholders in Iceland and other countries in the development process that all suitable indicators may be discovered and integrated into GSAP. The author recommends that the indicators in this document be subject to further stakeholder review in Iceland before proceeding any further with their development.

The indicators were applied to a geothermal energy project in the operation phase and have been assessed as being suitable for this purpose during this first iteration of the development process. Many of the indicators are also suitable for use in the other earlier geothermal life cycle project phases, but modifications to indicator benchmarks and scoring mechanisms will be necessary to reflect the differing purposes of assessments in earlier life cycle phases and also to reflect the availability of data at each phase. In the strategic phase of geothermal energy projects, results of a sustainability assessment could be used as a decision-making tool to allow choosing between different geothermal (or other) energy projects and therefore issues of a more strategic nature may be emphasized, depending on the requirements of the decision-making organization that is using the indicators. As it can provide a high-level view of an energy project´s contribution to sustainability for a national system, possible users of GSAP could include local or national planning authorities, potential investors in energy projects or certification bodies. This type of assessment could be carried out alongside a strategic environmental assessment to aid in the identification of likely impacts of geothermal energy projects and ensuring that the relevant issues are taken into account.

7.2 Further Work

In order to be applied to geothermal projects in other countries, the indicators would need to be analysed for suitability within each national environment and at different project phases and modified accordingly. It is recommended that several iterations of the indicator development process would be carried out before a globally applicable set of indicators is chosen.

It is further recommended that this current set of indicators be distributed internationally for review among a wide range of stakeholder. Input from different stakeholders could then be incorporated into the next iteration of the indicator set.

It is envisioned that the author will undertake further iterations of the indicators development process as part of a doctoral thesis, where the indicators will be developed further to allow tailoring to national needs, more comprehensive coverage at all levels and the development of software for easier reporting and use of the indicator. Further iterations of the indicator set will also include considerations of the direct use of geothermal resources as well as use of geothermal resources for electricity generation.

Following testing and implementations in different national environments, it is expected that a flexible yet objective assessment tool will be produced. The tool will be flexible as it will allow the comprehensive assessment of critical sustainability issues in different countries at different stages of development by permitting the user to choose between a variety of indicator metrics, some of which will be appropriate to developed countries and others to developing countries. The tool will allow objective assessment, as all issues, metrics and targets used in the indicator set will be discussed and agreed upon during a multi-stakeholder indicator development process in all countries of application.

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Appendix A

Appendix B

Appendix C

Appendix A

Scoring and Assessment Functions for Economic Indicators	
Indicator Name	**Scoring**
ECO-CB1 Government Debt	Scoring is based on the ratio of government foreign debt to revenues. The IMF recommend that this ratio does not exceed 290% **Score 0%** Government foreign debt to revenues ratio is equal to or exceeding 290% **Score 100%** Government foreign debt to revenues ratio is less than 290%
ECO- CB2 Ability of energy project to fulfill energy needs	Scoring is based on the percentage of national energy needs that will be fulfilled by the project in 2020. **Score 0%** Project does not contribute to demonstrated future energy needs for the nation (year 2020) **Score 100%** Project contributes to demonstrated future energy needs for the nation (year 2020) The year 2020 is chosen here because this is the period for which adequate projection data is available in Iceland. This may not be the case in other countries but this year was chosen for this pilot study in Iceland.
ECO-ECD1 Efficiency of Energy Utilization, Transmission and Distribution	This indicator is made up of two parts: ECO-ECD1-N for the national indicator and ECO-ECD1-L for the local indicator **ECO-ECD1-N** Scoring is based on the level of energy efficiency (percentage) attained during transmission and distribution of the energy produced from the geothermal energy project and how it compares to predicted transmission and distribution efficiency in the year 2030. Efficiency is within or better than the expected range for the year 2030 **Score 100%** Efficiency is below the expected range for the year 2030 **Score 0%** **ECO-ECD1-L** Scoring for this indicator is based on the utilization efficiency of the project geothermal resource The scoring is calculated by using the standard deviation and average values for the utilization efficiency of all geothermal plants in Iceland. Very poor utilization efficiency **Score 0%** Poor utilization efficiency **Score 25%** Average utilization efficiency **Score 50%** Good utilization efficiency **Score 75%** Very good utilization efficiency **Score 100%**

ECO-IE1 Energy Import Dependency	Scoring is based on the percentage of the nation´s energy that is domestically produced.
ECO-RR1 Renewable energy share in energy	Scoring is based on the percentage of the municipality or nation´s energy that is obtained from renewable sources
ECO-RR3 Reserve Capacity	Scoring is based on a) the reserve capacity ratio of the national geothermal resource b) the reserve capacity ratio of the geothermal system in which the utilized resource is located Reserve capacity ratio is below 0 **Score 0%** Reserve capacity ratio between 0 and 0.24 **Score 25%** Reserve capacity ratio between 0.35 and 0.49 **Score 50%** Reserve capacity ratio between 0.49 and 0.74 **Score 75%** Reserve capacity ratio between 0.74 and 1.0 **Score 100%**
ECO-DIV1 Energy Diversity	Scoring is based on the adjusted Shannon-Weiner index for the local and national energy diversity. This provides a score between 1 and 100.
ECO-IMT1 Reliability of Infrastructure	Scoring is based on the duration of outages experienced in the national transmission system. **Score 100%** Company meets own target for duration of outages **Score 0%** Company does not meet own target for duration of outages

Scoring and Assessment Functions for Environmental Indicators	
Indicator	**Scoring**
ENV-LU1 Land area used by energy project	**Score 0%** Additional land area used by energy project causes total area used to exceed average size of a geothermal plant **Score 100%** Additional land area used by energy project does not cause total area used to exceed average size of a geothermal plant **Note:** Energy projects in the operation phase are not penalized for having exceeded the average size of a geothermal power plant prior to the sustainability assessment. Scoring is only based on whether there have been any increases in land areas used since the year before the first assessment.
ENV-FOR1 Deforestation due to energy project	The score is the percentage of total forested area in a given region that is not affected by the geothermal energy project. **Note:** Energy projects in the operation phase are penalized for deforestation prior to the sustainability assessment, as the developer company may have the possibility of carrying out reforestation.
ENV-LSC1 Landscape Esthetics	This indicator measures the impact of the energy project on landscape esthetics. At the national level, the indicator ENV-LSC1-N is used and at the local level ENV-LSC1-L is used. **ENV-LSC1-N** In Iceland, protected areas are categorized into four categories known as Verndaflokkur, which take account the living organisms, natural monuments and landscape features found in a particular area. Project structures or infrastructures may be located in protected areas. The impact of additional structures or infrastructure on landscape esthetics is scored using the Icelandic Verndaflokkur scale as follows: Verndaflokkur 1 – Score 0% Verndaflkkur 2 - Score 33% Verndaflokkur 3 – Score 67% Verndaflokkur 4 – Score 100% **Note:** Energy projects in the operation phase are not penalized for impacts on landscape esthetics prior to the sustainability assessments. Scoring is based on whether there have been any further impacts on landscape esthetics since the prior to the first assessment. **ENV-LSC1-L** The impact of the project on landscape at a local level is measured by the impact of ground subsidence due to the energy project. Scoring is based on whether subsidence has positive or negative impacts. Major negative impacts **Score 0%** Moderate negative impacts **Score 25%** Minor negative impacts **Score 50%** Insignificant impacts **Score 75%** Some positive impacts **Score 100%**

ENV-TOX1

Environmental Toxicity

The score for this indicator is found by calculating the averages of parts a, b and c.

ENV-TOX1a – Toxicity of H2S gas

Exposure to H2S gas concentrations of 100ppb, with an averaging time of 24 hours, is considered acceptable by the World Health Organisation.

H2S gas exposure below 100ppb in recreational or residential areas – Score 100%
H2S gas exposure below 100ppb in recreational or residential areas – Score 0%

ENV-TOX1b – Toxicity of Hg gas

The World Health Organsation has set a reference value of 1 microgram / m3 for mercury vapour.

If Hg gas concentration in recreational and residential areas near the power plant are below WHO reference levels – Score 100%

If Hg gas concentration in recreational and residential areas near the power plant are above WHO reference levels – Score 0%

ENV-TOX1c

All metals in effluent are considered in this indicator. The score is based on the impact category of the metal with the most severe environmental impact.

Icelandic reference levels (μg/l) for metals in water are given in the table below.

	Hg	Cu	Zn	Cd	Pb	Cr	Ni	As	P
Group I <		0.5	5	0.01	0.2	0.3	0.7	0.4	20
Group II <		3	20	0.1	1	5	1.5	5	40
Group III <		9	60	0.3	3	15	4.5	15	90
Group IV <		45	300	1.5	15	75	22.5	75	150
Group V >	1	45	300	1.5	15	75	22.5	75	150

The “Umhverfismörk” impact categories are outlined in Icelandic law. (Reglugerdir 796 / 1999 and 800/1999)

Group I Very little or no risk of impact **Score 100%**
Group II Little risk of impact **Score 75%**
Group III Impact on certain organisms **Score 50%**
Group IV Impacts can be expected **Score 25%**
Group V Serious impacts on ground water quality **Score 0%**

ENV-AW1 – Air and Water Pollution

The score for this indicator is found by calculating the averages of parts a and d.

ENV-AW1a – Acidifying Air Pollutants in emissions
Scoring is based on levels of emissions of acidifying air pollutants (H_2S, SOx and NOx) compared to the average level of the past decade.

Score 0%
H_2S, SOx or NOx emissions are higher than the average of the past decade.

Score 50%
H_2S, SOx or NOx emissions are equal to the average of the past decade.

Score 100%
H_2S, SOx or NOx emissions are lower than the average of the past decade.

ENV-AW1d – Thermal Pollution

Scoring is based on the EU Water Framework Directive specifications for the physio-chemical characteristics or rivers and lakes, **including temperature,** for high, good, moderate and poor status rivers or water bodies.

High Status - Score 100%
The values of the physico-chemical elements correspond totally or nearly totally to undisturbed conditions. Nutrient concentrations remain within the range normally associated with undisturbed conditions. Levels of salinity, pH, oxygen balance, acid neutralising capacity and temperature do not show signs of anthropogenic disturbance and remain within the range normally associated with undisturbed conditions.

Good Status – Score 75%
Temperature, oxygen balance, pH, acid neutralising capacity and salinity do not reach levels outside the range established so as to ensure the functioning of the type specific ecosystem and the achievement of the values specified above for the biological quality elements. Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.

Moderate Status – Score 50%
Conditions consistent with the achievement of the values specified for the biological quality elements. (Includes phytoplankton, Macrophytes and phytobenthos, Benthic invertebrate fauna, Fish fauna)

Poor Status – Score 25%
Waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor.

Bad Status – Score 0%
Waters showing evidence of severe alterations to the values of the biological quality elements for the surface water body type and in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent, shall be classified as bad.

ENV-NSE1 Noise Pollution

Scoring is based on the level of noise from the power plant that can be heard in industrial, recreational (outdoor) and residential areas.

Icelandic regulations sets the limit of 70dB on noise levels in industrial areas. The World Health Organisation provides community noise guidelines as follows:

Environment	Critical health	Sound level	Time hours

	entertainment	impairment		

	Score 0% Noise levels exceed limit for industrial, recreational or residential areas. **Score 50%** Noise levels are on the threshold of limits for industrial, recreational or residential areas. **Score 100%** Noise levels remain below limits for industrial, recreational or residential areas.
ENV-NSE2 Odour	Scoring is base on whether the smell of H_2S gas is detectable in recreational or residential areas around the power plant. In concentrations above 4,7 ppb, H_2S odour is detectable by 50% of humans. **Score 0%** If H_2S concentrations are above 4,7ppb in residential or recreational areas **Score 50%** **If** H_2S concentrations are at 4,7ppb in residential or recreational areas **Score 100%** **If** H_2S concentrations are below 4,7 ppb in residential or recreational areas.
ENV-ECO1 Hotspots of biodiversity	Scoring is based on whether or not a biodiversity hotspot are likely to be impacted by the energy project **Score 0%** Biodiversity hotspot likely to be impacted **Score 100%** Biodiveristy hotspot not likely to be impacted. Lists of biodiversity hotspots around the world are kept by conservation organizations such as Conservation International[1].
ENV-ECO2 Threatened Species	Scoring is based on whether or not threatened species are likely to be impacted by the energy project **Score 0%** Threatened species likely to be impacted. **Score 100%** Threatened species not likely to be impacted. Lists of threatened around the world are kept by conservation organizations such as the International Union for Conservation of Nature[2].
ENV-ECO3 Ecosystem disturbance	Scoring is based on the EU Water Framework Directive specifications for the general characteristics or rivers and lakes , including physio-chemical, hydromorphological and biological elements.

[1] http://www.biodiversityhotspots.org/
[2] http://www.iucn.org/

	High Status – Score 100% There are no, or only very minor, anthropogenic alterations to the values of the physio-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. These are the type-specific conditions and communities. **Good Status – Score 75%** The values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions. **Moderate Status – Score 50%** The values of the biological quality elements for the surface water body type deviate moderately from those normally associated with the surface water body type under undisturbed conditions. The values show moderate signs of distortion resulting from human activity and are significantly more disturbed than under conditions of good status. **Poor Status – Score 25%** Waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor. **Bad Status – Score 0%** Waters showing evidence of severe alterations to the values of the biological quality elements for the surface water body type and in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent, shall be classified as bad.
ENV-GLB1 Global	Scoring is based on (a) the level of national GHG emissions from geothermal energy in relation to internationally agreed targets compared to baseline levels from 1990. (b) the level of project GHG emissions in relation to internationally agreed targets compared to baseline levels from 1990. The new Icelandic Kyoto target was agreed in 2009. The target for Iceland is to maintain GHG emissions at 30% below 1990 levels by 2020. **Score 100%** (a) National GHG emissions from geothermal energy are 30% below 1990 levels (b) Project GHG emissions are 30% below 1990 levels **Score 50%** (a) National GHG emissions from geothermal energy are 15% below 1990 levels (b) Project GHG emissions are 15% below 1990 levels **Score 0%** (c) National GHG emissions from geothermal energy are equal to or above 1990 levels (d) Project GHG emissions are equal to or above 1990 levels

ENV-RES1 Productive Lifetime of Resource	The scoring for this indicator is based on (a) how many years the national geothermal resource can sustain the current level of production (b) how many years the project geothermal resource can sustain the current level of production Under 25 years **Score 0%** 25- 49 years **Score 25%** 50-74 years **Score 50%** 75-100 years **Score 75%** 100 years or more **Score 100%**
ENV-RES2 Changes in Dissolved Chemicals	The scoring for this indicator is based on whether dissolved chemicals will have positive or negative impacts on the geothermal resource. Major negative impacts **Score 0%** Moderate negative impacts **Score 25%** Minor negative impacts **Score 50%** Insignificant impacts **Score 75%** Some positive impacts **Score 100%**
ENV-RES3 Utilization Efficiency	Scoring for this indicator is based on (a) the utilization efficiency of the national geothermal resource (b) the utilization efficiency of the project geothermal resource The scoring is calculated by using the standard deviate and average values for the utilization efficiency of all geothermal plants in Iceland. Very poor utilization efficiency **Score 0%** Poor utilization efficiency **Score 25%** Average utilization efficiency **Score 50%** Good utilization efficiency **Score 75%** Very good utilization efficiency **Score 100%**
ENV-RES4 Micro-Seismic Activity	Scoring is based on the type of impact micro-seismic activity has (a) on the national geothermal resource (b) on the project geothermal resource Negative impacts **Score 0%** Some negative impacts **Score 25%** Neutral impacts **Score 50%** Some positive impacts **Score 75%** Positive impacts **Score 100%**

ENV-RES5 Reclamation Time	Scoring is based on (a) the length of time it would take the national geothermal resource to recover from exploitation in terms of pressure and temperature. (b) the length of time it would take the project geothermal resource to recover from exploitation in terms of pressure and temperature. Not possible to reclaim **Score 0%** Longer than productive lifetime **Score 25%** Close to productive lifetime **Score 50%** Shorter than productive lifetime **Score 75%** No reclamation time needed **Score 100%**

Scoring and Assessment Functions for Institutional Indicators	
Indicator Code	**Scoring**
INST-OCP2 Standard of Company Management Systems	Scoring is based on whether the developer company has an adequate environmental management system. **Score 0%** The developer company has no basic environmental management system in place **Score 100%** The developer company has a basic environmental management system in place A basic environmental Management system should include an environmental policy, environmental programme or action plan, organisational structure, integration into operations, a documentation system in order to collect, analyze, monitor and retrieve information, corrective & preventive action, EMS audits, management review, training and external communications.[1] In the EU companies are encouraged to voluntarily adopt international EMS standards such as ISO14001, however in other countries legislation regarding the use of environmental management systems may not exist at all.
INST-REG1 Environmental and Social Protection in Policy or Law	As it is difficult to determine exactly how much money a nation should spend on environmental protection, the scoring for this indicator is based on the yearly amount the local and national government dedicates to expenditure on environmental protection as a percentage of GDP compared to the lowest amount in the past decade. **Score 0%** Government expenditure on environmental protection as a percentage of GDP is below the average for the past decade. **Score 50%** Government expenditure on environmental protection as a percentage of GDP is the same as the average for the past decade. **Score 100%** Government expenditure on environmental protection as a percentage of GDP is above the average the past decade.
INST-GOV1 Agreement of political form of government with cultural and social norms	Scoring is based on the scale used by Transparency International in their Corruptions Perception Index [2] The Corruption Perceptions Index (CPI) measures the perceived level of public-sector corruption in 180 countries and territories around the world. The CPI is based on 13 different expert and business surveys. Countries are awarded a score between 1 and 10. A score of 10 indicates that the perceived corruptions levels in the country are as low as possible.

[1] http://ec.europa.eu/environment/emas/about/enviro_en.htm
[2] http://www.transparency.org/

	For the purposes of this assessment the scores are then converted to a percentage.
INST-GOV2	Scoring is based on the number of cases against the owner company in the supreme court per year compared to the average number of cases in the past decade. **Score 0%** Number of cases against the owner company in the supreme court is above the average for the past decade. **Score 50%** Number of cases against the owner company in the supreme court is the same as the average for the past decade. **Score 100%** Number of cases against the owner company in the supreme court is below the average for the past decade.
INST-POL1 Democracy	Scoring is based on the scale used by Freedom House to measure the level of democracy for a nation. Freedom House scores range between 1 to 7, with a score of 1 being the most free. For the purposes of this assessment the scores are then converted to a percentage.
INST-POL3 Political Alienation	Scoring is based on the percentage of the electorate that voted in the last elections.
INST-R&D1 Company support of energy R&D expenditure	As it is difficult to determine the ideal amount of support companies should contribute to geothermal energy R&D, scoring is based on the yearly percentage of company expenditure on energy R&D compared to the average level of expenditure for that decade. **Score 0%** Company expenditure on energy R&D is below the average level for the past decade **Score 50%** Company expenditure on energy R&D is the same as the average level for the past decade **Score 100%** Company expenditure on energy R&D is above the average level for the past decade
INST-R&D2 Government contribution to organizational capacity dedicated to energy R&D	As it is difficult to determine the ideal amount of support governments should contribute to geothermal energy R&D capacity, scoring is based on the numbers of personnel working in the geothermal energy theme in public institutions compared to the average numbers for that decade **Score 0%** Number of personnel working in the geothermal energy theme in public institutions is below the average for the past decade. **Score 50%** Number of personnel working in the geothermal energy theme in public institutions is the same as the average for the past decade. **Score 100%** Number of personnel working in the geothermal energy theme in public institutions is above the average for the past decade.
INST-R&D3	As it is difficult to determine the ideal amount of support governments

Government support of energy R&D expenditure	should contribute to geothermal energy R&D expenditure, scoring is based on the amount of total geothermal R&D expenditure support by government compared to the average numbers for that decade **Score 0%** Government contribution to total geothermal energy R&D expenditure is below the average for the past decade. **Score 50%** Government contribution to total geothermal energy R&D expenditure is the same as the average for the past decade. **Score 100%** Government contribution to total geothermal energy R&D expenditure is above the average for the past decade.

Scoring and Assessment Functions for Social Indicators	
Indicator Code	**Scoring**
SOC-SW1 Contribution to society	Scoring is based on a) Local level: the income to expenditure ratio of the host municipality for the geothermal energy project b) National level: the income to expenditure ratio of municipalities likely to be affected by the energy project. **Score 0%** a) Municipality income to expenditure ratio is less than 1 b) Average of all affected municipalities less than 1 **Score 50%** a) Municipality income to expenditure ratio is equal to 1 b) Average of all affected municipalities equal to 1 **Score 100%** a) Municipality income to expenditure ratio is greater than 1 b) Average of all affected municipalities greater than 1
SOC-SW2 Security of support service processes	Scoring is based a) on how the percentage of unlicensed teachers in schools in the region affected by the energy project compares to the national average for unlicensed teachers. b) on how the percentage of unlicensed teachers in schools in the municipality affected by the energy project compares to the regional average for unlicensed teachers. **Score 0%** a)Percentage of unlicensed teachers in schools in the region is higher than the national average b) Percentage of unlicensed teachers in schools in the municipality is higher than the regional average **Score 50%** a)Percentage of unlicensed teachers in schools in the region is the same as the national average b) Percentage of unlicensed teachers in schools in the municipality is equal to the regional average **Score 100%** a)Percentage of unlicensed teachers in schools in the region is lower than the national average b) Percentage of unlicensed teachers in schools in the municipality is lower than the regional average
SOC-EMP1 Unemployment	Scoring is based on a) how the rate of unemployment in the region affected by the energy project compares to the national unemployment rate b) how the rate of unemployment in the municipality affected by the energy project compares to the regional unemployment rate **Score 0%** a) Regional unemployment rate is higher than national unemployment rate b) Municipal unemployment rate is higher than regional unemployment rate **Score 50%** a) Regional unemployment rate is equal to national unemployment rate

	b) Municipal unemployment rate is equal to regional unemployment rate **Score 100%** a) Regional unemployment rate is lower than national unemployment rate b) Municipal unemployment rate is lower than regional unemployment rate
SOC-EMP2 Employee Origin	Scoring is based on the percentage of locally based or nationally based employees. Local Level: Percentage of project workers based locally National Level: Percentage of project workers residing in Iceland
SOC-INC1 Security of development of the individual	Scoring is based on a) how income levels in the region affected by the energy project compares to the national income levels b) how income levels in the municipality affected by the energy project compares to the regional income levels **Score 0%** a) Average regional income levels are lower than average national income levels b) Average municipal income levels are lower than average regional income levels **Score 50%** a) Average regional income levels are equal to average national income levels b) Average municipal income levels are equal to average regional income levels **Score 100%** a) Average regional income levels are higher than average national income levels b) Average municipal income levels are higher than average regional income levels
SOC-INC2 Access to shelter (or nutrition)	Scoring is based on the difference between changes in housing prices and changes in income levels at the national and local level. The local level means the municipality affected by the energy project. **Score 0%** a) National average housing prices increase at a faster rate than national average income b) Municipal average housing prices increase at a faster rate than municipal average income **Score 50%** a) National average housing prices increase at the same rate as national average income b) Municipal average housing prices increase at the same rate as municipal average income **Score 100%** a) National average housing prices increase at a slower rate than national average income b) Municipal average housing prices increase at a slower rate than municipal average income
SOC-INC3 Poverty	Scoring is based on the percentage of the national and local population below the poverty line compared to the EU-27 average. Percentage below EU-25 **Score 100%** Percentage the same as EU-25 **Score 50%**

	Percentage above EU-25 **Score 0%**
SOC-QS2 Economic diversity	Scoring is based on a) the level of economic diversity for a region compared to the level of economic diversity for a nation b) the level of economic diversity for a municipality compared to the level of economic diversity for a region **Score 0%** a) Regional economic diversity is less than national economic diversity b) Municipal economic diversity is less than regional economic diversity **Score 50%** a) Regional economic diversity is equal to national economic diversity b) Municipal economic diversity is equal to regional economic diversity **Score 100%** a) Regional economic diversity is more than national economic diversity b) Municipal economic diversity is more than regional economic diversity
SOC-QS3 Level of education and skills	Scoring is based on a) the percentage of developer company workers with university education level compared to percentages of municipal labour force with university education. b) the percentage of developer company workers with university education level compared to percentages of national labour force with university education. **Score 0%** a) Percentage of Landsvirkjun staff with university degrees is lower than the municipal average b) Percentage of Landsvirkjun staff with university degrees is lower than the national average **Score 50%** a) Percentage of Landsvirkjun staff with university degrees is equal to the municipal average b) Percentage of Landsvirkjun staff with university degrees is equal to the national average **Score 100%** a) Percentage of Landsvirkjun staff with university degrees is higher than the municipal average b) Percentage of Landsvirkjun staff with university degrees is higher than the national average
SOC-QS4 Level of education of least educated groups	Scoring is based on a) the average education level of the least educated 20% of Landsvirkjun employees compared to the the least educated 20% of the municipal workforce. b))the average education level of the least educated 20% of Landsvirkjun employees compared to the he least educated 20% of the national workforce. **Score 0%** a) Least educated 20% of Landsvirkjun staff has lower education level than least educated 20% of the municipal workforce b) Least educated 20% of Landsvirkjun staff has lower education level than least educated 20% of the national workforce **Score 50%**

	a) Least educated 20% of Landsvirkjun staff has same education level as least educated 20% of the municipal workforce b) Least educated 20% of Landsvirkjun staff has same education level as least educated 20% of the national workforce **Score 100%** a) Lowest educated 20% of Landsvirkjun staff has higher education level than lowest educated 20% of the municipal workforce b) Least educated 20% of Landsvirkjun staff has higher education level as least educated 20% of the municipal workforce
SOC-CH1 Cultural heritage or recreational areas	Scoring is based on the protection status of the area used by the power plant structures and infrastructure during the assessment year The Icelandic classification of protected areas divides areas into four groups **Score 0%** Project structures or infrastructure built since previous assessment are located in a Group I protected area **Score 25%** Project structures or infrastructure built since previous assessment are located in a Group II protected area **Score 50%** Project structures or infrastructure built since previous assessment are located in a Group III protected area **Score 75%** Project structures or infrastructure built since previous assessment are located in a Group IV protected area **Score 100%** Project structures or infrastructure built since previous assessment are not located in a protected area Energy projects in the operation phase are not penalized for buildings and infrastructure located in protected areas prior to the first sustainability assessment.
SOC-ACC1 Energy access	Scoring is based on the percentage of the population with access to high quality energy or electricity.

SOC-AFF1 Energy affordability	Scoring is based on the percentage of disposable income that low income households in the municipality and nation spend on electricity, gas and other fuels. The threshold for energy poverty is 10% of disposable income.[1] **Score 0%** Expenditure on electricity, gas and other fuels is more than 10% of disposable income for the lowest income quartile of the population **Score 50%** Expenditure on electricity, gas and other fuels is 10% of disposable income for the lowest income quartile of the population **Score 100%** Expenditure on electricity, gas and other fuels is lower than10% of disposable income for the lowest income quartile of the population
SOC-IE1 Income Inequity	The score is calculated by finding the average of part a and part b. **SOC-IE1a Income Inequity** Scoring is based on the value of the gini coefficient for the municipality and for Iceland. The gini coefficient is a measure of the disparity in income of a nation´s different income groups. Scores for the gini coefficient range between 0 and 100. A gini score of 0 indicates complete equality between income groups and therefore should be given the score of 100% for the assessment. All other scores are calculated using the following formula: (100-gini coefficient)% **SOC-IE1b Income Inequity Between Genders** Scoring is based on how the female-to-male income ratio for Landsvirkjun employees compares to local and national female-to-male income ratios. **Score 0%** Landsvirkjun female-to-male income ratio is lower than national or local female-to-male income ratio **Score 50%** Landsvirkjun female-to-male income ratio is equal to national or local female-to-male income ratio **Score 100%** Landsvirkjun female-to-male income ratio is higher than national or local female-to-male income ratio
SOC-OE1 Opportunities Inequity	Scoring is based on the percentage of Landsvirkjun female employees with university education compared to the percentage of local and national female workers with university education. **Score 0%** Percentage of female employees in Landsvirkjun with university education is lower than the percentage of local and national female workers with university education **Score 50%** Percentage of female employees in Landsvirkjun with university education is equal to the percentage of local and national female workers with university education

[1] http://www.inforse.org/europe/EU_energypoverty.htm

	Score 100% Percentage of female employees in Landsvirkjun with university education is higher than the percentage of local and national female workers with university education
SOC-EHS1 Worker safety or satisfaction	Scoring is based on the percentage of Landsvirkjun employees who are satisfied in their job.
SOC-SHS1 Standard of health care	Scoring is based on a) the rate of infant mortality for the nation compared to world infant mortality rates. b) the rate of infant mortality for the municipality compared to regional infant mortality rates **Score 0%** a) National infant mortality rate is lower than the world average b) Local infant mortality rate is lower than regional life expectancy **Score 50%** a) National infant mortality rate is equal to the world average b) Local infant mortality rate is equal to regional life expectancy **Score 100%** a) National infant mortality rate is higher than the world average b) Local infant mortality rate is higher than regional life expectancy
SOC-SHS2 Standard of Living	Scoring is based on a) the average life expectancy for the nation compared to world life expectancy b) the average life expectancy for the municipality compared to regional life expectancy. **Score 0%** a) National life expectancy is lower than the world average b) Local life expectancy is lower than regional life expectancy **Score 50%** a) National life expectancy is equal to the world average b) Local life expectancy is equal to regional life expectancy **Score 100%** a) National life expectancy is higher than the world average b) Local life expectancy is higher than regional life expectancy
SOC-SHS3 Adverse effects on communities	Scoring is based on the percentage of local population(s) that is required to relocate due to the energy project. Scores are calculated with the following formula: (100- percentage of local population that must relocate) %
SOC-PP1 Public participation during energy project	Scoring is based on the fulfillment of legal requirements regarding public participation during the energy project lifecycle. For countries with no regulations regarding public participation, any efforts to include the public in decision-making should be considered. **Score 0%** No public participation OR Public participation does not meet legal requirements

	Score 100% Public participation meets legal requirements

Sustainability Goal: Economic and Financial Viability (Goal 9)
Dimension /Theme / Sub-theme: Economic / Cost & Benefits

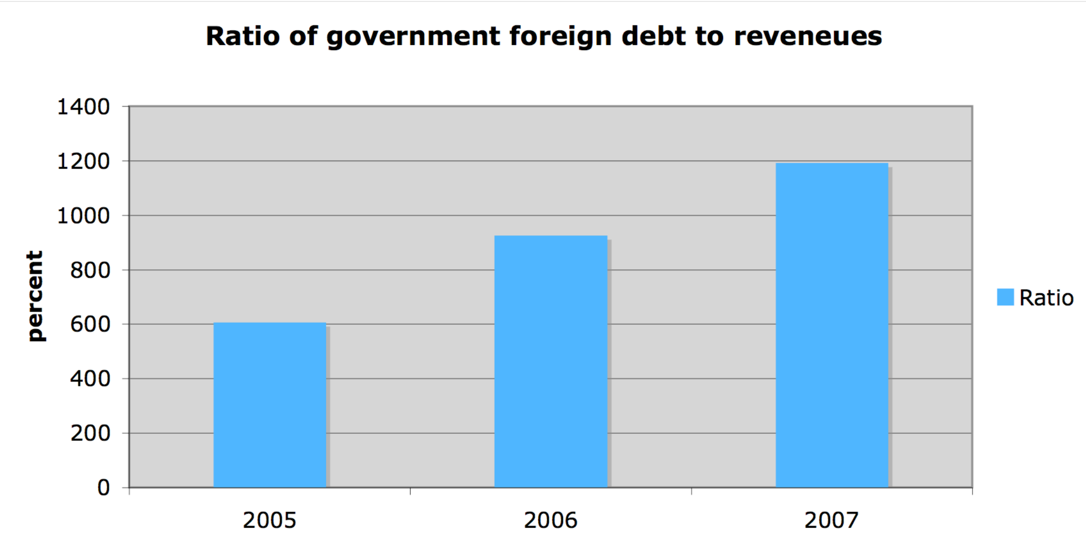
Metric:
Government foreign debt ratio

Target:
Debt to Revenue ratio should be below 290%

Project Phase: Operation

To be successful and profitable geothermal energy projects require a stable economic climate. The indebtedness of a national government provides an indication of the stability of government resources.

Indicator Trends



Source: *Central Bank of Iceland, Iceland Statistics*

Additional Information

From 2005 onwards, Icelandic foreign debt to revenue ratios are well above 290% , the level recommended by the IMF.

In the last quarter of 2008, foreign debts were ISK 14,327,425 million

As foreign debt for local governments is not calculated, the indicator is considered to be the same at both local and national level.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

ECO-CB2 Energy needs fulfilled

Sustainability Goal: Economic and Financial Viability (Goal 9)

Theme / Sub-theme: Economic / Costs & Benefits

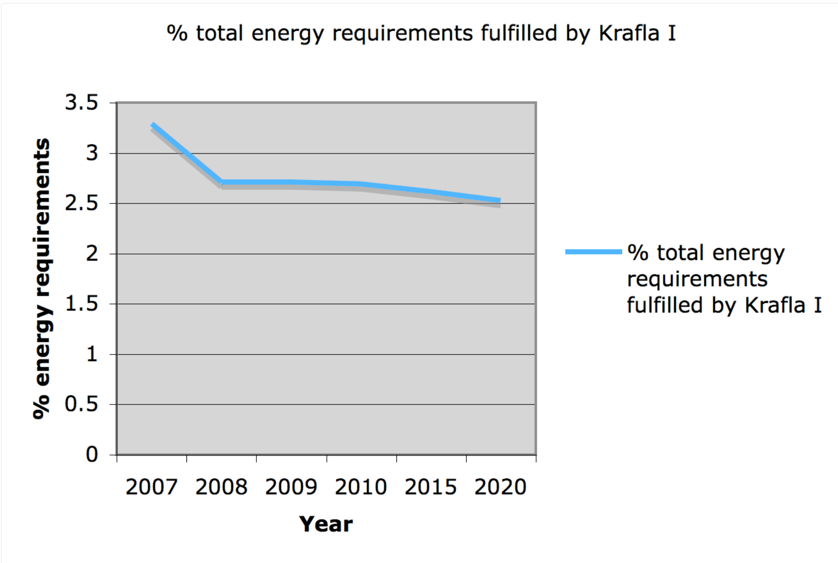
Metric:
Percentage of future energy needs fulfilled by the project

Target:
Project should fulfill valid energy needs

Project Phase: Operation

Geothermal energy projects should fulfill demonstrated energy needs for a nation. A geothermal energy project should only be undertaken if the need is clearly demonstrated.

Indicator Trends



Source: *Icelandic National Energy Authority (Raforkuspá 2008)*

Additional Information

The energy project at Krafla produces 60MW. In 2020, this would be 2.5% of the nations total energy needs, thus this project continues to fulfill genuine energy needs for the nation. As local energy needs are not calculated separately in Iceland, the score is the same for both local and national levels.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

ECO-DIV1 Energy diversity

Sustainability Goal: Energy Security (Goal 8)
Dimension /Theme / Sub-theme: Economic / Energy Security / Energy Diversity

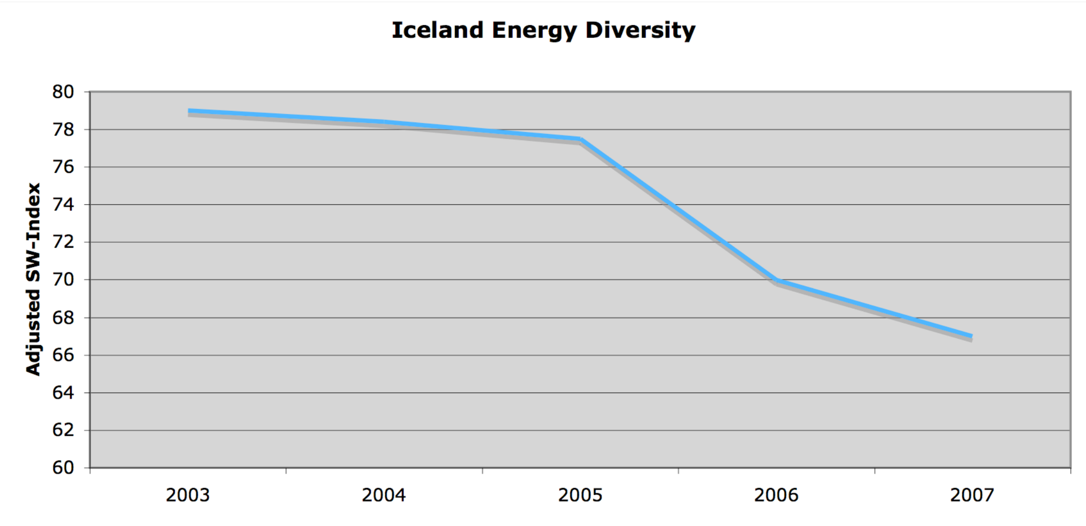
Metric:
Shannon-Weiner index of diversity for energy sources

Target:
Adjusted SW Index of 100%

Project Phase: Operation

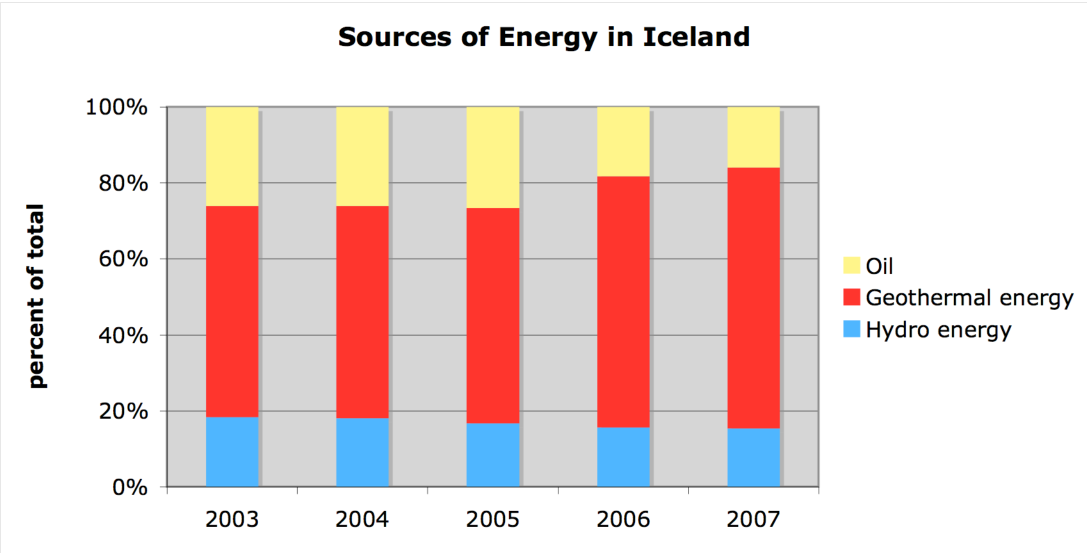
Geothermal energy projects may change the energy diversity of a nation. Energy diversity is desirable for energy security, however energy from local renewable sources may also lead to greater security due to reduced dependence on imported fossil fuels

Indicator Trends



Source: *Iceland Statistics*

Additional Information



Energy diversity is decreasing in Iceland due to reduced dependency on imported oil and coal and increased use of geothermal energy compared to energy from hydropower or other sources.

Data is only available up to 2007 for this indicator. As no data is available for types of energy used at local level, it is assumed that the local and national indicators show the same trends and are thus awarded the same score for the purpose of this assessment.

Score: 67% **2008**
(National)

Score: 67% **2008**
(Local)

Sustainability Goal: Efficiency (Goal

Dimension/ Theme / Sub-theme: Economic / Energy Efficiency

Metric:
Utilization efficiency for plant

Total efficiency of transmission and distribution

Sustainable energy is energy that is produced and distributed with maximum efficiency. The efficiency of a geothermal energy project will depend on the efficiency of utilization and the transmission and distribution system it uses.

Target:
Utilization efficiency should be high compared to other Icelandic power plants

Total efficiency of transmission and distribution should be within expect range predicted by 2030

Project Phase: Operation

Indicator Trends

The Krafla power plant has average utilization efficiency, compared to other power plants in Iceland. Krafla power plant does not operate as a cogeneration plant.

The overall efficiency for the distribution and transmission systems in 2008 is calculated as 93%. Distribution losses were 4.2% and transmission losses were 2.75%.

Additional Information

National transmission efficiency is predicted to be in the range of 2-3% in Iceland in 2030. Distribution efficiency is predicted to be between 3.9-4.9%
Total losses are therefore predicted to be in the range of 5.9-7.9% in 2030. Based on this, overall efficiency of the Icelandic transport and distribution system is predicted to be 92 -94% in 2030.

Exergy analyses for the Krafla power plant were performed to determined the efficiency of utilization. The results of this analyses were compared to results for other geothermal power plants in Iceland and the efficiency of utilization for Krafla was found to be average.

Source(s):
Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010.
Rósa Guðmundsdóttir, Well to Wheel Analysis of Future Hydrogen Pathway in Iceland, University of Iceland, 2009

Score: 100% 2008
(National)

Score: 60% 2008
(Local)

ECO-IE1 Energy import dependency

Sustainability Goal: Energy Security (Goal 8)
Dimension / Theme / Sub-theme: Economic / Energy Security / Imported Energy

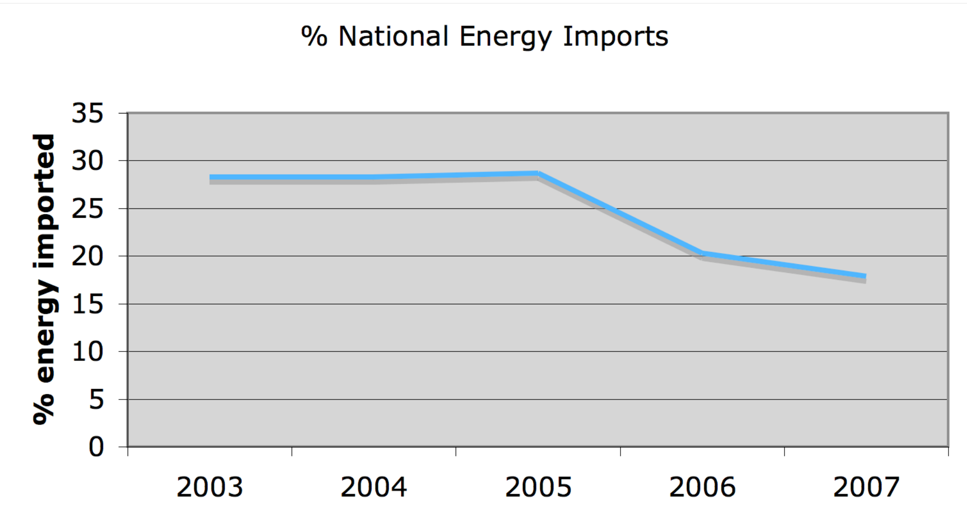
Metric:
Percentage imported energy sources

Target:
100% domestically produced energy

Project Phase: Operation

Geothermal energy projects can contribute to a nation's energy security by reducing dependency on imported fuels.

Indicator Trends



***Source:** Icelandic National Energy Authority*

Additional Information

Energy imports were 18% of total energy for Iceland in 2007.

Energy is not imported at the local level so the indicator is taken to be the same both at local and national level.

Score: 82% 2008
(National)

Score: 82% 2008
(Local)

ECO-IMT1 Reliability of Infrastructure

Sustainability Goal: Energy Equity (Goal 7)

Dimension / Theme / Sub-theme: Economic / Infrastructure / Maintenance

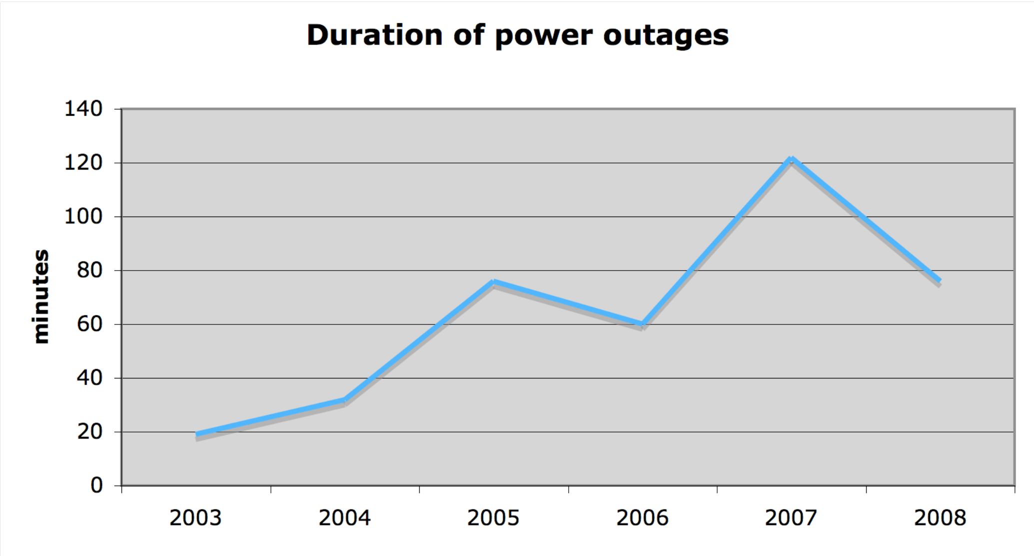
Metric:
Duration of power outages per year

Target:
Landsnet target – less than 50 minutes of outage per year

Project Phase: Operation

Geothermal projects require a reliable well-maintained infrastructure to efficiently and effectively supply energy to households and other users. The availability of the energy supplied by geothermal projects will depend upon the performance of the transmission or distribution systems in that country.

Indicator Trends



Source: *Landsnet*

Additional Information

Data for outages at the local level was not available, so the data for the whole national transmission system is applied to both local and national level indicators.

The target Landsnet have set for themselves is to have less than 50 minutes of outages per year. In 2008 they did not fulfil this target.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

ECO-RR1 Share of renewables in domestic energy production

Sustainability Goal: Energy Security (Goal 8)
Dimension / Theme / Sub-theme: Economic / Energy Security / Resources & Reserves

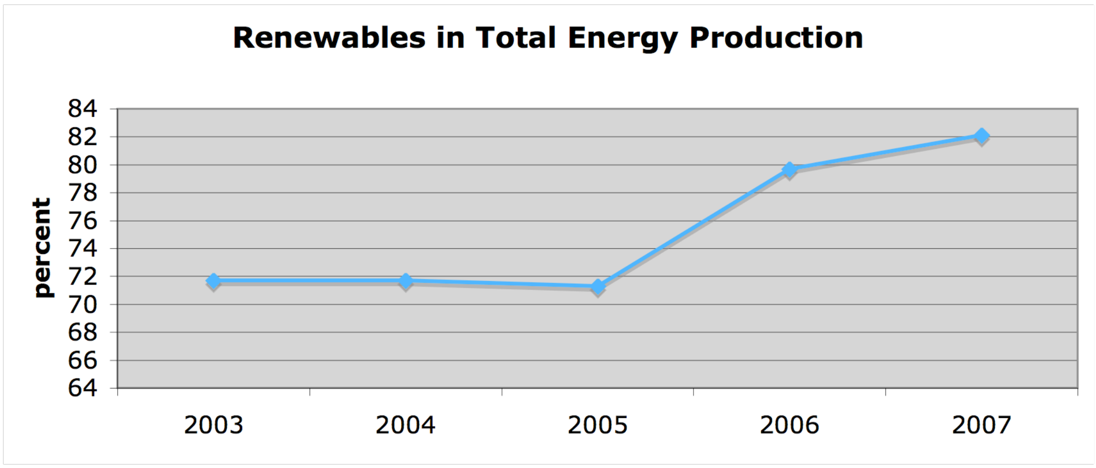
Metric:
Percentage of renewable energy in total energy production

Target:
100%

Project Phase: Operation

Geothermal energy projects contribute to the share of renewable energy production in a country. The use of sustainable renewable energy is encouraged in order to reduce a nation´s dependence on fossil fuels and increase its energy security.

Indicator Trends



Source: *Iceland Statistics*

Additional Information

The European Union a directive sets the quantitative target of 21% for electricity from renewable energy by the year 2010, as well as indicative targets for each Member State. Iceland has set its own target of having 100% of its energy from renewable sources by 2050.

Data is not available for 2008 so 2007 figures are used instead.
Data is not available for the use of renewables at local level so the national statistics are used as a substitute.

Score: 82% 2008
(National)

Score: 82% 2008
(Local)

ECO-RR3 Reserve Capacity

Sustainability Goal: Renewability (Goal 1), Energy Security (Goal 8)

Dimension/ Theme / Sub-theme: Economic / Energy Security /Resources & Reserves

Metric:
National reserve capacity ratio

Reserve capacity ratio for greater volcanic system

Target:
Reserve capacity of 0.5 or higher

Project Phase: Operation

For geothermal utilization to be sustainable it should be possible to rest one geothermal field and use another to maintain the same level of production from the system for 100 years or more. If the proven reserve capacity of the field is higher than total reserve capacity then there is a risk of overexploitation of the resource.

Indicator Trends

The reserve capacity ratio for the Krafla field is 0.7, leaving more than half of the reserve unused, therefore the geothermal resource is being used sustainably

The total reserve capacity for Iceland is 0.82, suggesting that on the national level, the reserve capacity ratio is excellent.

Source(s):

Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010.
J. Ketilsson et al, Mat á vinslugetu háhitasvæða, Orkustofnun, OS-2009/09

Additional Information

The national indicator is calculated by getting the average reserve capacity ratio for all geothermal systems that are currently utilized.

Total proven reserves for Iceland were 765MW in 2009 and estimated probable reserves were 4255MW for 50 years.

The Krafla geothermal project is located in the Krafla volcanic system. There are two high temperature geothermal fields associated with the Krafla system – Krafla and Námafjall.

Using the volumetric method, probable reserves for the whole Krafla volcanic system for 50 years is estimated at 322 MW.

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Score: 100% **2008**
(National)

Score: 75% **2008**
(Local)

ENV-AW1a Acidifying air pollutants in emissions

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Air & Water Pollution / Acidifying Substances

Metric:
Tonnes acidifying air pollutant released into the atmosphere due to geothermal operations

Geothermal energy projects may result in the release of acidifying air pollutants to the atmosphere during their construction and operation. These air pollutants can contribute to the acidification of air and water and have adverse environmental impacts.

Target:
Emissions per energy produced should not be higher than the average levels of the past decade.

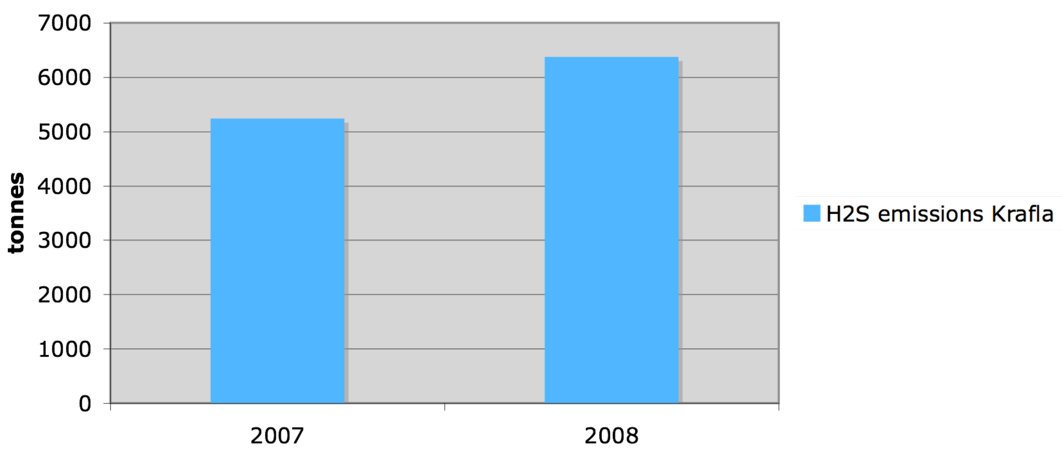
Project Phase: Operation

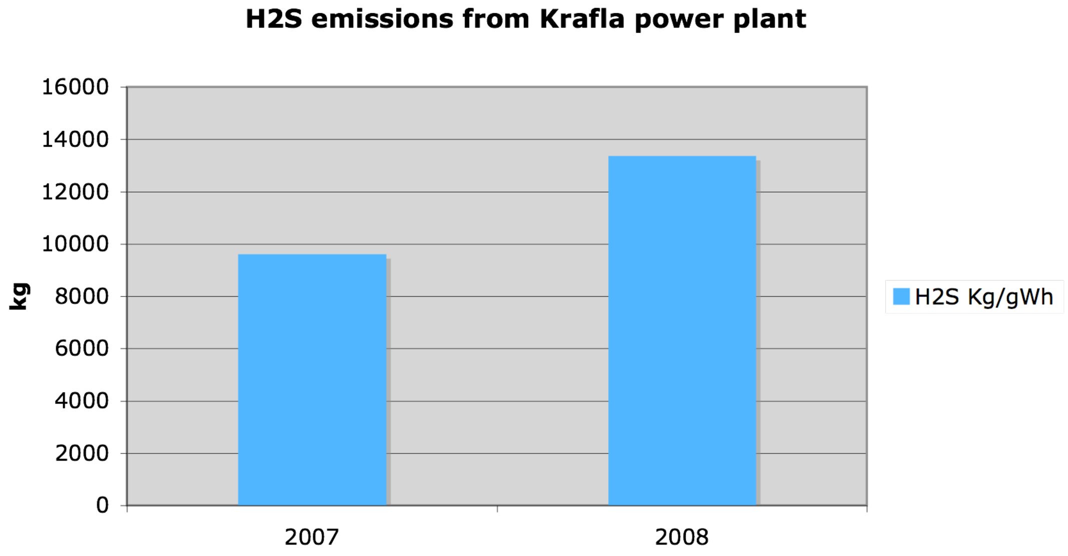
Indicator Trends

The Krafla geothermal power plant does not emit sulphur oxides (SOx) or nitrogen oxides (NOx)

Hydrogen Sulphide (H_2S) gas is emitted and may be oxidized to SOx. On average the Krafla plant emits 4300 tonns H_2S per year.

H2S emissions from Krafla power plant





Source(s):

Krafla og Bjarnaflag, Afköst borhola og efnainnihald vatns og gufu í borholum og vinnslurás árið 2007. Trausti Hauksson og Jón Benjamínsson. LV-2008/071

Landvirkjun Environmental Report, 2008

Stækkun Kröfluvirjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034

Additional Information

Geothermal energy exploitation is by far the largest source of sulphur emissions in Iceland. Sulphur from geothermal power plants is in the form of H_2S. Emissions have increased by 283% since 1990 due to increased activity in this field. (source Environmental Agency, GHG Inventory report 2009)

The European National Emisions Ceiling Directive (NECD) sets celings on emissions of various substances including SO2 and NOx, however, H_2S is not included in the list of substances.

Iceland has not as yet set any ceiling on the amount of H_2S that may be emitted by geothermal power stations in Iceland.

H_2S emissions per energy production for the Krafla plant increased in 2008 compared to 2007. Older data on the amount of H_2S emissions from the Krafla plant was not available.

It should also be noted that further studies are required to determine how the amount of H_2S emissions from geothermal power plants differs from the amount of H_2S emissions from natural sources.

This indicator is scored in the same way for both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on H2S emissions from all operating geothermal power plants in Iceland and assessing the projects contribution to these trends.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

Sustainability Goal: Minimal Environmental Impacts
Dimension / Theme / Sub-theme:
Environment / Air & Water Pollution / Thermal Pollution

Metric:
Temperature of water released from the geothermal power plant into the environment

Target:
Discharged fluid temperature should not differ from ambient levels

Project Phase: Operation

Geothermal energy projects may result in the release of hot water into the environment during construction or operation. Elevated water temperature typically decreases the level of dissolved oxygen in water, which can harm aquatic organisms. Thermal pollution may also increase the metabolic rate of aquatic animals and may also result in the migration of organisms to a more suitable environment. Biodiversity can be decreased as a result.

Indicator Trends

Temperature of Effluent Waters from Krafla Power Plant (2007)

	Temp °C
LÞ Skiljuvatn	124
Skiljustöð	72,8
Kæliturnar	46,2
V-yfirfall	36,3
Austurlandsvegur	26,7

Water of 100°C is discharged from the Krafla power plant into Hliðardalslækur at 125 kg/s. This affects plants on the surface of the river as it changes the chemical concentrations in the water.

Source:

Krafla og Bjarnaflag, Afköst borhola og efnainnihald vatns og gufu í borholum og vinnslurás árið 2007. Trausti Hauksson og Jón Benjamínsson.
LV-2008/071
Stækkun Kröfluvirjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034

Additional Information

According to the EU water framework directive, waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor.

The Krafla power plant has been in operation for several decades and the impact of thermal pollution from the plant has caused changes in biological communities. If thermal pollution were to be mitigated in the plant, this could change the state of existing biological communities that have developed since the power plant began operation. Further discussion is needed to determine which baseline conditions are appropriate: those before the power plant began operation or more recent conditions that existed before the sustainability assessment took place.

Baseline data was not present for the temperature of water bodies around the Krafla plant. It is assumed that the temperature of these water bodies was lower than any of the discharged fluids from the plant.

As water bodies are considered important nationally (as tourist attractions and fishing areas) this indicator is scored on both the local and national level. However, a more accurate view of the national performance of this indicator could potentially be assessed by collecting data on thermal pollution from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 25% 2008
(National)

Score: 25% 2008
(Local)

ENV-ECO1 Hotspots of Biodiversity

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Ecosystem /Biodiversity

Metric:
Likelihood of impact on hotspot of biodiversity

Geothermal energy resources are sometimes located in regions classified as biodiversity hotspots. Such hotspots are bio-geographic regions with a significant reservoir of biodiversity that are already threatened with destruction. Geothermal development projects may therefore put biodiversity hotspots at risk.

Target:
Development should not have impacts on hotspots of biodiversity.

Project Phase: Operation

Indicator Trends

The geothermal power plant at Krafla is not located near or in any hotspots of biodiversity and is unlikely to have an impact on any hotspot of biodiversity. There have been no expansions of the plant into any such areas.

Source(s): Stækkun Kröfluvirjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034
Gróðurfar við Kröflu, Halldór Sverrisson og Jón Guðmundsson, 2000
Athuganir á fuglum á áhrifsvæði Kröfluvirkjunar, Halldór Walter Stefánsson, 2000

Additional Information

This indicator is considered to act the same way on both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on impact on biodiversity hotspots from all operating geothermal power plants in Iceland and assessing the project´s contributionto these trends.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

ENV-ECO2 Threatened Species

Sustainability Goal: Minimal Environmental Impact (Gal 5)
Dimension / Theme / Sub-theme:
Environment / Ecosystem / Threatened Species

Metric:
Liklihood of impact on threatened species due to the power project

Target:
Development should not have any impact on threatened species

Geothermal energy developments may have impact on threatened species by changing their habitat through buildings, infrastructure or the release of effluent or chemicals into the environment.

Project Phase: Operation

Indicator Trends

No threatened species are found in the region where the power project is located and no threatened species are likely to be affected due to the project.

Source(s): Stækkun Kröfluvirjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034
Gróðurfar við Kröflu, Halldór Sverrisson og Jón Guðmundsson, 2000
Athuganir á fuglum á áhrifsvæði Kröfluvirkjunar, Halldór Walter Stefánsson, 2000

Additional Information

This indicator is considered to act the same way on both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on impacts on threatened species from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

ENV-ECO3 Ecosystem Disturbance

Sustainability Goal: Minimal Environmental Impact (Goal 5)
Dimensions / Theme / Sub-theme:
Environment / Ecosystems / Disturbance

Metric:
General status of ecosystem s according to EU water framework directive guidelines for water

Target:
High status

Project Phase: Operation

Geothermal energy developments may result in the disturbance of ecosystems. The release of geothermal brines into the environment may affect the state of surrounding aquatic or terrestrial ecosystems.

Indicator Trends

Hot waste water from the plant flows into Hlíðardals Lake and affects the surface plants, as dissolved chemicals in the water act as a fertilizer for them.

More wetland plants grow by the river due to a rise in groundwater, which has created ponds and floodlands. This has made these areas less hospitable for dry land plants.

The river and lake bottom is less permeable due to the deposition of chemicals since the developments in Leirbotnar and Krfafhliðum. The lake bottom in Dalleiru has been raised which causes the river to divert more often than before.

Source: Stækkun Kröfluvirjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034

Additional Information

According to the EU water framework directive, waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor.

As water bodies are considered important nationally (as tourist attractions and fishing areas) this indicator is scored on both the local and national level.

This indicator is considered to act the same way on both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on ecosystem disturbance from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 25% 2008
(National)

Score: 25% 2008
(Local)

ENV-FOR1 Deforestation due to energy project

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Land / Forests

Metric:
Percentage of forest area taken by energy project

Target:
No deforestation

Project Phase: Operation

Deforestation is a global environmental concern. Geothermal energy sources may be located in forested areas and developers will face the decision of where to locate the geothermal power generation facilities and infrastructure in order to minimize deforestation.

Indicator Trends

The Krafla area is sparsely vegetated and there are no areas that can be considered as forests, therefore the geothermal energy development in Krafla has not resulted in any deforestation during its construction or operation to date.

Source: *Landsvirkjun*

Additional Information

This indicator is considered to act the same way on both national and local levels. However a more accurate view of the national performance of this indicator could potentially be assessed by collecting data on deforestation from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

Sustainability Goal: Minimal Environmental impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Global Environmental Impacts

Metric:
Level of national GHG emissions from geothermal energy

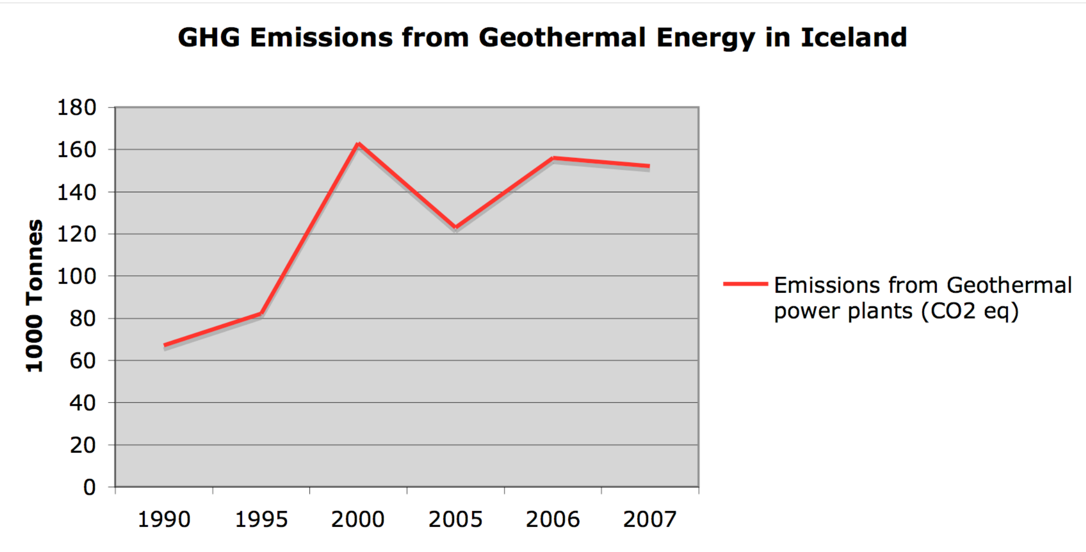
Level of emissions from geothermal energy project

Geothermal energy projects may produce green house gas emissions during their construction and operation, which contributes to a nations greenhouse gas inventory.

Target:
30% below 1990 levels (Kyoto target)

Project Phase: Operation

Indicator Trends



Source: *Iceland Statistics*

Additional Information

National GHG Emissions from Geothermal Energy

The Icelandic target for GHG emissions is 30% below 1990 levels by the year 2020. GHG emissions from geothermal were 67,000 tonnes in 1990. In 2007 they were 152,000 tonnes, well above this target.

Project GHG Emissions

Data for GHG emission in 1990 from the Krafla project is not available at present.

In 2008 and 2007, GHG emissions were 46,388 and 49,047 tonnes respectively.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

ENV-LSC1-L Subsidence

Sustainability Goal: Minimal Environmental Impacts (Goal)

Dimension/ Theme / Sub-theme:
Environmental / Land / Landscape

Metric:
Type of impact of subsidence on geothermal reservoir – positive or negative

Ground subsidence may be a result of geothermal fluid withdrawal during energy production. Subsidence is dependent on pressure drop in the reservoirs and geological rock formations above the reservoir. This may cause nearby structures to become unstable or may causes changes to landscape.

Target:
Positive impacts on reservoir from subsidence

Project Phase: Operation

Indicator Trends

The current rate of subsidence in the Krafla geothermal field is 1cm/year.
The subsidence center seems to moving from above the center of the magma chamber over to the center of the production area. There has not been any negative impacts due to ground subsidence at Krafla.

Source: *Rut Bjarnadóttir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010*

Additional Information

Note: This indicator is the local level component for the indicator ENV-LSC1. Scoring is for the local level only.

Score: N/A 2008
(National)

Score: 75% 2008
(Local)

ENV-LSC1-N Landscape esthetics

Sustainability Goal: Minimal Environmental Impact (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Landscape / Esthetics

Metrics:
Highest Icelandic protection rating of location of additional structures or infrastructure since year prior to first assessment

Many geothermal energy resources are located in regions that are considered to be of great natural beauty, in national parks or in aesthetically or historically valuable areas. The geothermal station may have an impact on the aesthetic quality of the landscape. It is therefore important that potential impacts are identified before development of new plants or expansion of current plants takes place.

Targets:
Verndaflokkur 4 (least protected areas)

Project Phase: Operation

Indicator Trends

The power plant in operation at Krafla is located near several protected areas, but there have not been any further expansions to the plant in recent years, therefore there has been no impact on protected areas.

Source: *Landsvirkjun*

Additional Information

In Iceland, protected areas are categorized into four categories known as Verndaflokkur, which takes account the living organisms, natural monuments and landscape features found in a particular area.

Although impacts on landscape are local, this indicator is scored on the local and national level because national tourist areas may be affected.

This indicator is the national level component of the indicator ENV-LSC1

Score: 100% 2008
(National)

Score: N/A 2008
(Local)

ENV-LU1 Land area used by energy project and infrastructure

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension/ Theme / Sub-theme:
Environmental / Land / Land Use

Metric:
Additional land area used by energy project since year prior to first assessment

During their lifetime, geothermal projects may increase the land area that they use due to the building of new structures, roads or the drilling of additional wells. It should be ensured that any planned land use is absolutely necessary.

Target:
Additional land area used should not cause total land area used by the energy project to exceed the average size of a geothermal plant.

Project Phase: Operation

Indicator Trends

There have been no further expansions of the energy project at Krafla since the nineties. Compared to 2007, the land use for Krafla I cannot be said to have exceeded the average land area for geothermal projects in 2008 (year of the first sustainability assessment), as there has been no additional land use apart from current structures.

Source: *Landsvirkjun*

Additional Information

The average land use for a geothermal power plant is 1-8 acre /MW

Source: Renewable Energy Policy Project[1]

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

[1] http://www.repp.org

ENV-NSE1 Noise pollution

Sustainability Goal: Minimal Environmental Impacts
Dimension / Theme / Sub-theme:
Environmental / Noise & Odour / Noise

Metric:
Noise levels (dB) in area surrounding the geothermal energy project

Geothermal energy projects may result in noise pollution due to noise produced during drilling, construction or operation. Noise pollution may affect human health and disturb nearby ecosystems.

Target:
Noise levels should not exceed WHO acceptable levels for any area.

Project Phase: Operation

Indicator Trends

Noise levels exceed acceptable levels for industrial areas (79dB) at turbines 1 and 2 and at the powerhouse.

Source: Landsvirkjun Environmental Report 2008

Additional Information

Noise is considered to be a local environmental impact, but the indicator is scored on the national level, as popular tourist areas may be affected. However, a more accurate view of the national performance of this indicator could potentially be assessed by collecting data on noise pollution from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

ENV-NSE2 Odour

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Noise & Odour / Odour

Metric:
Concentration of H_2S gas

Target:
Below 4,7 ppb in residential and recreational areas

Project Phase: Operation

Geothermal energy projects may result in the release of H_2S gas during construction and operation. H_2S gas can be an odour nuisance after a certain level.

Indicator Trends

According to H_2S levels were at at 7ppb around Viti. In Suðurhlíðar, a hiking area, H_2S levels were at 29ppb. This indicates that there is a detectable H_2S odour in tourist areas.

Source: *Stækkun Kröfluvirjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034*

Additional Information

Although odour nuisance is a local environmental impact, this indicator is also scored on the national level, as national tourist areas may be affected. However, a more accurate view of the national performance of this indicator could potentially be assessed by collecting data on odour from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

ENV-RES1c Changes in Dissolved Chemicals

Sustainability Goal: Renewability (Goal 1)

Dimension/ Theme / Sub-theme:
Environmental / Resource

Metric:
Dissolved SiO2 and Cl concentrations

Maintaining the temperature of the geothermal system is important as it allows production to continue. The concentration of dissolved chemicals in the water can then be used to estimate the temperature in the geothermal system. Some fields react to long term production by forming a steam cap. Production can also cause drawdown in the system and leading to inflow of cold causing the Cl concentration to decrease. Excessive production can cause the host rock to cool and that changes the SiO2 concentration

Target:
Dissolved SiO2 and Cl concentrations should indicate positive impacts for resource and should not indicate cooling of the resource

Project Phase: Operation

Indicator Trends

The average changes in all the wells indicate that the Cl concentration is increasing by 0.3% annually and the tSiO2 is decreasing by 1.4°C annually. In the Krafla field the change in dissolved Cl is associated with a change in enthalpy;
increase in dissolved Cl indicates that the enthalpy is increasing. The increase in Cl concentration has also been associated with an inflow of acidic fluid into the wells and a decrease when the acidic veins close up because of precipitation in the wells. The origin of this acidic fluid is from volcanic gases. The average overall changes in the Cl are very small, 0.3%, and can be considered as insignificant.
The decrease in $tSiO_2$ indicates that the host rock in the reservoir is cooling because of the fluid extraction, but this cooling is very small and can be considered as insignificant.

It is concluded that the geothermal production in the Krafla field has insignificant impacts on the chemical composition and there is very little indication of cooling in the reservoir.

Source:

Additional Information

Trends show a gradual increase in

For the years 2005-2007, the

ENV-RES1 Productive Lifetime

Sustainability Goal: Renewability (Goal 1)

Dimension/ Theme / Sub-theme:
Environment / Resource

Metric:
Number of years the geothermal resource can sustain current levels of production

Renewability is seen as a necessary characteristic of sustainable energy, as the resource in question must remain available for future generations. The productive lifetime of the geothermal resource is dependent on the change in physical properties of the fluid in the resource, mainly pressure drawdown and temperature changes. Overexploitation of the resource can shorten its productive lifetime, thus taking from its renewability.

Target:
100 years or more

Project Phase: Operation

Indicator Trends

Small temperature and pressure changes have been observed in the Krafla field which indicates a long productive lifetime of between 75 and 100 years.

Source: *Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010*

Additional Information

Data is not available for the productive lifetime of the national geothermal resource.

Score: N/A 2008
(National)

Score: 75% 2008
(Local)

ENV-RES1 Changes in Dissolved Chemicals

Sustainability Goal: Renewability (Goal 1)

Dimension/ Theme / Sub-theme:
Environmental / Resource

Metric:
Dissolved SiO2 and Cl concentrations

Target:
Dissolved SiO2 and Cl concentrations should indicate positive impacts for resource and should not indicate cooling of the resource

Project Phase: Operation

Maintaining the temperature of the geothermal system is important as it allows production to continue. The concentration of dissolved chemicals in the water can then be used to estimate the temperature in the geothermal system. Some fields react to long term production by forming a steam cap. Production can also cause drawdown in the system and leading to inflow of cold causing the Cl concentration to decrease. Excessive production can cause the host rock to cool and that changes the SiO2 concentration

Indicator Trends

The average changes in all the wells indicate that the Cl concentration is increasing by 0.3% annually and the tSiO2 is decreasing by 1.4°C annually. In the Krafla field the change in dissolved Cl is associated with a change in enthalpy;
increase in dissolved Cl indicates that the enthalpy is increasing. The increase in Cl concentration has also been associated with an inflow of acidic fluid into the wells and a decrease when the acidic veins close up because of precipitation in the wells. The origin of this acidic fluid is from volcanic gases. The average overall changes in the Cl are very small, 0.3%, and can be considered as insignificant.
The decrease in $tSiO_2$ indicates that the host rock in the reservoir is cooling because of the fluid extraction, but this cooling is very small and can be considered as insignificant.

It is concluded that the geothermal production in the Krafla field has insignificant impacts on the chemical composition and there is very little indication of cooling in the reservoir.

Source:

Additional Information

Trends show a gradual increase in

For the years 2005-2007, the

ENV-RES2 Changes in Dissolved Chemicals

Sustainability Goal: Renewability (Goal 1)

Dimension/ Theme / Sub-theme:
Environmental / Resource

Metric:
Dissolved SiO_2 and Cl concentrations

Maintaining the temperature of the geothermal system is important as it allows production to continue. The concentration of dissolved chemicals in the water can then be used to estimate the temperature in the geothermal system. Some fields react to long term production by forming a steam cap. Production can also cause drawdown in the system and leading to inflow of cold causing the Cl concentration to decrease. Excessive production can cause the host rock to cool and that changes the SiO_2 concentration

Target:
Dissolved SiO_2 and Cl concentrations should indicate positive impacts for resource and should not indicate cooling of the resource

Project Phase: Operation

Indicator Trends

In Krafla, the average overall changes in the Cl are very small, 0.3%, and can be considered as insignificant.

The decrease in $tSiO_2$ indicates that the host rock in the reservoir is cooling because of the fluid extraction, but this cooling is very small and can be considered as insignificant.

It is concluded that the geothermal production in the Krafla field has insignificant impacts on the chemical composition and there is very little indication of cooling in the reservoir.

Source: *Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010*

Additional Information

Data is not available for changes in dissolved chemicals for the national geothermal resource.

Score: N/A 2008
(National)

Score: 75% 2008
(Local)

Sustainability Goal: Efficiency (Goal 3)

Dimension/ Theme / Sub-theme: Economic / Energy Efficiency

Metric:
Utilization efficiency for plant

Sustainable energy is energy that is produced and distributed with maximum efficiency. The efficiency of a geothermal energy project will depend on the efficiency of utilization of extracted energy.

Target:
Utilization efficiency should be high compared to other Icelandic power plants

Project Phase: Operation

Indicator Trends

The Krafla power plant has average utilization efficiency, compared to other power plants in Iceland. Krafla power plant does not operate as a cogeneration plant.

Source(s):
Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010.

Additional Information

Exergy analyses for the Krafla power plant were performed to determined the efficiency of utilization. The results of this analyses were compared to results for other geothermal power plants in Iceland and the efficiency of utilization for Krafla was found to be average.

Data for the utilization efficiency for the national level is not yet available.

Score: N/A 2008
(National)

Score: 50% 2008
(Local)

ENV-RES4 Seismic Activity

Sustainability Goal: Minimal Environmental Impacts (Goal 5)

Dimension/ Theme / Sub-theme:
Environment / Resource

Metric:
Extent of impact of micro-seismic activity.

Micro seismic events are usually associated with geothermal systems, such activity usually has good influence on the geothermal system. The movement in the ground helps prevent precipitation build up in cracks in the reservoir and therefore help maintain permeability. The micro seismic activity can also have negative impacts; this is when the seismic events damage above ground constructions in the area.

Target:
The micro seismic events have positive impacts the geothermal system and enhances permeability considerably.

Project Phase: Operation

Indicator Trends

Micro-seismic activity in the Krafla geothermal system has positive impacts on the resource by enhancing permeability. There are no negative impacts on surrounding constructions due to micro-seismic events.

Source: *Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010.*

Additional Information

Data on micro-seismic events for the national geothermal resource as a whole is not available.

Score: N/A 2008
(National)

Score: 75% 2008
(Local)

ENV-RES5 Reclamation Time

Sustainability Goal: Renewability (Goal 1)

Dimension/ Theme / Sub-theme:
Environment / Resource

Metric:
The time in years it takes the resource, in terms of pressure and heat, to recover from exploitation

Exploitation of the geothermal resource at certain levels will deplete to resource to an extent that it must be rested for a certain period in order to recover in terms of pressure and heat. If the reclamation time is longer than the production time of the resource then the utilization is not considered sustainable. Overexploitation of the resource can increase the recovery time to unacceptable levels.

Target:
The reclamation time should not be longer than the production time of the resource.

Project Phase: Operation

Indicator Trends

There is currently little to reclaim in the Krafla field and it is not estimated to take a long time for the pressure to recover. There is little pressure drawdown or temperature decrease, so it is estimated that the resource would not take long to recover in terms of temperature and pressure, and is therefore being used in a fairly sustainable manner.

***Source:** Rut Bjarnadottir, Sustainability evaluation of geothermal systems in Iceland, Indicators for sustainable production, University of Iceland, 2010.*

Additional Information

Currently no models are available for the Krafla resource to enable estimation of reclamation time, so instead it was estimated by examining the available data on temperature and pressure.

There is no data at present for the reclamation time of the national geothermal resource.

Score: N/A 2008
(National)

Score: 75% 2008
(Local)

ENV-TOX1a Toxicity of H2S

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Environmental Toxicity / Toxicity of H2S

Metric:
Concentration of H_2S gas in recreational and inhabited areas (ppb)

Target:
No exposure above 100ppb to H_2S gas in recreational or inhabited areas.

Project Phase: Operation

Geothermal energy developments may result in the release of H_2S gas into the atmosphere during the exploration and operation phases of a project. The gas may be present in residential or recreational areas. H_2S gas is toxic in certain concentrations.

Indicator Trends

A 1993 model of H_2S concentration shows that levels will be more than zero in certain tourist areas e.g. Viti, Mt. Krafla and around the power plant itself. Levels do not exceed the 100ppb limit (0.15mg/m3). No inhabited areas are affected by the H_2S gas that is released from the power plant.

This is the only model for H_2S gas concentrations available for the Krafla area.

The model shows levels do not exceed 39ppb in any area.

Source: *Stækkun Kröfluvirkjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/034*

Additional Information

Baseline levels of H_2S gas were not available for the area around the Krafla plant and so they could not be taken into account for this indicator.

Although H_2S gas has a local impact, the same scoring is also applied at the national level, as areas affected by H_2S may be of national significance as tourist, cultural or recreational areas.

This indicator is considered to act the same way on both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on H_2S toxicity from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

ENV-TOX1b Toxicity of mercury gas

Sustainability Goal: Minimal Environmental Impacts (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Environmental Toxicity / Toxicity of Mercury gas

During exploration and operation, geothermal energy projects may result in the release of mercury (Hg) gas into the atmosphere. Mercury is toxic at certain levels.

Metric:
Concentration of mercury gas in the vicinity of the plant

Target:
Below WHO reference value

Project Phase: Operation

Indicator Trends

A 1993 report on mercury levels in the Krafla area shows Hg to be 2,0 ng/m3 in all areas. This is below the WHO reference value of 1 microgram / m3 for mercury vapour.

Mercury gas has not emitted in steam from the Krafla plant to date.

Source: *Stækkun Kröfluvirkjunar í Skútustaðahreppi, Suður-Þingeyjarsýslu um 40 MW, Mat á Umhverfisáhrifum, Landsvirkjun 2001, LV-2001/03*

Additional Information

Baseline levels of mercury gas were not available for the area around the Krafla plant and so they could not be taken into account for this indicator.

This indicator is considered to act the same way on both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on Hg toxicity from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 100% **2008**
(National)

Score: 100% **2008**
(Local)

Sustainability Goal: Minimal Environmental Impact (Goal 5)
Dimension / Theme / Sub-theme:
Environment / Environmental Toxicity / Toxicity of Metals

Metric:
Concentration of metals in effluent

Target:
Metals in effluent waters being released into the environment should remain below reference levels

During the construction and operation phases of geothermal energy projects, metals may be released into the environment through effluent from boreholes or runoff. Metals are toxic in certain concentrations.

Project Phase: Operation

Indicator Trends

Concentration of Metals in Effluent Waters for Krafla Power Plant in 2007

	Pumped water	Separation water	Cooling Tower Runoff water	Run-off Water to Hliðardals Lake	Hlíðardals-Lake
Hg	<0,002	0,008	0,0077	0,0275	0,0221
Cr	0,0465	0,0215	1,42	0,712	0,506
Cu	<0,1	0,811	0,143	0,514	1,19
As	**13,1**	**41,8**	**1,21**	**21,2**	**18,7**
Pb	<0,01	**0,105**	**0,0805**	**0,0684**	**0,0848**
Zn	0,488	1,5	2,68	2,04	2,14
Ni	0,0566	0,144	0,719	0,766	0,803
Cd	<0.002	<0.002	<0.002	<0.002	<0.002

The bolded numbers indicate where levels of metals exceed the recommended reference value and pose a threat to the environment, according to limits set by Icelandic law. (Reglugerdir 796 / 1999 and 800/1999)

***Source:** Krafla og Bjarnaflag, Afköst borhola og efnainnihald vatns og gufu í borholum og vinnslurás árið 2007. Trausti Hauksson og Jón Benjamínsson.
LV-2008/071*

Additional Information

Arsenic levels fall into group IV for three out of five effluent release points.

Baseline levels for metals in water bodies near the Krafla power plant were not available and so it could not be assessed if the levels in effluent released into the environment were higher than ambient levels. Icelandic reference values were used to assess toxicity.

The impact levels of toxic chemicals in ground water are as follows according to Icelandic law:

Group I	Very little or no risk of impact
Group II	Little risk of impact
Group III	Impact on certain organisms
Group IV	Impacts can be expected
Group V	Serious impacts on ground water quality

(Reglugerdir 796 / 1999 and 800/1999)

This indicator is considered to act the same way on both national and local levels. However a more accurate view of national performance of this indicator could potentially be assessed by collecting data on metals toxicity from all operating geothermal power plants in Iceland and assessing the project´s contribution to these trends.

Score: 25% 2008
(National)

Score: 25% 2008
(Local)

Sustainability Goal: All
Dimensions / Theme / Sub-theme:
Institutional / Governance / Government

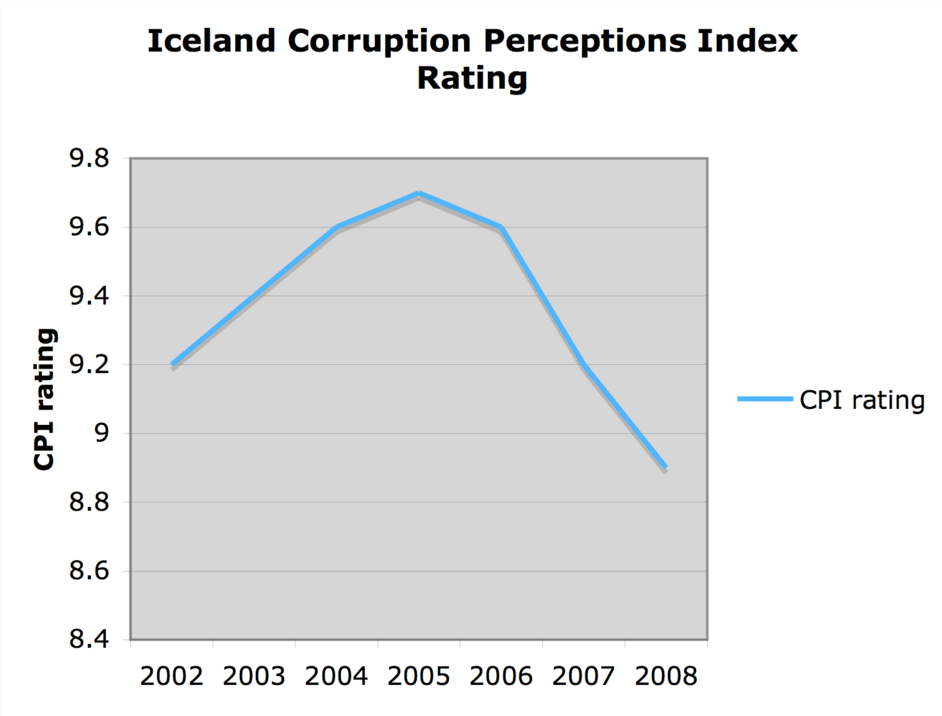
Metric:
Transparency International Corruption Perceptions Index

Target:
Grade 10 of CPI scale

Project Phase: Operation

Stable political and economic environments are desirable for geothermal energy developments. Increased corruption or perceptions of corruptions in a host country can leave the geothermal project open to risks stemming from political or economic instability.

Indicator Trends



Source: *Transparency International* [1]

[1] Transparency International recommends that due to the methodology used in calculating the CPI, the only reliable way to compare a country's score over time is to go back to individual survey sources, each of which can reflect a change in assessment. (http://www.transparency.org)

Additional Information

National Trends

Iceland ranked as no. 6 in the world in 2007 and no. 7 in 2008.

The Icelandic corruption perception index fell to its lowest in six years in 2008.

Regional / Municipal Trends

As regional and municipal data is not collected for this indicator, the national data is used as a substitute.

Score: 89% 2008
(National)

Score: 89% 2008
(Local)

INST-GOV2 Corporate corruption

Sustainability Goal: Corporate Social Responsibility (Goal 10)
Dimension/ Theme / Sub-theme:
Institutional / Governance / Company

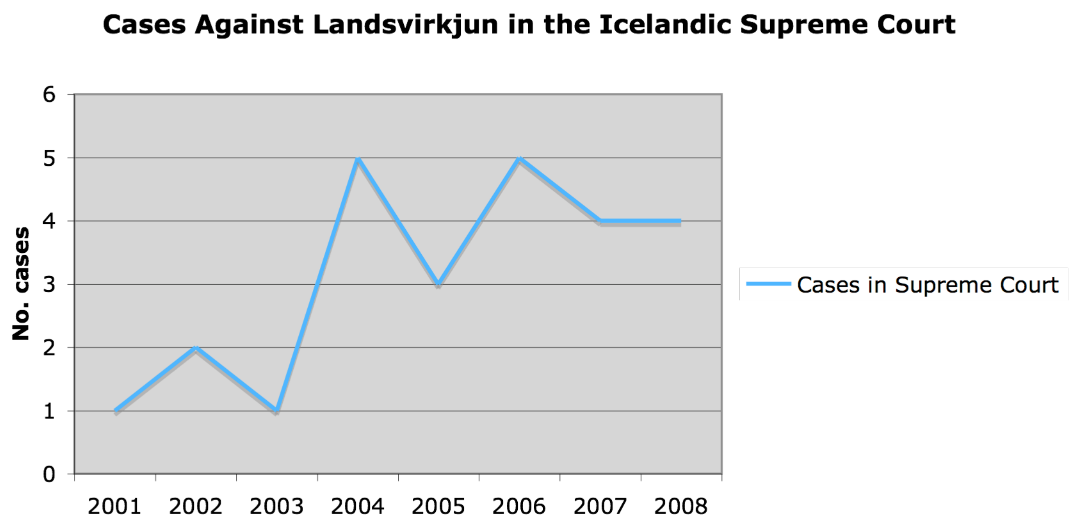
Metric:
Number of cases against the owner company in the supreme court per year

Geothermal energy projects benefit from the developer company having a good corporate image. This is more likely to attract investment and avoid reputational risk and community resistance to projects.

Target:
Number of cases per year should be lower than average number of cases in the last decade.

Project Phase: Operation

Indicator Trends



Source: *Icelandic Supreme Court*

Additional Information

There were 4 cases against Landsvirkjun in the Supreme Court in 2008. The average number of cases over the last decade is 3.

As the company operates both locally and nationally, the scores for both levels are taken to be the same.

Score: 0% **2008**
(National)

Score: 0% **2008**
(Local)

INST-OCP2b Presence of Environmental Monitoring System

Sustainability Goal: All
Dimension / Theme / Sub-theme:
Institutional / Capacity / Owner Capacity

Metric:
Presence of a published program for environmental monitoring with listing of what is being monitored.

Geothermal energy projects have environmental impacts that need to be monitored during during the project life cycle. Companies may use internationally recognized management systems or simply have a published program with a listing of what is being monitored.

Target:
Company should have an environmental monitoring system.

Project Phase: Operation

Indicator Trends

Since January 2009, all of Landsvirkjun´s operations had received environmental management certification in accordance with ISO 14001.

Landsvirkjun has used Green Accounting since 2006 to report on Landsvirkjun´s energy division. The 2008 green accounting report includes information on all of Landsvirkjun´s operations. Landsvirkjun has set out an environmental policy and objectives against which it measures progress by reporting on a number of environmental factors that are considered important.

Source: *Landsvirkjun*

Additional Information

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

Sustainability Goal:
System / Subsystem:
Orientor of Viability:
Theme / Sub-theme: Institutional /

Metric:
Freedom House democracy rating

Target:
Free status

Project Phase: Operation

According to democratic peace theory, democratic countries have lower levels of political risk. It is desirable that the host country for a geothermal energy project carries as little risk as possible, therefore it is more favourable to locate in a country with democracy status.

Indicator Trends

Since 2002, Iceland has been evaluated on the basis of political rights and civil liberties by Freedom House and given a status of "Free" . The three Freedom House statuses are Free, Partly Free and Not Free.

Source: *Freedom House*

Additional Information

National Trends

Iceland is considered a free democracy and thus is unlikely to be subject to serious political instability that would jeopardize the future of geothermal energy developments

Regional / Municipal Trends

Freedom House only evaluates democracy levels at a national level, therefore the national data is used here as a substitute for regional or municipal data.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

INST-POL3 Political Alienation

Sustainability Goal: All
Dimension / Theme / Sub-theme:
Institutional / Political Risk

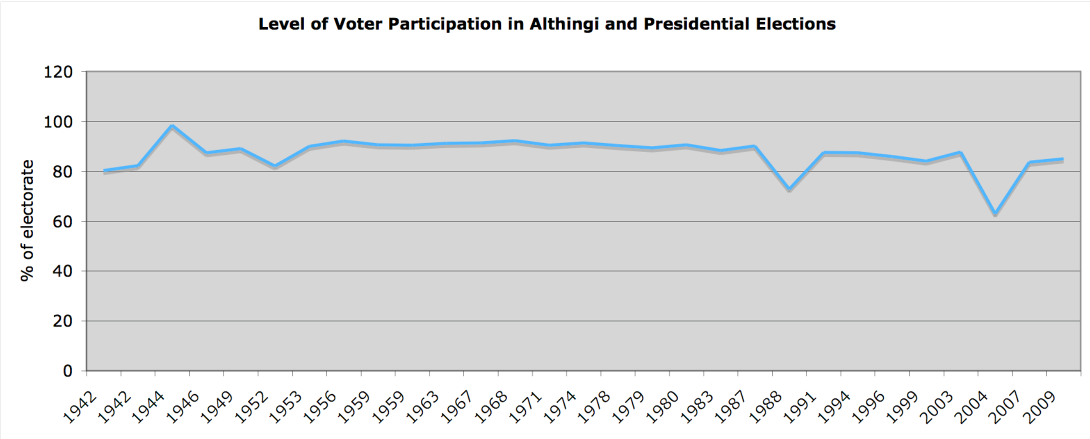
Metric:
Level of voter participation in elections

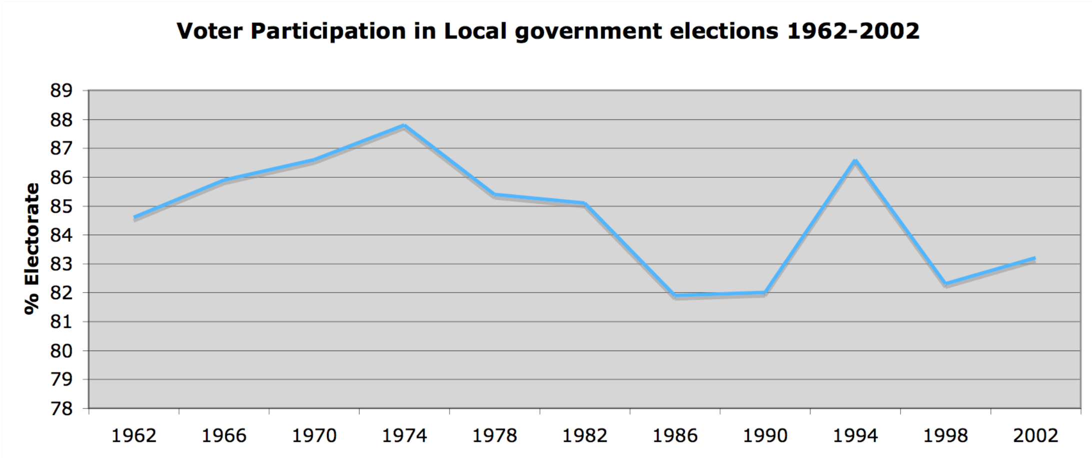
Target:
100% participation

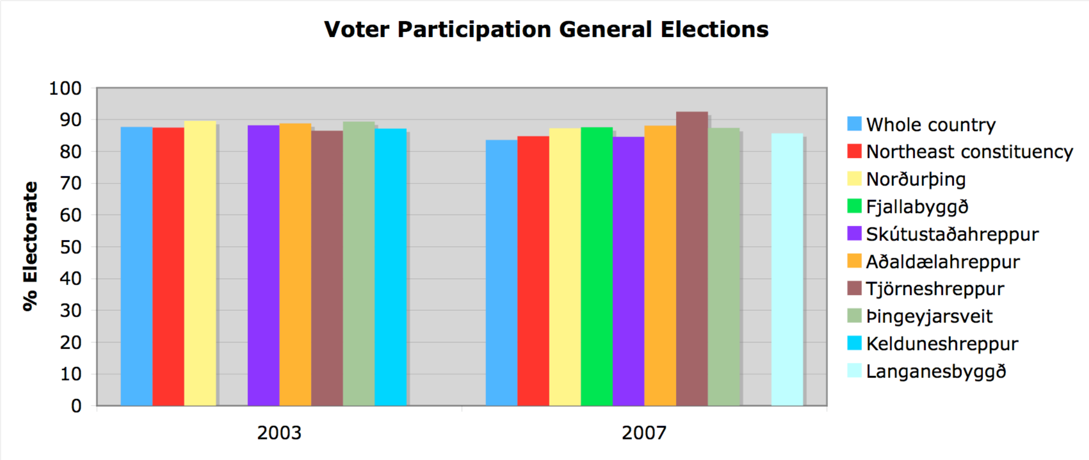
Project Phase: Operation

Very high or very low voter participation can represent a growing distrust of a government or disagreement with that form of government. It is important to monitor trends in political alienation as a political climate with high levels of political alienation may not provide the stable environment necessary for a successful geothermal energy project.

Indicator Trends







Source: *Iceland Statistics*

Additional Information

National Trends

National voter participation in parliamentary and presidential elections appears to follow a gradual downward trend until 2007. This data was not used for the indicator as more recent data is available for general elections 2009.

In april 2009, emergency general elections were held in Iceland following the economic crises, with a voter turnout of 85%
(*Source: Iceland Statistics / National Electoral Commission of Iceland*)

This does not represent a drastic deviation from the overall national trend , however and is therefore most likely not indicative of serious political instability.

Region and Municipality Trends

Voter turnout for local government elections appears to be dropping in the late nineties and rises again slightly in 2002. Further data is not available.

Due to the lack of recent data, national voter participation for 2009 will be used as a substitute for local election data.

Score: 85% **2008**
(National)

Score: 85% **2008**
(Local)

INST-R&D1 Owner company contribution to energy R&D expenditure

Sustainability Goal: Innovation & Research (Goal 4)
Dimension/ Theme / Sub-theme:
Institutional / R&D

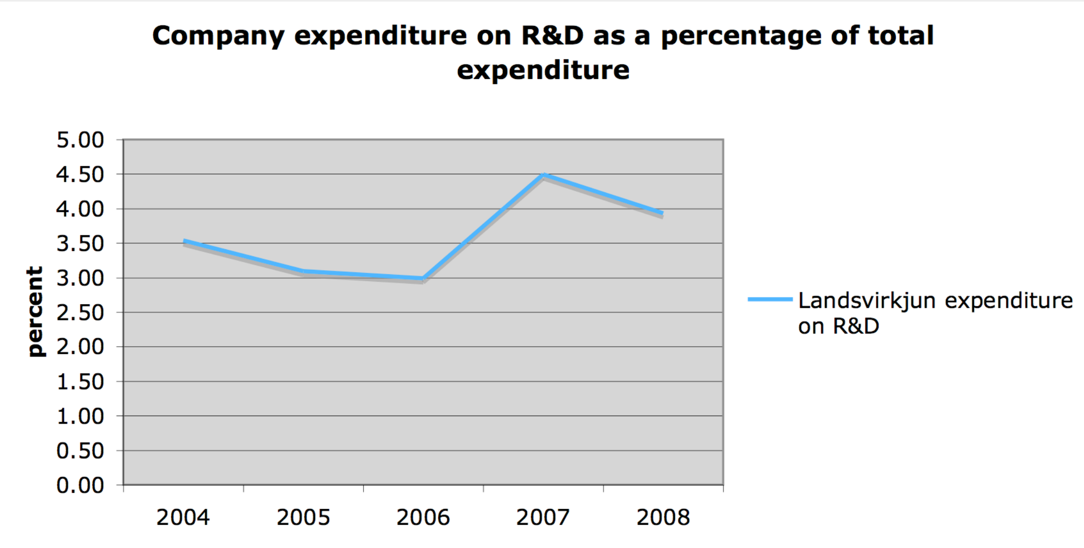
Metric:
Percentage of total developer company expenditure going to support of energy R&D

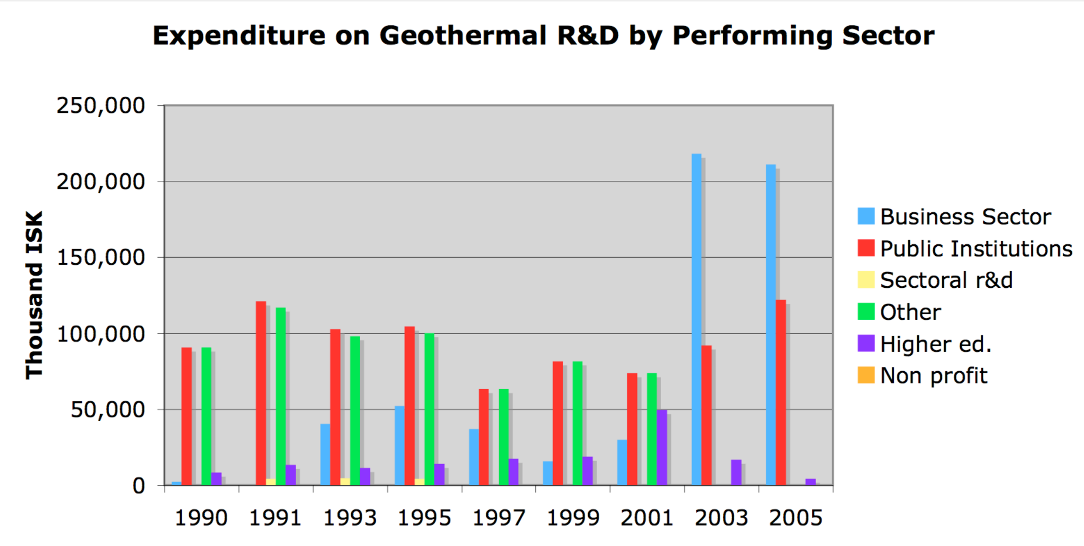
The support of the energy company for energy R&D for sustainable energy indicates their support for sustainable energy development. Investing in research and development will ensure higher quality energy development projects using the knowledge they have acquired.

Target:
Percentage should not be lower than the average percentage in the past decade.

Project Phase: Operation

Indicator Trends





Source: *Landsvirkjun, Rannis*

INST-R&D1 Owner company contribution to energy R&D expenditure

Additional Information

National Business Sector

Expenditure by the business sector in the geothermal power R&D theme is the largest among all performing sectors.

Note:
This indicator is considered to act the same way on both national and local levels.

Company

The company has decreased its expenditure on general research between 2007 and 2008. The average expenditure on research over the last decade (between 2004 and 2008) was 3.61%.

In 2008 expenditure was 3.93%.

It is not however possible to say how much of this expenditure was dedicated to geothermal research alone.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

INST-R&D2a Government support of geothermal energy R&D capacity

Sustainability Goal: Innovation & Research (Goal 4)
Dimension /Theme / Sub-theme:
Institutional / R&D

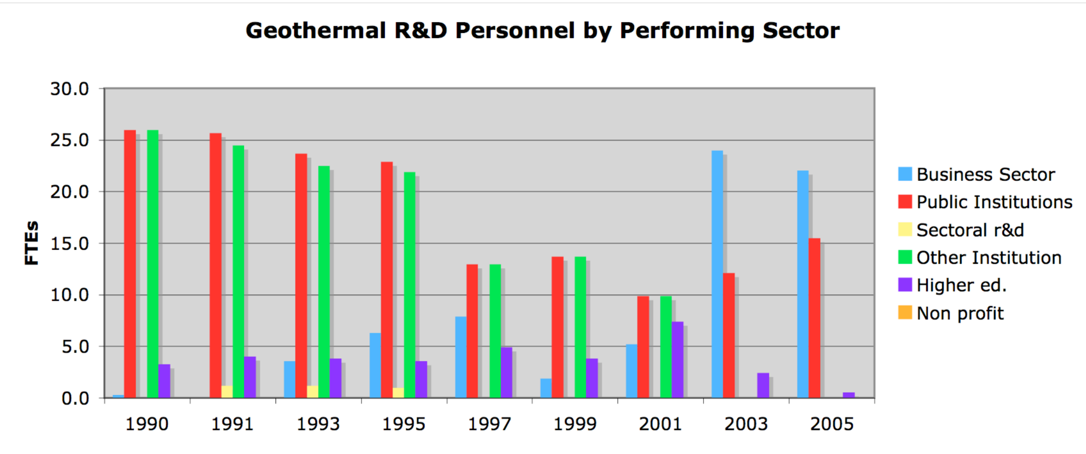
Metric:
Number of R&D personnel working in the geothermal power theme in public institutions.

Research & development benefits current and future geothermal development projects. Government institutions can provide capacity in geothermal power R&D by supporting research personnel. A nation that has strong institutional support for geothermal energy R&D is more likely to provide a favourable environment for geothermal energy projects.

Target:
Number should not be lower than average level in the last decade.

Project Phase: Operation

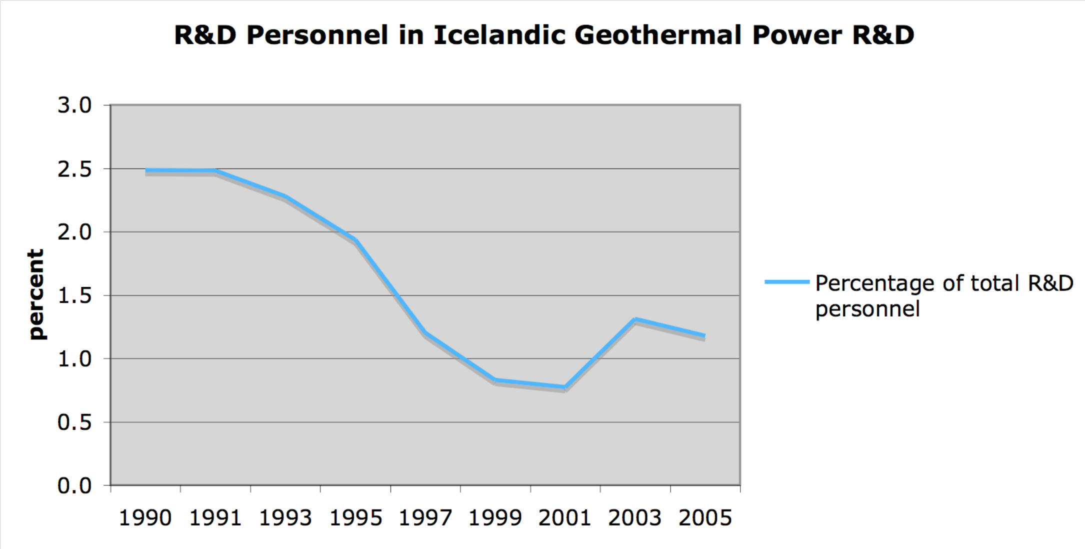
Indicator Trends



Source: *Rannis (Icelandic Centre for Research)*

INST-R&D2a Government support of geothermal energy R&D capacity

Additional Information



Source: *Rannis (Icelandic Centre for Research)*

National Trends

Total capacity (personnel) for geothermal power R&D has decreased as a percentage of total R&D capacity since 1990.

Note: this indicator is intended to be suitable for developed countries. A more suitable indicator would need to be chosen for a developing country, as developing country governments may prioritise expenditure in other areas.

Government Support of Geothermal R&D Capacity

The average number of R&D staff in public institutions working in the geothermal theme was 13 between 1999 and 2005. Further data is not available.

In 2005, there were 15.5 staff employed by public institutions.

Note: This indicator is considered to act the same way at local and national level.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

INST-R&D3 Government support of geothermal energy R&D expenditure

Sustainability Goal: Innvoation & Research (Goal 4)
Dimension / Theme / Sub-theme:
Institutional / R&D

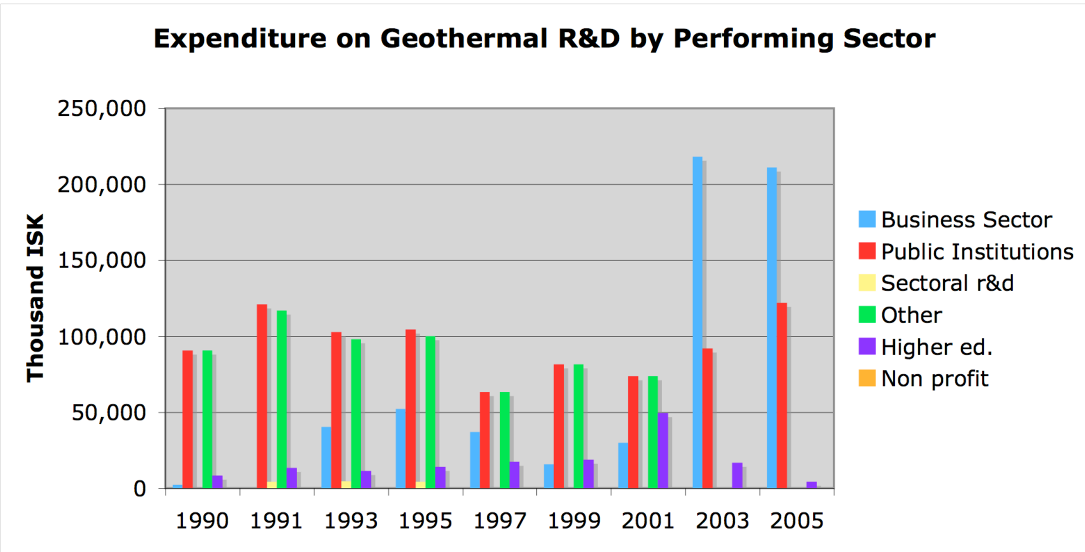
Metric:
Percentage of expenditure on geothermal R&D contributed by public sector (government) sources

Research & development benefits current and future geothermal development projects. Government can provide funding for geothermal power R&D to encourage new discoveries and innovations relating to geothermal energy development. A nation that has strong institutional support for geothermal energy R&D is more likely to provide a favourable environment for geothermal energy projects.

Target:
Percentage must not fall below the average level percentage of the past decade.

Project Phase: Operation

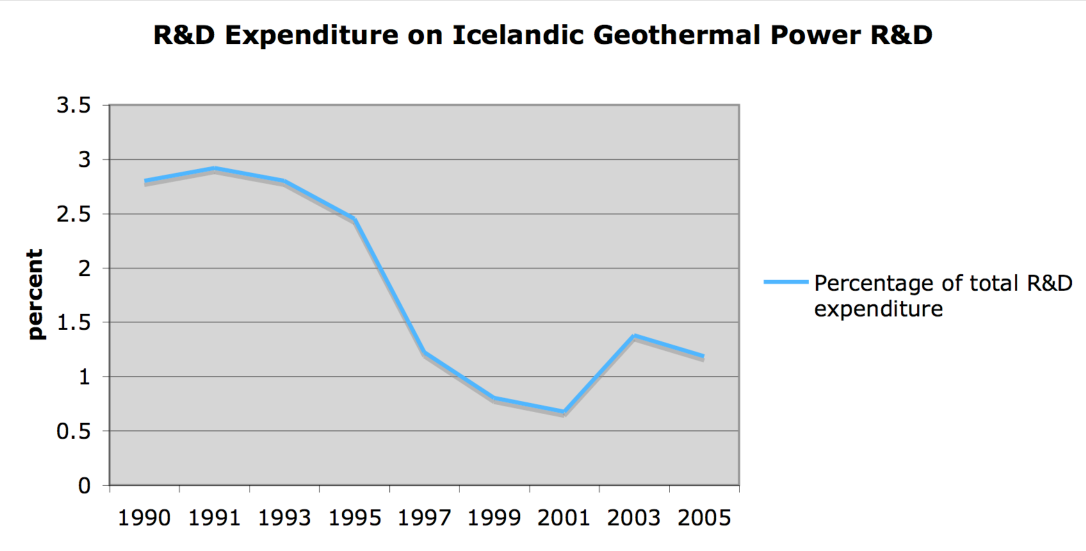
Indicator Trends



Source: *Rannis (Icelandic Centre for Research)*

INST-R&D3 Government support of geothermal energy R&D expenditure

Additional Information



Total National Geothermal R&D Expenditure

Total national expenditure on geothermal power R&D has decreased since 1990 and there appears to be a decline in 2005. Data is not available for later years so it assumed the trend continues.

Note: This indicator is considered to act the same way for local and national levels.

Note: this indicator is intended to be suitable for developed countries. A more suitable indicator would need to be chosen for a developing country, as developing country governments may prioritise expenditure in other areas.

Public Expenditure

Average public sector support of geothermal power R&D expenditure was ISK92.41m between 2003 and 2005. In 2005 expenditure was ISK121.991m

No data is available for later years.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

INST-REG1 Social and Environmental Protection

Sustainability Goal: All
Dimension / Theme / Sub-theme:
Institutional / Regulation / Government

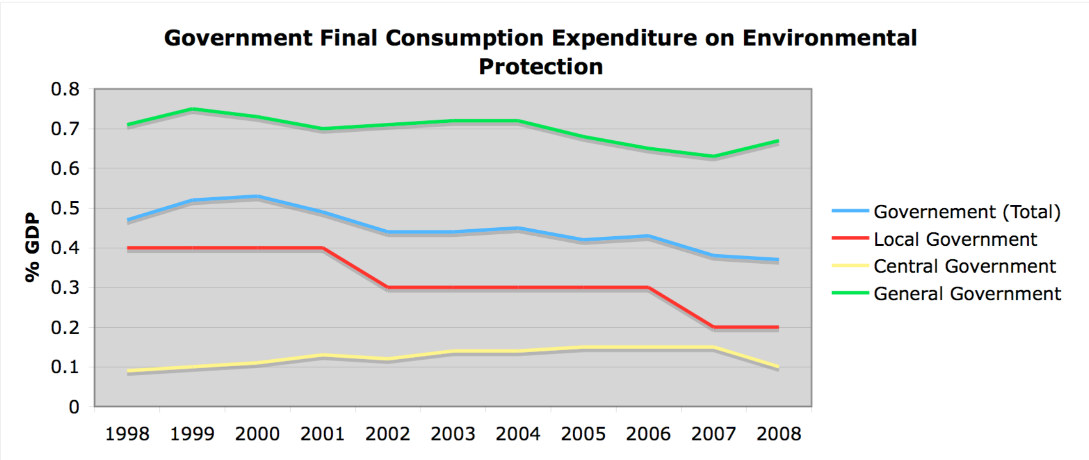
Metric:
Percentage of GDP spent on environmental protection

Target:
Remain higher than the average percentage in the past decade

Project Phase: Operation

Geothermal energy projects benefit from a political environment that has a high level of environmental protection. Countries with high commitment from government on environmental issues are more likely to host sustainable energy projects, as companies are encouraged to follow best practices. The likelihood of moral hazard and reputational risk are reduced.

Indicator Trends



Source: *Iceland Statistics*

Additional Information

National Trends

In general, spending on environmental protection appears to be declining in the 1998-2008 period.

In all government sectors except general government, expenditure is the lowest it has ever been for the past decade in 2008

The average level of expenditure by general government on environmental protection from 1998 to 2008 was 0.7% of GDP. In 2008 expenditure was 0.67% of GDP.

Municipal Trends

Local government expenditure on environmental protection appears to increase slightly up until 2007, where it drops to the lowest level in the decade. Between 2007 and 2008, there is no change in expenditure levels.

The average level of expenditure by local government on environmental protection from 1998 to 2008 was 0.32% of GDP. In 2008 expenditure was 0.2% of GDP.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

SOC-ACC1 Access to Energy

Sustainability Goal: Energy Equity (Goal 7)
Dimension / Theme / Sub-theme: Social / Energy Equity / Access to Energy

Metric:
Percentage of the population with access to high quality energy

Target:
100%

Project Phase: Strategic

Geothermal energy projects may increase the percentage of people with access to commercial energy or electricity.

Commercial energy services are crucial to providing adequate food, shelter, water, sanitation, medical care, education and access to communication. Lack of access to modern energy services contributes to poverty and deprivation, and limits economic development. Furthermore, adequate, affordable and reliable energy services are necessary to guarantee sustainable economic and human development.

Indicator Trends

100% of the population of Iceland has access to electricity.

Source: Icelandic National Energy Authority

Additional Information

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-AFF1 Energy Affordability

Sustainability Goal: Energy Equity (Goal 7)
Dimension / Theme / Sub-theme: Social / Energy Equity / Affordability

Metric:
Expenditure on energy as percentage of lowest income household disposable income

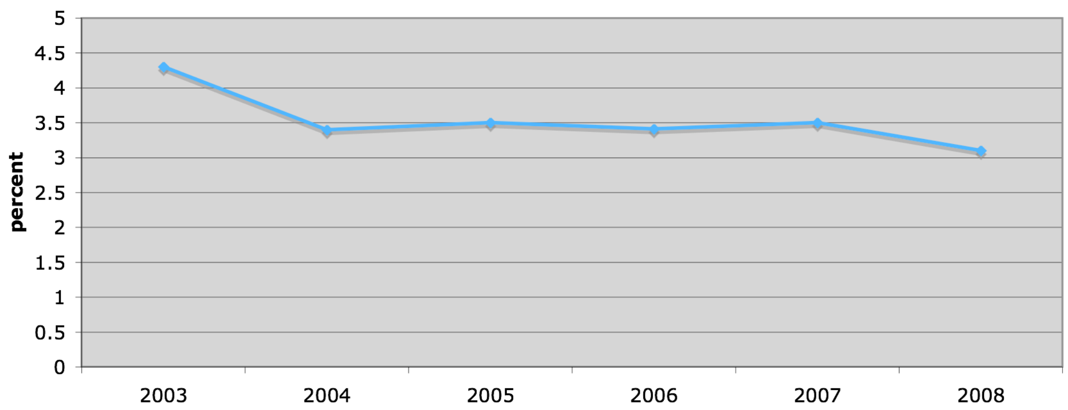
Geothermal energy projects contribute to a nation´s energy supply. For the energy supplied to be equitable, it must be equally affordable across all income groups and regions.

Target:
Below 10% (fuel poverty threshold)

Project Phase: Operation

Indicator Trends

Percentage of Disposable Income going to Energy Expenditure for Low Income Households



Source: *Iceland Statistics*[1]

Additional Information

National Trends

Expenditure on energy for the low-income Icelandic household has remained well below the fuel poverty threshold of 10%.

Municipalities

Data is not available at the municipality level, therefore it is assumed that municipalities follow the same trends as nationally.

Score: 100% **2008**
(National)

Score: 100% **2008**
(Local)

[1] Household Expenditure Surveys

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Cultural Heritage

Metric:
Level of impact on protected cultural or recreational areas (Icelandic Verndaflokkur classification or areas affected by the power project)

Geothermal energy projects in operation may need to expand by drilling new production wells or new structures, which may be located in areas of cultural significance or recreational value. Having access to places of rest, beauty, spirituality and culture is important for wellbeing and psychological health, therefore minimal impact on such areas should be a goal of geothermal energy projects.

Target:
No impact on protected cultural or recreational areas

Project Phase: Operation

Indicator Trends

The area around the current Krafla power plant is popular with hikers and tourists and contains some natural beauty spots and geothermal features. There has been no expansion in Krafla since 1997, therefore there have been no further impacts on protected areas of cultural or recreational value as far as can be ascertained.

Source: *Landsvirkjun*

Additional Information

Protected areas in Iceland are classified into four groups, with group 1 being the most protected. These protection categories take into account wildlife, natural features and landscape characteristics. These areas are of both local and national significance. For the purposes of this assessment, this indicator is considered to act the same way on local and national levels. However, further studies into the impacts on cultural or recreational areas for geothermal power production for the entire nation, taking into account the average score of impacts for all geothermal power plants would allow more accurate assessment with the national level indicator.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-EHS1 Employee Safety or Satisfaction

Sustainability Goal: Positive Social Impacts (Goal 6), Corporate Social Responsibility (Goal 10)
Dimension / Theme / Sub-theme: Social / Health & Safety / Employee Health & Safety

Metric:
Percentage of Landsvirkjun employees that are satisfied in their job

Target:
100%

Project Phase: Operation

Geothermal energy projects may increase employment in a region. Employees with high job satisfaction are more likely to stay in their jobs and this leads to more stable employment rates in the region.

Indicator Trends

In 2008, 87% of Landsvirkjun employees said they were satisfied in their job.

Source: *Landsvirkjun*

Additional Information

Data is from a survey performed by Gallup for Landsvirjun. Data was not available for contractor companies.

Score: 87% 2008
(National)

Score: 87% 2008
(Local)

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Employment

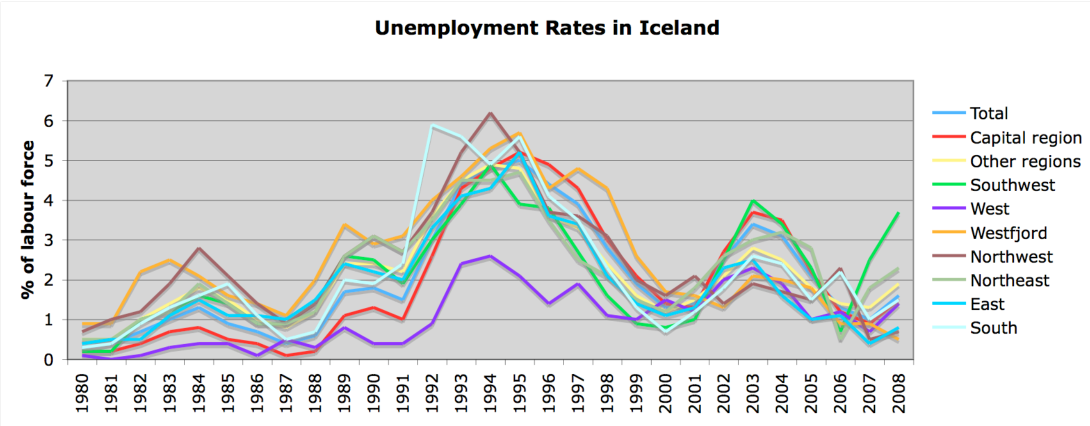
Geothermal energy projects may lead to reductions in unemployment as new jobs are created. Jobs may or may not be long-lasting, depending on how many people the new power plant may employ as well as the effect the project will have on local and regional business activity.

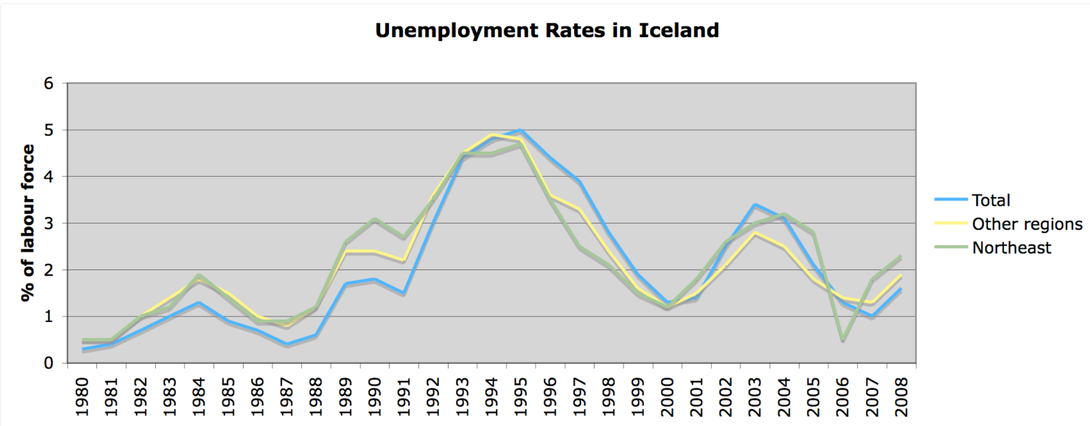
Metric:
Unemployment rates in the area compared to regional and national average

Target:
Remain below national average

Project Phase:
Construction/Operation

Indicator Trends





Source: *Iceland Statistics*

Additional Information

Regional Trends

Unemployment rates in the North East have followed national trends since 1980, athough unemployment levels fell below the national average during the nineties and from 2006. In 2008 however, they are greater than the national average and regional average.

Municipality of Skútustaðahreppur

There is no data available on unemployment rates at the municipality level, so the municipality rate may not be compared to the regional unemployment rate. Regional data is used here as a substitute for municipal data

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

SOC-EMP2 Employee Origin

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Employment

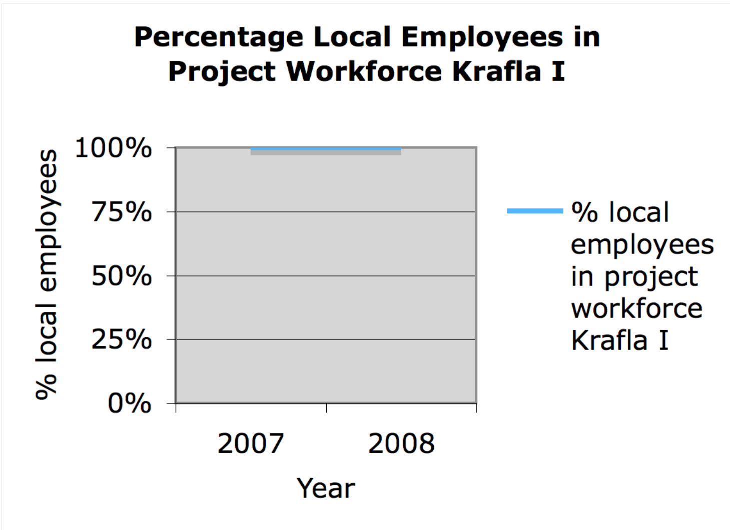
Metric:
Local: Percentage of full-time project workers based locally
National: Percentage of full-time project workers residing in Iceland

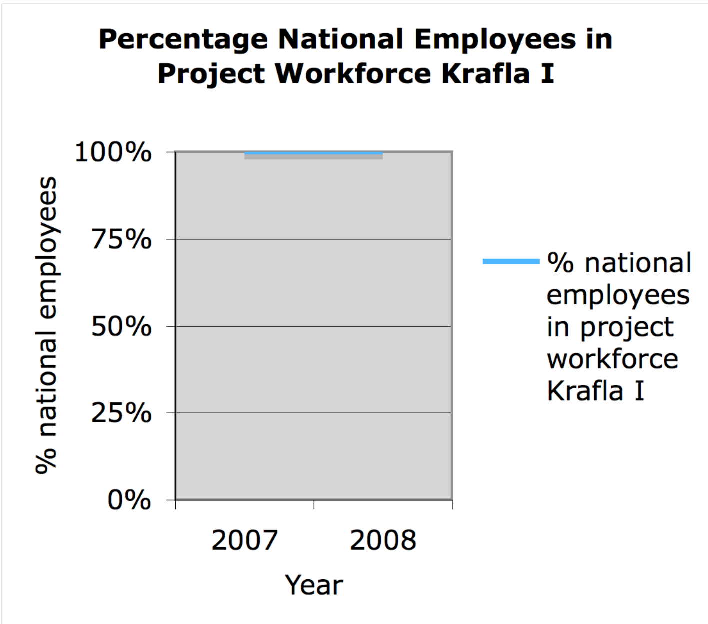
Geothermal energy projects require workers to come to the project area during construction and operation. For the municipality or region to benefit from the employment created by the project, it is desirable that full-time employees be hired locally or remain in residence locally or live in the same country as the project.

Target:
100% locally or nationally based employees

Project Phase: Construction / Operation

Indicator Trends





***Source:** Landsvirkjun*

Additional Information

The Krafla I workforce consists of 17 full-time permanent employees working in the power plant at Krafla, all of whom live and work in the municipality of Skútustaðahreppur. The plant employees students as summer staff but this is not counted for this indicator as it is concerned only with long-term, full-time employment generated by the project.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Equity / Income Equity

Metric:
Gini coefficient

Target:
Complete equality

Project Phase: Operation

Geothermal energy projects may raise income levels and living standards. Ideally, such a raise in living standards should be equally distributed across all income groups.

Indicator Trends

Source: *Iceland Statistics*

Additional Information

National Trends

Trends show a gradual increase in income inequity in Iceland between 2003 and 2006. It is assumed that this trend continues to 2008.

Complete income equality is represented by a Gini coefficient of zero.

Municipalities

There is not enough data available to allow calculation of the Gini coefficient at municipality level, therefore the national Gini coefficient is used as a substitute.

Score: 72% **2008**
(National)

Score: 72% **2008**
(Local)

SOC-IE1b Income Equity Between Genders

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Equity / Income Equity

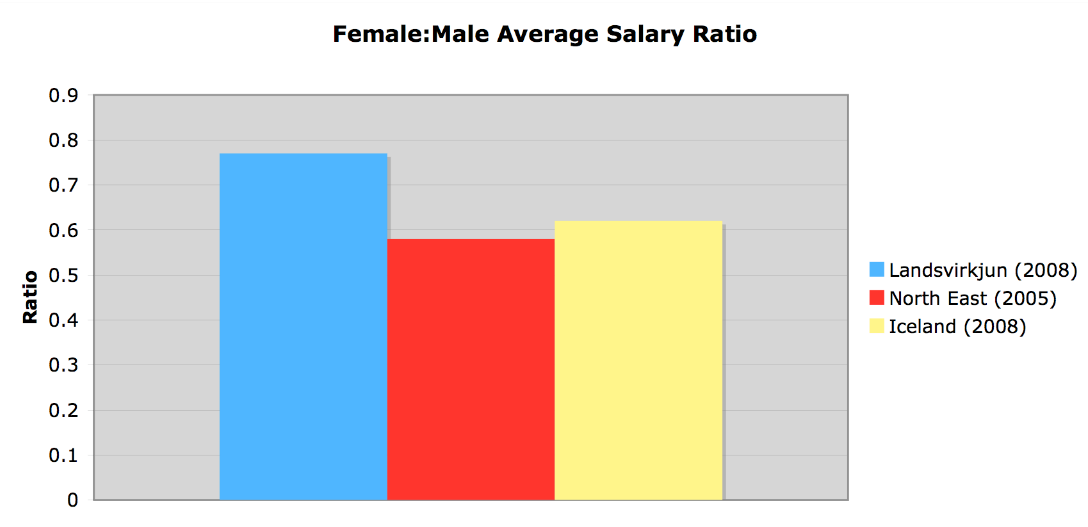
Metric:
Female:Male income ratio for Landsvirkjun compared to local and national ratios

Geothermal energy projects may lead to a rise in employment and income levels and may give female workers the opportunity to earned better incomes in the region rather than relocating elsewhere to get better salaries. The female:male income ratio for the developer company will influence the ratio of the region of the project and also has an influence on national trends.

Target:
Above regional or national ratios

Project Phase: Operation

Indicator Trends



Source: *Human Development Report / Landsvirkjun / Iceland Statistics*

Additional Information

National and Regional Trends

In 2008, the Human Development Report shows that females in Iceland earn on average 62% of what males earn.

Regional data is only available up to 2005 and shows females in the North East region as earning 59% of what males earn.

Municipality

Data is not available at the municipality level for female: male income ratios, however the North East regional average is used as a substitute.

The Landsvirkjun female:male salary ratio is show to be higher than both regional and national ratios

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-INC1 Income Levels

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Income

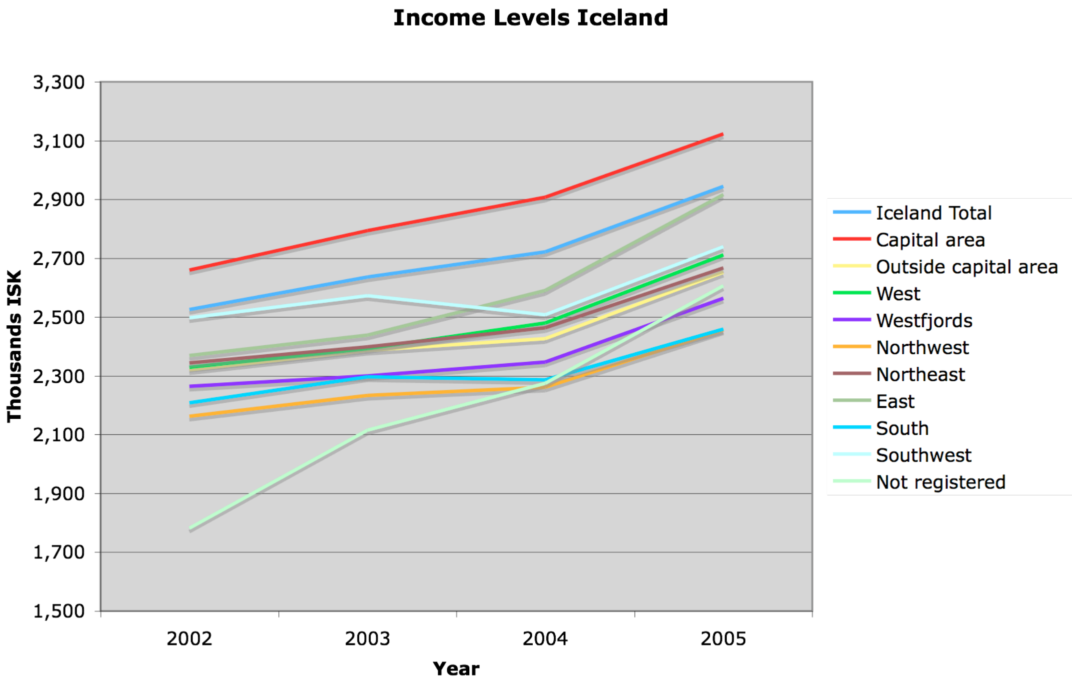
Metric:
Average income levels for the region/municipality compared to national/regional income levels (for regions outside the capital)

Geothermal energy projects are likely to have an impact on per capita income levels for the area. The income effects may be direct, for employees and indirect for suppliers of goods and services in the area and their employees.

Target:
Remain above national /regional average

Project Phase: Operation

Indicator Trends



Source: *Statistics Iceland*

Additional Information

Regional Trends

Trends show a gradual increase in average income levels for all areas in Iceland from 2002 to 2005. No further data is available from Statistics Iceland after 2005.

The North East region remains below the national average for the entire period. However average income levels in the North East remain slightly above average income levels for regions outside of the capital area for the entire period.

Assuming the same trends continue in the region, the North East will fulfil the target of remaining above the national average (excluding the capital area) for income levels.

Municipality of Skútustaðahreppur

There is no data available to compare average income levels of the Skútastaðahreppur municipality with national income levels. However data for income levels in the North East region is used here as a substitute.

Score: 100%
(National)

Score: 100%
(Local)

SOC-INC2 Access to shelter (or nutrition)

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Income

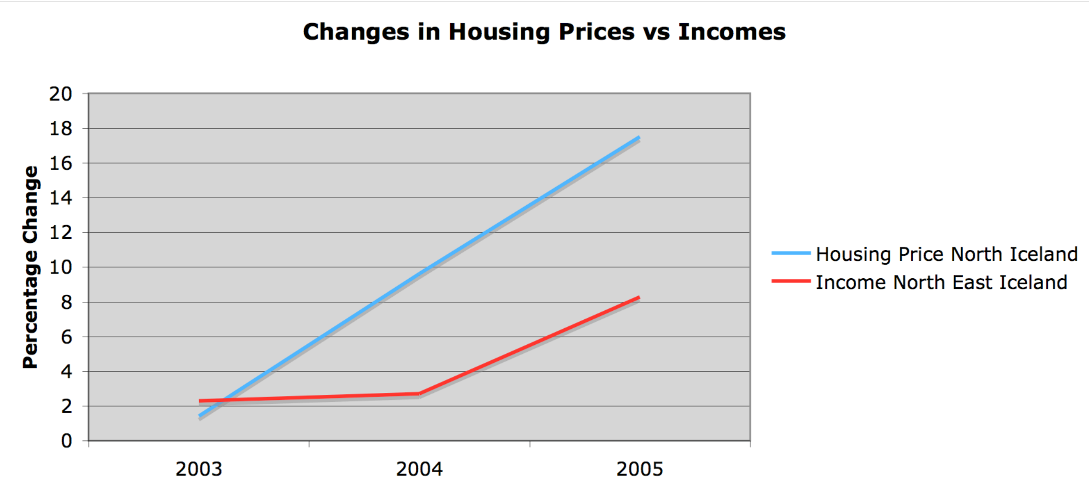
Metric:
Difference between change in average national and municipal house prices and income levels

Geothermal energy projects may cause an influx of people to an area to work or to provide goods or services. This can increase demand for housing. In the long term housing costs should not increase at a greater rate than income levels for the region.

Target:
Income levels increase at higher rate than housing prices

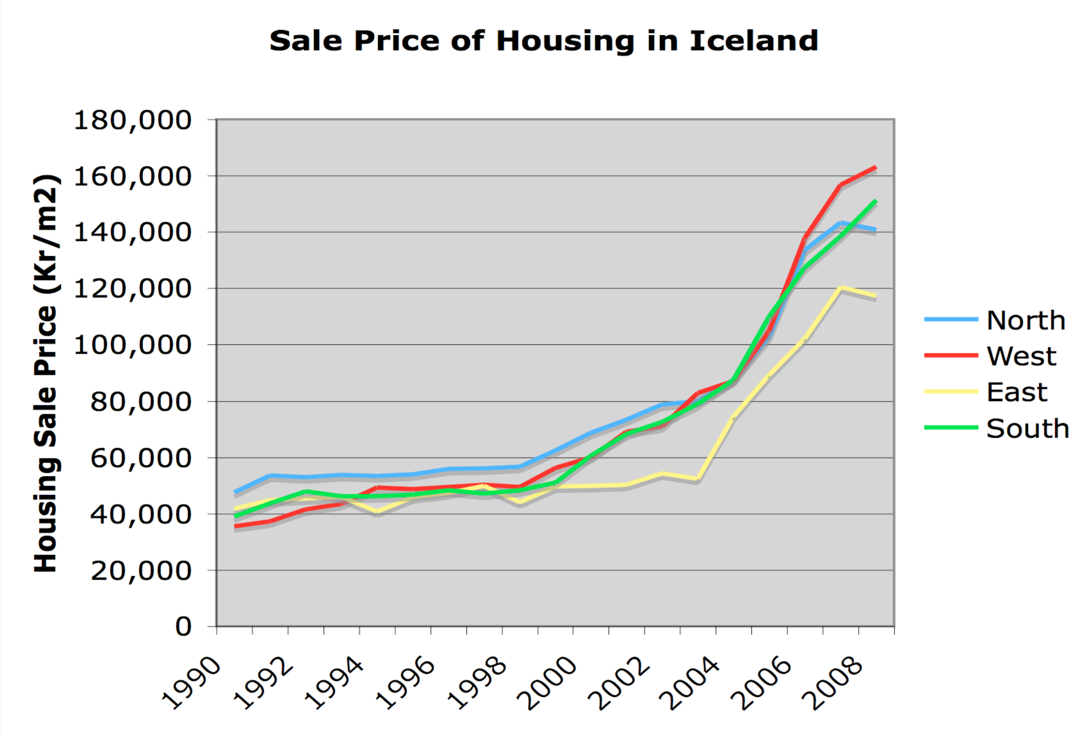
Project Phase: Construction /Operation

Indicator Trends



***Source**: Icelandic Property Registry (Fasteignaskrá Íslands), Iceland Statistics*

Additional Information



***Source**: Icelandic Property Registry (Fasteignaskrá Íslands)*

Regional Trends

Between 2002 and 2005, housing prices increased on average around 15% per year in Iceland but average income levels by only around 6% on average.

No further data is available for income levels after 2005 but housing prices have continued to rise until 2008

Municipality of Skútustaðahreppur

There is no available data for income levels or housing prices at the municipality level, so regional data is used as a substitute.

For the North East region, income levels increased faster than housing prices in 2002, but rates fell again from 2003 onward.

Assuming that these trends have continued until 2008, housing prices appear to be increasing in an unsustainable manner compared to income levels, although these trends have been experienced in all regions.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Income

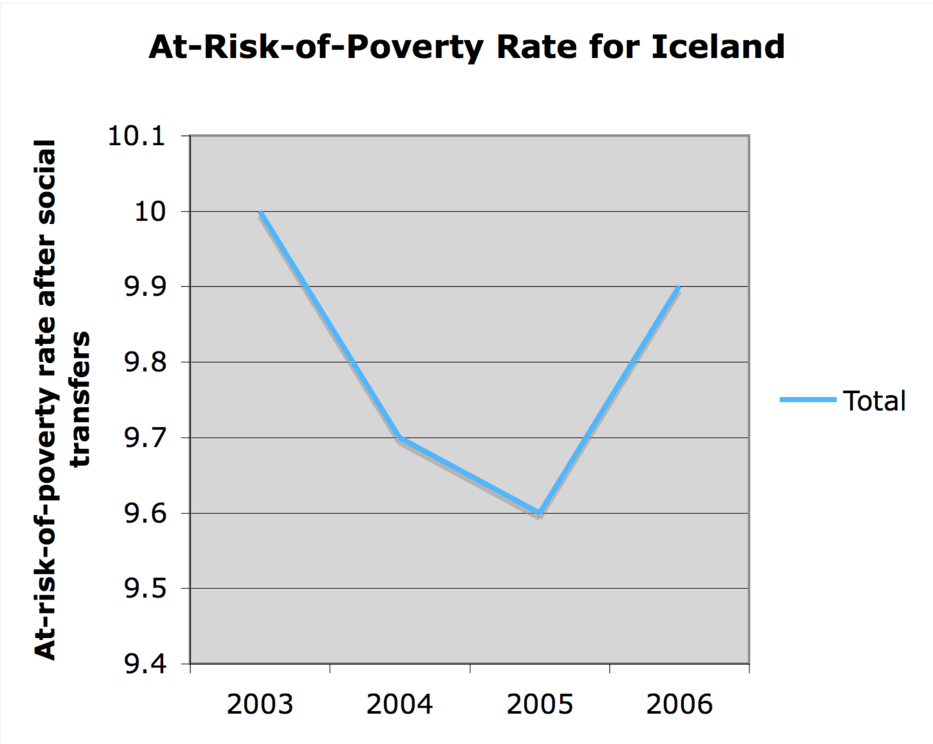
Metric:
Percentage of population below poverty line in nation/municipality compared to world / region

Geothermal energy projects have potential to raise living standards as they may increase employment or income levels in an area and boost economic activity. Access to energy is also believed necessary for the achievement of the millenium development goal of reduction of poverty worldwide.

Target:
National / municipal poverty levels lower than world / regional poverty levels

Project Phase: Operation

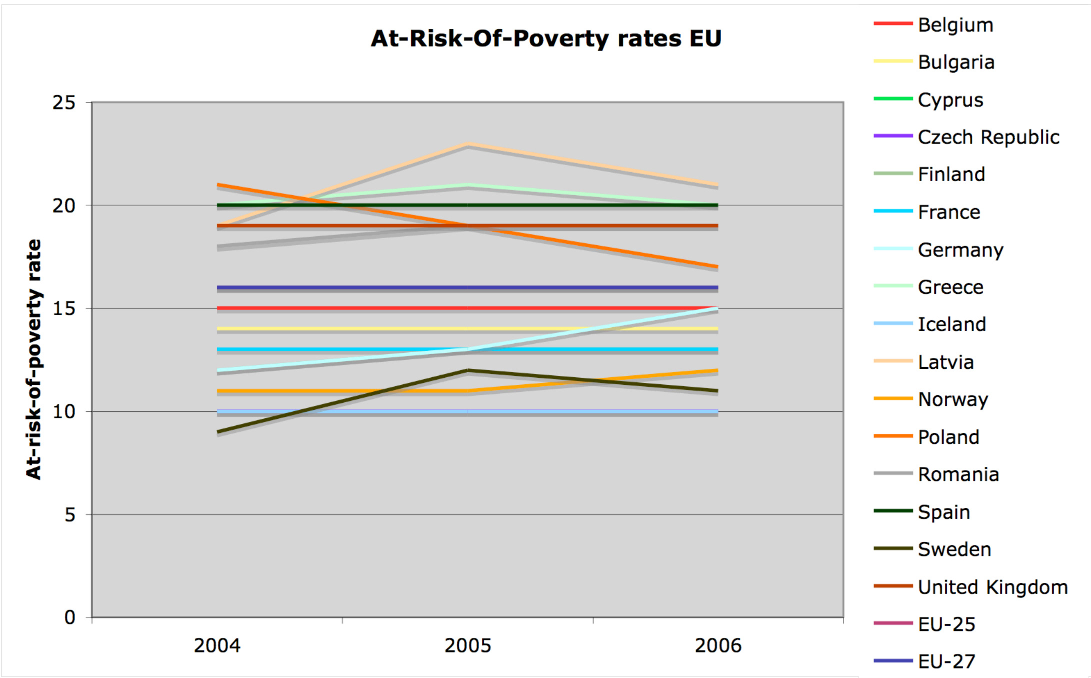
Indicator Trends



The at-risk-of-poverty rate is the rate of individuals that falls under the at-risk-of-poverty threshold. The at-risk-of-poverty threshold is defined as 60% of the median equivalised disposable income.

Source: *Iceland Statistics*

Additional Information



National Trends

Compared to other EU countries from 2004-2006, Iceland had among the lowest at-risk-of-poverty rates.

Data is available only up to 2006, however, so there may have been changes in this rate especially given recent economic conditions.

Municipality of Skútustaðahreppur

There is no data for at-risk-of-poverty rates for the Icelandic municipalities so it is assumed that the local rate is the same as the national rate in this case.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-OE1b Opportunity Equity

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension /Theme / Sub-theme: Social / Social Equity / Opportunities Equity

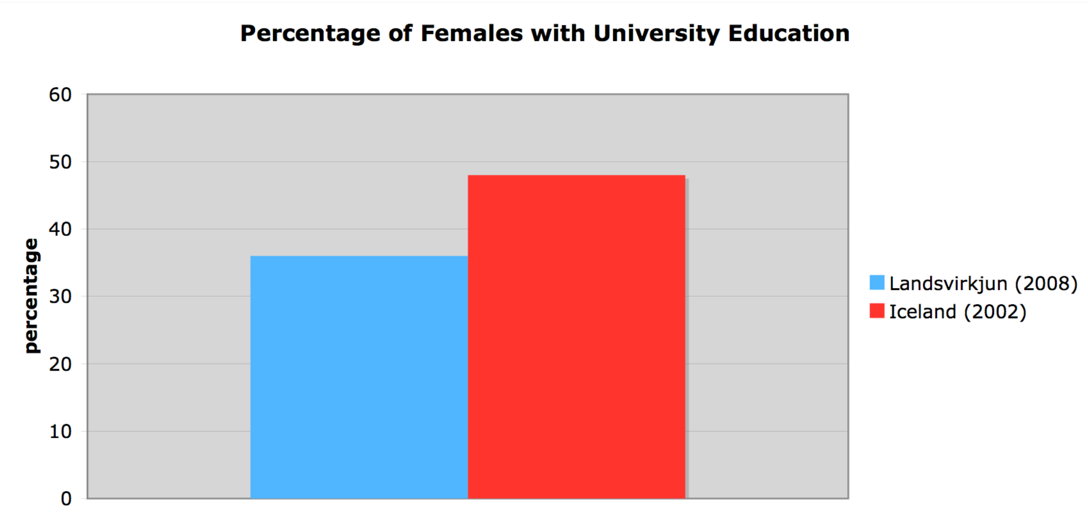
Geothermal energy projects may result in increased training levels for staff and may influence educational trends in a region as economic development occurs. Regional instability may occur if females are less educated than males, as they may have to leave the region to find suitable employment.

Metric:
Percentage of females in developer company with university education compared to percentage of females with university education nationally and locally

Target:
Higher than local or national average

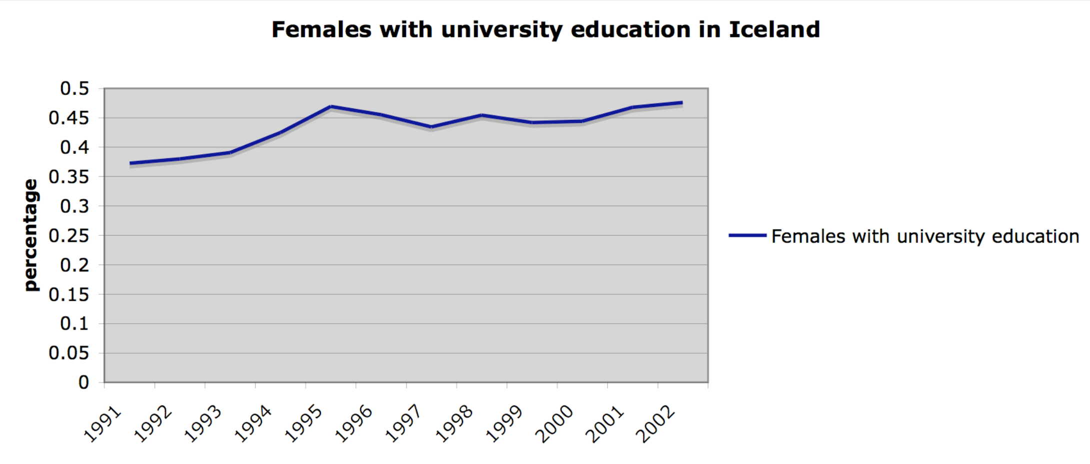
Project Phase: Operation

Indicator Trends



Source: *Iceland Statistics*

Additional Information



National Trends

Statistics on education levels for males and females in the labour force are only available from 2002. There is no data available at the regional level.

Trends suggest however, that the ratio of females with a university education is increasing gradually.

Municipality

No data is available at the municipality or regional level so national data is used as a substitute.

It is assumed that given the upward trend in 2002 for the percentage of females with university education nationally, that the 2008 Landsvirkjun percentage is most likely lower than the national average.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Public Participation

Metric:
Level of public participation in relation to legal requirements

Target:
Public Participation fulfils minimum legal requirements

Project Phase: Operation

Geothermal energy projects affect many stakeholders, so it is important to include the public through the development process. During environmental impact assessments, public participation is normally encouraged at various stages of the process, however legal requirements will depend on the country.

Indicator Trends

Public participation has been in accordance with Icelandic legal requirements during the operation of the Krafla power plant.

Source: *Landsvirkjun*

Additional Information

Icelandic law does not require that the public be actively involved in decisions made during the general operation of the geothermal power plant, however public comment and participation is required if there is to be any expansions to the existing operations, as a part of the environmental impact assessment process.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-QS2 Economic diversity

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension/ Theme / Sub-theme: Social / Social Welfare Benefits / Qualifications & Skillls

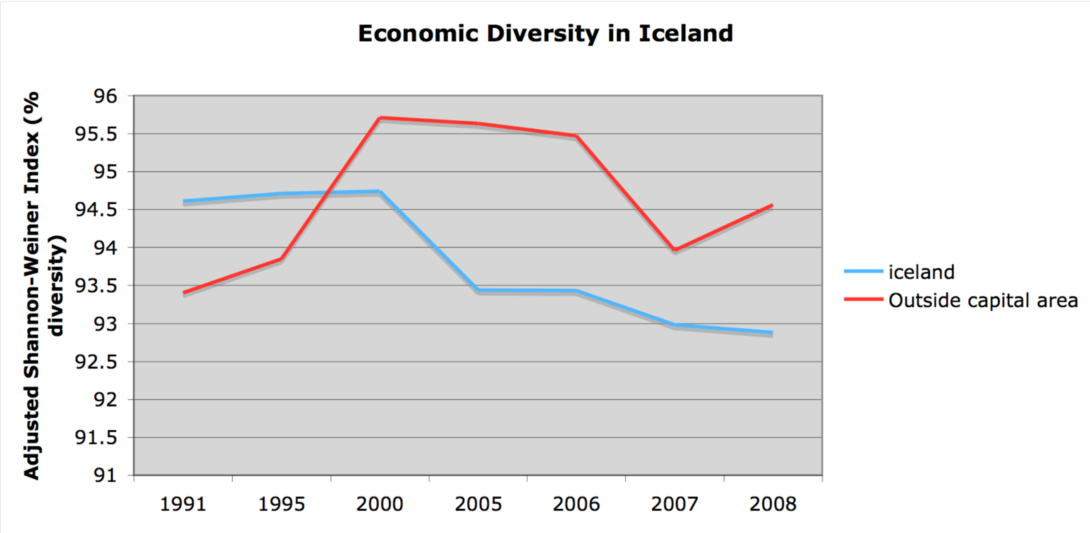
Metric:
Economic diversity in local area compared to region and nation

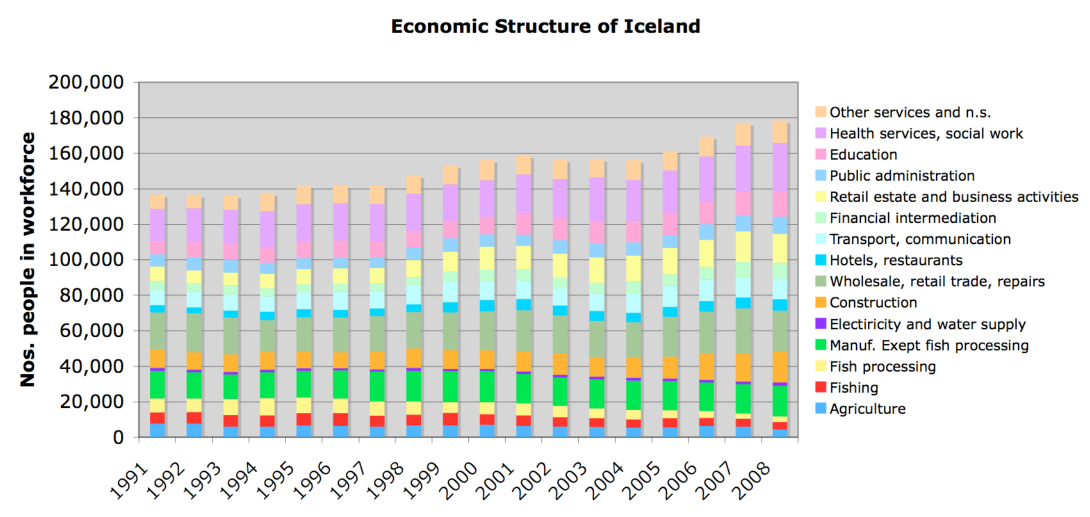
Target:
Municipal / regional economic diversity should not be lower than the economic diversity of the region / nation

Geothermal energy projects can change the structure of a region´s economy. A diverse economy is more likely to withstand shocks and be more stable, as employment in a region would not depend on a small number of industries.

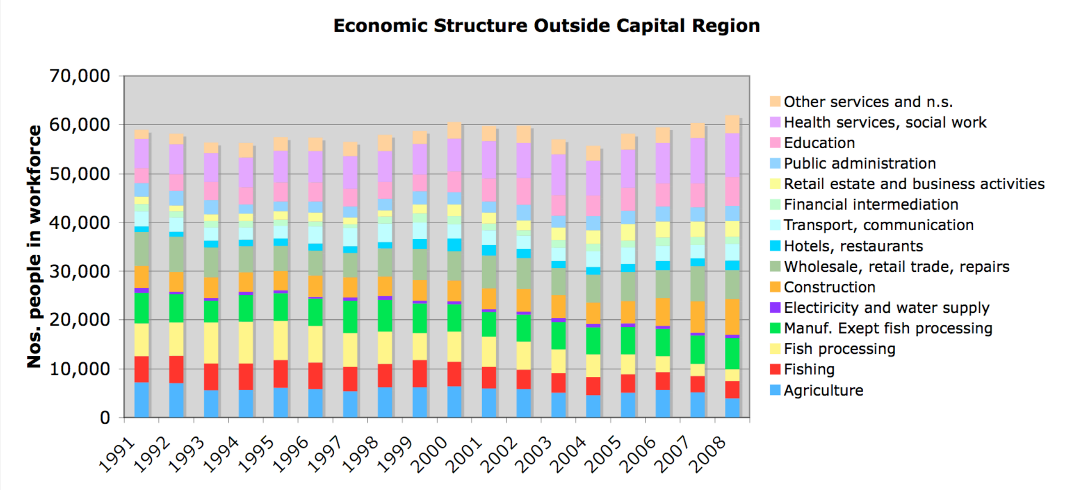
Project Phase: Operation

Indicator Trends





SOC-QS2 Economic diversity



Source: *Iceland Statistics*

Additional Information

National Trends

Nationally, there appears to be a decrease in economic diversity since 2000.

Regional Trends

Regions outside the capital area show a more diverse economic structure than the nation as a whole since the nineties.

It is not possible to calculate local (municipal) economic diversity compared to regional economic diversity.

For the purposes of this assessment both national and local indicators are awarded the same score.

Score: 100% **2008**
(National)

Score: 100% **2008**
(Local)

SOC-QS3 Education and Skills Levels

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Qualifications & Skills

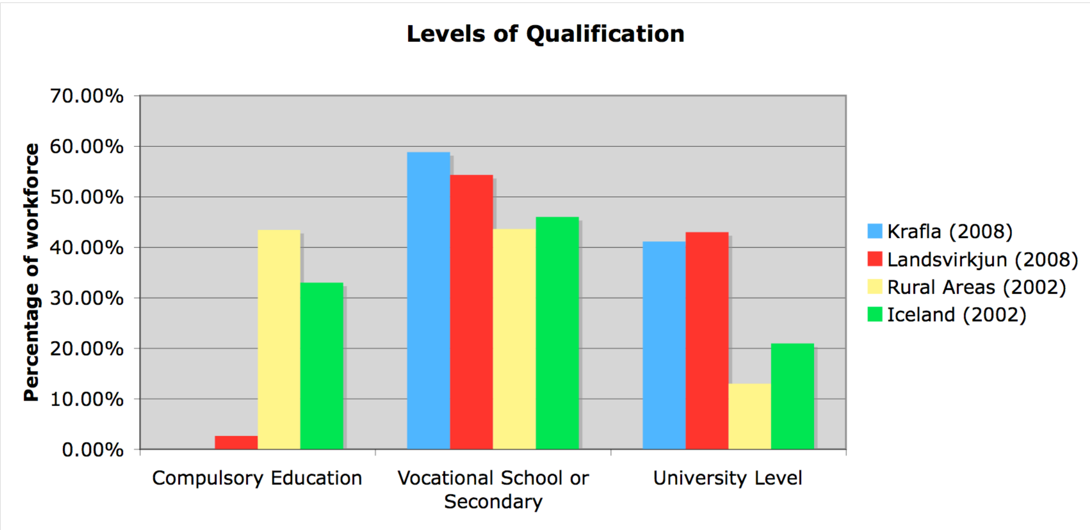
Metric:
Percentage developer company workers with university education level compared to percentages of regional or national labour force with university education.

Geothermal energy projects may result in higher education levels for the workers living in the areas affected by the power project by providing additional training and employment opportunities. The increase in education and skill levels can promote economic development in a region and higher earnings for workers.

Target:
Remain above national or municipal education levels

Project Phase: Operation

Indicator Trends



Source: *Iceland Statistics (Hagstofa Íslands)*

Additional Information

Data was not available for contractors working on the project. The company workforce is taken to be the staff of the Landsvirkjun power company.

No data was available for education levels in the municipality where the power project is based, so comparisons were made against regional data instead.

Data for regional and national education levels is from 2002. Historical data for education levels of Landsvirkjun employees is not available

Levels of education of all Landsvirkjun employees are used as a metric at the national level, as other staff apart from power plant staff are involved in running the Krafla power project. These staff members may not be located in the locality, but will nonetheless have an impact nationally.

Company Workforce Compared to National Workforce Education Levels

Landsvirkjun employees tend to have higher education than both rural areas and the nation as a whole.

Project Workforce Compared to Regional Workforce Education Levels

The education levels for Landsvirkjun employees and workers at the Krafla plant are also shown to be higher than the average for rural areas, with a higher percentage of Landsvirkjun employees having university degrees compared to the regional average.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-QS3 Level of Education and Skills

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Qualifications & Skills

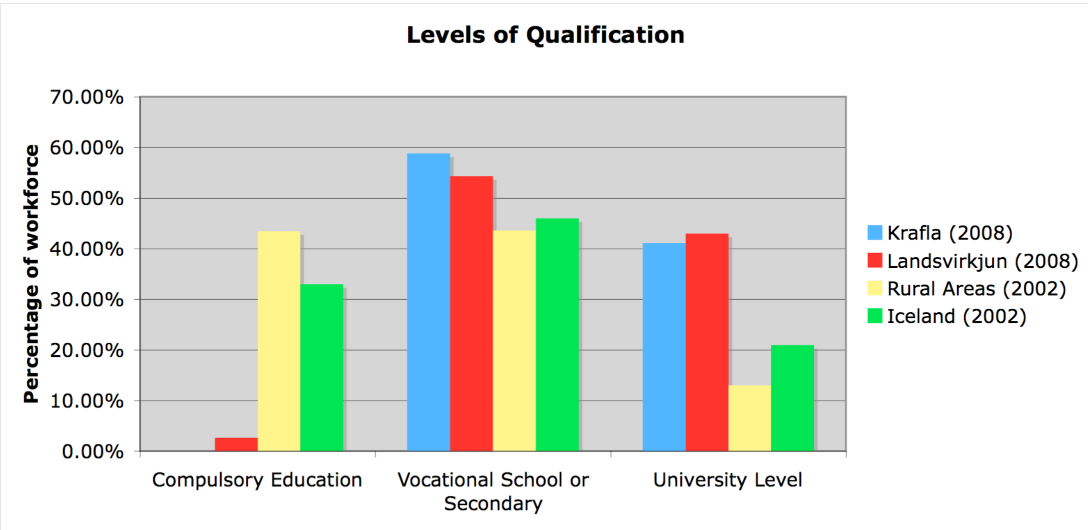
Metric:
Percentage developer company workers with university education level compared to percentages of regional or national labour force with university education.

Geothermal energy projects may result in higher education levels for the workers living in the areas affected by the power project by providing additional training and employment opportunities. The increase in education and skill levels can promote economic development in a region and higher earnings for workers.

Target:
Remain above national or municipal education levels

Project Phase: Operation

Indicator Trends



Source: *Iceland Statistics (Hagstofa Íslands)*

Additional Information

Data was not available for contractors working on the project. The company workforce is taken to be the staff of the Landsvirkjun power company.

No data was available for education levels in the municipality where the power project is based, so comparisons were made against regional data instead.

Data for regional and national education levels is from 2002. Historical data for education levels of Landsvirkjun employees is not available

Levels of education of all Landsvirkjun employees are used as a metric at the national level, as other staff apart from power plant staff are involved in running the Krafla power project. These staff members may not be located in the locality, but will nonetheless have an impact nationally.

Company Workforce Compared to National Workforce Education Levels

Landsvirkjun employees tend to have higher education than both rural areas and the nation as a whole.

Project Workforce Compared to Regional Workforce Education Levels

The education levels for Landsvirkjun employees and workers at the Krafla plant are also shown to be higher than the average for rural areas, with a higher percentage of Landsvirkjun employees having university degrees compared to the regional average.

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-QS4 Education level of least educated groups

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension/ Theme / Sub-theme: Social / Social Welfare benefits / Qualifications & Skills

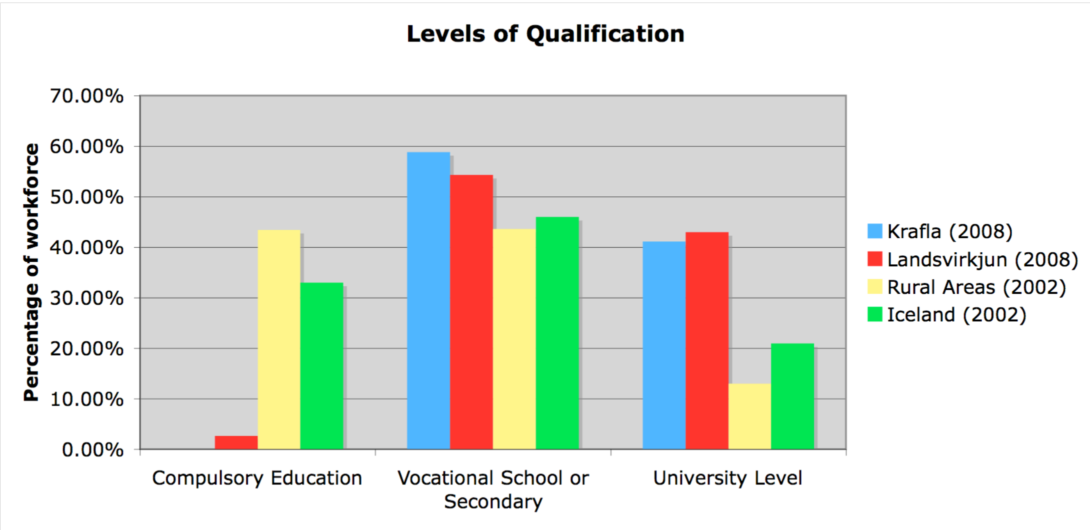
Metric:
Education level of least educated 20% of project workforce compared to region and nation

Geothermal energy projects may result in higher education levels for the least educated workers living in the areas affected by the power project by providing additional training and employment opportunities. The increase in education and skill levels for least educated workers can increase the adaptability of this group.

Target:
Education level should not be lower than regional or national average

Project Phase: Operation

Indicator Trends



Source: *Iceland Statistics, Landsvirkjun*

Additional Information

Data was not available for contractors working on the project. The company workforce is taken to be the staff of the Landsvirkjun power company.

No data was available for education levels in the municipality where the power project is based, so comparisons were made against regional data is used instead.

Data for regional and national education levels is from 2002. Historical data for education levels of Landsvirkjun employees is not available

Levels of education of all Landsvirkjun employees are used as a metric at the national level, as other staff apart from power plant staff are involved in running the Krafla power project. These staff members may not be located in the locality, but will nonetheless have an impact nationally.

Company Workforce Compared to National Workforce Education Levels

The majority of the least educated 20% of Landsvirkjun employees have a vocational or secondary qualification, whereas the least educated 20% of the national workforce had been educated up to compulsory education levels only.

Score: 100% **2008**
(National)

Project Workforce Compared to Regional Workforce Education Levels

The majority of the least educated 20% of Krafla employees have a vocational or secondary qualification, whereas the least educated 20% of the regional workforce had been educated up to compulsory education levels only

Score: 100% **2008**
(Local)

SOC-SHS1 Standard of Healthcare

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Health & Safety / Social Health & Safety

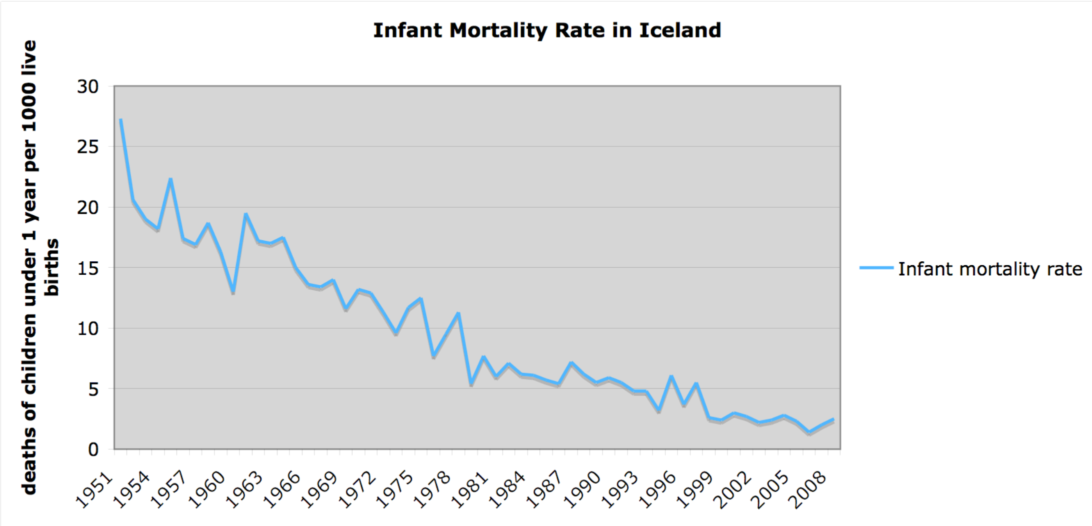
Metric:
Number of deaths of children under 1 year per 1000 live births

Target:
To attain lower infant mortality rates compared to international, national or local rates.

Project Phase: Operation

Geothermal energy projects provide essential energy services which can raise living standards and increase access to clean water and sanitation. In developing countries, this should be particularly noticeable.

Indicator Trends



Source: *Iceland Statistics*

Additional Information

Comparison to Other Countries

According to the United Nations World Population Prospects report, for the period 2005-2010 and the CIA World Factbook, 2009, Iceland ranks among the countries with some of the lowest infant mortality rates in the world.

It ranks lowest in the world in List by the United Nations Population Division list (total 195 countries) and 7th lowest in the CIA World Factbook List (total 224 countries). This puts Iceland into at least the 96th percentile for the whole world.

The World infant mortaiity rate is 49.4 according to the United Nations and 42.09 according to the CIA World Fact Book.

National Trends

Infant mortality rates have declined steadily since 1951, around the time electrification began in Iceland, and has now reached such a low level that further improvements are unlikely to be seen. As such, it is difficult to attribute any further improvement to increased energy use, also considering that the entire Icelandic population has access to commercial energy.

Regional and Municipality Trends

No data is available for infant mortality rates at the regional or municipal level, so it is assumed that infant mortality rates are similar to the national level

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-SHS2 Standard of Living

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Health & Safety / Social Health & Safety

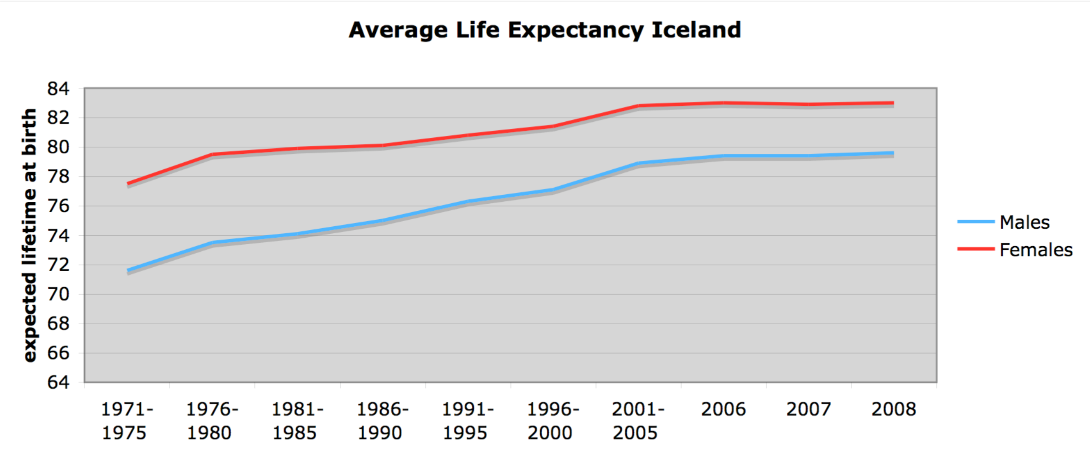
Metric:
Average life expectancy at birth

Target:
Remain above the average life expectancy internationally, nationally or regionally.

Geothermal energy projects increase energy supply and may raise living standards leading to increases in life expentancy. Changes in this indicator should be particularly noticeable in developing countries

Project Phase:

Indicator Trends



Source: *Statistics Iceland*

Additional Information

Comparison to Other Countries

Iceland ranks 3rd in the world according to the 2006 revision of the United Nations World Population Prospects report (total 195 countries), for the period 2005-2010 and 14th in the world according the the CIA World Factbook 2009 (total 223 countries)

The World life expectancy at birth is 67.2 according to the UN and 66.57 according to the CIA World Factbook.

National Trends

Life expectancies are shown to have increased steadily since the seventies and begin to level off over the decade.

Regional and Municipal Trends

There is no data at the regional or municipal level for life expectancy at birth so it is assumed that municipal life expectancy is the same as the national life expectancy

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-SHS3 Adverse Effects on Communities

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Health & Safety / Social Health & Safety

Metric:
Percentage of community residents that must relocate due to energy project

Target:
0%

Project Phase: Operation

Geothermal energy projects may impact on communities by requiring people to relocate or change their livelihoods. Social management planning can help to reconcile the needs of the energy project with the needs of the community in which it may be located.

Indicator Trends

There has been no required human displacement due to the Krafla project since its inception. The power plant is situated in an uninhabited area.

Additional Information

Score: 100% 2008
(National)

Score: 100% 2008
(Local)

SOC-SW1 Contribution to Social Security

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Social Welfare Benefits

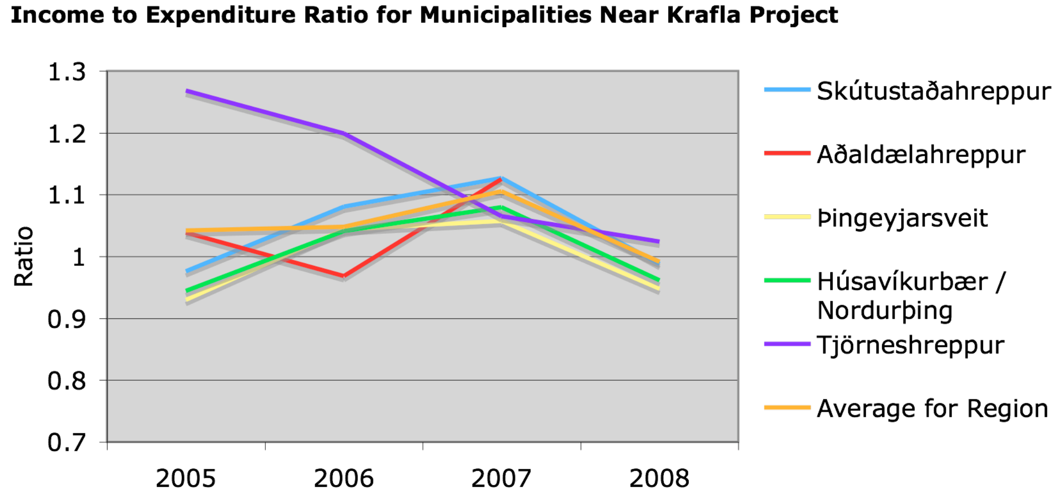
Metric:
Income to expenditure ratio for local municipality and municipalities likely to be affected by the energy project

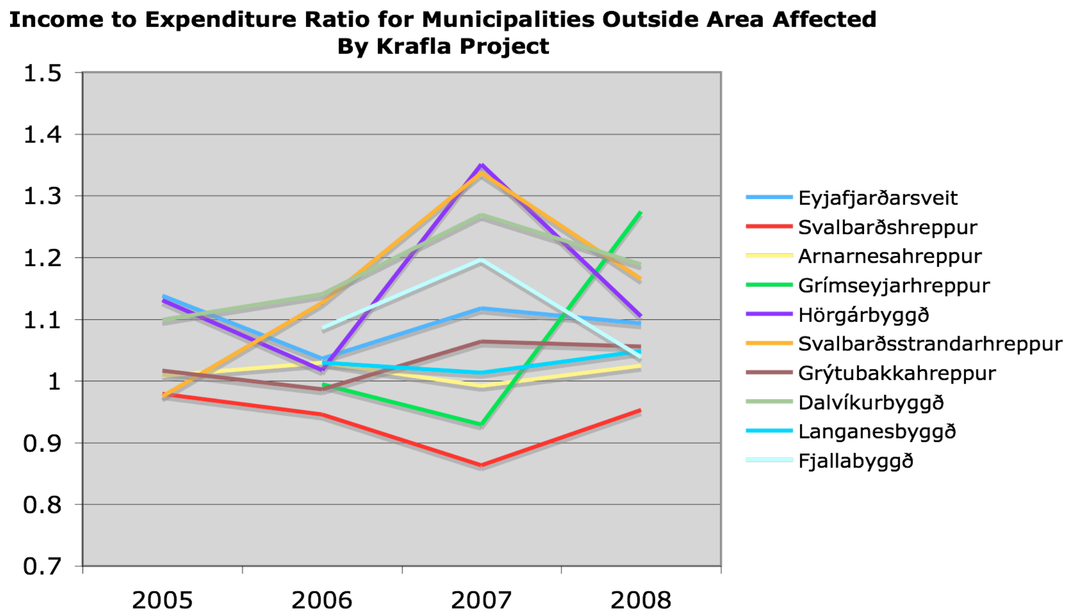
Geothermal energy projects lead to increases in employment and can contribute to funds for social security processes by allowing municipalities to collect more income or property taxes. Increases in municipality expenditures are also possible due to increased demands for social services.

Target:
To maintain a ratio greater than or equal to one

Project Phase: Operation

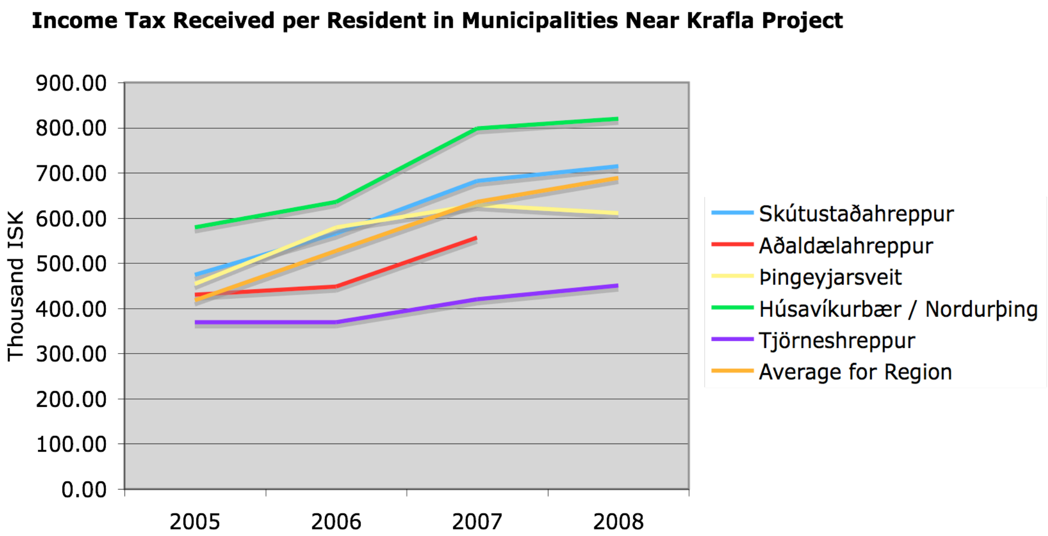
Indicator Trends





Source: *The Association of Local Authorities in Iceland (Samband Íslenskra Sveitarfélaga)*

Additional Information



Source: *The Association of Local Authorities in Iceland (Samband Íslenskra Sveitarfélaga)*

Regional Trends

Trends show a gradual increase in municipality tax income per resident for municipalities closest to or likely to be affected by the Krafla I project in Skútustaðahreppur.

The municipalities of Norðurþing and Skútustaðahreppur are above the regional average from 2005 to 2008. However there is a decline in the income:expenditure ratio for all five municipalities between 2007 and 2008 and only in Tjörneshreppur does the ratio remain above one.

The municipalities closest to the project show overall worse performance in this regard for 2008, having an average income-to-expenditure ratio of 0.98. 89% of the other municipalities in the North East have ratios above one.

This would suggest that despite having the power plant at Krafla I, the financial performance of municipalities has not significantly improved in the period 2005 to 2008.

Municipality of Skútustaðahreppur

For the years 2005-2007, the municipality of Skutustaðahreppur has had an Income:Expenditure ratio of 1 or greater, however in 2008 this drops to below 1.

The exact reasons for this are not evident from the data. As the Krafla I project came online in 1977 and is now in the operation phase it is not likely that increases in the municipality population e.g. due to construction works have caused increased social expenditures. In fact the population of the municipality dropped by 9 percent between 2005 and 2008.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

SOC-SW2 Security of Support Services

Sustainability Goal: Positive Social Impacts (Goal 6)
Dimension / Theme / Sub-theme: Social / Social Welfare Benefits / Social Welfare Benefits

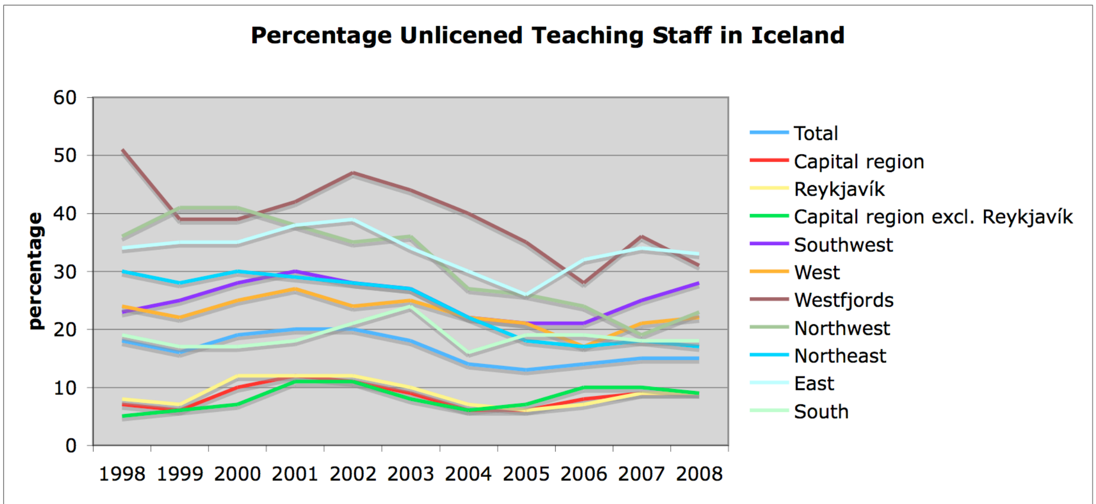
Metric:
Percentage of unlicensed teachers in North East region compared to national average

Target:
Remain below national average

Project Phase:
Construction/Operation

Geothermal energy projects may result in the influx of people into the area due to increased employment in construction or related sectors and increases in other business services. The increase in population of the area may put a strain on support services such as schools.

Indicator Trends



Source: *Iceland Statistics*

Additional Information

Regional Trends

Since 1998 there has been a gradual decrease in the percentage of unlicenced teachers in all regions.

The percentage of unlicensed teachers in the North East has remained above the national average for the last ten years, although the percentage has moved closer to the national average in recent years, showing an improvement.

In 2008 the percentage of unlicensed teachers nationally was 15% and for the North East was 17%.

Municipality of Skútustaðahreppur

There is no data for the municipality of Skútustaðahreppur so percentages may not be compared to the national average. Percentages for the North East region are used here as a substitute.

Score: 0% 2008
(National)

Score: 0% 2008
(Local)

Appendix B

Evaluation of Indicators for Suitability – Economic Indicators

Indicator Name	ECO-CB1 Government Debt	
Metric	Ratio of annual government foreign debt service cost to government revenues	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Relevant to stability of the economy but may also reflect energy project benefits to the economy over time
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data
	10. Data regularly updated of good quality	National statistics updated yearly
Resolution	Use for all phases	

Indicator Name	ECO-CB2 Ability of energy project to fulfill energy needs	
Metric	Fraction of future energy requirements to be fulfilled by project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No local data
	10. Data regularly updated of good quality	Model of future energy requirements updated year to year
Resolution	Use for all phases taking account of updates to power generation models and power usage models	

Evaluation of Indicators for Suitability – Economic Indicators

Indicator Name	ECO-CB3a Project costs vs. benefits	
Metric	Ratio of external (social and environmental) costs of economic operations to value of economic transaction for project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No CBA done for Krafla I or II projects
	10. Data regularly updated of good quality	No
Resolution	Do Not Use	

Indicator Name	ECO-CB3b Impact on hydrological features or hot springs of touristic or aesthetic value	
Metric	Presence of impact	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Not always possible to say if changes in geothermal features due to geothermal utilization
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No international standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Monitoring data not available
	10. Data regularly updated of good quality	Not known if hydrological features activity regularly monitored
Resolution	Do Not Use	

Evaluation of Indicators for Suitability – Economic Indicators

Indicator Name	ECO-CB3c Impact on other water uses – drinking water, water for irrigation etc	
Metric	Percentage of total water usage for area used by the power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No ideal benchmarks for acceptable levels of water usage
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data on cooling and other water used by power plant available No data on water usage of local area
	10. Data regularly updated of good quality	Unknown
Resolution	Do Not Use	

Indicator Name	ECO-ECD1a Efficiency of energy generation	
Metric	-	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Unknown
	10. Data regularly updated of good quality	Yes
Resolution	Part of another project	

Indicator Name	ECO-ECD1b Efficiency of energy transmission	
Metric	Percentage of transmission loss annually	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (not at local level)
	10. Data regularly updated of good quality	Yes updated yearly in annual report
Resolution	Use for all phases	

Indicator Name	ECO-ECD1c Level of efficiency of energy distribution	
Metric	Percentage of distribution loss annually	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	
	9. Data readily available /cost-effective to make available	No data
	10. Data regularly updated of good quality	No
Resolution	Do not use	

Indicator Name	ECO-EU1 Encouragement of efficient energy use	
Metric	Rate of tax on energy use	
Source	RSK	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data for taxes received from energy use but related data for tax rates and energy prices in Iceland.
	10. Data regularly updated of good quality	Yes – related data updated yearly
Resolution	Do not use	

Indicator Name	**ECO-IE1** Energy Import Dependency	
Metric	Percentage of imported energy	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data
	10. Data regularly updated of good quality	Data up to 2007 only
Resolution	Use for all phases	

Evaluation of Indicators for Suitability – Economic Indicators

Indicator Name	ECO-RR1 Renewable energy share in energy	
Metrci	Percentage of renewable energy in the total energy mix	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (no local data)
	10. Data regularly updated of good quality	Yes
Resolution	Use for all phases	

Indicator Name	**ECO-RR2** Availability of geothermal resources in region to facilitate continued power production (Strategic resource flows)	
Metric	Estimated remaining available geothermal power in the region	
Issues	1. **Clarity**	Not likely to give a clear result
	2. Responsiveness	Unlikely that models would be updated regularly
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	No reference value
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Models not always available
	10. Data regularly updated of good quality	In early project stages no models available or only rough estimates
Resolution	Part of another project	

Indicator Name	ECO-RR3 Ability of geothermal resources to meet consumption patterns (Resource to Production ratio)	
Metric	Ratio of predicted future flows of geothermal energy to predicted production or consumption patterns	
Issues	1. **Clarity**	yes
	2. Responsiveness	Unlikely that models would be updated regularly
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Models not always available
	10. Data regularly updated of good quality	In early project stages no models available or only rough estimates
Resolution	Part of another project	

Indicator Name	ECO-DIV1 Energy diversity	
Description of Data	National statistics	
Source	Hagstofa	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (No municipal data)
	10. Data regularly updated of good quality	Yes (last year available 2007)
Resolution	Use for all phases	

Indicator Name	ECO-IMT1 Reliability of Infrastructure	
Metric	Security of fixed cost and upkeep financing of energy infrastructure for next 20 years	
Source	Landsnet	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	No known standards.
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data but related data available for existence of infrastructure: No. of failures in distribution system
	10. Data regularly updated of good quality	Yes – Landsnet annual reports for related data
Resolution	Modify using another metric: Duration of power outages annually Use for all phases.	

Evaluation of Indicators for Suitability – Economic Indicators

Indicator Name	ECO-PRF1 Owner company profitability	
Metric	Return on assets	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Yes
	3. **Relevance**	Yes
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	No
	6. **Conceptually sound**	Yes
	7. **Based on international stds**	Yes
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	Yes
	10. **Data regularly updated of good quality**	Yes
Resolution	Do Not Use	

Indicator Name	ECO-DBT1a Owner company debt status	
Metric	Owner company short term debt to total debt ratio before project	
Source	Landsvirkjun Annual Report	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Yes
	3. **Relevance**	Yes
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	No
	6. **Conceptually sound**	Yes
	7. **Based on international stds**	Yes
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	Yes
	10. **Data regularly updated of good quality**	Yes
Resolution	Do Not Use	

Indicator Name	ECO-DBT1b Owner company debt status - leverage	
Description of Data	Owner company leverage ratio	
Source	Landsvirkjun Annual Report	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	ECO-DBT1c Owner company debt status – exchange rate	
Description of Data	Balance Sheet Effects of Exchange Rate Changes	
Source	Landsvirkjun Annual Report	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	ECO-RSK1a Owner Company Financial Risk	
Metric	level of financial risk associated with energy project for owner company	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	no
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes. Not available at strategic phase.
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	ECO-RSK1b Financial soundness of owner company	
Metric	Interest Payments / Operational Cashflow	
Source	Landvirkjun Annual Reports	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Evaluation of Indicators for Suitability – Economic Indicators

Indicator Name	ECO-RSK1c Owner company foreign currency exposure	
Metric	Unhedged foreign currency exposure of owner company	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	Ye
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	ENV-GLB1 Global Environmental impacts	
Metric	Annual national GHG emissions (CO2 Eq)	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Yes
	3. **Relevance**	Yes
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	Yes
	6. **Conceptually sound**	Yes
	7. **Based on international stds**	Yes
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	Entire lifecycle data unavailable[1] Local information not available for GHG / CO2 GHG estimates unavailable for Krafla II in strategic phase
	10. **Data regularly updated of good quality**	Yes
Resolution	Use for construction and operation phases.	

[1] Figures for entire geothermal project lifecycle not available. Not a big issue for operation phase as the changes are only from the power plant. Could be ideal to have lifecycle estimate in the first stages of the assessment – strategic, preparation , etc as an overall picture

Evaluation of Indicators for Suitability – Environmental Indicators

Indicator Name	ENV-LU1 Land area affected by energy project and associated infrastructure	
Metric	Area taken by plant buildings and infrastructure	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	No
Resolution	Use for all phases	

Indicator Name	ENV- FOR1 Deforestation due to energy project	
Metric	Percentage of forested areas removed due to energy project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for Krafla I and estimates for Krafla II
	10. Data regularly updated of good quality	Yes
Resolution	Use for all phases	

Evaluation of Indicators for Suitability – Environmental Indicators

Indicator Name	ENV-LSC1 Impact on regional landscape esthetics	
Metric	Verndaflokkur ranking – Icelandic protected areas classification	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No international standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for Krafla I Krafla II: no data but estimates possible
	10. Data regularly updated of good quality	Yes, data from environmental impact assessments will be available before any planned expansion of plant.
Resolution	Use for all phases	

Indicator Name	ENV-LSC2 Level of ground subsidence as a result of geothermal energy development	
Metric	-	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Consistent data not available
	10. Data regularly updated of good quality	No – measured every 5 years
Resolution	Part of another project	

Indicator Name	ENV-TOX1a Toxicity of H2S	
Metric	Concentration of H2S in vicinity of power plant (ppb)	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for Krafla I only. Estimates for Krafla II.
	10. Data regularly updated of good quality	Last report from 1993. No later studies on H2S concentrations in the Krafla area available
Resolution	Use for construction and operation phases	

Indicator Name	**ENV-TOX1b Toxicity of Hg**	
Metric	Concentration of Hg gas in the vicinity of the power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for Krafla I only. Estimates for Krafla II.
	10. Data regularly updated of good quality	Last report from 1993. No later studies on Hg concentrations in the Krafla area available
Resolution	Use for all phases.	

Indicator Name	**ENV-TOX1c Metals in effluent**	
Metric	Concentrations of metals in effluents released from the power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Last report from 2007, not clear if updated regularly
Resolution	Use for all phases	

Indicator Name	ENV-AW 1a Emissions of acidifying air pollutants	
Metric	Amount in tons of SO_2, Nox and H_2S emitted from power plant per year	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	None at present
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for Krafla I power plant Air pollution sampling not done in Krafla area – Myvatn station only measures PM-10
	10. Data regularly updated of good quality	Yes, yearly report from LV
Resolution	Use for all phases	

Indicator Name	**ENV-AW 1b** Level of acidity/alkalinity of discharge	
Metric	pH of effluent released from power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data on pH of Krafla I effluent water available, but no baseline data for pH of rivers or water bodies.
	10. Data regularly updated of good quality	Last data from 2007
Resolution	Do Not Use	

Indicator Name	ENV-AW 1c Levels of chloride and sulphides (Measured in milligrams per litre)	
Metric	Concentration of chlorides and sulphides in effluent released from power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	No
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for effluent from Krafla I power plant. No data for baseline values / ambient values for Krafla area
	10. Data regularly updated of good quality	Last data from 2007
Resolution	Do Not Use	

Indicator Name	**ENV-AW 1d** Thermal Pollution	
Metric	Temperature of hot water released from power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data for Krafla I power plant available No baseline for ambient water temperatures in Krafla area
	10. Data regularly updated of good quality	Last data from 2007
Resolution	Use for all phases	

Indicator Name	ENV-NSE1 Noise Pollution	
Metric	Noise levels in the vicinity of the power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No noise predictions for Krafla II project.
	10. Data regularly updated of good quality	Data from 2001, silencers have been fitted since then Data does not cover all tourist attractions and residential areas
Resolution	Use for all phases	

Indicator Name	ENV-NSE2 Odour	
Metric	Level of unacceptable unpleasant odours due to energy project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data from 1993 report only for Krafla I No smell model for Krafla II
	10. Data regularly updated of good quality	Last report available in 1993
Resolution	Use for all phases	

Indicator Name	ENV-ECO1 Impact on hotspots of biological diversity	
Metric	Presence of biodiversity hotspot in vicinity of the geothermal energy development	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Use for all phases	

Indicator Name	ENV-ECO2 Impact on threatened species	
Metric	Presence of threatened species in the area near the power plant	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Reports from 2001 available but not updated regularly
Resolution	Use for all phases	

Indicator Name	**ENV-ECO3 Level of disturbance of ecosystems**	
Description of Data	Company reports	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Reports from 2001 available but not updated regularly
Resolution	Use for all phases	

Evaluation of Indicator Suitability – Institutional Indicators

Indicator Name	INST-CAP1 Government agency capacity	
Metric	Time taken to complete cases	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	100% ideal
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	INST-CAP2 Government competent authority effectiveness	
Metric	Time taken to complete EIA process	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Evaluation of Indicator Suitability – Institutional Indicators

Indicator Name	INST-OCP1a - Owner effectiveness in energy projects	
Metric	Level of customer satisfaction	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	100% customer satisfaction
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No release of data allowed
	10. Data regularly updated of good quality	Unknown
Resolution	Do Not Use	

Indicator Name	INST-OCP1b Owner effectiveness in energy projects	
Metric	Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with laws and regulations by owner.	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data
	10. Data regularly updated of good quality	Unknown
Resolution	Do not use	

Indicator Name	INST-OCP2a Level of qualification of owner staff	
Metric	Average education level of staff	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	May not be relevant as companies often outsource certain functions
	4. Allows international comparison	No
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	INST-OCP2b Standard of Company Management Systems	
Metric	Quality of Environmental Monitoring System	
Source	Landsvirkjun Environmental Report	
Issues	**1. Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes – though developing countries may not have any EMS as not legally required.
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Use in all phases	

Evaluation of Indicator Suitability – Institutional Indicators

Indicator Name	INST-GCP1 Average skills and qualifications per person	
Metric	Average qualification levels of government employees	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	INST-REG1 Agreement of legal system with interests of other regions	
Metric	Suitable metric unavailable	
Issues	1. **Clarity**	No
	2. Responsiveness	No
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	No
	6. Conceptually sound	No
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Evaluation of Indicator Suitability – Institutional Indicators

Indicator Name	INST-REG2 Environmental and Social Protection in Policy or Law	
Metric	% GDP spent on environment and development policies	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Yes
	3. **Relevance**	Yes
	4. **Allows international comparison**	No
	5. **Threshold / Ref value**	No
	6. **Conceptually sound**	No
	7. **Based on international stds**	No
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	Available (no local data) Have related data - % GDP spent on environment and development policies
	10. **Data regularly updated of good quality**	Related data updated regularly
Resolution	Use in all phases	

Indicator Name	INST-GOV1 Agreement of political form of government with cultural and social norms	
Metric	Corruption Rate – Transparency International Index	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Yes
	3. **Relevance**	Yes
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	yes
	6. **Conceptually sound**	Yes
	7. **Based on international stds**	Yes
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	Yes (no local data)
	10. **Data regularly updated of good quality**	Yes
Resolution	Use in all phases	

Evaluation of Indicator Suitability – Institutional Indicators

Indicator Name	INST-GOV2 Corporate Corruption	
Metric	Total number of legal actions in supreme court for anticompetitive behavior, anti-trust, sustainability or environmental issues, monopoly practices, in the last 10 years	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Use in all phases	

Indicator Name	INST-POL1 Democracy	
Metric	Freedom House Democracy Level	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (no local data)
	10. Data regularly updated of good quality	yes
Resolution	Use in all phases	

Indicator Name	INST-POL2 Internal and external security	
Metric	Number of deaths due to crime and war per year	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Indicator Name	INST-POL3 Political alienation	
Metric	Percentage of voter turnout	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (no local)
	10. Data regularly updated of good quality	Yes
Resolution	Use in all phases	

Indicator Name	INST-POL4 Perceptions of project at home and abroad	
Metric	Number of national or international protests related to the project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Not a common indicator
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data for international protest Limited data on legal procedings
	10. Data regularly updated of good quality	Legal data updated regularly
Resolution	Do Not Use	

Evaluation of Indicator Suitability – Institutional Indicators

Indicator Name	INST-R&D1 Company support of energy R&D expenditure	
Metric	Percentage of owner company expenditure spent on R&D	
Description of Data	Company data	
Source	Landsvirkjun	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No international standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (not broken down by locality)
	10. Data regularly updated of good quality	Yes – annual reports
Resolution	Use for all phases	

Indicator Name	INST-R&D2a Government contribution to amount of organizational capacity dedicated to energy R&D	
Metric	Pecentage of research personnel employed employed in energy R&D	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data on capacity (nos. employed) in different places
	10. Data regularly updated of good quality	Unknown
Resolution	Use for all phases	

Indicator Name	INST-R&D2b Owner contribution to organizational capacity dedicated to geothermal energy R&D	
Metric	Percentage of total geothermalenergy R&D staff funded by owner company	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data not up to date
	10. Data regularly updated of good quality	Every 2 years by Rannis
Resolution	Do Not Use	

Indicator Name	INST-R&D3 level of government support of energy R&D	
Metric	Percentage of total R&D expenditure coming from government (public institutions)	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No standards at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes
Resolution	Use for all phases	

Indicator Name	SOC-SW1 Contribution to society	
Metric	Income to Expenditure ratio for municipalities affected by project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No international standard
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yearly accounts
Resolution	Use for construction and operation phase	

Indicator Name	SOC-SW2 Security of support service processes	
Metric	Social support ratio (children + old + sick + unemployed)/ working population	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Less responsive on national level for smaller projects. May only show trends over longer periods.
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Base year
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available for Iceland for numbers of sick or disabled people No municipal data
	10. Data regularly updated of good quality	-
Resolution	Use with other metric – Quality of Schools – Percentage of unqualified teachers in local schools Use in preparation / in construction / operation phase	

Indicator Name	SOC-SW3 Contribution to surplus uncommitted funds for social services by development project	
Metric	Percentage of municipality surplus uncommitted funds coming from energy project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Unknown
	5. Threshold / Ref value	Base year
	6. Conceptually sound	-
	7. Based on international stds	No standards
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do Not Use	

Indicator Name	SOC-EMP1 Unemployment	
Metric	Local unemployment rate compared to national unemployment rate	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data at municipal level Related data available for north east region
	10. Data regularly updated of good quality	Yes
Resolution	**Use** for construction and operation phases	

Indicator Name	SOC-EMP2 Employment	
Metric	Percentage of nationals in project staff Percentage of locally based employees in project staff	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Data available for operating project at Krafla I Estimates available for Krafla II but not known where employees come from.
	10. Data regularly updated of good quality	Yes
Resolution	Use for construction and operation phases	

Indicator Name	SOC-INC1 Security of development of the individual	
Metric	Debt to income ratio for household	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Less responsive on national level for smaller projects. Probably responsive over longer periods for national level.
	3. **Relevance**	Yes
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	No
	6. **Conceptually sound**	Yes
	7. **Based on international stds**	No international standards for this ratio
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	No local or national data No data for estimated income for workers of Krafla II project
	10. **Data regularly updated of good quality**	National data updated yearly
Resolution	Modify metric to Income Levels: Municipality income levels compared to national income levels Use in construction and operation phases	

Evaluation of Indicator Suitability – Social Indicators

Indicator Name	SOC-INC2 Access to shelter (or nutrition)	
Metric	Change in percentage of household income spent on housing compared to change in income levels	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Initially housing costs may increase as living standards raise but should not increase much in the long term
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No international standard at present
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes (no local data, only regional)
	10. Data regularly updated of good quality	National data updated yearly
Resolution	Use in construction / operation phases	

Indicator Name	SOC-INC3 Poverty	
Metric	Percentage of population below poverty line	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Less responsive at national level for smaller projects
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No local data
	10. Data regularly updated of good quality	Data only available up to 2006
Resolution	Use for construction / operation stage	

Indicator Name	SOC-QS1 Organizational and management skills	
Metric	Hours of training for workers in municipality compared to hours of training for workers nationally	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	No
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	National or municipal data not available for hours of training in organizational and mgt skills
	10. Data regularly updated of good quality	-
Resolution	Do Not Use	

Indicator Name	SOC-QS2 Economic diversity	
Metric	Hackman economic diversity index OR SW Index	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes – use of ISCED scale
	5. Threshold / Ref value	National spectrum
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No local data
	10. Data regularly updated of good quality	Yes, data from national statistics office 2007
Resolution	Use this indicator for construction, operation phase	

Indicator Name	SOC-QS3 Level of education and skills	
Metric	Level of education in municipality compared to level of education nationally	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data but can use regional instead
	10. Data regularly updated of good quality	Yes, data from national statistics office 2007
Resolution	Use this indicator for construction or operation phase	

Indicator Name	SOC-QS4 Level of education of least educated groups	
Metric	Education level of least educated quintile of the project workforce compared to municipality and national population	
Source	Hagstofa, LVP	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data but can use regional instead
	10. Data regularly updated of good quality	Yes, data from national statistics office 2007
Resolution	Use this indicator for operation stage	

Indicator Name	SOC-CH1 Cultural heritage or recreational areas	
Metric	Icelandic Verndaflokkur classification system for protected areas	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Yes – national cultural and protected resources known and catalogued
Resolution	Use indicator	

Indicator Name	SOC-ACC1 Energy access	
Metric	Percentage of population with access to commercial energy	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	National data available. Municipality data not available
	10. Data regularly updated of good quality	Yes
Resolution	Use indicator for operation phase	

Indicator Name	SOC-AFF1 Energy affordability	
Metric	Percentage of household income spend on fuel and electricity	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	National statistics available up to 2008 No municipal data available
	10. Data regularly updated of good quality	Yes
Resolution	Use indicator for operation phase	

Indicator Name	SOC-DIS1a Disparity of energy use between income groups	
Metric	Gini coefficient for energy use between income groups	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-DIS1b Disparity of energy use between genders	
Metric	Ratio of male energy use to female energy use	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-DIS1c Disparity of energy use between ethnicities	
Metric	Gini coefficient for energy use by ethnicities	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-IE1a Income Inequity	
Metric	Gini coefficient	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Available nationally but not at municipal level
	10. Data regularly updated of good quality	latest data from 2006
Resolution	Use indicator for construction and operation phase	

Indicator Name	SOC-IE1b Income inequity between genders	
Metric	Ratio of average female income to average male income in project staff compared to municipality and national ratios	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes –
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data but can use regional instead
	10. Data regularly updated of good quality	Regional data from 2005 only
Resolution	Use for preparation, construction and operation phase	

Indicator Name	SOC-IE1c income inequity between ethnicities	
Metric	Gini coefficient for income inequity between ethnicities	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Not relevant to Iceland
	4. Allows international comparison	Yes
	5. Threshold / Ref value	-
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-OE1a Levels of overall education inequity between income groups	
Metric	Gini coefficient for education inequity between income groupss	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	May be more relevant for a developing country
	4. Allows international comparison	Yes
	5. Threshold / Ref value	yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-OE1b Education inequity between genders	
Metric	Ratio of average level of male to female education in project workforce compared to municipal and national ratios	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	Yes
	3. **Relevance**	Yes
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	yes
	6. **Conceptually sound**	Yes
	7. **Based on international stds**	Yes
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	No municipal data but can use regional instead
	10. **Data regularly updated of good quality**	Data up to 2002 only (last labour market report)
Resolution	Use indicator for preparation, construction and operation phase	

Indicator Name	SOC-OE1c Education inequity between ethnicities	
Metric	Gini coefficient for education inequity between ethnicities	
Issues	1. **Clarity**	Yes
	2. **Responsiveness**	More responsive at local level for small projects
	3. **Relevance**	Not relevant to Iceland
	4. **Allows international comparison**	Yes
	5. **Threshold / Ref value**	Gini score of 0 ideal
	6. **Conceptually sound**	Yes, gini a commonly used indicator
	7. **Based on international stds**	Yes
	8. **Ease of use for information systems**	Yes
	9. **Data readily available /cost-effective to make available**	No data available. Related data available for education levels between genders
	10. **Data regularly updated of good quality**	-
Resolution	Do not use	

Evaluation of Indicator Suitability – Social Indicators

Indicator Name	SOC-EHS1 Worker safety or satisfaction	
Metric	Percentage of satisfied workers	
Issues	**1. Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Surveys performed every year for Landsvirkjun
Resolution	Use for all phases	

Indicator Name	SOC-SHS1 Standard of health care	
Metric	Infant mortality rates	
Issues	**1. Clarity**	Yes
	2. Responsiveness	Less responsive at national level for smaller projects
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data
	10. Data regularly updated of good quality	Data up to 2005
Resolution	Use for construction and operation phases.	

Indicator Name	SOC-SHS2 Standard of Living	
Metric	Life expectancy at birth	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Less responsive at national level for smaller projects
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No municipal data
	10. Data regularly updated of good quality	Yes
Resolution	Use for construction and operation phases	

Indicator Name	SOC-SHS3 Adverse effects on communities	
Metric	Percentage of human displacement in local communities due to energy project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No international standards as yet
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	No system in place but should be easy to implement
Resolution	Use for all phases	

Indicator Name	SOC-SHS4 Health effects of geothermal energy project	
Metric	External cost of environmental pollution from energy project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	cost-benefit analysis for projects not carried out
Resolution	Do not use	

Indicator Name	SOC-SHS5 Predicted family contact levels for population	
Metric	Distance between worker residence and family home	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	No
	6. Conceptually sound	Not commonly used
	7. Based on international stds	No standards
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No national or municipal data
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-SHS6 Perceived Levels of fairness of Project	
Description of Data	Percentage of project budget on locally based suppliers	
Issues	1. **Clarity**	Definition of "locally-based" should be clarified
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Indicator Name	SOC-SHS7 Safety of geothermal projects	
Metric	Number of accident fatalities due to geothermal energy developments	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	No
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	No data available for accidents in geothermal industry
	10. Data regularly updated of good quality	-
Resolution	Do not use	

Evaluation of Indicator Suitability – Social Indicators

Indicator Name	SOC-PP1 Public participation during energy project	
Metric	Degree of public participation during environmental impact assessment process	
Issues	1. **Clarity**	yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	No
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Yes
	10. Data regularly updated of good quality	Data not updated but can be sought when required
Resolution	Use for preparation, construction and strategic phases	

Indicator Name	SOC-PP2 Perceptions of Project at home and abroad	
Metric	Number of national and international protest against project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Mannvit / LV were not willing to release this data until later on in the process.
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Evaluation of Indicator Suitability – Social Indicators

Indicator Name	SOC-PP3 Perceptions of infrastructure projects relating to energy project at home and abroad	
Description of Data	Number of national and international protest against energy infrastructure related to the project	
Issues	1. **Clarity**	Yes
	2. Responsiveness	Yes
	3. Relevance	Yes
	4. Allows international comparison	Yes
	5. Threshold / Ref value	Yes
	6. Conceptually sound	Yes
	7. Based on international stds	Yes
	8. Ease of use for information systems	Yes
	9. Data readily available /cost-effective to make available	Mannvit / LV were not willing to release this data until later on in the process.
	10. Data regularly updated of good quality	Yes
Resolution	Do Not Use	

Evaluation of Resource Indicators for Suitability

Indicator Name	*ENV-RES3 Utilization efficiency, η_B*	*ENV-RES1 Productive lifetime*	*ECO-RR3 Reserve Capacity ratio*	*ENV-RES5 Reclamation time*	*ENV-RES2 Dissolved chemicals*	*ENV-LSC1-L Ground subsidence*	*ENV-RES4 Micro seismic activity*
Description of Data	Production reports from owner	Production reports and models from owner	Production reports and data from owner	Production reports and models from owner	Production reports from owner	Measurement report from owner	Measurement report from owner
1. Responsiveness	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Relevance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Available data that is updated regularly	Yes	Yes & No	Yes	Yes & No	Yes	Yes	Yes
4. Clear and unambiguous	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5. International comparison and standards	Yes & No	Yes & No	Yes & No	Yes & No	Yes & No	Yes & No	Yes & No
6. Threshold or reference value	Yes	No	Yes	Yes	Yes	Yes	Yes
7. Theoretically well founded	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Resolution	Use	Use	Use	Use	Use	Use	Use
Benchmark	Comparison of power plants – Mean value and standard deviation	100 years is sustainable	Reserve capacity ratio should be higher than 0,5	Not longer than the productive lifetime	Chemical changes should not indicate much cooling	Subsidence should not have negative impacts on the surroundings	Micro seismic activity should not have negative impacts on the surroundings

This Appendix is taken from the results of another masters thesis project *Sustainability Evaluation of geothermal systems in Iceland: Indicators for sustainable production* by Rut Bjarnadóttir, 2010.

Appendix C

Evaluation of Resource Indicators for Suitability

Indicator Name	*ENV-RES3 Utilization efficiency, η_B*	*ENV-RES1 Productive lifetime*	*ECO-RR3 Reserve Capacity ratio*	*ENV-RES5 Reclamation time*	*ENV-RES2 Dissolved chemicals*	*ENV-LSC1-L Ground subsidence*	*ENV-RES4 Micro seismic activity*
Description of Data	Production reports from owner	Production reports and models from owner	Production reports and data from owner	Production reports and models from owner	Production reports from owner	Measurement report from owner	Measurement report from owner
1. Responsiveness	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Relevance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Available data that is updated regularly	Yes	Yes & No	Yes	Yes & No	Yes	Yes	Yes
4. Clear and unambiguous	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5. International comparison and standards	Yes & No	Yes & No	Yes & No	Yes & No	Yes & No	Yes & No	Yes & No
6. Threshold or reference value	Yes	No	Yes	Yes	Yes	Yes	Yes
7. Theoretically well founded	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Resolution	Use	Use	Use	Use	Use	Use	Use
Benchmark	Comparison of power plants – Mean value and standard deviation	100 years is sustainable	Reserve capacity ratio should be higher than 0,5	Not longer than the productive lifetime	Chemical changes should not indicate much cooling	Subsidence should not have negative impacts on the surroundings	Micro seismic activity should not have negative impacts on the surroundings

This Appendix is taken from the results of another masters thesis project *Sustainability Evaluation of geothermal systems in Iceland: Indicators for sustainable production* by Rut Bjarnadóttir, 2010.