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Development of a sustainability assessment framework for geothermal energy projects

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ABSTRACT

With the increasing global energy consumption, geothermal energy usage is set to increase in the future. Geothermal developments may result in both positive and negative environmental and socio-economic impacts. Sustainability assessment tools are useful to decision-makers in showing the progress of energy developments towards sustainability. Due to the unique characteristics of geothermal energy projects, a customized framework for assessing their sustainability is required. This paper presents the development of an appropriate indicator assessment framework, through a case-study in Iceland. The results reveal Icelandic stakeholder views on sustainability issues relating to geothermal energy projects. Environmental and economic indicators were regarded as more relevant than social or institutional indicators. A Delphi survey revealed that the priority sustainability goals for stakeholders were related to renewability, water resource usage and environmental management. The top five indicator choices were related to resource reserve capacity, utilization efficiency, estimated productive lifetime of the geothermal resource and air and water quality.

Introduction

Geothermal energy and sustainable development

Energy usage worldwide is increasing. It has been predicted that global energy will increase by over one-third by 2035 and fossil fuels are still dominating the global energy mix (International Energy Agency, 2012), but the use of alternatives such as geothermal energy is set to increase, since the world has only a finite supply of fossil fuels. Furthermore, in order to combat climate change and fulfill international agreements, low carbon energy sources such as geothermal energy are now being tapped on a larger scale. In 2008, geothermal energy represented around 0.1% of the global primary energy supply, but estimates predict that it could fulfill around 3% of global electricity demand, as well as 5% of global heating demand by 2050 (Intergovernmental Panel on Climate Change, 2012).

While energy is needed for economic growth and sustainable development, energy development also has environmental and social impacts. Like any other energy source, geothermal energy developments can result in positive as well as negative socio-economic and environmental impacts (UNDP, 2002). For example, geothermal projects can result in socio-economic benefits particularly in developing countries and rural communities by improving infrastructure, or stimulating local economies. They can also act as a good source of base-load power for a region's energy system. However, certain issues need to be addressed as many geothermal energy developments result in negative social or environmental impacts (Shortall et al., 2015).

The wide variety of available sustainability assessment frameworks in existence today highlights the ambiguity surrounding the meaning of sustainability for different user groups, cultures and regions or organizations. As shown by the county pilot studies undertaken using the CSD indicator set, for example, customized indicator sets were often developed to suit local conditions (Pinter et al., 2005). Given the unique issues associated with geothermal energy projects, a specialized assessment tool is required to ensure that geothermal projects will be properly guided into following best practices and result in positive impacts in all sustainability dimensions: environmental, social and economic.

Objective

The purpose of this paper is to

1. Review the literature on means of developing sustainability indicators for energy developments.
2. Describe the steps needed to develop an assessment framework for geothermal energy projects, with highly organized participatory processes, through a case-study in Iceland.

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The paper will illustrate the methods used in establishing a stakeholder-qualified indicator framework in the Icelandic context and reflect on the learning process therein. The framework may then be applied in Iceland and elsewhere. The paper concludes with recommendations for the development process of the assessment framework. The Icelandic case study presented in this paper represents the first iteration of the indicator development process. Further iterations are to be carried out in Kenya and New Zealand to further refine the indicator set and reveal its suitability in these regions.

Background

Many international organizations, such as the United Nations Commission for Sustainable Development (CSD) (Pinfield, 1996), have made case that indicators are needed to guide countries or regions towards sustainable energy development and the necessity of developing sustainability indicators is clearly set out in Agenda 21. There have also been further calls in the literature for the use of sustainability indicators as a means to measure sustainability (Bell and Morse, 2008). Sustainability assessment is a means of showing if development projects contribute to a progress towards or away from sustainability. Sustainability assessments are used for many different types of projects, including energy developments. Various assessment tools, many of which involve the use of sustainability indicators, exist from the national level, to the local level (Pinter et al., 2005). Such indicators must provide a holistic view of sustainability, and thereby include all sustainability dimensions. Furthermore, as well as indicators, sustainability criteria or goals are also important for sustainability measurement. Such criteria and indicators should not be rigid but take account of the local context as well as changes in opinions over time (Lim and Yang, 2009). In order to ensure this, broad stakeholder engagement is an essential part of the indicator development process (Fraser et al., 2006).

Assessment frameworks range from overarching guidelines, such as the Bellagio STAMP principles to specific sustainability indicator development approaches, such as the Pressure-State-Response (PSR)/Driving Force-State-Response (DSR) framework or the theme based approach (Shortall et al., 2015). The most widely used development approach, especially for national indicator sets, is theme-based. In such frameworks, indicators are grouped according to sustainability issue-areas or themes, which are chosen based on their policy-relevance. Theme-based indicator sets allow decision-makers to link indicators to policies or targets (United Nations, 2007). While the various impacts of geothermal projects have been discussed in depth by the authors (Shortall et al., 2015), some examples of unsustainably management of geothermal clearly illustrate the need for better sustainability monitoring systems.

The Hellisheidi geothermal power plant is the largest combined heat and power plant in Iceland. Turbines were brought online in a series of phases between 2006 and 2011. Decisions on how large the Hellisheidi Power Plant should be were made before enough steam had been proved by drilling. No production data was available and therefore the decisions were based on the initial state of the reservoir alone. By 2040, the draw down and cooling of the geothermal field will most likely render production uneconomic, leaving the resource with a total productive lifetime of only 34 years. A total of 66 production wells will need to be brought online by the end of 2040 (Gunnarsson et al., 2011). In the Icelandic context, this is at odds with the acceptable resource lifetime of at least 100–300 years (National Energy Authority, 2010). It is predicted that pressure will return in 60–80 years if all production is terminated by 2040, but temperature could take up to 1000 years to recover. This could have been avoided by using more appropriate resource management strategies (Gunnarsson et al., 2011).

A further example of unsustainable management can be seen with the Wairakei power plant in New Zealand where separated geothermal water and cooling water are discharged into the section of the Waikato river between Lake Taupo and Ohaaki Bridge (Ray, 2001). The arsenic level in the Waikato River has more than doubled since the station opened in the 1950s and now exceeds drinking water standards (Waikato Regional Council, 2012).

In Iceland, assessment of the impacts of geothermal projects on sustainable development is mainly limited to the pre-development phase. An energy Master Plan has been proposed in Iceland that ranks the desirability of potential energy projects according to a number of environmental, social and economic criteria. Environmental impact assessments are done for proposed geothermal projects, as for any major development, yet the outcome of these assessments can vary significantly. While routine environmental monitoring is carried out by various agencies nationally, no specific requirements to monitor the environmental, social and economic impacts of geothermal projects are currently specified in legislation for the sustainable management of geothermal projects.

Sustainability indicators and energy

As has been illustrated (Shortall et al., 2015), the impacts of geothermal energy developments have significant implications for sustainable development, and require specific monitoring tools to ensure the impacts are managed in a sustainable manner. Several indicator frameworks exist to measure sustainable development in the context of energy developments. While they are not all suited to assessing geothermal projects in themselves, they can be used as guidelines to further the development of a framework to assess geothermal energy developments. These frameworks and the methods used to create them are described below. For a more in-depth discussion of such frameworks, please refer to the author's previous work.

International atomic energy agency energy indicators of sustainable development

In 2005 the International Atomic Energy Agency (IAEA) created a set of energy indicators for sustainable development (EISDs) (International Atomic Energy Agency (IAEA), 2005) 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.

The EISD indicators are intended for use at a national level and cover many different types of energy usage. For this reason, they are unsuited to assessing individual geothermal projects, but their conceptual framework provides some basis for the design of a framework for geothermal energy assessment in particular.

International hydropower association sustainability assessment protocol

The International Hydropower Association has developed a sustainability assessment tool for hydropower projects (IHA-SAP) (International Hydropower Association, 2006). Although not based on indicators as such, the IHA-SAP assesses various strategic and managerial aspects of proposed or operational hydropower projects (International Hydropower Association, 2008).

Gold Standard foundation indicators for carbon projects and credits

The Gold Standard Foundation provides 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 (The Gold Standard Foundation, 2012). The Gold Standard is an accreditation system for greenhouse gas (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) only) reduction projects, whose eligibility is evaluated under a number of criteria such as the project scale or location (The Gold Standard Foundation, 2012). The Gold Standard indicators are general and therefore not specifically tailored to geothermal projects. As a result, they are not suitable to be used themselves to carry out geothermal assessments, since they do not deal with all of the unique sustainability issues associated with geothermal development projects.

Other frameworks

The Commission for Sustainable Development (CSD) provides guidelines for developing national level sustainability indicators, including energy indicators (United Nations, 2007). In the EU, these indicators were incorporated into a monitoring framework, to monitor the implementation of the main EU directives and other policies relating to sustainable energy development (European Commission, 2005).

This framework exists at the national level and is not specific enough and thus not suitable as a geothermal assessment tool, but the themes of the CSD conceptual framework are useful for categorizing geothermal sustainability issues that should be assessed (Shortall et al., 2015). The CSD thematic framework can therefore be taken further by applying additional stakeholder engagement methods to develop indicators for geothermal developments.

The Energy Sustainability Index, developed by the World Energy Council, looks at the impact of energy policies of different countries and ranks them in terms of energy sustainability based on the three dimensions of energy security, social equity, and environmental impact mitigation. The index uses two types of indicator, energy performance indicators, covering supply and demand, affordability and access; and contextual indicators, covering broader issues such as living standards and the economic and political conditions (World Energy Council, 2011). This index uses national-level information for its indicators, therefore is not suited to assessing individual energy projects but nonetheless highlights important issues that should be considered in 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-Energy, 2007). However no indicators exist for assessing the sustainability of geothermal power.

Development method

Overview of the development process

A sustainability assessment framework consists of a set of sustainability goals and indicators that allow monitoring of geothermal projects during their entire life cycle.

This section describes the methods used to carry out the first iteration of the indicator development process. Initially an extensive literature review of the impacts of geothermal energy projects on sustainable development (Shortall et al., 2015) was carried out in order to identify the most important sustainability issues in geothermal energy developments. An initial set of potential indicators and goals was established by the authors providing a starting point for which further stakeholder input would be sought later in the process in an iterative process (Davidsdottir et al., 2007) with the intention of carrying out iterations in a number of different geographical locations. Each iteration constitutes a separate, yet interconnected, case study. The purpose of the iterative approach is to allow the progressive refinement of the indicator set following each iteration.

Once the sustainability goals were established, the boundaries of the system that the framework would assess were defined. The system boundaries were conceptualized within the dimensions of sustainable development (social, environmental, economic) and then further broken down into a number of sustainability themes (Shortall et al., 2015). Following the literature review, stakeholders were selected to take part in the development process via a pre-engagement World Café workshop and online Delphi survey. In the pre-engagement workshop, stakeholders rated and commented on the draft list of indicators, presented to them by the authors, which were then reduced in number based on stakeholder input. Some new indicators were also suggested at this stage. Later, in the Delphi survey, this list of indicators was refined further and the draft list of sustainability goals was also reviewed and refined. The refined sustainability goals and indicators were then calculated in a trial assessment, using data from the Nesjavellir geothermal power project. It should be noted that the results of this trial assessment are beyond the scope of this paper. At the end of this process, it was possible to evaluate the indicators for suitability to their purpose using the set of criteria shown in the section on Iterative indicator development method. Guiding principles known as the Bellagio STAMP (Box 3-1) were incorporated into the entire development process.

Iterative indicator development method

An iterative approach, shown in Fig. 3-1 (Davidsdottir et al., 2007) to indicator development was chosen because it lends itself well to the trialing of the indicator set in several countries, allowing refinement of the indicators, after each iteration, and to account for regional specificities. This was also intended to reduce country or stakeholder biases, which could arise if stakeholders in only one country were consulted.

The method consists of the following steps, which may be repeated as necessary, in an iterative fashion.

1. Definition of sustainability goals;
2. specification of dimensions;
3. selection of themes and sub-themes;
4. selection of indicators;
5. selection of aggregation function;
6. selection and calculation of weights (if needed);
7. calculation of indicators; and
8. reporting of indicators.

The first four steps of the iterative process (Fig. 3-1) required stakeholder input, which in this case was obtained through pre-engagement “World Café” workshops (World Café workshop section) and the Delphi technique (The Delphi technique section). These methods are explained in detail in the next section.

During the first four steps, following the literature review, the facilitators' personal expert judgment and stakeholder input were used to determine sustainability goals, dimensions and themes and the best and most suitable indicators, using as a guidance the suitability criteria shown below. Once indicators were chosen, they were then calculated in a trial assessment on the existing Nesjavellir geothermal energy project in Iceland. By carrying out trial calculations, issues such as lack of data, the suitability of reference values or responsiveness of the indicator were identified. The indicators were again evaluated for their suitability to their purpose against the following suitability criteria (OECD, 1993; United Nations, 2007):

- clear and unambiguous and able to show trends over time;
- responsive to changes in the environment and related human activities;
- relevant to assessing sustainable development progress;
- provide a basis for international comparisons;
- 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;

Box 3-1
List of Bellagio STAMP principles.

1. Guiding vision
   Assessing progress towards sustainable development is guided by the goal to deliver well — being within the capacity of the biosphere to sustain it for future generations.
2. Essential considerations
   Sustainability assessments consider the following:
   - The underlying social, economic and environmental system as a whole and the interactions among its components.
   - The adequacy of governance mechanisms.
   - Dynamics of current trends and drivers of change and their interactions.
   - Risks, uncertainties, and activities that can have an impact across boundaries.
   - Implications for decision-making, including trade-offs and synergies.
3. Adequate scope
   Sustainability assessments adopt the following:
   - Appropriate time horizon to capture both short and long-term effects of current policy decisions and human activities.
   - Geographical scope ranging from local to global.
4. Framework and indicators
   Sustainability assessments are based on the following:
   - A conceptual framework that identifies the domains that core indicators have to cover.
   - The most recent and reliable data, projections and models to infer trends and build scenarios.
   - Standardized measurement methods, wherever possible, in the interest of comparability.
   - Comparison of indicator values with targets and benchmarks, where possible.
5. Transparency
   The assessment of progress towards sustainable development:
   - Ensures the data, indicators and results of the assessment are accessible to the public.
   - Explains the choices, assumptions and uncertainties determining the results of the assessment.
   - Discloses data sources and methods.
   - Discloses all sources of funding and potential conflicts of interest.
6. Effective communication
   In the interest of effective communication, to attract the broadest possible audience and to minimize the risk of misuse, sustainability assessments:
   - Use clear and plain language.
   - Present information in a fair and objective way, that helps to build trust.
   - Use innovative visual tools and graphics to aid interpretation and tell a story.
   - Make data available in as much detail as reliable and practical.
7. Broad participation
   To strengthen their legitimacy and relevance, sustainability assessments should:
   - Find appropriate ways to reflect the views of the public, while providing active leadership.
   - Engage early on with users of the assessment so that it best fits their needs.
8. Continuity and capacity
   Assessments of progress towards sustainable development require the following:
   - Repeated measurement.
   - Responsiveness to change.
   - Investment to develop and maintain adequate capacity.
   - Continuous learning and improvement.

- theoretically well founded in technical and scientific terms;
- based on international standards and international consensus about its validity to the extent possible;
- lend itself to being linked to economic models, forecasting and information systems;
- use data which is readily available or made available at a reasonable cost/benefit ratio; and
- use data which is updated regularly or adequately documented and of known quality.

The assessment is not designed to result in one final value and weights were not assigned to the indicators in this study, as it was felt that the aggregation of the indicators into one number would result in loss of important insights provided by individual indicators.

Overarching guidelines: the Bellagio STAMP

To guide the process of developing a sustainability assessment framework, the principles of the Bellagio group, known as the Bellagio STAMP were used as overarching guidelines. The International Institute of Sustainable Development's Bellagio STAMP principles are a set of guiding principles designed to be applied when improving sustainability assessment systems and have been widely adopted (IISD, 1997). The Bellagio STAMP was developed with the aim of addressing the shortcomings of indicator schemes recognized by the research community; harmonizing indicator sets internationally; and improving co-ordination among measurement and assessment processes (IISD, 2012). The principles are intended to guide the choice and design of indicators, their interpretation and their communication. While the Bellagio STAMP principles seek to promote desirable characteristics of sustainability assessment tools, they do not offer a detailed methodological approach required for the development of an indicator set.

Stakeholder engagement methods

The meaning of sustainable development depends on a group or society's opinions and values regarding issues that are important to them. These values will determine which goals should be pursued and what should be measured (Meadows, 1998; Shields et al., 2002). The wide-ranging topic of geothermal sustainability therefore requires the combined expert input of a varied group of experts, obtained by using an appropriate stakeholder engagement technique.

General description of engagement methods

Stakeholder engagement is “the process used by an organization to engage relevant parties for a clear purpose to achieve accepted outcomes” (UK Institute of Social and Ethical Accountability, 2011) and is now also regarded as a type of accountability mechanism. In order for stakeholder engagement programs to be successful, they must clearly define the scope of the issue to be addressed, include an pre-approved decision making process, focus on stakeholder-relevant issues,

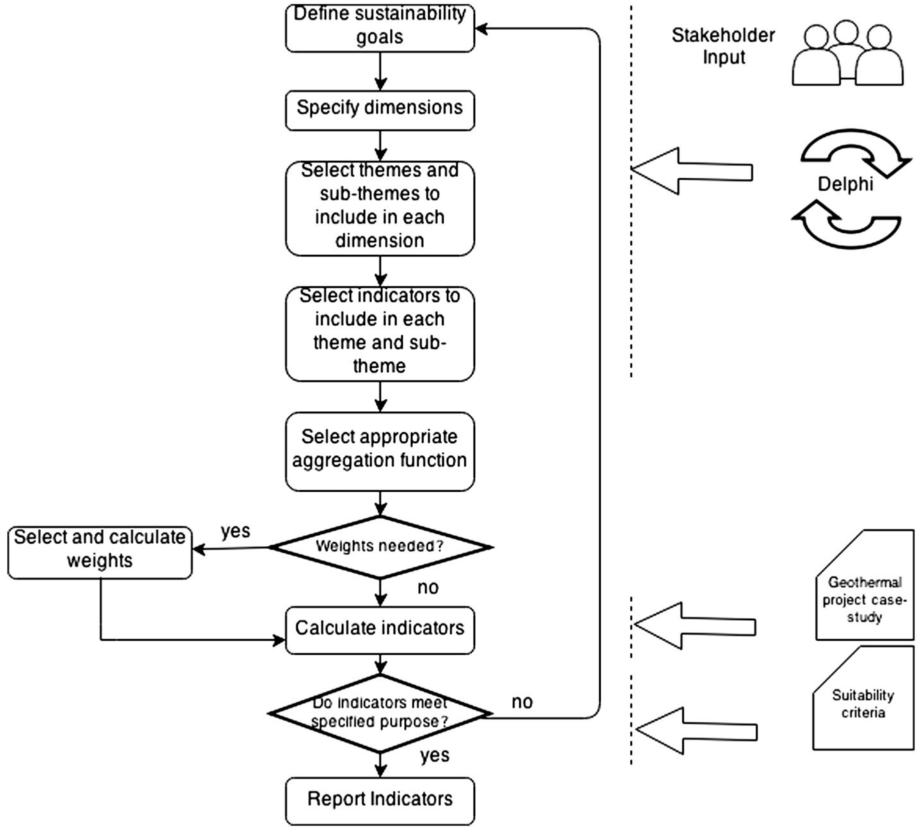

Fig. 3-1. Iterative indicator development process.
Diagram modified from Davidsdottir et al. (2007).

encourage dialogue, use culturally appropriate methods and be transparent, timely and adaptable (UK Institute of Social and Ethical Accountability, 2011). Stakeholder engagement techniques have been used to address sustainability issues in diverse sectors, including mining (Azapagic, 2004), forestry (Sharma and Henriques, 2005), transportation (Mihyeon Jeon and Amekudzi, 2005), aviation (Amaeshi and Crane, 2006) and environmental management (Reed, 2008).

Stakeholder mapping. Stakeholders are generally defined as “persons or groups who are directly or indirectly affected by a development project, as well as those who may have interests in a project and/or the ability to influence its outcome, either positively or negatively” (International Finance Corporation, 2007). Another definition of stakeholders is as follows:

> Stakeholders are not just members of communities or non-governmental organisations. They are those individuals, groups of individuals or organisations that affect and/or could be affected by an organisation's activities, products or services and associated performance with regard to the issues to be addressed by the engagement.
>
> [UK Institute of Social and Ethical Accountability, 2011, p. 10]

For a geothermal project, stakeholders may include local communities, the geothermal industry, government authorities (local, regional or national), political or religious leaders, non-governmental organizations, academics, or other businesses, such as suppliers or those that may use the geothermal power.

A stakeholder mapping exercise was carried out before the engagement process to identify individuals or organizations that would potentially be impacted by or have an interest or impact in the sustainable operation of geothermal projects. Stakeholders were chosen based on a number of characteristics, as recommended by the Australian government stakeholder engagement practitioner handbook (Australian Government, 2008):

- Responsibility: people to whom a hypothetical geothermal development would have responsibility to, such as the local community or general public, community representatives or NGOs, environmental organizations, local businesses, future generations.
- Proximity: those people who would have most interaction with a hypothetical geothermal project, such as the following: the geothermal industry itself, researchers, governments, local communities.
- Dependency: those who depend directly or indirectly on a geothermal project, such as the following: power companies, financiers, potential users of the energy, the local community, local businesses.
- Representation: those people that represent a constituency impacted by geothermal projects, such as the following: NGOs representing the environment or “voiceless” things such as landscape, geothermal features, delicate ecosystems, forests and so on; indigenous peoples representatives, other community group representatives such as local authorities, trade unions, or local leaders.
- Policy and Strategic intent: those people to whom geothermal projects (or companies) address their policy or value statements, such as the following: NGOs, activists, community groups, financiers.

The chosen stakeholders then interacted in a world café workshop and during a Delphi process.

World Café workshop. The World Café is described as “a powerful social technology for engaging people in conversations that matter” and is based on the understanding that conversation is the core process that drives personal, business, and organizational life (Brown and Isaacs, 2005). The method has the advantage of being flexible and easily adapted to suit the needs of the group. Generally, participants meet in a Café style setting, seated at tables where they hold conversations exploring a particular question, moving between tables at prescribed time intervals (Brown and Isaacs, 2005). In this way, the method allows diverse information to be gathered as well as the sharing of ideas and insight. Participants learn collectively, allowing the group to find solutions to the given question, based on their new insights (Brown and Isaacs, 2005).

The disadvantages of using the World Café technique, as for any type of stakeholder group meeting (Thompson, 2007), include the potential for conflict in a group setting, due to differences in opinion of stakeholders. The success of the World Café will depend on the participants present. Furthermore, the cost of organizing and facilitating the workshop may be prohibitive and participants may need to travel long distances to reach the location. Few studies using the World Café method exist in the literature, however the method has, for example, been applied in social science research in order to help develop a culture of enquiry among practitioners in social service (Fouché and Light, 2011). Further examples of its use appear in fields such as nursing (Brooma et al., 2013).

The Delphi technique. The Delphi technique is used for policy, decision, and goal setting, when consensus is required from a group of stakeholders with widely divergent opinions or backgrounds (Lim and Yang, 2009). The technique uses a structured format to elicit opinions and potential consensus among a group of stakeholders or experts in their field. As a result, the method has become increasingly popular and widely used in technology, education and other fields (Lim and Yang, 2009), and has been used successfully in developing indicators of sustainability in diverse fields such as road infrastructure projects (Lim and Yang, 2009), ecotourism (Barzekar et al., 2011) and communities (Hai et al., 2009).

For the Icelandic Delphi 70 stakeholders were invited for the survey. This would have been too large a group to facilitate the effective extraction of opinions in a short time frame. It would also have been difficult and costly to arrange repeated face-to-face meetings with the number of people involved. Even though a pre-engagement World Café workshop was organized, it was not possible to arrange similar meetings for all three Delphi rounds. Furthermore, the Icelandic stakeholder group consisted of members of government and other institutions with differing views. Since Iceland is a small community, the Delphi technique was chosen as a way to circumvent political differences that could arise in a group setting.

Implementation of engagement methods

As per the recommendations of the Bellagio STAMP (IISD, 2012), a diverse group of stakeholders was selected to contribute to the process of developing the sustainability assessment framework. The group consisted of participants from diverse backgrounds, from government to industry to NGOs. As can be seen from Fig. 3-1, stakeholder engagement is an integral part of the iterative indicator development process. Stakeholders have an influence through their comments during the pre-engagement "World Café" workshop and the Delphi process, from the choice of sustainability goals and indicators (Fig. 3-1). Their input also defines the scope of the assessment itself by identifying the most important sustainability issues that will be considered.

The World Café workshop technique was used as a starting point or pre-engagement method. The purpose of this workshop was to present the research project to the stakeholder group, informing them of their role in the process; as well as to elicit an initial response to a list of sustainability indicators only during the literature review period. The responses of this stakeholder group would then be incorporated into a more in-depth engagement process in the form of a Delphi. Before the workshop, emails were sent to participants with explanatory information, along with a list of indicators that they would be required to comment on. The workshop involved having participants seated in small groups around tables, where they were provided with lists of indicators. They were asked to deal with each indicator on the list systematically, discussing and voting as a group and making comments individually on sheets of paper. Participants voted by show of hands. For convenience, the indicators were divided into three themes: Environment, Society (including Institutional indicators) and Economy. Table hosts were seated at each table and remained at the same table throughout the workshop. Participants were put into groups of 5–6 and moved from one table to the next after each thematic round. Once all participants had covered the three dimensions, the main opinions of each group were presented and discussed as a group. Comment sheets were then gathered from table hosts and participants. The table hosts also took note of the overall opinion of each group for each indicator and noted any prominent discussion topics at each table regarding the indicators. Following the World Café in Iceland, the following steps were taken to refine the initial sustainability indicator set:

- Discard indicators which were voted to have low or no relevance (attempt to have less indicators overall).
- Discard indicators that are hard to understand, even with supplementary information.
- Include new indicator suggestions, if they fulfill the criteria for good indicators.

The Delphi technique was the main stakeholder engagement method used in the study. The main steps taken by the facilitators in the Delphi technique (Linstone and Turoff, 2002; Barzekar et al., 2011; Lim and Yang, 2009) are as follows:

1. Assemble/choose participants.
2. Present list of goals and indicators to be rated and added to by the group through an online survey.
3. Rate and comment on each item.
4. Record each participant's ratings and modify the list based on ratings or comments (may involve adding or eliminating items).
5. Return the statistics to all participants.
6. Rate and comment on items again.
7. Repeat the process (steps 3–6) for three rounds.
8. Select the highest rated goals and indicators (those with the highest mean score) to use in final assessment framework.

The Icelandic Delphi consisted of three rounds in total. In Round 1, the participants were presented with an initial set of indicators and asked to rate and comment on each one. In this instance, indicators had already been suggested in the pre-engagement workshop as a starting point for the Delphi. Stakeholders were asked to suggest sustainability goals themselves in Round 1. The participants were also given the opportunity to suggest new indicators in the comments section. After Round 1, the facilitators modified the list based on ratings and synthesized comments. Comments on reference values or perceived relevance of indicators were taken into account. New goals and indicator suggestions were also incorporated into the modified list. In Rounds 2 and 3, the participants were requested to rate the modified list and make comments if they desired. After each round, the

Table 3-1
Scoring system for Delphi survey.

Score	Relevance
1	Irrelevant
2	Somewhat irrelevant
3	Neither relevant not irrelevant
4	Somewhat relevant
5	Extremely relevant

Table 4-1
Types of stakeholders, Iceland.

Organization type	World Café	Delphi
Energy industry	6	9
Other business	5	7
Non-governmental	2	2
Government	7	5
Academia	3	10
Total	23	33

facilitators modified the list as before. After Round 3, the final list was taken to represent a broader consensus of the participants on the most appropriate goals and indicators. Scores were allocated by participants on a scale of 1–5 (Table 3-1), according to the perceived relevance of the sustainability goal or indicator.

In general, items with a mean score below 3 were discarded. Items with a low score but high standard deviation were resubmitted to the next round if there was evidence that more information or a modification could result in a different score.

Indicators were discarded if they clearly did not fulfill the criteria for good indicators, e.g. if there was a difficulty finding a reference value for them, for example, with newly suggested indicators, or if they were unsuitable in the opinion of the facilitators (e.g. not clearly understandable to the general public, or clearly missing the point of the exercise). For example, there was no reference value for the total number of cases lost in the Supreme Court by the energy company per year. The same was true for the area of land used due to geothermal energy project. The indicators for odor experience from H_2S gas and acidifying air pollutants were discarded because stakeholders considered these issues to be covered already by the air quality indicator.

Results

The stakeholder engagement process was designed according to the Bellagio principles (Box 3-1), in order to obtain as diverse a range of views as possible regarding the choice of sustainability goals and indicators. The results of the stakeholder engagement process for the Icelandic iteration of the indicator development process are described below.

Stakeholder participation

The group of stakeholders listed in Table 4-1 agreed to take part in the indicator development process in Iceland.

Pre-engagement workshop (World Café)

Although time was a limiting factor for the workshop, the participants still managed to provide insightful comments on many of the indicators presented to them by the authors, which helped the facilitators to refine the list further before the Delphi process. Results of group voting and comments on the individual indicators are presented in the Appendix A. The economic indicators received quite high votes overall (Appendix A). Comments suggested that economic costs and benefits for the project-affected community should be measured by the indicators, with less emphasis on the financial performance of the energy company. Measures of economic diversity such as the Hackman index or Shannon–Weiner index were not understood by most stakeholders.

Table 4-3
Sustainability goals with scores after each Delphi round.

Goal	Score after Round 2	Score after Round 3
Goal 1 — Renewability	4.72	4.55
Goal 2 — Water resource usage	4.68	4.09
Goal 3 — Environmental management	4.65	4.45
Goal 4 — Efficiency	4.18	3.64
Goal 5 — Economic management & profitability	4.12	4.09
Goal 6 — Energy equity	4.04	3.64
Goal 7 — Energy security & reliability	4.12	4.00
Goal 8 — Community responsibility	4.5	4.00
Goal 9 — Research and innovation	4.4	4.18
Goal 10 — Dissemination of knowledge	4.4	4.27

The indicator measuring the difference between change in average national and municipal house prices and income levels was also unclear to some people. The institutional indicators (Appendix A) achieved few votes overall. Comments generally questioned the relevance, clarity or methods of the institutional indicators and called for less R&D indicators. The comments suggested that almost all of the environmental indicators (Appendix A) were considered relevant. There were a few suggestions for combining some of the environmental indicators. For instance, the indicators on odor from H_2S gas and acidifying air pollution were considered to be already covered by the air quality indicator and were therefore eliminated. The social indicators received a mixed vote overall. In many cases, stakeholders called for more information on the rationale behind certain indicators, while low relevance to sustainability for developed countries was cited in other cases. For example, the indicators on life expectancy at birth and number of unlicensed teachers in the project-affected area were only considered relevant in developing countries by the stakeholders. The participants put forward a number of suggestions for new indicators, which are shown in the Appendix A, categorized into dimensions of sustainability. Not all of these suggestions were suitable for use as indicators for various reasons. Table hosts recorded any notable comments from discussion at each table. Further comments were provided by individual participants on comment sheets or post-its, which were collected afterwards (see Appendix A). Based on the results of the World Café, it became clear how the indicator set would need to be refined for this iteration. The comments of the stakeholder groups were taken into account and a number of steps were taken to improve the indicator set, taking into account the suitability criteria for indicator selection shown in the section on Iterative indicator development method. It also became clear that modifications would also be necessary regarding how the indicators were presented. The following tasks were therefore required:

- Rearrange indicators into more meaningful clusters/themes/sub-themes, for certain user groups.
- Reduce the number of indicators where possible or simplify by condensing or combining indicators.
- Classify indicators more clearly according to phase and scope.
- Improve and distribute supplementary information for all of the indicators where necessary.
- Clarify the future use focus of the indicators according to the following:

a. scale: project/local/regional/national;
b. project phase: assessment vs. monitoring;

Table 4-2
Response rates of Delphi participants.

	Invited	Response rate	Responded (partial/complete)
Round 1	70	47%	33 (11/22)
Round 2	70	23%	16 (3/13)
Round 3	70	16%	11 (2/9)

Table 4-4
Highest scoring goals — Icelandic Delphi.

Goal	Mean score
Goal 1 — Renewability	4.55
Goal 3 — Environmental management	4.45
Goal 10 — Dissemination of knowledge	4.27

Table 4-5
Lowest scoring goals — Icelandic Delphi.

Goal	Mean score
Goal 4 — Efficiency	3.64
Goal 6 — Energy equity	3.64
Goal 7 — Energy security	4

c. scope: direct or indirect impact from project, inclusion of cascaded uses;
d. focus: developer company, government or other groups;
e. economy type: developed vs. developing countries;
f. project type: high heat (electricity) or Low heat (other uses) projects; and
g. project size: small or large projects.

Delphi results

As stated before stakeholders in Iceland were invited to take part in an online Delphi, beginning in March 2013 and ending in August 2013.

Response rates

It should be noted that during the Delphi, invitations were sent out to a pool of seventy potential participants for all three rounds. In each round a portion of this pool responded, but the same people did not necessarily respond each time. The response rates of participants are shown in Table 4-2.

Sustainability goals

Once sustainability goals were suggested by stakeholders in the first Delphi round, in Round 2 the participants were requested to award a score between 1 (irrelevant) and 5 (extremely relevant) to each item on the list of sustainability goals (Table 4-3). Since the participants suggested goals in the first round, they could only rate the goals in the second and third rounds. The number of goals remained the same during the course of the Delphi.

Agreement and consensus: goals. At the end of three rounds, there was a general consensus between the stakeholders on the most relevant and least relevant goals. Tables 4-4 and 4-5 show the highest and lowest scoring goals in the Delphi.

The standard deviation serves as a measure of agreement between participants on the relevance on a given item. After the final Delphi round for Iceland, the scores with the highest standard deviation were those of Energy Equity and Efficiency. These, as expected, were also among the lowest scoring goals in terms of perceived relevance. The scores with the lowest standard deviation were those of Renewability and Environmental Management. These goals were also the highest scoring in terms of perceived relevance. Fig. 4-1 shows the change in standard deviation for the sustainability goals between Rounds 2 and 3.

For all the goals in the Icelandic Delphi, the standard deviation decreased between Round 2 and Round 3, indicating an increased agreement between participants on the relevance of these goals.

Sustainability indicators

The number of indicators reduced from 38 to 24 after three Delphi rounds. Table 4-6 shows the change in indicator numbers after each round.

As with the sustainability goals, the participants were requested to award a score between 1 (irrelevant) and 5 (extremely relevant) to each item on the list of initial sustainability indicators. The scores received by the indicators after each round are shown in Table 4-7. Indicators that were eliminated during the Delphi are not shown in this table. These indicators are discussed later.

Some indicators were added after Round 1 based on suggestions of the stakeholders and therefore have an "n/a" score. Indicators that were eliminated after a round also have an "n/a" score in the next round. The five highest scoring indicators after three Delphi rounds are shown in Table 4-8. These are the indicators that the participants considered most relevant to geothermal sustainability.

The five lowest scoring indicators are shown in Table 4-9. These are the indicators that the participants considered least relevant to geothermal sustainability.

Agreement and consensus: indicators. The standard deviation for the lower scoring indicators was generally wider than for the higher scoring ones, indicating less agreement on these indicators between stakeholders. Tables 4-10 and 4-11 show the indicators with the five highest and lowest standard deviations for the Delphi.

The standard deviation decreased for the majority of indicators between Round 1 and Round 3 (Fig. 4-2), indicating a higher level of agreement between the Icelandic Delphi participants.

Elimination of indicators. The Delphi facilitators used personal expert judgment and stakeholder input to determine the best and most suitable indicators. Indicators were also calculated from the available data

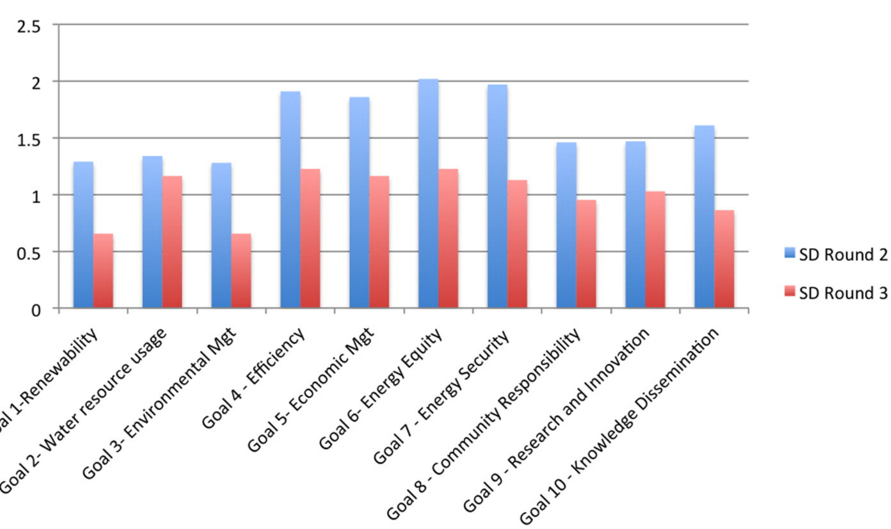

Fig. 4-1. Sustainability goals Iceland — comparison of standard deviation between Round 2 and Round 3.

Table 4-6
Change in indicator numbers after each Delphi round.

Round	Number of indicators before	Number of indicators after	% increase/decrease
Round 1	38	24 + 2 new	−32%
Round 2	26	24	−8%
Round 3	24	24	0%

Table 4-8
Highest scoring indicators after Round 3.

Indicator	Mean score
Resource reserve capacity ratio of the geothermal resource	4.22
Utilization efficiency	4.22
Estimated productive lifetime of geothermal resource	4.56
Water quality	4.67
Air quality	4.78

and evaluated for suitability after this. Indicators were eliminated based on facilitator judgments and stakeholder comments on their suitability. An indicator was eliminated if it could clearly not fulfill all of the suitability criteria shown in Box 3-1. In most cases, the indicator's score would also reflect its suitability. Otherwise, if a modification of the indicator would mean it fulfilled the criteria, then this modification was suggested in the next round and stakeholders scored the indicator again. Table 4-12 shows the indicators that were eliminated during the Delphi, along with the reasons for elimination.

Discussion

In this section the following questions regarding the effectiveness of the indicator development process are addressed:

- Was the stakeholder process effective and valid?
- Is the framework suited to its intended purpose?
- What modifications should be made based on the experience gained?

Effectiveness and validity of the stakeholder process

The stakeholder process was designed to obtain as broad ranging set of views as possible. Stakeholders from a wide range of sectors participated in the process. The World Café and Delphi Technique were the dominant methods used to gain stakeholder input during the indicator development process. Their validity and effectiveness is discussed below.

Pre-engagement World Café workshop

The World Café workshop had a high attendance with a broad range of stakeholders.

This showed the interest of the participants in the topic and a willingness to be involved in the process. The high attendance may also have been due in part to the fact that many of the people invited already work in the Reykjavik area and the fact that Reykjavik is a small and easily navigable city. The participants found that they did not have enough time in some cases to complete the voting on each dimension of the indicators as well as suggest new indicators. Furthermore a convergence in the voting was observed when “show of hands” voting was used in the groups, suggesting a possible “bandwagon” effect. Not all participants provided comments on their answer sheets. The knowledge of participants regarding indicators in general also varied significantly, although this was to be expected and even desirable (Fraser et al., 2006). However the pre-engagement workshop did serve to provide many useful ideas regarding the modification of the indicator set, as well as putting suggestions for new indicators forward. It also provided local insights and qualitative information, which although not directly useful for indicator development, did help to highlight important issues regarding geothermal development in the Icelandic context. The facilitators modified the list of initial indicators based on the workshop outputs and used this list for the first round of the Delphi process.

Delphi process

Proponents of the Delphi technique propose that a successful Delphi must provide a more accurate result than would otherwise be achieved

Table 4-7
Comparison of mean scores for indicators between Delphi rounds.

Indicator	Mean R1	Mean R2	Mean R3
Air quality in the surrounds of the geothermal power plant	4.28	4.36	4.78
Average income levels in project-affected communities	2.32	2.72	3.33
Direct and indirect local job creation over lifetime of project	3.09	2.93	3.44
Duration of plant power outages per year	3.07	3.36	3.89
EBIDA ratio per project	n/a	3.04	3.33
Estimated productive lifetime of geothermal resource	4.48	4.68	4.56
Expenditure on heat and electricity as a percentage of household income	3.09	3.25	3.33
Impact on important or vulnerable geothermal features	3.47	4.20	4.00
Imported energy as a percentage of total (national level)	3.13	3.43	3.56
Income-to-expenditure ratio for project-affected municipalities	3.22	3.43	3.56
Initial phase capacity as a percentage of estimated total capacity	2.35	3.0	n/a
Level of induced seismicity per year	3.22	3.61	3.67
Noise levels in working, recreation and residential areas in the surrounds of the geothermal power plant.	3.66	3.71	4.22
Number of accidents leading to work absence in the energy company per year	2.93	3.65	4.22
Percentage of community residents that must be relocated due to energy project	3.73	3.75	3.89
Percentage of energy company expenditure given to R&D per year	3.04	3.79	3.33
Percentage of protected area removed/affected due to geothermal project	4.27	4.04	4.11
Percentage of renewables in total energy supply nationally	3.66	4.22	3.33
Project internal rate of return (IRR)	3.61	3.68	3.67
Rate of subsidence in the geothermal field	3.26	3.97	4.11
Ratio of average male income to female income for the project-affected area	2.25	3.65	3.89
Ratio of reinjection to production	n/a	4.00	n/a
Resource reserve capacity ratio of the geothermal resource	4.04	4.22	4.22
Tons of greenhouse gas emissions resulting from geothermal operations	3.76	4.04	4.11
Utilization efficiency for the geothermal power plant	4.04	4.25	4.22
Water quality	4.13	4.54	4.67

Table 4-9
Lowest scoring indicators after Round 3.

Indicator	Mean score
Average income levels in project-affected communities	3.33
EBITDA ratio per project	3.33
Expenditure on heat and electricity as a percentage of household income	3.33
Percentage of energy company expenditure given to R&D per year	3.33
Percentage of renewables in total energy supply nationally	3.33

Table 4-11
Indicators with lowest standard deviations after Round 3.

Indicator	Mean score	Standard deviation
Tons of greenhouse gas emissions resulting from geothermal operations	4.11	0.57
Air quality in the surrounds of the geothermal power plant	4.78	0.63
Noise levels in working, recreation and residential areas in the surrounds of the geothermal power plant	4.22	0.63
Utilization efficiency for the geothermal power plant	4.22	0.63
Water quality	4.67	0.67

by individuals or interacting groups. The Delphi technique may avoid the interpersonal conflict of groups, or the domination of a group by perceived powerful personalities (Powell, 2003). The main advantages of the Delphi technique are said to be its ability to be used in areas of uncertainty as well as its relatively low cost. Through its feedback mechanism, it can expand the knowledge of participants and stimulate new ideas. It is also a way of gathering a broad range of direct expert knowledge into a decision-making process, with few geographical limitations (Powell, 2003). Conversely, disadvantages may include a high time commitment; hasty decisions by participants; the risk of producing a "watered down" opinion; the risk of lack of accountability for opinions due to anonymity; or the potential for low response rates (Powell, 2003). In addition, the facilitators may unintentionally influence opinions and there the level of expertise among participants may vary greatly (Hsu and Sandford, 2007). Furthermore, clustering at the high end of the scale may occur when category scales are used to score items, making it difficult to interpret the result (McGeary, 2009).

Indicators of sustainability are only likely to be effective if they provide users and the public with meaningful information they can relate to. Users like policy- and decision-makers will be in a better position to set attainable policy goals if they understand environment–society interactions well, and this is all the more likely to happen if indicators are derived from a participatory process, as they will reflect the objectives and values of the public (Shields et al., 2002). In this iteration of the indicator development process, both the sustainability goals and indicators were chosen by stakeholders, so the list should prove useful to useful to future users, such as policy-makers or regulators in the Icelandic context. In order to be influential, consensus must exist among policy actors that the indicators are legitimate, credible and salient (Cash et al., 2003). This means that the indicators must not only answer questions that are relevant to the policy actor, but also provide a scientifically plausible and technically adequate assessment. To be legitimate, the indicators must be perceived to be developed through a politically, socially and ethically acceptable procedure. The results of the Delphi show a definite increase in the level of consensus among the participants by the end of the third round. This is evident from the change in the standard deviation for the majority of the goals and indicators between rounds (Figs. 4-1 and 4-2). We suggest that the Delphi process used in this study lends legitimacy, credibility and saliency to goals and indicators that were produced.

Although the range of stakeholders used in this study was extremely diverse, including both experts and non-experts, this did not necessarily pose a problem, since inclusion of non-expert or local participants can lead to community empowerment as well as providing detailed local knowledge to the experts in the group, which in turn can lead to community support for future policies (Fraser et al., 2006). As well as having varying degrees of influence on policy making, developing indicators alone can have an influence by stimulating social learning (Lehtonen, 2013). Social learning takes place between actors in a social network through social interactions or processes. It can be said to occur when a change in understanding took place in the individuals involved and the change went beyond the individual to be embedded in a wide social unit or community (Reed, 2010).

Table 4-10
Indicators with highest standard deviations after Round 3.

Indicator	Mean Score	Standard Deviation
Imported energy as a percentage of total (national level)	3.56	1.26
Project internal rate of return (IRR)	3.67	1.33
EBIDA ratio per project	3.33	1.33
Percentage of energy company expenditure given to R&D per year	3.33	1.33
Expenditure on heat and electricity as a percentage of household income	3.33	1.49

While it is difficult to precisely measure whether group learning or social learning occurred as a result of the Delphi, without doing a post-Delphi survey, it can be assumed that participants most likely came away from the Delphi with a greater understanding of the issues surrounding sustainable geothermal developments, as well as an increased understanding of the functioning of indicator frameworks and the design of effective indicators. The stakeholder input for this Delphi was also very useful to the authors in designing better indicators generally, as problems with the theory behind certain indicators or reference values were pointed out. Thus, the authors will be better prepared for future Delphis and save time in the indicator evaluation stage.

If we look only at the overall result of a Delphi, we may neglect the minority views that are present. Where minority views are not taken into account, the participant may be tempted to drop out of the Delphi, leading to a "false consensus" in the final result. The Delphi must therefore "explore dissension" (Linstone and Turoff, 2002).

The results show that for the majority of items, both goals and indicators, that the standard deviation reduced between rounds, suggesting an increased consensus by the end. Although, the mean score for items reduced in some cases, this can be attributed to new stakeholders joining the Delphi after the first or second round and rating items with lower scores. In spite of this, consensus levels still increased in the final round for the majority of items. More consensus existed on certain issues than others. Regarding the sustainability goals, those dealing with energy equity and efficiency had the highest standard deviation in the final round, whereas renewability and environmental management had the lowest standard deviation. The comments, such as those show in Boxes 5-1 and 5-2 throw some light on the reasons for the consensus levels, and we suggest that these comments be used to inform policy- or decision-makers further.

Among the Icelandic Delphi participants, some mentioned a lack of free time as a reason for not completing the survey, or completing it later than the allocated time. Response rates reduced significantly between the first and third rounds (Table 4-2), suggesting diminishing interest or burnout on the part of the stakeholders. Incentives in the form of prizes were offered in an attempt to boost the Delphi response rate. In future Delphis, giving participants more time will be considered as a measure for boosting response rates. Score clustering did occur to some extent, suggesting that a different score allocation system may have been more appropriate (McGeary, 2009). However, In order to maintain consistency of research methods, the same scoring system

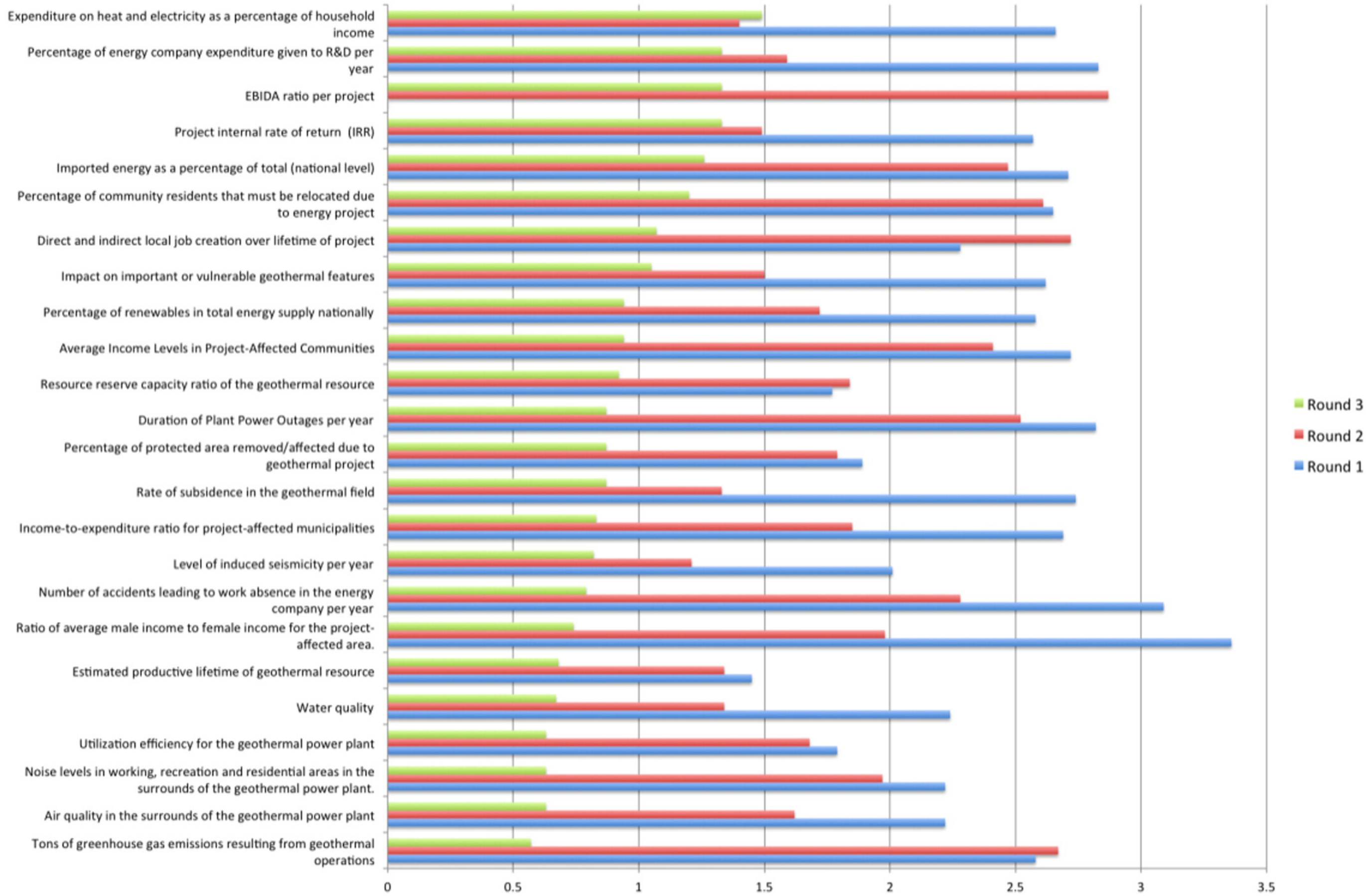

Fig. 4-2. Changes in standard deviations between rounds for indicators.

will need to be used in subsequent Delphis. The participants were obliged to give each Delphi item a score in the survey, but comments were optional. This meant that the reasons for giving indicators a particular score were not always clear. It also meant that the participants may have rushed through the survey without giving much thought to their responses in some cases. The participants also tended to score items based on their relevance in the Icelandic context, even though the item may have had relevance in other contexts. This was to be expected and for that reason, further iterations of the indicator development process will be carried out in other countries.

Suitability for intended purpose

The list of indicators produced in this first iteration has been critically evaluated through a stakeholder engagement process in Iceland and also against a set of theoretical criteria to determine their suitability to

Table 4-12
Indicators eliminated during Delphi.

Indicator	Final score	Round eliminated	Reason for elimination
Total cases lost in supreme court by energy company per year	1.57	Round 1	No clear reference value available
Ratio of rate of change in housing prices to rate of change in income levels (housing affordability)	1.9	Round 1	Indicator not easily understandable
Housing value in the area compared to national average	2.1	Round 1	Not considered relevant to geothermal sustainability
Initial phase capacity as a percentage of estimated total capacity	3.00	Round 2	No clear reference value available
Percentage of satisfied workers in the energy company per year	2.4	Round 1	Not considered relevant to geothermal sustainability
Percentage of females with university education in local energy company	2.4	Round 1	Not considered relevant to geothermal sustainability
Unemployment rate in project affected areas	2.43	Round 1	Already covered by the employment indicator (double counting)
Income equity in project-affected communities	2.48	Round 1	Not considered relevant to geothermal sustainability
Energy diversity index for project-affected regions	2.76	Round 1	Not considered relevant to geothermal sustainability
Make-up holes as a function of time	2.79	Round 1	Indicator not easily understandable
Ratio of reinjection to production	4.00	Round 2	No clear reference value available
Percentage of population with access to commercial energy in project-affected area	2.98	Round 1	Not considered relevant to geothermal sustainability (in Iceland)
Area of land used due to geothermal energy project (including infrastructure)	3.04	Round 1	No clear reference value available
Economic diversity of project-impacted areas	3.16	Round 1	No clear reference value available
Odor experience from H_2S gas in residential or recreational areas near the power plant	3.65	Round 1	Already covered by air quality indicator (double counting)
Tons of acidifying air pollutants (H_2S, SO_2) emitted as a result of geothermal operations	4.3	Round 1	Already covered by air quality indicator (double counting)

Box 5-1
Example comments for a goal with high level of consensus.

Goal 1 — renewability:
In order to ensure the geothermal resource remains replenishable, sustainable production* should be the goal in all geothermal projects.
*For each geothermal area and each mode of production there exists a certain maximum level of production, E0, so that with production below E0 it is possible to sustain steady energy production from the system for at least 100–300 years. If the level of production exceeds E0 it is not possible to sustain steady production from the system for so long. Geothermal production that is less than or equal to E0 is defined as sustainable production but production exceeding E0 is not sustainable.
Comments (in support)
"Is geothermal renewable? i.e. high enthalpy areas?"
"If possible, even longer production periods should be looked at."
"We build our society on having access to the energy we need — electrical and thermal. It is a basis for the function of our society. One obligation of today is to ensure the possibility of this access in the future as well — ethically — but also (and this is usually what creates the strongest urgency) to maintain the foundation for the future economy in Iceland. If we use up everything now, then what will be built on in the future? "Þetta reddast?""
"If this is not fulfilled then the extraction is not sustainable in other words."

Box 5-2
Examples comments for a goal with low level of consensus.

Goal 4 — efficiency:
Geothermal utilization shall be managed in such a way as to maximize the utilization of exergy available where practical at sustainable production levels. The desired maximum efficiency for electricity generation should be based on the theoretical maximum efficiency for converting heat to electrical energy (Carnot efficiency).
Comments (in support)
"Efficiency is an important goal, but I think it might be phrased better, more simply and "where practical" who decides where it is practical to maximize the utilization. Is it possible to put a specific percentage of efficiency?"
"What means where practical? If sustainable usage, and renewability suffers from electricity production then the exergy optimisation may be devastating."
"As long as the theoretical maximum efficiency is defined within sustainable utilization, I agree with this, otherwise not."
"This is the whole point of striving towards sustainability — fulfilling the energy (electrical & thermal) while at the same time using the primary resource as sparingly as possible."

their purpose. However, the development process has also highlighted other advantages and drawbacks of developing the assessment framework. 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. 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 value of supplementary or qualitative information should not be ignored when reporting the indicators in an assessment. For example, with subsidence, it may be necessary to state whether or not the subsidence is likely to impact negatively on residential areas, which is a qualitative judgment. Another example might be income-to-expenditure ratio for project-affected municipalities, which may be higher or lower due to other factors that should be explained clearly with supplementary information. In the early phases of a geothermal project, especially, qualitative information will be very important, since some indicator data will not yet be available. In such cases, predictions about the sustainability of a future project may need to be made based on the available information. Assessments using indicators alone may not be sufficient and other types of investigation, such as a detailed socio-economic analysis, may need to be done. The list of indicators produced by this one study is not prescriptive, in that it is entirely possible to find alternative metrics for any of the indicators produced using the methods described in this paper. For example, the social benefits of geothermal energy projects may differ significantly from country to country and the Icelandic stakeholder group rejected indicators that would be considered relevant in developing countries, such as access to energy or the percentage of females with university education.

It was decided not to create a composite index from the indicators or add weights, as it was felt that too much information would be lost due to the "information iceberg" effect (Molle and Mollinga, 2003) if the indicators were to be aggregated. As well as this, the choice of weights is a politically sensitive and value-laden process, prone to arbitrariness and inconsistency (Bohringer and Jochem, 2007). The framework could form the basis, however, for the calculation of an index that uses weights, but careful consideration would need to be given to the themes that would be aggregated as well as the units used. It was felt that assigning weights at this point was inappropriate as the weightings of each theme or issue-areas are likely to differ depending on the region or country. The stakeholder process in Iceland was intended only to result in the choice of an initial set of goals and indicators. Stakeholders were not involved in any actual assessment using the indicators. The results of any trial assessment using the indicators are beyond the scope of this paper.

Modifications and further research

Based on this first iteration of the indicator development process in Iceland, it is clear that inevitably, each geothermal energy project will face unique sustainability challenges, due to the differing environmental and socio-economic setting in which it is found. We suggest that qualitative information be supplied alongside the reported indicators in order to provide the end user with site-specific information. By carrying out further iterations of the indicator development process, we suggest that the final assessment framework produced will be more likely to take into account the diverse and unique circumstances surrounding geothermal developments. Further iterations of the indicator development process will also produce better, more refined indicators and further study may reveal issues that may have been neglected previously. It should be possible to produce a framework of goals and indicators, with in-built flexibility of indicator choice. However we suggest that it would also be beneficial to have an associated stakeholder input process that runs simultaneously with a sustainability assessment in order to ensure that the indicators reflect the evolving nature of sustainable development. Such stakeholder inclusion methods should be culturally appropriate and agreed to by all parties before they are implemented (Meadows, 1998). The lessons learned from this iteration in the Icelandic context will be applied to further iterations in New Zealand and Kenya. Following these iterations, more insights on the assessment framework will become apparent and allow for a more comprehensive evaluation of its suitability.

Conclusion

This paper describes the first steps in the development of a sustainability assessment framework for geothermal energy projects, using the input of an Icelandic stakeholder group and internationally recognized methods. The first iteration of the indicator development process has been completed in Iceland illustrating that the process can be applied elsewhere. As a result, further iterations will be carried out in New Zealand and Kenya before a finalized set of goals and indicators is produced.

Acknowledgments

We gratefully acknowledge the GEORG geothermal cluster as our project sponsor, without whom this project would not have been possible. This project had its beginnings in 2009 as a Masters thesis at the University of Iceland, which was generously sponsored by Orkustofnun (National Energy Authority of Iceland), Landsvirkjun Power and RANNIS (Icelandic Research Fund). We also acknowledge the support of the University of Iceland, University of Auckland, Reykjavik Energy (Orkuveita Reykjavikur) and the Kenya Electricity Generating Company Ltd. (KenGen). Furthermore, we sincerely thank the numerous stakeholders in Iceland, New Zealand and Kenya and the UNU Fellows that took part in our stakeholder process.

Appendix A. Results of pre-engagement World Café workshop in Iceland

Table A-1
Indicator list with corresponding comments and votes.

Indicator	Main comments	Group vote
N-1 Land area used by plant and infrastructure	Applies to high-temperature only. The amount of area used is not a good indicator. Consider the quality of land and surroundings — i.e. land-use and possibility.	56%
N-2 Percentage of forested areas in the region removed due to energy project	What about wetland? Forest not applicable in Iceland. Include soil erosion. Consider previous use of land, for instance, agriculture and whether these kind of activities are being displaced.	89%
N-3 Highest Icelandic *verndaflokkur* protected area classification rating of the location of structures or infrastructures	Political classification. Not relevant. Ok if categorizing is done on trustworthy basis and agreement (i.e. a more transparent scale than this needs to be developed). Visual effects rather than verndaflokkur. Consider using view-shed analysis results.	100%
N-4 Type of impact of ground subsidence (positive or negative)	Should be assessed in preparation phase.	100%
N-5 Concentration (ppb) of H_2S in recreational and inhabited areas around power plant	Not a problem in Iceland generally. Consider using only when H_2S is an issue.	100%
N-6 Concentration of mercury (Hg) gas in vicinity of power plant	May be repeating N-7, could be combined with effluent indicators. Not heard of in Iceland.	87.5%
N-7 Concentration of metals (Hg, Cr, Cu, As, Pb, Zn, Ni, Cd, etc.) in effluents released from power plant	Local indicator.	100%
N-8 Amount in tonnes of acidifying air pollutants (SO_2, Nox and H_2S) emitted from power plant per year	Repeats N-5.	100%
N-9 pH of effluent released from power plant into the environment		100%
N-10 Concentration of chlorides and sulphides released in effluent from power plant	Have one single indicator for “effluent”.	100%
N-11 Temperature of hot water released from power plant into the environment	Look at temperature AND quantity of water.	100%
N-12 Noise levels (dB) in the area surrounding the geothermal energy project	Occupational vs. ambient.	100%
N-13 Concentration of H_2S gas in the areas around the geothermal energy project	The same as N5. Measure “experience” — use “odor” instead of “concentration” in the indicator description (experience of discomfort).	74%
N-14 Likelihood of impact on biodiversity hotspots in vicinity of power plant, construction area or infrastructure	Yes. Usually increased (i.e. algae in the Blue Lagoon). Biodiversity can increase and decrease (whether this is good or bad depends on the situation).	100%
N-15 Likelihood of impact on threatened species in vicinity of power plant, construction or infrastructure	Link to use of land. Needs a lot of research — depends on existing data.	100%
N-16 Status of rivers and lakes in vicinity of power operations according to EU Water Framework Directive	Look at combining with effects of effluents on ground water. Yes. Compared to fossil fuels. Would work well with a baseline assessment. Misleading to say “disturbance” — instead consider water quality. Rephrase this better and single out relevant part of measurement.	84%
N-17 Annual national greenhouse gas emissions (CO_2 eq) from geothermal energy	Context can be confusing, misleading. Combine into one indicator for gas releases. Could compare to emissions from fossil fuel plants.	100%
N-18 Productive lifetime of geothermal resource	Significant controversy surrounding this indicator. Use “estimated” productive lifetime. Consider scale. 100 years currently gets 100%. Maybe too short. High temperature and low temperature resources may differ. Should be 300 years. 30 years is too short. Yes. Also depends on the geothermal field. Very difficult to predict. Resource vs. reserve measurement: define clearly.	100%
N-19 Concentrations of dissolved chemicals (SiO_2 and Cl) indicating	Pressure decline, water table — status of geothermal resource.	100%

Table A-1 (*continued*)

Indicator	Main comments	Group vote
cooling	Flawed — first observe pressure lowering in both high and low temp and then changing chemicals.	
N-20 Utilization efficiency of geothermal plant	Energy quality levels.	100%
N-21 Level of micro-seismic activity	Should be taken into account in regards to social effects of power plant — positive here but negative for society. Distinguish between good for the resource and negative for the people. Consider induced seismicity. Earthquakes should be in social indicators.	100%
N-22 Years to recovery of resource pressure and heat after exploitation	Depend on a lot of factors and the type of field. Very site specific. Many systems operate with constant temperature, like Svartsengi. So the indicator will say it is inexhaustible. Needs more reliable data. Yes but can be difficult to obtain information based on facts — now models that need more work, based on probabilities. Combine with N18 as lifetime performance indicator.	74%
E-1 Government foreign debt ratio	Political. Project ownership important. Government responsibility — hard to interpret. How is that interpreted in context with sustainability?	80%
E-2 Percentage of future energy needs fulfilled by project	Varies when talking about high temp or low temp area. Ok, but Is bigger better? Define needs. Public or industry? Is it related to energy policy? Future energy demand — how to predict?	70%
E-3 Ratio of social and environmental costs of operations to value of economic transactions for the project (Cost benefit analysis)	Define better. Is cost–benefit analysis the only method? Difficult to put monetary value on environmental and social costs. Limited, future value — economic view.	100%
E-4 Impact on hydrological features or hot springs	Should this be in the economic or environmental dimension? Yes, reduced activity of hot springs e.g. Waireiki or increased impact of hot springs on water use conflicts with other use. Tourism. Water pollution by geothermal. Define/explain relevance better.	82%
E-5 Percentage of total water usage for the area used by energy project	Consider moving into the social dimension. Depends on location and population. Consider combining with E-3. For developing countries, use access to water. Difference between developed and developing countries. Access to fresh water. Needs indicators which take into account future use, such as fish farming, Blue Lagoon, etc. Extra gains.	80%
E-6 Utilization Efficiency	Same as N-20 environmental indicator.	100%
E-7 Percentage of transmission loss annually	E7 to E10 deal with national aspects, if looking at individual power plant then this should be skipped. (a question of scale)	70%
E-8 Percentage of distribution loss annually	As above. E-6 is the most important as more directly related to the project.	70%
E-9 Imported energy as a percentage of total energy	Price volatility of fuels. A previous study will show the impact of the establishment and development of the geothermal power plant over the energy needs and the mix.	100%
E-10 Renewable energy share in total energy production	Better definition.	100%
E-11 Ratio of predicted future flows of geothermal energy to predicted production or consumption patterns	Unclear. Too difficult to define. Similar issues to E-2.	53%
E-12 Reserve capacity ratio nationally	Define “reserve” better. Clarify this indicator. Is it viable energy? Considering technology, natural preservation.	94%
E-13 Reserve capacity for greater volcanic system		94%
E-14 Shannon–Weiner index of energy diversity	Unclear.	70%
E-15 Duration of power outages per year		100%
E-16 Return on assets of developer company	Political issues. Does production exceed needs?	100%
E-17 Short term debt to total debt ratio of developer company	Combine E17–E21. E17–E21: ownership and risk. Social duty/obligation of power companies vs. Ownership of resources. Fulfill needs of the community (heating, electricity, plumbing, etc.) first.	100%
E-18 Owner company leverage ratio	Combine E17–E21.	100%
E-19 Balance sheet effects of exchange rate changes	Combine E17–E21.	80%
E-20 Level of financial risk associated with energy project	Combine E17–E21.	100%
E-21 Unhedged foreign currency exposure of owner company	Combine E17–E21.	80%
S-1 Income to expenditure ratio for project-affected municipalities	Unclear. The municipality's obligations should be clear. Government responsibility as cost. Municipality may have sharp increase in expenditure during construction.	100%

(continued on next page)

Table A-1 (*continued*)

Indicator	Main comments	Group vote
S-2 Percentage of unlicensed teachers in region compared to national average	Not relevant or applicable in Iceland, maybe in developing countries.	8%
S-3 Local unemployment rate compared to regional or national average	No because if it hard to measure and differentiate from other effects. (indirect impact)	100%
S-4 Percentage of full-time project workers residing in Iceland Percentage of full-time project workers based locally	Include national and regional numbers, direct vs indirect employment. Matters most during construction phase. Should be looked at for long term. Locally trained workers? Annual work of service industry instead? Look at energy company employees.	76%
S-5 Average income levels for project-affected municipalities compared to regional income levels	Only if change in income levels is brought about by the geothermal project. Use only for smaller communities. Applicable for larger geothermal projects only.	100%
S-5 Average income levels for project-affected regions compared to national income levels	As above. Energy company workforce. The number of jobs created in the geothermal sector is less than other industries (direct impact on employment is small).	62%
S-6 Difference between change in average national and municipal house prices and income levels	Unclear, needs to be rephrased. Property value? Better as an economic indicator? Needs to be confirmed that they are related and impacted by a project.	86%
S-7 Percentage of population below poverty line in project affected municipality compared to regional percentage	Not applicable to Iceland, more for developing countries.	85%
S-7 Percentage of population below poverty line nationally compared to global average	Too many variables enter this on a global scale. Hard to compare vastly different societies.	62%
S-8 Hackman economic diversity index or Shannon–Weiner index	Unclear or unfamiliar index.	57%
S-9 Level of education in developer company compared to level of education regionally/nationally	Not applicable in Iceland. The education of employees when hired e.g. BSc and MSc industrial degree or education and training within the company — could increase knowledge/know-how in the area. Use experience rather than education if talking about energy company. Change in level of education since being employed by energy company?	24%
S-10 Level of education of least educated 20% of project workforce compared to municipality and national population	Should be in context with the locality or region since geothermal projects will be done with qualified people anyway.	43%
S-11 Icelandic *verndaflokkur* rating of project-affected areas	Define better. Will newly discovered cultural treasures replace/amount to those destroyed? No, development sites in Iceland are usually in uninhabited areas. Badly defined word (verndaflokkur) — political, not rational. Too political.	86%
S-12 Percentage of population with access to high quality energy	Define high quality.	86%
S-13 Expenditure on energy as percentage of lowest income household disposable income		100%
S-14 Gini coefficient for energy use between income groups		67%
S-15 Ratio of male energy use to female energy use	Relevant in developing countries. Define use better — maybe "access" is better?	38%
S-16 Gini coefficient		63%
S-17 Ratio of average female to male income in project staff compared to municipality and national ratios		67%
S-18 Percentage of females with university education in developer company compared to percentage of females with university education locally	Also technical trade education e.g. Truck drivers, electrician, etc. Does this relate to sustainability?	56%
S-19 Percentage of females with university education in developer company compared to percentage of females with university education nationally	Micro economy in power companies. Does this relate to sustainability?	75%
S-20 Percentage of satisfied workers in developer company	Define satisfaction. Measurement of life quality and other factors?	57%
S-21 Infant mortality rates in project-affected area and nationally	Developing countries. Regional development should have benchmark of the state of the area to begin with.	76%
S-22 Life expectancy at birth in project-affected area and nationally	Developing countries.	81%
S-23 Percentage of community residents that must relocated due to energy project	Not such a problem in Iceland as sparsely populated.	44%
S-24 Number of accident fatalities due to energy projects		100%
S-25 Degree of public participation during environmental impact assessment in relation to legal requirements	Doubts about method. General participation — not enough to count the participants of cases.	100%
I-1 Time taken to complete cases in government agencies	Quality of public administration. Important for permitting process.	30%
I-2 Level of customer satisfaction for developer company	Unclear.	25%
I-3 Value of fines or number of sanctions for regulatory non-compliance of developer company	Hard to measure, hard to interpret.	30%
I-4 Average education level of staff in developer company	Experience rather than education. Should this be in the social dimension?	35%
I-5 Presence of environmental management system	Include quality management.	55%

Table A-1 (*continued*)

Indicator	Main comments	Group vote
I-6 Percentage of GDP spent on environmental protection	Certification rather than presence. Presence of an EMS does not imply good management. Unclear. Better to use as % of project expenditure rather than GDP.	0%
I-7 Transparency International corruption perceptions index		30%
I-8 Total cases in supreme court involving developer company per year	Use cases lost instead.	10%
I-9 Freedom House democracy levels	Rather emphasis governance.	10%
I-10 Percentage of voter turnout	Does not work in practice.	0%
I-11 Percentage of developer company expenditure given to R&D	Not directly linked to a project. Define R&D better. R&D training.	55%
I-12 Percentage of total geothermal energy R&D staff nationally funded by developer company	R&D training.	24%
I-13 Percentage of research personnel employed in geothermal energy theme in public institutions.	What about multinational corporations. Combine with other R&D indicators.	47%
I-14 Percentage of total national R&D expenditure contributed by government sources (public institutions)	Look at combining and simplifying all R&D indicators. Define R&D clearly.	0%

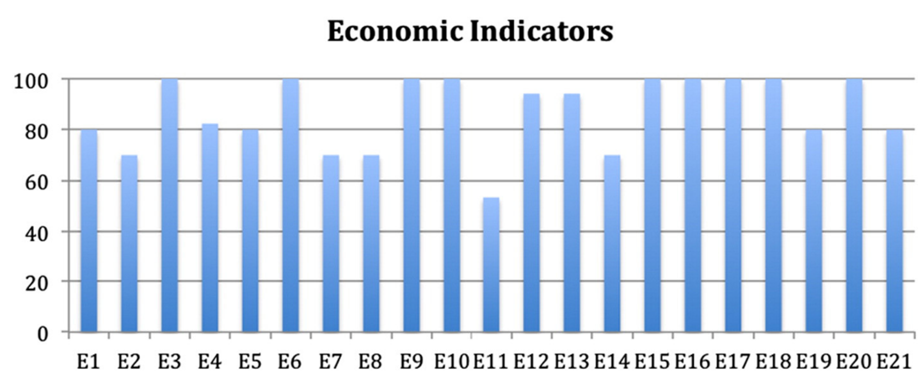

Fig. A-1. Voting scores (%) for economic indicators.

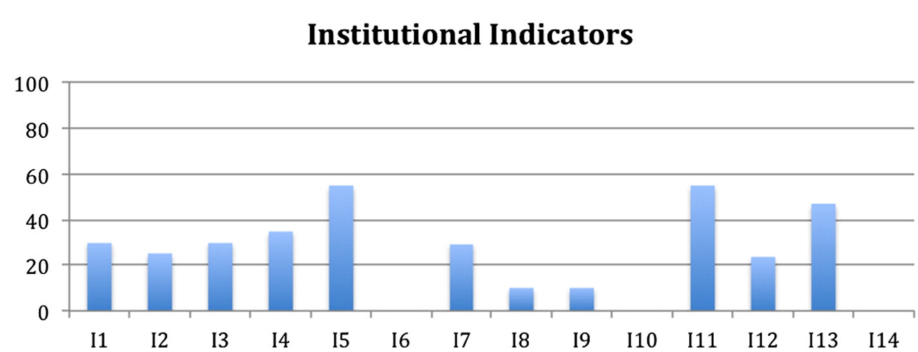

Fig. A-2. Voting scores (%) for institutional indicators.

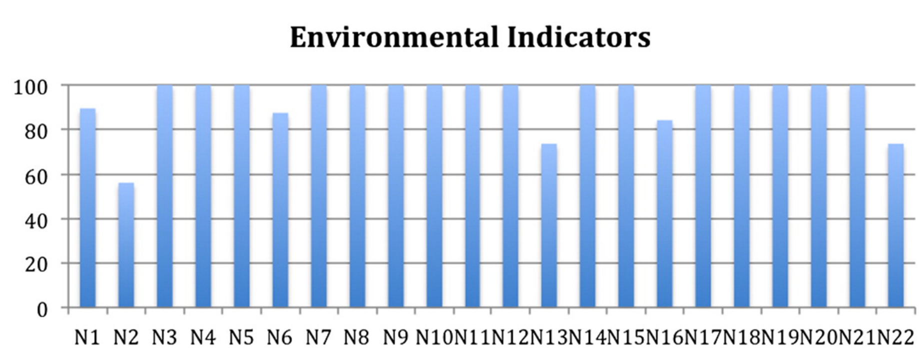

Fig. A-3. Voting scores (%) for environmental indicators.

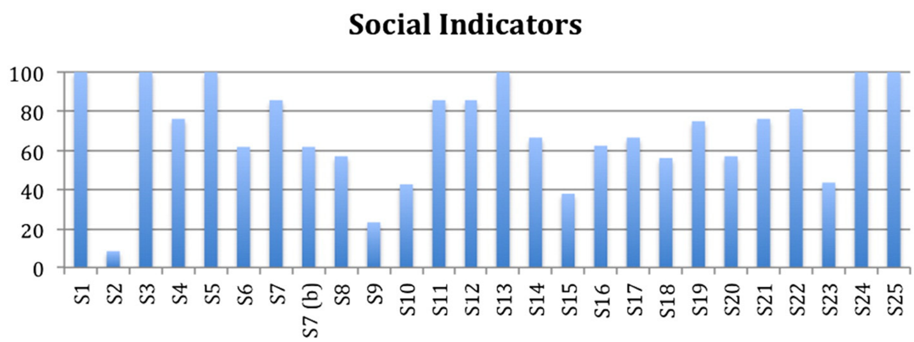

Fig. A-4. Voting scores (%) for social indicators.

Table A-2
New indicator suggestions from stakeholders.

Social	Economic/institutional	Environmental
Ownership of the resource	Staff to energy output	% lava removed (is protected in Iceland)
Look at effects from cascaded use/by-products	Direct and indirect jobs	% protected area removed/affected
More indicators to show economic benefits or costs to society	Quality jobs for long term	Visibility (view-shed)
Minor seismic activity.	Government keeping of set time goals	Make-up holes as a function of time
Number of accidents/mishaps leading to work absence	Initial phase capacity as a % of estimated total capacity	Wetlands/visibility/vegetation/species endangered
Change in literacy level (phase 3)	Housing value in the area compared to national	Soil erosion in the area
Opportunities provided by energy companies for training and adult education	Percentage of females with university education in local energy company	Access to fresh water (in developing countries)
Future use of water — how it is impacted by project. E.g. fish farming Blue lagoon — added gains (cascaded use)	An indicator to measure economic benefits of a new plant in a greater surrounding with a broader view than only developer — linked to social impacts	Indicators that replace a cost benefit analysis
Indicator to take account of quality of the land and surroundings, the possible land uses that would be impacted (e.g. agriculture)	Quantity of hot water	Indicator for induced seismicity to make it clearer when seismicity is harmful

References

Amaeshi KM, Crane A. Stakeholder engagement: a mechanism for sustainable aviation. Corp Soc Respons Environ Manag 2006;13(5):245–60.

Australian Government. Stakeholder engagement practitioner handbook. Department of Immigration and Citizenship. National Communications Branch of the Department of Immigration and Citizenship; 2008.

Azapagic A. Developing a framework for sustainable development indicators for the mining and minerals industry. J Clean Prod 2004;12(6):639–62.

Barzekar G, Aziz A, Mariapan M, Mohd Hasmadi IM. Delphi technique for generating criteria and indicators in monitoring ecotourism sustainability in Northern forests of Iran: case study on Dohezar and Sehezar watersheds. Folia Forest Pol 2011; 53(2):130–41.

Bell S, Morse S. Sustainability indicators, measuring the immeasurable? London: Earthscan; 2008.

Bohringer C, Jochem PE. Measuring the immeasurable — a survey of sustainability indices. Ecol Econ 2007;63(1):1–8.

Brooma M, Brady B, Kecskes Z, Kildea S. World Café methodology engages stakeholders in designing a neonatal intensive care unit. J Neonatal Nurs 2013;19(5):253–8.

Brown J, Isaacs D. The world cafe: shaping our futures through conversations that matter. Berrett-Koelher; 2005.

Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, et al. Knowledge systems for sustainable development. Proc Natl Acad Sci 2003:8086–91.

Davidsdottir B, Basoli DA, Fredericks S, Lafitte Enterline C. Measuring sustainable energy development: the development of a three dimensional index — the SEE index. Frontiers in environmental valuation and policy. Cheltenham, UK: Edward Elgar; 2007.

European Commission. Measuring progress towards a more sustainable Europe. Sustainable development indicators for the European Union. Luxemburg: Office for Official Publications of the European Communities; 2005.

Fouché C, Light G. An invitation to dialogue: 'The World Café' in social work research. Qual Soc Work 2011;10(28).

Fraser ED, Dougill AJ, Mabee WE, Reed M, McAlpine P. Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. Journal of Environmental Management, 78. Elsevier; 2006.

Gunnarsson G, Arnaldsson A, Oddsdóttir AL. Model simulations of the Hengill Area, Southwestern Iceland. Transp Porous Media 2011;90:3–22.

Hai LT, Hai P, Khoa N, Hens L. Indicators for sustainable development in the Quang Tri Province, Vietnam. J Hum Ecol 2009;27(3):217–27.

Hsu C-C, Sandford BA. The Delphi technique: making sense of consensus. Pract Assess Res Eval 2007;12(10).

IISD. Assessing sustainable development: principles in practice. IISD; 1997.

IISD. Measuring and assessing progress identifying approaches, patterns and practices. Retrieved November 4, 2012, from the International Institute of Sustainable Development http://www.iisd.org/measure/principles/progress/, 2012.

Intergovernmental Panel on Climate Change. Renewable energy sources and climate change mitigation: special report of the intergovernmental panel on climate change. Intergovernmental panel on climate change. New York: Cambridge University Press; 2012.

International Atomic Energy Agency (IAEA). Energy indicators for sustainable development: methodologies and guidelines. Vienna: International Atomic Energy Agency (IAEA), United Nations Department of Economic and Social Affairs (UNDESA), International Energy Agency (IEA), Eurostat, European Environment Agency (EEA); 2005.

International Energy Agency. Energy technology perspectives 2012: pathways to a clean energy system; 2012.

International Finance Corporation. Stakeholder engagement: a good practice handbook for companies doing business in emerging markets. Washington D.C.: International Finance Corporation; 2007

International Hydropower Association. Sustainability assessment protocol; 2006.

International Hydropower Association. IHA connect issue, 3 (3); 2008.

Lehtonen M. The non-use and influence of UK energy sector indicators. Ecological Indicators, 35. Elsevier; 2013. p. 24–34.

Lim S, Yang J. A Delphi study on the critical sustainability criteria and indicators for Australian road infrastructure projects. In: van den Dobbelsteen A, editor. Proceedings of the 3rd CIB International Conference on Smart and Sustainable Built Environments. Delft: Delft University of Technology; 2009. p. 1–7.

Linstone HA, Turoff M. The Delphi method: techniques and applications. In: Linstone HA, Turoff M, editors. New Jersey Institute of Technology; 2002.

McGeary J. A critique of using the Delphi technique for assessing evaluation capability-building needs. Eval J Australas 2009;9(1):31–9.

Meadows D. Indicators and information systems for sustainable development. A report to the Balaton Group; 1998.

Mihyeon Jeon C, Amekudzi A. Journal of infrastructure systems. Addressing sustainability in transportation systems: definitions, indicators, and metrics, 11; 2005. p. 31–50 [Special Issue: Sustainability Of Transportation And Other Infrastructure Systems].

Molle F, Mollinga P. Water poverty indicators: conceptual problems and policy issues. Water Policy 2003;5:529–44.
National Energy Authority. Eðli Jarðhitans og Sjáflbær Nýting Hans: Álitsgerð faghóps um sjálfbæra nýtingu jarðhita; 2010 [Orkustofnun].
OECD. Core set of indicators for environmental performance reviews. OECD; 1993.
Pinfield G. Beyond Sustainability indicators. Local Environment 1996;1(2):151–63.
Pinter L, Hardi P, Bartelmus P. Indicators of sustainable development: proposals for a way forward. IISD; 2005.
Powell C. The Delphi technique: myths and realities. J Adv Nurs 2003;41(4):376–82.
Ray D. Wairakei power plant: effects of discharges on the Waikato River. Contact Energy; 2001.
Reed MS. Stakeholder participation for environmental management: a literature review. Biol Conserv 2008;141(10):2417–31.
Reed M. What is social learning? Ecol Soc 2010;15(4).
Sharma S, Henriques I. Stakeholder influences on sustainability practices in the Canadian forest products industry. Strateg Manag J 2005;26(2):159–80.
Shields D, Šolar S, Martin W. The role of values and objectives in communicating indicators of sustainability. Ecological Indicators, 2. Elsevier; 2002. p. 149–60.
Shortall R, Davidsdottir B, Axelsson G. Geothermal energy for sustainable development: a review of sustainability impacts and assessment frameworks. 2015;44:391–406.
The Gold Standard Foundation. The Gold Standard Toolkit 2.2. Geneva, Switzerland: The Gold Standard Foundation; 2012.
Thompson K. Delphi collective group intelligence tool: powerful and free. April 27. Retrieved October 21, 2012, from bioteams.com http://www.bioteams.com/2007/04/27/delphi_collective_group.html, 2007.
UK Institute of Social and Ethical Accountability. Stakeholder engagement standard AA1000. AccountAbility; 2011.
UNDP. Energy for sustainable development: a policy agenda. New York: UNDP; 2002.
UN-Energy. Sustainable bioenergy: a framework for decision makers. UN-Energy; 2007.
United Nations. Indicators of sustainable development: guidelines and methodologies. 3rd ed. United Nations; 2007.
Waikato Regional Council. Waikato Regional Council. Retrieved October 31, 2012, from waste water discharges http://www.waikatoregion.govt.nz/Environment/Natural-resources/Water/Rivers/Waikato-River/Wastewater-discharges/, 2012.
World Energy Council. Policies for the future 2011: assessment of country energy and climate policies. London: World Energy Council; 2011.
WWEA. Sustainability and due diligence guidelines. WWEA; 2005.
WWF. Sustainability standards for bioenergy. WWF; 2006.