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Introducing the Concept of Sustainable Geothermal Utilization into Icelandic Legislation

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ABSTRACT

In this study the term sustainable geothermal utilization is discussed, based on the principles of sustainable development, and legal implementation suggested in the form of mending a derivative regulation from laws that are already in place. The development of a comprehensive assessment framework of sustainability indicators is introduced taking into consideration economic prosperity, environment and social justice. Sustainable development as defined by the World Commission on Environment and Development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This definition is inherently vague, and is often understood in various ways. In an attempt to link sustainable development to the management of geothermal resources two approaches are introduced; weak sustainability which assumes the validity of growth and places equal importance on environment, social justice and economic prosperity and strong sustainability having the environment as a foundation to social justice and economic prosperity. In simple terms, strong sustainability focuses on the viability and health of the geothermal system to sustain exploitation, whereas weak sustainability believes in economic forces and technological advances. In this paper the main methods of sustainable geothermal utilization are outlined. Those methods have also been categorized as either weak or strong sustainable approaches.

1. INTRODUCTION

This paper is the work of a group of geothermal professionals established by the Icelandic Ministry of Industry as a part of the Framework Programme for Protection and Utilization of Hydro and Geothermal Energy Resources. The professionals come from power companies, the regulator, research institutes and universities. The objective is to propose how to define sustainable geothermal utilization and how to assess sustainable potential of geothermal resources and to propose different sustainable utilization modes in accordance with the Rio Declaration from 1992. The group has sought advice from e.g. a philosopher, national economists, a historian, a resource economist, an environmental management specialist, an environmental engineer and an environmental lawyer. A postgraduate student was as well funded to create sustainability indicators for geothermal utilization and apply it to the Krafla geothermal power plant.

It is the policy of the Government of Iceland to increase the utilization of the renewable energy resources further, e.g. for fuelling the transport sector. A broad consensus on conservation of valuable natural areas has been influenced by social opposition, increasing over the last decade, against large hydropower and some geothermal projects. Moreover, some energy companies plan to take green-initiatives in minimizing visual impact of geothermal power-plants to further increase public acceptance of geothermal utilization for electric power production. The Icelandic Government decided in 1997 to develop a Framework Programme for potential power projects. All proposed projects are being evaluated and categorized on the energy efficiency and economics but also on the basis of the impact that the power developments would have on the environment. This complete Framework Programme on the energy resources and the value of their conservation is to be presented to the Icelandic Parliament for formal consideration in 2010.

Geothermal energy plays an important role in providing the nation with clean and reliable energy and is fundamental to the Icelandic economy as well as Icelandic welfare and independence, with 66% of the primary energy consumption coming from geothermal in year 2007. It has been estimated that the present value of the total savings of harnessing geothermal energy instead of using fossil fuel for house heating between 1970 and 2007, using 2% real interest rate over the building price index, is at $17,000 million. In 2007 the estimated savings of that year amount to about 3% of the national budget (Ketilsson et al., 2010).

Effective policy making for sustaining a renewable energy society in Iceland, as well as providing an effective legislature, is crucial for sustaining a long-term lifespan of the resource. Due to the abundance of hydropower and geothermal energy in Iceland relative to the population, Iceland can possibly afford to utilize the resources in a sustainable manner. Thus the aim of this paper is to look into how the concept of sustainable geothermal utilization can be introduced and defined in Icelandic legislation.

2. SUSTAINABLE DEVELOPMENT

As is widely recognized today, sustainable development was first introduced in the Brundtland Report in 1987 (World Commission on Environment and Development, 1987). The report, *Sustainable Development, Our Common Future, World Commission on Environment and Development* was drafted by the World Commission on Environment and Development, an internationally diversified group of politicians, civil servants and experts on environmental law and development, according to the UN General Assembly's declaration to convene a conference on environment and development. The report laid down a wide framework of environmental and developmental policies for the future as well as highlighting urgent environmental and developmental problems affecting the world and portraying misdistribution of wealth between different states. The report provided a key statement on sustainable development, defining it in the following way: *"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."* The report introduced draft rules where all basic principles of international environmental law where formulated in a complete document. The report clearly suggests that the term sustainable development indicates a broad policy, both as an objective as well as a principle (Johannsdottir, 2005).

The Rio Conference held in Brazil in 1992 came in the wake of the Brundtland Report. However, the origins of the Rio Conference can be traced directly back to the United Nations Conference on the Human Environment, also known as the Stockholm Conference, in 1972. This was the first UN's major conference on international environmental issues. The Rio Declaration on Environment and Development was accepted along with Agenda 21. In Chapter 5.2 of Agenda 21 sustainable development is described as having a synergistic relationship with demographic trends and factors. Agenda 21 is a comprehensive plan of action to be implemented globally, nationally and locally by organizations affiliated to the United Nations System, state governments, and major groups in every area in which human activity impacts on the environment (United Nations Division for Sustainable Development, 2005).

Even though the Rio Declaration is regarded as a soft law instrument (see Johannsdottir, 2005) the principles laid down in the declaration have had tremendous effect on the evolution of environmental law since its formation, especially from an international stand point. That being said the various principles of the declaration have had different degrees of influence. For example, it is not contested that Principle 2 of the Declaration, that it is the sovereign right of states to exploit their own natural resources in accordance with their own environmental and developmental policies and that it is their obligation to ensure that the utilization causes no harm to the environment beyond their jurisdictional realms, has achieved the status of international custom. To contrast this, the status of the precautionary principle that is put forth in Principle 15 of the Declaration has not achieved this status and is debated regularly. The same can be said about the polluter principle, dictated in Principle 16 of the Declaration (Johannsdottir, 2005).

Sustainable development has been the axiom of environmental policies worldwide ever since the Brundtland Report was first published. According to Johannsdottir (2005) "The term has a certain built-in tone of encouragement and positive aspiration; however at the same time, it reflects uncertainties and lacks demarcation." This ambiguity of the concept has Dr. Klaus Bosselmann, the Director of the New Zealand Centre for Environmental Law, regarded having both pros and cons (Bosselmann, 2002). The focal point of Bosselmann's argument is that one must distinguish between on the one hand strong sustainability and on the other weak sustainability. By strong sustainability Bosselmann refers to when certain limitations of environment are accepted, mainly to say that sustainable development should take place within ecological limits, and all human action should be kept within those limits. Bosselmann's notion of weak sustainability refers to that sustainability should build on the suggestion that the environment, nature and ecosystem should have the same standing as economic and social factors and the two should be balanced together, see Figure 1.

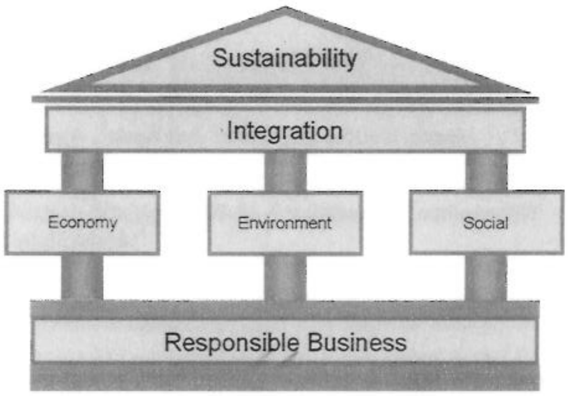

Figure 1. Weak Sustainability – Environment, nature and ecosystem have the same standing as economic and social factors.

Sustainable geothermal utilization has been discussed to some degree in the literature in recent years, partly because the term "sustainable" has become quite fashionable. A general and logical definition has been missing, however, and the term has been used at will. In addition the terms renewable and sustainable are often confused. The former should refer to the nature of a resource while the latter should refer to how it is used. Geothermal energy has been defined to be renewable, e.g. by the EU (Directive 2009/28/EC). As examples of recent discussions of the issue the papers by Axelsson et al. (2005), Stefansson and Axelsson (2005), Sanyal (2005), Ungemach et al. (2005), O'Sullivan and Mannington (2005) and Bromley et al. (2006), as well as the report by Bjornsson (2005), may be mentioned. Rybach and Mongillo (2006) present a good review of recent sustainability research.

3. GEOTHERMAL RESOURCES IN ICELAND

The geothermal systems of Iceland are manifestations of the thermal energy that is in-place as well as flowing through the crust of the country. The size of these components was estimated separately in the 1980's. Bodvarson (1982) estimated, on one hand, the size of the total steady state energy current through the crust while Palmason *et al.* (1985), on the other hand, estimated the amount of thermal energy stored in the crust. In these two studies the geothermal potential of Iceland is estimated quite differently, which reflects in fact the dual nature of geothermal resources.

The results of these studies have not been comprehensively updated or revised since they were completed, partly because no new data that seriously alter their main results have become available. It may be mentioned that Stefansson (2000) has combined the results of both studies in a unified presentation. Both studies relied on available temperature gradient and heat-flow maps of Iceland. Such maps have been revised and updated as more data have become available, without drastically changing the overall picture (Flovenz and Saemundsson, 1993).

Bodvarsson (1982) estimated that the energy current from below Iceland is about 30 GW (1 GW = 10^9 W) on the average. This includes 24 GW by flowing magma and 5 GW by heat conduction and 1 GW by radiogenic heat production. He only considered land above sea-level, while considerable additional energy also flows up through the ocean floor around the island. This energy flows through the crust, which also stores great amounts of energy (see below), up to the surface. Bodvarsson estimated that at the

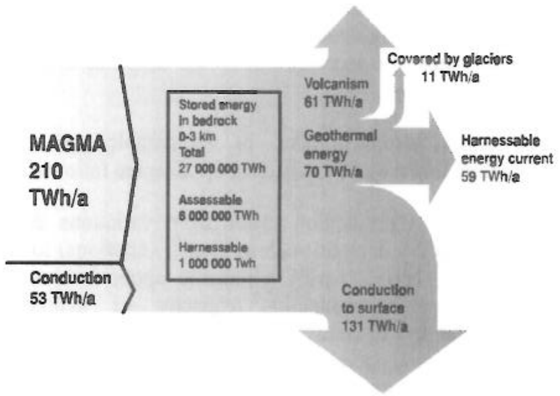

Figure 2: Terrestrial energy current through the crust of Iceland and stored heat (Stefansson, 2000).

surface the energy current splits between 7 GW by volcanic activity, 8 GW by water- and steam-flow in geothermal areas and 15 GW by heat conduction. According to these numbers the energy flux through Iceland is about 5-fold the world average. Bodvarsson (1982) also estimated that the energy transported by water and steam in geothermal areas in Iceland is about 1/10 of the corresponding world-wide land-based flow.

The principal result of Palmason *et al.* (1985) is that the total energy stored in the crust of Iceland, from surface down to 10 km depth, amounts to about 1.2 EJ (1 EJ = 10^{24} J). Above 3 km depth the energy stored is only about 0.1 EJ (termed accessible energy). Again these results only apply to the crust directly below the section of the country above sea-level. According to this study the energy density (concentration) is greatest within the volcanic zone, in particular in the high-temperature systems. The thermal energy stored in five of the largest high-temperature systems is estimated to account for 70% of the total energy stored in all high-temperature systems in Iceland. Figure 2 presents a simple sketch of both components of the geothermal potential of Iceland.

By combining the estimated energy stored and energy current it is possible to estimate roughly how long it has taken the thermal energy above 10 km depth to accumulate in the crust, or the time-scale on which this stored energy is renewed. In this way an estimate of the order of 1.3 million years is obtained. But it is clear that this replenishment takes place at drastically variable time-scales, depending on the mode involved. Thus energy replenishment through the flow of magma, water or steam is several orders of magnitude faster than replenishment by heat conduction alone.

4. SUSTAINABLE UTILIZATION OF GEOTHERMAL RESOURCES

Experience from utilization of numerous geothermal systems the last half a century has shown that it's possible to produce geothermal energy in such a manner that a geothermal system, which previously was in an undisturbed natural state, reaches a new equilibrium (at least a semi-equilibrium)) after massive production starts, which may be maintained for a long time. This is because pressure decline in geothermal systems, due to production, can cause the recharge to the systems to increase approximately in proportion to the rate at which mass is extracted.

Axelsson and Stefansson (2003) and Axelsson *et al.* (2005) discuss a few such examples. One of the best examples is the Laugarnes geothermal systems in Reykjavik, from which the average yearly mass extraction has been about 5 Mm^3 (about 160 l/s average production) the last four decades. This has not caused a substantial pressure decline in the system, except for the first few years. Therefore, it is believed that the inflow, or recharge, to the systems is now about tenfold what it was before production started. Axelsson *et al.* (2009) present other comparable Icelandic low-temperature examples. Another good example is the Matsukawa geothermal system in Japan (Hanano, 2003), which also has been utilised for about four decades for an approximately steady electricity generation (about 60 kg/s average steam production). In other cases geothermal production has been excessive and it has not been possible to maintain it in the long-term. The utilization history of the Geysers area in California is a good example of excessive production of the mass reserve. Total generation in the area has been reduced by almost half because of a nearly steady pressure decline in the system (Barker, 2000).

It seems natural to classify sustainable geothermal utilization as energy production that somehow can be maintained for a very long time. Based on this understanding and case histories, such as the ones mentioned above, Axelsson *et al.* (2001) have proposed the following definition for the term "sustainable production of geothermal energy from an individual geothermal system":

For each geothermal system, and for each mode of production, there exists a certain level of maximum energy production, $\boldsymbol{E_0}$, *below which it will be possible to maintain constant energy production from the system for a very long time (100-300 years). If the production rate is greater than* $\boldsymbol{E_0}$ *it cannot be maintained for this length of time. Geothermal energy production below, or equal to* $\boldsymbol{E_0}$, *is termed* ***sustainable production*** *while production greater than* $\boldsymbol{E_0}$ *is termed* ***excessive production.***

This definition applies to the total extractable energy, and depends in principle on the nature of the geothermal system in question. It does, however, neither consider load-factors, utilization efficiency, economical aspects, environmental issues nor technological advances. The value of $\mathbf{E_0}$ may be expected to increase with time through technological advances, e.g. through deeper drilling targets. In addition the definition depends on the mode of production, which may involve free-flow, pumping, injection or periodic production. It must be emphasized that this definition is simply based on the Brundtland definition, but does not imply economical sustainability, which normally is considered on a much shorter time scale, normally of the order of 30 years.

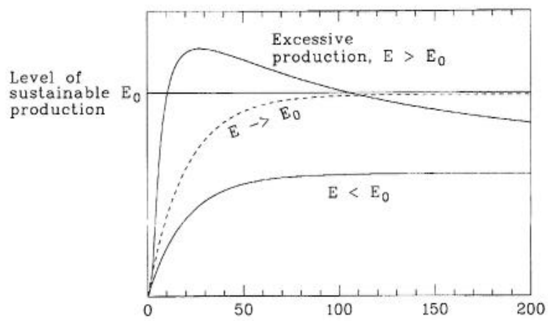

Figure 3. A schematic figure illustrating the difference between sustainable and excessive production (Axelsson *et al.*, 2001).

The definition is based on a much longer time-scale. In contrast, the time since Iceland was settled (1000 years) could also be used as a time-frame, or a period on the geological time-scale, such as the time since the end of the last ice-age (10.000 years). These time-frames are considered unrealistic in view of the time-scale of human endeavours. Therefore, a time-frame within the bounds of these different time-scales was chosen.

Even though geothermal resources are normally classified as renewable energy sources, because they are maintained by a continuous energy current, such a classification may be an oversimplification. Geothermal resources are in essence of a double nature, i.e. a combination of an energy current (through heat convection and conduction) and stored energy. The renewability of these two aspects is quite different as the energy current is steady (fully renewable) while the stored energy is renewed relatively slowly, in particular the part renewed by heat conduction. The semi-equilibrium reached in cases such as Laugarnes and Matsukawa may reflect the renewability of the corresponding geothermal resources. The renewable component (the energy current) is greater than the recharge to the systems in the natural state, however, because production has induced an additional inflow of mass and energy into the systems (Stefansson, 2000). In the case of Laugarnes it may have increased by a factor of 5-10.

If energy production from a geothermal system is within the sustainable limit defined above one may assume that the stored energy is mined relatively slowly and that the energy in the reservoir is renewed at approximately the same rate as it is extracted at. Once again the Laugarnes system provides a good example. To maintain such a semi-steady state for a long time thus requires the renewable part of the underlying resource to be relatively powerful. Yet it is likely that the "volume of influence" of the geothermal energy extraction is very large and that the renewability is to some degree supported by energy extraction from the outer and deeper parts of the geothermal system in question.

The value of $\mathbf{E_0}$ is not known a priori, but it may be estimated for individual systems, through modelling, on the basis of exploration and production data as they become available. Axelsson *et al.* (2005) present a few such examples. For Iceland as a whole it is proposed that total utilization less than, or comparable to, the total heat-flow through the island can be considered sustainable. This amounts to about 29 GW of thermal energy. Of course only a small part of the heat-flow can be captured to generate energy, but generation at this rate for 100-300 years would only amount to about 0.015% of the thermal energy stored in the crust of the island down to 10 km depth and to about 0.2% of the energy stored down to 3 km depth.

It seems evident that geothermal resources can be utilised through various different modes of operation, all of which may adhere to the sustainability definition presented above. In addition to utilization modes in which production is always below the sustainable limit much more aggressive utilization modes can be envisioned (not sustainable in the long-term), either initially or intermittently. Modelling studies have demonstrated that following a period of excessive production geothermal systems are able to recover approximately back to their pre-production state, i.e. the effects of intense production are mostly reversible (see later). Such production modes are more in-line with the utilization of many high-temperature geothermal systems today. They are harnessed in large steps, which are unlikely to be sustainable along the lines of the definition above, but are economically feasible due to their size. They are also intended to meet a demand for electrical power that grows in large steps, for example due to the demands of power-intensive industry.

The main methods/modes of sustainable geothermal utilization that may be envisioned are thus the following:

(1) Constant production (aside from variations due to temporary demand such as annual variations) for 200 years. This is hardly a realistic option because the sustainable production capacity of geothermal systems is unknown beforehand. Therefore, a kind of test-period is required initially until the sustainable potential has been assessed.
(2) Production increased in a few steps until the sustainable potential has been assessed and the sustainable limit attained.
(3) Excessive production (not sustainable) for a few decades (perhaps about 30 years) with total breaks in-between, perhaps a little longer than the production periods (about 50 years), wherein a geothermal system is able to recover almost fully.
(4) Excessive production for 30 – 50 years followed by a steady, but much reduced production for the next 150 – 170 years. The production following the excessive period would thus be much less than the sustainable potential at constant production (mode (1)).

Of these methods 1-2 and 3-4 can be considered strong and weak sustainable approaches respectively in accordance with Bosselmann (2002). It should be pointed out that the sustainable development of energy resource utilization must eventually be viewed in a broader context than for single geothermal systems independent of other systems. The following must be kept in mind:

(i) During long-term utilization some interference, even considerable, may be expected between adjacent geothermal fields being used, even over considerable distances (tens of km). This possible interference must be kept in mind but can possibly be mitigated with known measures like reinjection.
(ii) If single geothermal systems are being utilised in an intense/excessive manner during a certain period other geothermal systems may need to be available in the same general region, which could then be utilised while the former systems are being rested. Thus the overall geothermal resource utilization in the region may be managed as sustainable, even though single geothermal systems are not.

If geothermal development in a region is, on the other hand, in a step-wise manner the development may be required to be ongoing in several geothermal fields at the same time, because the steps in each field are likely to be so small.

5. ASSESSING THE SUSTAINABLE POTENTIAL $\mathbf{E_0}$

The concept of strong and weak sustainability allows for coupling standard reservoir engineering tools into the permitting and legislative processes that accompany decision making in geothermal projects. Two permitting categories can be envisioned, for new green field projects and where existing power projects are to be expanded based on available production history and detailed numerical reservoirs models. The legislative decision making will nevertheless always have a political flavour, in particular when a developer has plans for large power projects. The first rule of thumb may therefore be that the larger a project is in terms of extracted mass and heat from depth, the weaker is its sustainability. For such instances the political responsibility is to make sure that large projects generate the manpower-need, technology and sciences to raise the sustainable potential E_0 from its initial estimate, optimally making an initially non sustainable production strategy into a sustainable one.

Green field geothermal projects have in general no single methodology for estimating their long term (>100 years) generating capacity. Most common are simple methods based on surface exploration that produce an area estimate for resistivity anomaly coupled with structural maps, chemistry of fumaroles and other parameters that set likely ranges in deep reservoir temperatures and fluid chemistry. By drilling a few exploration wells the deep reservoir temperature, permeability and fluid quality is determined. Based on these a volumetric generating capacity estimate can be put forward, surprisingly often resulting in a normalized area based capacity of some 10-20 MW/km^2 electric (Sarmiento and Bjornsson, 2007). Other analysis such as comparison with similar reservoirs elsewhere also can support the early generating capacity estimate. Applying numerical reservoir models at the early stage is more controversial. For example pressure drawdown data are scarce or missing, forcing the modeller to use his own intuition to set the outer reservoir permeability. The model is therefore biased by the modeller's background and experience. Resource discoveries also may still have to be made. As an example, the 120 MW Nesjavellir project in Iceland had an early numerical model that was calibrated against downhole data collected in wells outside the hottest part of the reservoir. This led to pessimistic enthalpy predictions and thus reduced the initial generating capacity estimate (Sarmiento and Bjornsson, 2007).

Developed geothermal projects, in particular where some 5-30 years of production data are at hand collected in tens of wells, can be granted expansion licences based on detailed well by well numerical models that consider much longer prediction times than the common 15-30 years for financial recovery of the investment. At this stage the numerical models are properly constrained by field data to account for boundary recharge that accompanies pressure drawdown, a property that may be the single most important parameter in estimating E_0. The boundary recharge is to be complemented with other activities such as optimal location of injection wells, an issue that is hard to assess without detailed numerical modelling. Finally, the numerical models allow for studies on the recovery rates of mass and heat reserves, after a large power project goes into a resting or reduced production period. All this modelling activity is to make sure that the development complies with the minimum 100 year criterion for sustainable development being proposed by the authors of this paper. A recent modelling study that incorporates the sustainability concept is for example given by Bjornsson *et al.* (2006).

Finally, with the sustainable generating potential E_0 at hand, it appears reasonable that governmental licensing authorities grant annual extraction licences that are based on produced heat instead of MW installed. This allows the geothermal developer to later optimise power plants and well field without reapplying for the various licenses and permits that otherwise might be necessary.

6. SUSTAINABILITY INDICATORS

The Bellagio Principles for Assessment give guidelines for assessing progress toward sustainable development. They include the whole assessment process including the choice and design of indicators, their interpretation and communication of the result. (Hardi and Zdan, 1997):

The first step of defining Geothermal Sustainability Assessment Protocol (GSAP) is to define clear sustainability goals for geothermal utilization. The Working Group has agreed on eleven goals;

Resource Management / Renewability

(1) See definition above (4. Sustainable utilization of geothermal resources). If possible, sustainable production should be the goal during geothermal utilization. However, in cases where excessive production is necessary (e.g. for electricity generation), a geothermal reservoir must be afforded a recovery period. Such recovery periods should be on a timescale acceptable to society and the use of other geothermal reservoirs should be possible in the meantime. Resource management strategies should therefore consider a number of geothermal systems based around a central volcanic system.

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

Efficiency

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

Research and Innovation

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

Environmental Impacts

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

Social Aspects

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

Energy Security, Accessibility, Availability and Diversity

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

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

Economic and Financial Viability

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

(10) The enterprise managing the geothermal resource practises corporate social responsibility (Shortall, 2009).

Knowledge Sharing

(11) Knowledge and experience gained during the development of geothermal utilization projects should be

accessible and transparent to the public and other interested groups.

Table 1: Systems and subsystems used in systems analysis for indicator development (Shortall, 2009).

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

The second step is to develop sustainability indicators. Two different methods are suggested. The first method involves developing thematic indicators, where the indicators are grouped into the following themes: Environment, Social, Economic and Institutional and further into sub-themes similar to the approach used in the development of the Hydropower Sustainability Assessment Protocol (IHA-SAP, retrievable at hydropower.org). The other method is system based and involves finding indicators for the three main systems relevant to sustainable development i.e. Human, Natural and Support, and their subsystems (Bossel, 1999). While the theme-based approaches are more common for national energy indicator sets and allow for more emphasis on the systematic cross-linkages between the indicators, the systemic approach offers a more structured, holistic view of the sustainability of the systems (Shortall, 2009).

In Iceland a Geothermal Sustainability Assessment Protocol (GSAP) is being developed based on the systemic approach (Shortall, 2009). The three main systems are broken up into seven sub-systems as shown in Table 1. For each subsystem, seven orientors of viability must be satisfied in order for the sub-system to be viable or sustainable. The seven orientors are: Effectiveness, Efficiency, Freedom of Action, Security, Adaptability, Coexistence and Psychological Needs. More than 100 sustainability indicators have been defined but only eight are directly linked to the geothermal resource itself. In this approach no indicator is deemed more important than another (Shortall, 2009).

In 2009-2010 the GSAP will be implemented for a project involving the Krafla geothermal power plant in N-Iceland. Further testing of the protocol will be performed in the near future for different geothermal projects and for countries at different stages of development to ensure the validity of the indicators for different national conditions

7. IMPLEMENTATION INTO ICELANDIC LEGAL FRAMEWORK

The Icelandic legislature has incorporated the concept of Sustainable Development into several acts. The acts worthy of mention, i.e. acts that have to do with environmental law, are The Planning and Building Act no. 73/1997, The Nature Conservation Act no. 44/1999 and The Strategic Environmental Assessment Act no. 105/2005. Adding to this list is The European Economic Agreement Act no. 2/1993 which stipulates the induction of EU legislation into the Icelandic legal system. These laws all share a common denominator, which is that Sustainable Development is always an objective of the law rather than being strictly stipulated. The reference to Sustainable Development in these acts is also rather vague e.g. Paragr. 3, Art. 1 of The Nature Conservation Act which states that the Act is to, among other things, promote protection and utilization of resources on the grounds of sustainable development. This is the only reference in the Act and no attempt is made to define what is meant by sustainable development. The same can be said about the aforementioned Acts which cite sustainable development. An article is worth mentioning for a thorough overview of Icelandic legal framework and national policy in regards to geothermal utilization, (Ketilsson *et al.*, 2009).

The general and uncertain mentions of Sustainable Development in Icelandic law are in turn with the views expressed by scholars such as Bosselmann and Jacob (Johannsdottir, 2005) i.e. the weaknesses of the term itself. It is the authors' opinion that sustainable geothermal utilization should be defined and implemented into Icelandic law. A possible method of achieving this would be to model somewhat the Icelandic Electricity Act no. 65/2003. In the Electricity Act itself there is no mention of sustainable development or sustainable utilization. However the Act has a derivative regulation, Regulation no. 1040/2005, which implements the application of the Act in a more precise manner. The regulation takes on various aspects of the law that empowers it, such as defining various concepts, implementation of how power development licenses are issued and what conditions are to be met in order to acquire a power development licenses. In Paragr. 5, Art. 5 of the regulation it says (in Icelandic, translated unofficially here) that the Minister [of Industry] shall aspire to promote sustainable utilization of renewable resources. This is one of the more direct mentions of how sustainability shall be implemented by law but again, sustainable utilization or sustainability is not defined.

Our suggestions are that this should be done in regards of The Resource and Utilization Act no. 57/1998. In the Act there could be, as is in the aforementioned environmental acts, an article stating the objective of the Act. Then, a derivative regulation could be implemented, as has been in the case of the Electricity Act, which would then in turn define what is considered sustainable utilization of a geothermal resource. The regulation could go on to state that sustainable utilization is a condition of being granted and/or should be in the contents of a power development license. These parameters e.g. that go further than the already in place regulation derived from the Electricity Act, could also be applied to that same regulation, both included in the article on definitions, the article on power development licenses (both applications and conditions for the license) as well as the article which defines the content of each license.

CONCLUSIONS

In this study the term sustainable geothermal utilization is discussed, based on the principles of sustainable development, and legal implementation suggested into Icelandic legal framework. The main methods of sustainable geothermal utilization have also been outlined. Those methods have been categorized as either weak or strong sustainable approaches with Bosselmann's definitions in mind, i.e. weak sustainability assuming the validity of growth and placing equal importance on environment, social justice and economic prosperity and strong sustainability having the environment as a foundation to social justice and economic prosperity.

The development of a comprehensive assessment framework of sustainability indicators is introduced taking into consideration economic prosperity, environment and social justice based on the Bellagio principles from the International Institute for Sustainable Development.

The concept of sustainable utilisation of geothermal resources can be implemented into Icelandic legislation and defined in the form of mending a derivative regulation from laws that are already in place. However, protection and utilisation of energy resources is a political debate. The Framework Programme for Protection and Utilization of Hydro and Geothermal Energy Resources is to facilitate with decision making and will be presented to the Parliament in 2010. The results of this working group will facilitate in the discussion on sustainable utilization of energy resources in Iceland.

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