

THE RENEWABILITY OF GEOTHERMAL ENERGY

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dry rock “reservoirs” can hardly be classified as renewable on the same time scale.

ABSTRACT

International organisations have classified geothermal energy as a renewable energy source, but it is sometimes stated that this is not the case. The meaning of the concepts “renewable energy sources” and “sustainable energy production” is discussed in this paper. Comparison is made with the resources of hydropower and fish stocks in order to clarify the meaning of the two concepts. It is found, that the rate of energy recharge to geothermal systems is the most critical aspect for the classification of geothermal energy as a renewable energy source. In the exploitation of natural geothermal systems, the recharge of energy takes place by advection of thermal water at the same time scale as the production from the resource. This justifies the classification of geothermal energy as a renewable energy source. In the case of hot dry rock, and eventually some of the hot water aquifers in sedimentary basins, the energy recharge is only by thermal conduction and, due to the slowness of this process, hot dry rock and some sedimentary reservoirs should be considered as finite energy sources.

1. INTRODUCTION

International organisations have classified geothermal energy as a renewable energy source. This classification has been in use for a very long time, but occasionally it is stated that thermal depletion of geothermal reservoirs would require such a long time for recovery, that geothermal energy is not, strictly speaking, a renewable energy source on the human time scale (Ledingham, 1998). These conflicting messages might easily create confusion in the energy debate, where it is of importance that there is a common agreement on the basic concepts of the energy resources.

The present paper deals with the renewability of geothermal energy and links the discussion with the concept of sustainable development. Common properties of geothermal energy and hydropower are used to demonstrate that both energy sources are renewable. It is found that the transportation process of heat within the crust determines whether the geothermal energy should be considered renewable, or not. All natural geothermal systems are renewable on the human time scale, whereas hot

2. CLASSIFICATION OF ENERGY RESOURCES

Figure 1 shows the classification of energy resources applied by the International Standards Organization (ISO). The figure shows that the use of renewable energy sources in the world is now about 22% of the total, but depleting energy sources contribute 78% of the world energy use.

The share in the energy mix is given in the figure for each energy source. Furthermore, the expected reserves (in years) at the 1996 exploitation rate are given for the different depleting energy resources. For the renewable energy sources, the reserves are considered to provide continuous (unlimited) contribution to the exploitation.

The share of the finite energy resources is at present much larger than the contribution from the renewable energy sources and the known reserves of these sources are estimated to last for several decades or centuries at the present exploitation rate. However, the balance between renewable and depleting energy sources is bound to shift towards increased use of the renewable energy sources. In this situation it is of importance to realise the restrictions on the renewable energy sources and analyse how the renewable energy sources can in the best way contribute to a sustainable development. At present, geothermal energy contributes some 0.1% to the total use of energy in the world. Therefore, there seem to be abundant possibilities to increase the use of geothermal energy and hopefully also to increase its share in the energy mix.

3. DEFINITION OF CONCEPTS

Two concepts, *renewable* and *sustainable* are of importance in this discussion. As there seems to prevail some confusion about the meaning of these concepts, it is appropriate to clarify the author’s understanding of these concepts.

The concepts *renewable* and *sustainable* are not comparative. Renewable describes a property of the energy resource, whereas sustainable describes how the resource is utilised. For an Icelander, the comparison with the fish stocks is natural. The fish stocks are certainly renewable resources but the

exploitation (fishing) can be done in different ways. With a proper management of the fishing, a continuous sustainable yield can be obtained, but overexploitation can result in the collapse of the stock and depletion of the resource.

Similar examples of energy resources are perhaps not as obvious, but the experience from the Geysers in the USA might be of similar nature. There, power plants for electricity generation of some 2000 MW capacity were installed some decades ago. Operation of these plants for some time revealed that the geothermal system could not sustain this production for a long time. At present, the production is limited to some 1500 MW and reservoir studies indicate that sustainable utilisation (continuous utilisation at the same rate for a long time) is probably not more than about 1000 MW. In this case, the exploitation has not destroyed the resource (as is frequently the case for biological resources), but there are limits to the yield which can be extracted in a sustainable way from the resource.

From these examples it is evident that in order to obtain sustainable exploitation of an energy resource, the resource has to be renewable. Sustainable operation is characterised by some kind of equilibrium. For a long time operation, it is not possible to extract more energy out of the system than the amount of energy entering into the system. Therefore, sustainable exploitation can only be obtained from renewable energy resources.

Renewable energy sources are in one way or another linked to some continuous energy processes in nature. The conditions must be such, that the action of extracting energy from the natural process will not influence on the process or energy circulation in nature. Construction of a power plant in a river will not influence the rate of the precipitation, which is the source of the flow of water in the river.

A simplified description of renewability could be that the energy extracted from a resource is always replaced by additional amount of energy. Furthermore, we require that the replacement takes place on a similar time scale as that of the extraction. It could be argued that oil and gas are renewable energy sources on a geological time scale. For the human time scale this time is so long that there is a common agreement to classify oil and gas as finite energy sources.

Sustainable exploitation of the fish stocks in the ocean around Iceland is of a fundamental importance for the Icelandic society. This requires a proper management of the resource. It is therefore quite natural for Icelanders to assume that sustainable exploitation should be applied to energy resources also.

4. RENEWABILITY OF GEOTHERMAL ENERGY AND HYDROPOWER

In the geological environment of Iceland it is quite obvious that the geothermal energy has two components: The energy current from below and the energy (heat) stored in the bedrock of the country. A description and estimate of the energy current was presented by Bodvarsson (1982), and the estimate of the heat stored in the rocks (geothermal assessment) was carried out by Palmason et al. (1985).

At the surface the terrestrial energy current is observed as:

- ◆ volcanic activity
- ◆ geothermal energy
- ◆ heat conduction

Bodvarsson (1982) estimated that the terrestrial energy current through the crust of Iceland is some 30 GW. At the surface about 7 GW occur as volcanism, 8 GW as advection of geothermal water, and 15 GW as thermal conduction.

Comparison of geothermal energy with hydropower is quite appropriate to show the similarities and the dissimilarities of these two renewable energy sources. Figures 2 and 3 show schematically the properties of geothermal energy and hydropower in Iceland (Stefánsson and Eliasson, 1997).

The precipitation on the mountainous country makes up the energy current for the hydropower in Iceland (fig. 2). The mean power of the precipitation has been estimated at 285 TWh/a (Tomasson, 1982). The unit TWh/a is preferred to GW in order to underline that the value given is a mean value over one year. The precipitation varies from day to day but the flow of water is regulated considerably by the passage through soil and other geological formations. The flow of rivers is much smoother than the precipitation and dams furthermore regulate seasonal variation in the flow of rivers so that a constant energy production in power plants can be obtained. For hydropower, the time constant of one year is appropriate to describe the renewability of the energy resource. If a short time period (one day) during the dry season was selected, hydro might have similar properties as a finite energy resource. Figure 2 shows also how the energy current is distributed in nature among evaporation, glaciers, ground water and other components. The bottom line is that the technically exploitable part of the hydropower is about 64 TWh/a.

The energy current from the interior of the earth is the primary source of geothermal energy in Iceland as shown in fig. 3. The energy transport within the crust takes place by three processes:

- ◆ advection of magma
- ◆ advection of geothermal fluid
- ◆ thermal conduction

Energy (heat) transport with the advection of magma and thermal water is a relatively fast process. Time constants in the range of days or

months are suitable to describe these processes. On the other hand, thermal conduction is a relatively slow process where a time constant of the order of hundreds of years is needed to characterise the process. The utilisation of geothermal energy from natural geothermal systems is primarily governed by the advection of thermal fluid in the crust. Therefore, one year is also an appropriate time constant for geothermal energy.

Most of the thermal energy entering the crust beneath Iceland is in the form of advection of magma (fig. 3). On its way to the surface, there is a continuous interaction between the three energy transport processes. When the energy reaches the surface, about half of the energy current occurs as conduction, whereas volcanic activity and geothermal energy are the main manifestations of the other half. It should be pointed out, however, that although the energy current occurs in three forms at the surface, these manifestations are a part of a single energy current through the crust. About 1/3 of the magma entering the crust from below reaches the surface in the form of volcanic eruptions. The other 2/3 parts of the magma end up as intrusions in the crust. The heat (energy) in the intrusions consequently migrates to surface, either as thermal fluid or by conduction.

It is of interest to note that in Iceland, the energy current from below is of the same size as the energy current from above and that the technically usable hydropower is, within the limits of error, equal to the technically usable current of geothermal energy.

In addition to the energy current from above and from below, energy is stored at certain places in the two natural systems. Glaciers, lakes, and ground water reservoirs are examples of stored hydropower, whereas the heat stored in the bedrock is a huge storage for the use of geothermal energy. In order to underline the importance of the energy storage for both hydro and geothermal energy it should be noted that the energy storage in the glaciers (7600 TWh) corresponds to the current of the precipitation for 27 years and that the usable heat in the bedrock (1 000 000 TWh) corresponds to the energy current from below for 3800 years. All heat (usable and non-usable) in the crust corresponds to the current from below for 100 000 years.

The energy storage in the glaciers of Iceland contributes some 10% to the variation in the flow of rivers in the country. During some periods, the glaciers add more flow to the rivers than if there were no glaciers present while in other periods the flow is reduced because of accumulation of ice in the glaciers.

The energy storage in the bedrock is a somewhat more complex issue depending on the three energy transport processes. The advection of water (and magma) is such a fast energy transport process that geothermal energy meets all requirements being a renewable energy source, viz. energy is replaced on the same time scale as for the energy extraction. If the energy transport is only by thermal conduction

on the other hand, it is hardly possible to talk about “renewable” energy sources because the time constant of the energy replacement is much longer than the time constant of the exploitation.

All conventional exploitation of geothermal energy is based on energy extraction from natural geothermal systems where water transports the energy within and towards the systems and water also transports the energy to the surface where the utilisation takes place. Production causes a pressure decline in the geothermal system, which results in increased recharge of water and energy to the system under exploitation. These conditions are typical for renewable energy sources where the replacement of energy takes place on similar time scale as the extraction.

The exception from this rule is hot dry rock. In this case the idea is to create an artificial geothermal system in impermeable rocks by injecting water in one well and extracting the heat stored in the rocks through another well. This production method is still at the experimental stage and continuous production has only been possible for some months. It is not known whether this production method will be economically feasible within the near future, but the energy transport towards the “heat exchanger” of the hot dry rock system must be in the form of heat conduction alone. Due to the long time constant of the heat conduction process, the hot dry rock method can not be classified as renewable energy source. Hot dry rock is a finite energy source, whereas natural geothermal systems are renewable energy sources.

5. GEOTHERMAL ENERGY IN ICELAND

All production of geothermal energy in Iceland is from natural geothermal systems and it should therefore be classified as utilisation of a renewable energy source according to the description above. At present there are about 200 geothermal systems (small and large) in use in the country (Stefánsson and Fridleifsson, 1998). The longest continuous exploitation time for a single system is 70 years for the Laugarnes area, situated within the city of Reykjavik. In none of these cases has the production been discontinued because the source was depleted. On the contrary, the experience is such that the geothermal systems appear to be able to sustain continuous production for such a long time, that it is appropriate to talk about sustainable exploitation. The production from the Laugarnes field is a good example of these conditions.

For the first 25 years of exploitation in the Laugarnes field, the production was only by free flow from wells, but submersible pumps were introduced in the late fifties. The new production method made it possible to increase the production ten times as shown in figure 4. The response of the system was that the pressure (water level) fell but a new equilibrium state was reached where the water level was on the average 120 m below the initial

level when the production started in the year 1930. The increased production from the field has not caused changes in the reservoir temperature. The geothermal system in Laugarnes is approximately in equilibrium for the 6 Gl/a (160 l/s) production, which has been maintained there for the last 30 years. This means that the pressure decline has caused increased natural recharge and the rate of recharge is, on the average, the same as the rate of production from the system. It is quite obvious that the present production in Laugarnes is a sustainable exploitation and that the energy resource is renewable.

The next step in the discussion would be to "explain" how the geothermal energy in the Laugarnes field is renewed, or rather to put forward a conceptual model for the geothermal system. Two possibilities seem to be at hand for such a model:

- ◆ The lower pressure diverts a larger part of the geothermal fluid in the region through the production area.

- ◆ The increased recharge of cool water from the surroundings makes it possible to extract heat from a larger volume of rock than before.

As seen in fig. 3, the energy current from below reaches the surface in three components (volcanism, hot water, and conduction). If increased energy extraction at certain locations of the system makes the energy current to go preferably through that channel, we have obtained an indirect management of the terrestrial energy current. For example, an increased production of geothermal energy from a geothermal system close to a magma chamber, might result in more efficient cooling of the magma chamber and that less energy needs to go through the magma channel to surface. This effect would lower frequency of volcanic eruptions in the same area.

In the Krafla field, the time between the two last volcanic eruptions was 250 years. The volume of magma erupted during 1975-1984 was 0.35 km³. The heat transported to surface during this volcanic event was about $2 \cdot 10^{18}$ J. If this energy were distributed evenly over the 250 years between volcanic eruptions, it would correspond to a continuous 250 MW heat extraction (production) from the system. Therefore, it might not be unrealistic that geothermal production can influence (reduce) the frequency of volcanic eruptions.

6. GEOTHERMAL ENERGY IN THE WORLD

The discussion in this paper is based on the conditions of geothermal energy in Iceland. The question is then whether this discussion can be extended to other parts of the world. It seems quite imperative that high temperature fields all over the world are so similar in nature that all such systems can be classified as renewable energy sources. For the low temperature fields on the other hand, it is questionable whether the hot water aquifers in

sedimentary basins are renewable. One opinion is that the geothermal gradient is responsible for the existence of these hot water systems, whereas an other opinion is that these aquifers have hydrological connections over large areas, such as other natural geothermal systems. If the energy transport towards these aquifers is only through conduction (geothermal gradient) these systems should be classified as finite sources like hot dry rock, but if there is a natural hydrological energy recharge to the sedimentary aquifers, the resource is renewable.

7. SUMMARY AND CONCLUSIONS

The renewability of geothermal resources is discussed in this paper. Comparison is made with hydropower and with the exploitation of fish stocks. It is argued that the natural recharge of energy to most natural geothermal systems takes place on a similar time scale as the exploitation of these resources. Therefore, it is concluded as a general rule, that geothermal energy is truly a renewable energy source.

The exceptions from this general rule are the hot dry rock concept and the confined hot water aquifers in sedimentary basins. Some of the sedimentary systems might be renewable and other finite.

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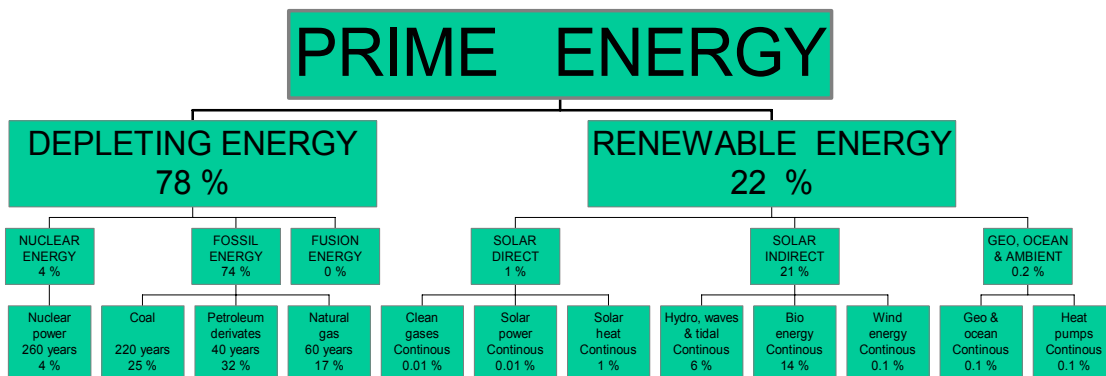


Figure 1. ISO’s classification of the energy resources (from Grob, 1998).

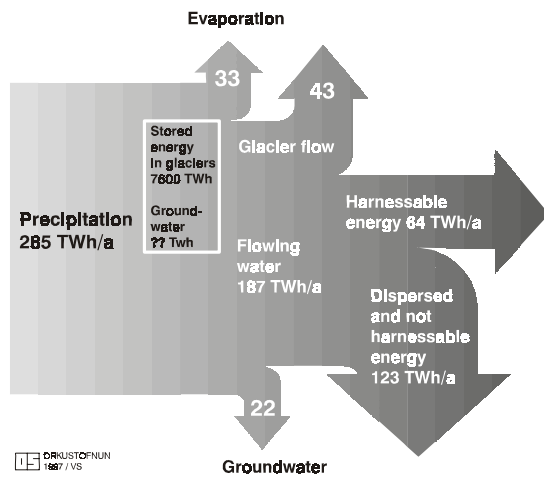


Figure 2. The energy current of hydropower in Iceland

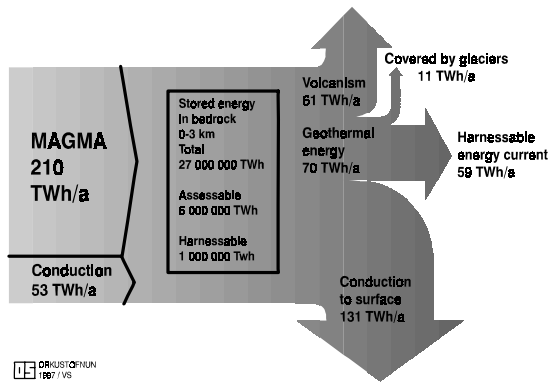


Figure 3. The terrestrial energy current in Iceland.

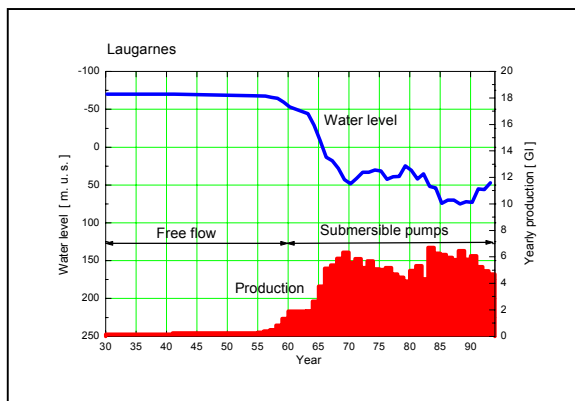


Figure 4. Production and water level in the Laugarnes field in Reykjavík