TEE RENEWABILITY OF GEOTHERMAL ENERGY

Valgardur Stefansson

Orkustohun, Grensasvegur **9,** Reykjavik – Iceland

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 "sustainableenergy 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 classifcation* **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 classifcation* **of** *geothermal energy* **as** *a renewable energy source. In the case* **of** *hot dry rock, and eventually some of the hot water aquifers in sedimentaty 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.*

1.0 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 it is the transportation process of heat within the crust, which determines whether the geothermal energy should be considered renewable, or not. All natural geothermal **systems** are renewable ***on*** **the** human time scale, whereas hot ***dry*** rock **"reservoirs"** *can* hardly be classified **as** renewable on the same time scale.

2.0 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 renewabie 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.

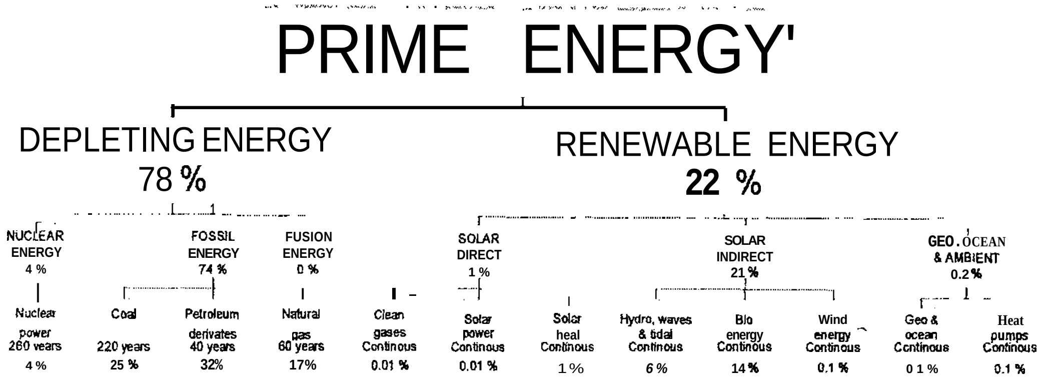

Figure 1. ISO's classification of the energy resources (from Grob, 1998).

3.0 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 fiom 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 fiom 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. *On* the other hand it should be stressed that *sustainable development* can be obtained by *the* exploitation of finite energy sources. This might need some further explanation.

In the report ***Ow Common Future,*** The World Commission on Environment and Development, under the chairmanship of Gro Harlem Bruntland, launched the concept of ***sustainable development*** (Bruntland, 1987). The definition given by the Commission is rather wide.

> ***Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts***
> - ***the concept of "needs", in particular the essential needs of the world's poor, to which overriding priority is given; and***
> - ***the idea of limitations imposed by the state of technology and social organizations on environment's ability to meet present andfuture needs.***

(Our Common Future, page 43)

It should be noted that the Commission used the word sustainable only in the context *sustainable* development. Later on, sustainable has been linked to a large number of activities. The sustainable exploitation of resources described above, is an example of such an extension of the definition. It can be discussed whether a more detailed definition of "sustainable" than the one given in *Our* Common *Future* is desirable or not. Regarding the fact that sustainable development can be obtained both with the exploitation of finite and renewable resources, but sustainable exploitation can only be obtained with renewable energy resources, it seems justified to apply the more detailed definition of sustainable.

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 in such way 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 fiom 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.

4.0 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 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 (Stefansson and Eliasson, 1997).

The precipitation on the mountainous country makes up the energy current for the hydropower in the country (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.

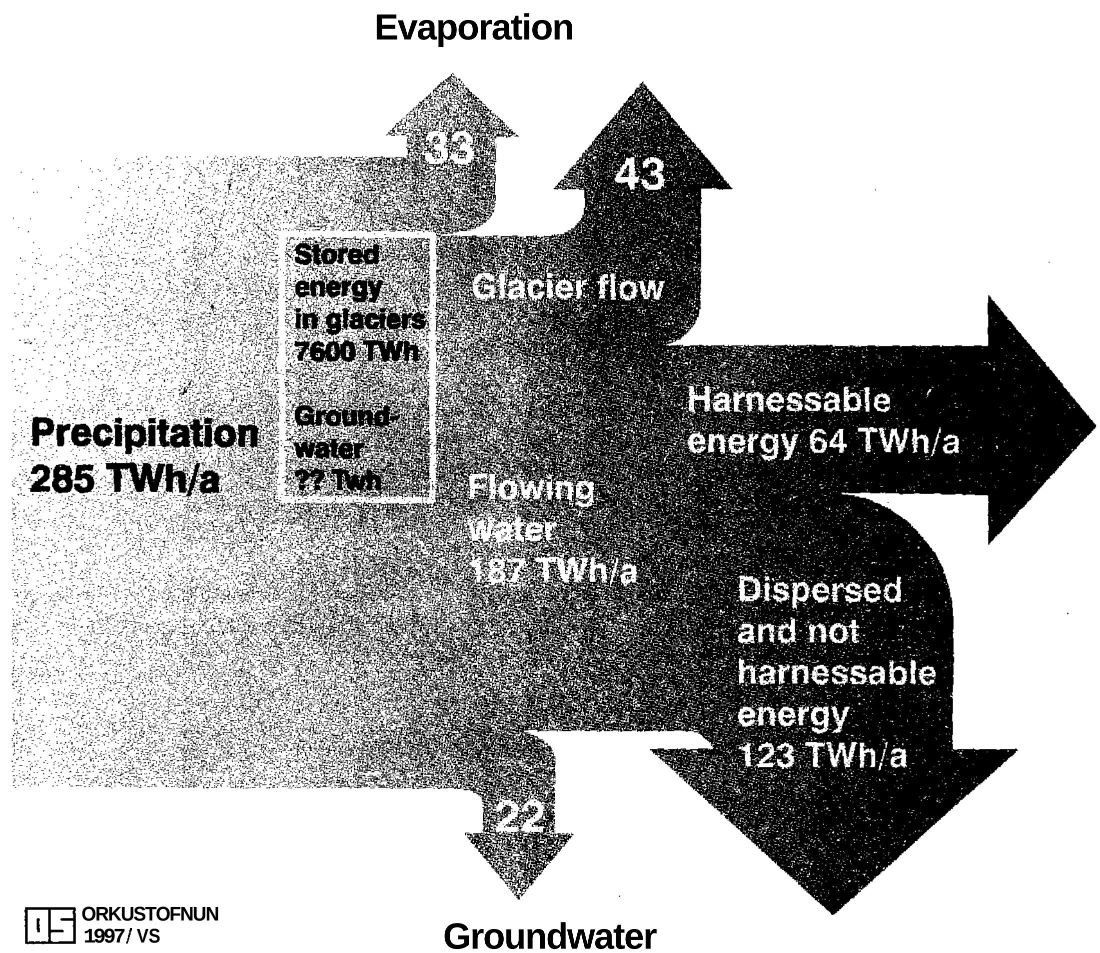

Figure 2. The energy current of hydropower in Iceland.

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 fluids 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 and 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 mor, equal to the technically usable current of geothermal energy.

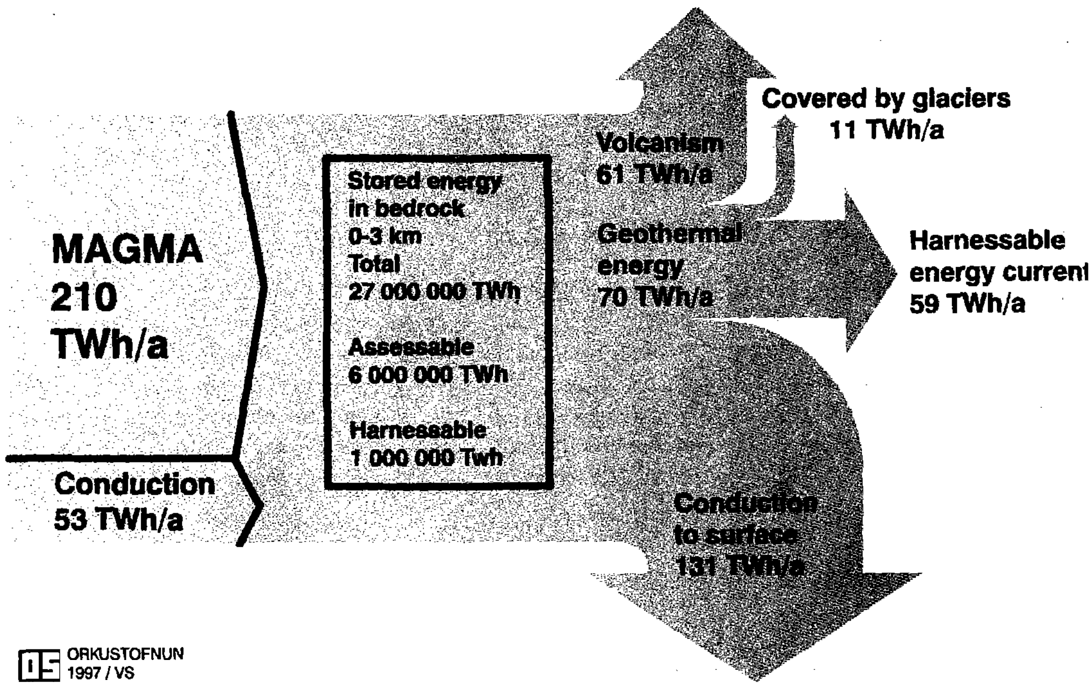

Figure 3. The terrestrial **energy current in** Iceland

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 fiom below for 3800 years. All **heat** (usable and non-usable) in the crust correspondsto 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 additional water and energy to the system under exploitation. These conditions are typical for renewable energy sources where the replacement of energy takes place on the same time scale as the extraction.

The exception fiom this rule is hot *dry* rock. In this *case* the idea is to create an artificial geothermal *system* m 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. 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.

5.0 GEOTHERMAL ENERGY IN ICELAND

All production of geothermal energy in Iceland is fiom 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, which is 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 rather 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 Laugames field is a good example of these conditions.

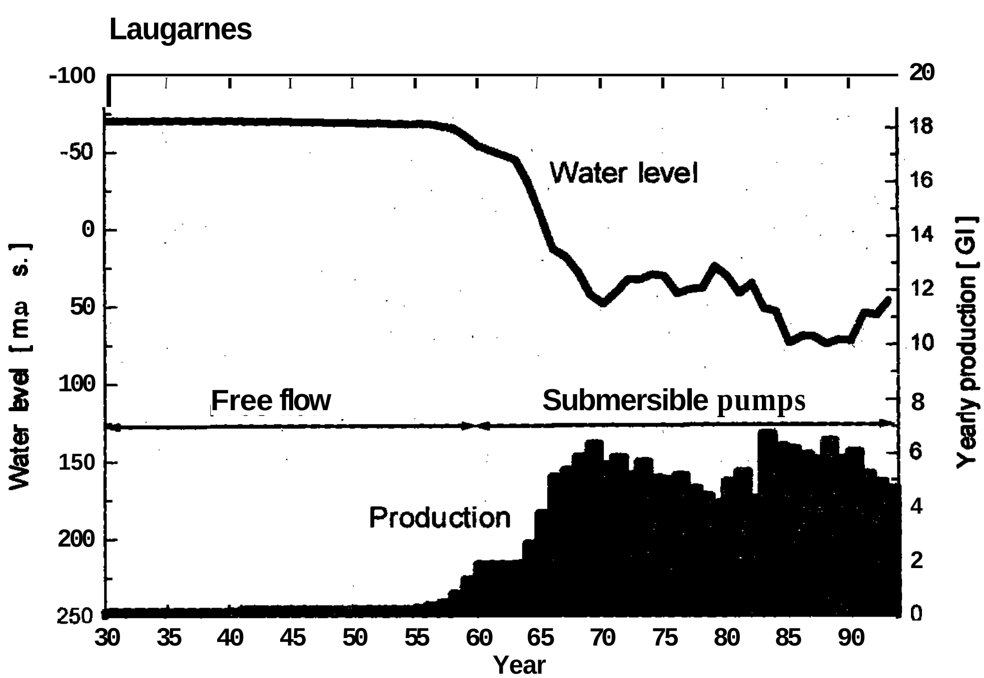

Figure 4. Production and water level in the Laugarnes field in Reykjavik.

For the first 25 years of exploitation m the Laugames 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 such that the pressure in the system (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. As the geothermal system in Laugarnes is approximately in equilibrium for the 6 Gl/a (160 Ys) production, which has been maintained there for the last 30 years, it means that the pressure decline has triggered increased natural recharge and that the rate of recharge is, on the average, the Same as the rate of production fiom the system. It is quite obvious that the present production m Laugarnes is a sustainable exploitation and that the energy resource is a renewable energy source.

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

- The lower pressure in the production area diverts a larger part of the geothermal fluid in the region through the production area than before.
- The increased recharge of partially colder water from the surroundings makes it possible to extract heat fiom a larger volume of rock than before.

As seen in Fig. 3, the energy current fiom below reaches the surface in three components (volcanism, hot water, and conduction). If increased energy extraction (energy production) at a certain locations of the system results in that the energy current goes preferably through that channel, we have obtained an indirect management of the terrestrial energy current. For example, an increased production of geothermal energy might result in lower fiequency 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 km^3. The heat transported to surface during this volcanic event was about $2*10^{18}$ J. If this energy were distributed evenly over the 250 years between volcanic eruptions, this would correspond to a continuous 250 MW heat extraction (production) fiom the system. Therefore, it might not be unrealistic that geothermal production can influence (reduce) the fiequency of volcanic eruptions.

6.0 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 m sedimentary basins are renewable or not. 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.

7.0 SUMMARY AND CONCLUSIONS

The renewability of geothermal resources is studied in this paper. Comparison is made with hydropower and with the exploitation of fish stocks. It is found that the natural recharge of energy to most natural geothermal systems takes place during a similar time frame 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 fiom this general rule are the hot dry rock concept and eventually the confined hot water aquifers in sedimentary basins. Some of the sedimentary systems might be renewable and other finite.

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