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GEOTHERMAL ENERGY IN THE WORLD WITH SPECIAL REFERENCE TO CENTRAL AMERICA

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ABSTRACT

The renewable energy sources are expected to provide 20-40% of the world primary energy in 2050, depending on scenarios. A key element in the mitigation of climate change is capacity building in renewable energy technologies in the developing countries, where the main energy use growth is expected. Based on the World Energy Assessment Report update on the status in 2001 (WEA, 2004), the primary energy consumption in the world was assessed as 400 EJ, with about 80% coming from fossil fuels, and only 14% from renewable energy sources. The contribution of the renewables is discussed and their possibilities. The current share of the renewables in the energy production is mainly from biomass and hydro, followed by wind, and geothermal energy.

Central America is one of the world´s richest regions in geothermal resources. Geothermal power stations provide about 12% of the total electricity generation of the four countries Costa Rica, El Salvador, Guatemala and Nicaragua. The electricity generated in the geothermal fields is in all cases replacing electricity generated by imported oil. Hydro stations provide 46% of the electricity for the four countries, and wind energy 2%. With an interconnected grid, it would be relatively easy to provide all the electricity for the four countries by renewable energy. The geothermal potential for electricity generation in Central America has been estimated some 4,000 MWe, and less than 500 MWe have been harnessed so far. With the large untapped geothermal resources and the significant experience in geothermal as well as hydro development in the region, Central America may become an international example of how to reduce the overall emissions of greenhouse gases in a large region.

1. INTRODUCTION

Amongst the top priorities for the majority of the world´s population is access to sufficient affordable energy. There is a very limited equity in the energy use in the different parts of the world. Some 70% of the world´s population lives at per capita energy consumption level below one-quarter of that of W-Europe, and one-sixth of that of the USA (WEC, 1993). Two billion people, a third of the world´s population, have no access to modern energy services. A key issue to improve the standard of living of the poor is to make clean energy available to them at prices they can cope with. World population is expected to double by the end of the 21st century. To provide sufficient commercial energy (not to mention clean energy) to the people of all continents is an enormous task.

The world primary energy consumption is about 400 EJ/year (WEA, 2004). It is mostly provided by fossil fuels (79%). The renewables collectively provide 14% of the primary energy, mostly in the form of traditional biomass (9%) and much less by large (> 10MW) hydropower stations (2%) and the "new renewables" (2%). Nuclear energy provides 7% of the world primary energy. The World Energy Council (WEC) has presented several scenarios for meeting the future energy requirements with varying emphasis on economic growth rates, technological progress, environmental protection and international equity (Nakicenovic et al., 1998). All the scenarios provide for substantial social and economic development, particularly in the developing countries. They provide for improved energy efficiencies and environmental compatibility. During 1990-2050, the primary energy consumption is expected to increase by some 50% according to the most environmentally conscious scenario and by some 275% according to the highest growth rate scenario. In the environmental scenario, the carbon emissions are expected to decrease slightly from 1990 levels. The high growth rate scenario is expected to lead to a doubling of the carbon emissions.

The renewable energy sources are expected to provide 20-40% of the primary energy in 2050. The technical potential of renewable energy sources is estimated 7600 EJ/year, and thus certainly sufficiently large to meet future world energy requirements. The question is how large a part of the technical potential can be harnessed in an economical, environmentally and socially acceptable way.

The main growth in energy use will be in the developing countries. It is thus very important to support developing countries with fast expanding energy markets, such as China and India, to try as possible to meet their growing energy demands by developing their renewable energy resources. In some countries in e.g. Central America and the East African Rift Valley, the majority of the grid connected electricity is already provided by hydro and geothermal energy. It is very important to assist them in developing their renewable energy resources further rather than to guide them to meet the fast growing energy demands by fossil fuels.

The technology has been developed for the main renewable energy sources. There is already a significant professional experience for exploration, construction and operations of renewable energy power stations, but the experience is mainly confined to the industrialized countries. A key element in the mitigation of climate change is capacity building in renewable energy technologies in the developing countries, where the main growth in energy use is expected (Fridleifsson, 2010).

2. WORLD ENERGY SOURCES

The scarcity of energy resources forecasted in the 1970s did not occur. With technological and economic development, estimates of the ultimately available energy resource base continue to increase. Economic development over the next century will apparently not be constrained by geological resources. Environmental concerns, financing, and technological constrains appear more likely sources of future limits (Fridleifsson, 2002).

In all WEC´s scenarios, the peak of the fossil fuel era has already passed (Nakicenovic et al., 1998). Oil and gas are expected to continue to be important sources of energy in all cases, but the role of renewable energy sources and nuclear energy vary highly in the scenarios and the level to which these energy sources replace coal. In all the scenarios, the renewables are expected to become very significant contributors to the world primary energy consumption, providing 20-40% of the primary energy in 2050 and 30-80% in 2100. They are expected to cover a large part of the increase in the energy consumption and to replace coal.

It is a very legitimate question to ask whether these scenarios are realistic. Table 1 shows the technical potential of renewable energy resources (WEA, 2000). The technical potential is the yearly availability of the renewable resources.

TABLE 1: Technical potential of renewable energy sources
Source: World Energy Assessment (WEA, 2000)

	EJ per year
Hydropower	50
Biomass	276
Solar energy	1575
Wind energy	640
Geothermal energy	5000
TOTAL	7600

There is no question that the technical potential of the renewables is sufficiently large to meet future world energy requirements. The question is, however, how large a part of the technical potential can be harnessed in an economical, environmentally and socially acceptable way. This will probably vary between the energy sources. It is worth noting, however, that the present annual consumption of primary energy in the world is about 400 EJ (Table 2).

Table 2 shows the world primary energy consumption in 2001 (WEA, 2004). Fossil fuels provide 80% of the total, with oil (35%) in first place, followed by coal (23%) and natural gas (22%). The renewables collectively provide 14% of the primary energy, mostly in the form of traditional biomass (9%) and much less by large (>10MW) hydropower stations (2%) and the "new renewables" (2%). Nuclear energy provides 7% of the world primary energy.

TABLE 2: World Primary Energy Consumption in 2001
Source: World Energy Assessment (WEA, 2004)

Energy Source	**Primary energy EJ**	**Percentage %**
Fossil fuels	**332**	**79.4**
Oil	147	35.1
Natural gas	91	21.7
Coal	94	22.6
Renewables	**57**	**13.7**
Large hydro (>10 MW)	9	2.3
Traditional biomass	39	9.3
"New renewables" (biomass, geothermal, solar, small hydro (<10MW), tidal, wind)	9	2.2
Nuclear	**29**	**6.9**
Total	**418**	**100**

If we only look at the electricity production, the role of hydropower becomes much more significant. The world electricity production was about 14,000 TWh in 1998 as compared with 6.000 TWh in 1973 (IEA, 2000). Most of the electricity was produced by coal (38%), followed by hydro (18%), nuclear (17%), natural gas (16%) and oil (9%). Only 2% of the electricity was provided by the "new renewables" (small hydro, biomass, geothermal, wind, solar and tidal energy).

Table 3 shows the installed capacity and electricity production in 2005 for renewable energy sources, namely hydro, biomass, wind, geothermal, and solar energy (from Fridleifsson et al., 2008). The data for the table is compiled from "Tables" in the 2007 Survey of Energy Resources (WEC, 2007). It should be noted that the installed capacity for biomass is not given in the "Tables", but reported as "In excess of 40 GW" in the text. The capacity factor for biomass is thus uncertain. No figures are given for the installed capacity and electricity production of tidal energy in the 2007 Survey of Energy Resources (WEC, 2007). Tidal energy is therefore absent from Table 3.

The table clearly reflects the variable capacity factors of the power stations using the renewable sources. The capacity factor of 73% for geothermal is by far the highest. Geothermal energy is independent of weather conditions contrary to solar, wind, or hydro applications. It has an inherent storage capability and can be used both for base load and peak power plants. The relatively high share of geothermal energy in electricity production compared to the installed capacity (1.8% of the electricity with only 1% of the installed capacity) reflects the reliability of geothermal plants which can be (and are in a few countries) operated at capacity factors in excess of 90%.

TABLE 3: Electricity from renewable energy resources in 2005
Compiled from Tables in 2007 Survey of Energy Resources (WEC, 2007)

	Installed capacity		**Production per year**		**Capacity factor**
	GWe	**%**	**TWh/yr**	**%**	**%**
Hydro	778	87.5	2,837	89	42
Biomass	40*	4.5	183	5.7	52*
Wind	59	6.6	106	3.3	21
Geothermal	8.9	1.0	57	1.8	73
Solar	4	0.4	5	0.2	14
Total	**890**	**100**	**3,188**	**100**	**41****

*The installed capacity for Biomass is not given in the WEC 2007 Survey of Energy Resources, but said "In excess of 40 GW" in the text. The capacity factor is thus uncertain.
**Weighted average.

It should be stressed that Table 3 is not published here in order to diminish the importance of wind or solar energy. On the contrary, it serves to demonstrate that renewable energy sources can contribute significantly more to the mitigation of climate change by cooperating than by competing. The table shows that geothermal energy is available day and night every day of the year and can thus serve as a supplement to energy sources which are only available intermittently. It is most economical for geothermal power stations to serve as a base load throughout the year, but they can also, at a cost, be operated to meet seasonal variations and as peak power.

Geothermal energy is one of the renewable energy sources that can be expected to play an important role in an energy future where the emphasis is no longer on fossil fuels, but on energy resources that are at least semi-renewable and long-term environmentally acceptable, especially with regard to emission of greenhouse gases and other pollutants. For developing countries which are endowed with good geothermal resources, it is a reliable local energy source that can at least to some extent be used to replace energy production based on imported (usually) fossil fuels. The technology is proven and cost-effective. For developing countries that have good resources and have acquired the necessary local expertise it has become very important. A good example of this is Kenya, as well as the Philippines, El Salvador and Costa Rica, where geothermal energy has become one of the important energy sources providing for 10-20% of the electricity production. Iceland should also be mentioned as the only country where geothermal energy supplies more than 60% of the primary energy used. This is done through direct use for space heating, bathing, etc., and through production of electricity (Ragnarsson, 2010).

TABLE 4: Top sixteen countries utilising geothermal energy in 2009;
data on electricity from Bertani (2010) and on direct use from Lund et al. (2010)

Geothermal electricity production		**Geothermal direct use**	
	GWh/yr		**GWh/yr**
USA	14,974	China	20,932
Philippines	10,311	USA	15,710
Indonesia	9,600	Sweden	12,585
Mexico	7,047	Turkey	10,247
Italy	5,520	Japan	7,139
Iceland	4,597	Norway	7,001
New Zealand	4,055	Iceland	6,768
Japan	3,064	France	3,592
Kenya	1,430	Germany	3,546
El Salvador	1,422	Netherlands	2,972
Costa Rica	1,131	Italy	2,762
Turkey	490	Hungary	2,713
Papua – New Guinea	450	New Zealand	2,654
Russia	441	Canada	2,465
Nicaragua	310	Finland	2,325
Guatemala	289	Switzerland	2,143

In 2009, electricity was produced from geothermal energy in 24 countries, increasing by 20% from 2004 to 2009 (Bertani, 2010). Table 4 lists the top sixteen countries producing geothermal electricity in the world in 2009, and those employing direct use of geothermal energy (in GWh/year). Figure 1 shows the top fourteen countries in the world with the highest percentage share of geothermal in their national electricity production. Special attention is drawn to the fact that El Salvador, Costa Rica and Nicaragua are among the seven top countries, and that Guatemala is in tenth place (Figure 1).

The largest geothermal electricity producer is the USA, with almost 15,000 GWh/a, but amounting to only half a percent of their total electricity production. It is different for most of the other countries listed in Table 4, with geothermal playing an important role in their electricity production. That certainly applies to the fourth country on the list, the Philippines, where the production of 10,300 GWh/a means that geothermal supplies 17% of the total produced electricity. The same applies to Kenya, the total production of 1,430 GWh/a puts the country in 9th place with regard to world production and constitutes 17% of the total electricity production in Kenya. For direct use (Lund et al., 2010), China heads the list followed by the USA, Sweden and Turkey. No Central American country is on the list of the 16 countries highest in direct use of geothermal energy.

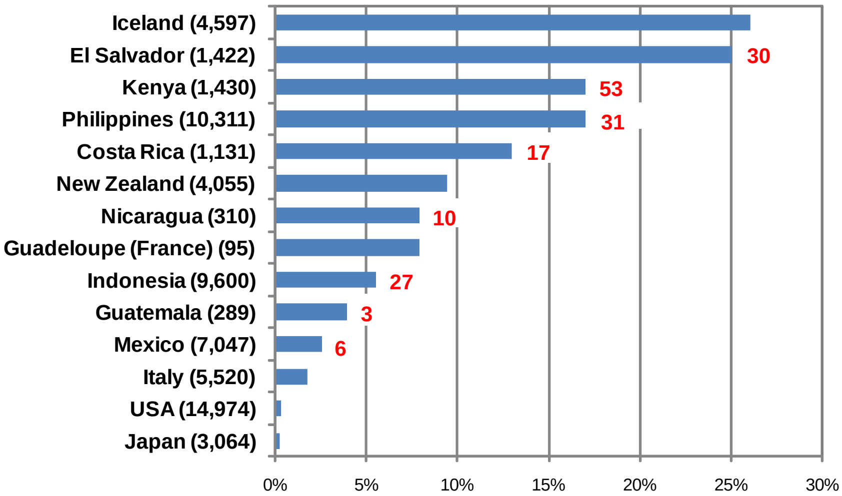

FIGURE 1: The fourteen countries with the highest % share of geothermal energy in their national electricity production. Numbers in parenthesis give the annual geothermal electricity production in GWh in 2009 (Bertani, 2010). The numbers of UNU-GTP graduates from each country are shown in red to the right of the columns.

3. GEOTHERMAL ELECTRICITY IN CENTRAL AMERICA

Central America is one of the world´s richest regions in geothermal resources. Geothermal power stations provide about 12% of the total electricity generation of the four countries Costa Rica, El Salvador, Guatemala and Nicaragua, according to data provided from the countries (CEPAL, 2010). The electricity generated in the geothermal fields is in all cases replacing electricity generated by imported oil. Hydro stations provide 46% of the electricity for the four countries, and wind energy 2%. With an interconnected grid, it would be relatively easy to provide all the electricity for the four countries by renewable energy. The geothermal potential for electricity generation in Central America has been estimated some 4 GWe (Lippmann 2002), and less than 0.5 GWe have been harnessed so far. With the large untapped geothermal resources and the significant experience in geothermal as well as hydro development in the region, Central America may become an international example of how to reduce the overall emissions of greenhouse gases in a large region (Fridleifsson, 2007; Fridleifsson et al., 2008). Similar development can be foreseen in the East African Rift Valley, as well as in several other countries and regions rich in high-temperature geothermal resources.

South America also hosts vast sources of geothermal energy that are largely unexploited (Haraldsson, 2010). In 1999, the Geothermal Energy Association estimated the continent´s potential for electricity generation from geothermal resources to be in the range of 4-9 GWe based on available information and assuming technology available at the time (Gawell et al., 1999).

The examples of Central America, Kenya and the Philippines clearly demonstrate how significant geothermal energy can be in the electricity production of countries and regions associated with volcanic activity and thus rich in high-temperature fields. There are examples from many developing countries of rural electrification and the provision of safe drinking water as well as schools and medical centres in connection with the development of geothermal resources. These projects are very much in line with the *Millennium Development Goals of the United Nations* (Fridleifsson, 2007).

4. DISCUSSION

One of the major concerns of mankind today is the ever increasing emission of greenhouse gases into the atmosphere and the threat of global warming. It is internationally accepted that a continuation of the present way of producing most of our energy by burning fossil fuels will bring on significant climate changes, global warming, rises in sea level, floods, draughts, deforestation, and extreme weather conditions. And the sad fact is that the poorest people in the world, who have done nothing to bring on the changes, will suffer most. One of the key solutions to avoid these difficulties is to reduce the use of fossil fuels and increase the sustainable use of renewable energy sources. Geothermal energy can play an important role in this aspect in many parts of the world.

More and more countries are seriously considering how they can use their indigenous renewable energy resources. The recent decision of the Commission of the European Union to reduce greenhouse gas emissions by 20% by 2020 compared to 1990 in the member countries implies a significant acceleration in the use of renewable energy resources. Most of the EU countries have already considerable geothermal installations. The same applies to the USA where the use of ground source heat pumps is widespread both for space heating and cooling.

Capacity building and transfer of technology are key issues in the sustainable development of geothermal resources. Many industrialised and developing countries have significant experience in the development and operations of geothermal installations for direct use and/or electricity production. It is important that they open their doors to newcomers in the field. We need strong international cooperation in the transfer of technology and the financing of geothermal development in order to meet the Millennium Development Goals and the threats of global warming.

REFERENCES

Bertani, R., 2010: Geothermal power generation in the world. 2005-2010 update report. *Proceedings World Geothermal Congress 2010, Bali, Indonesia*, 41 pp.

CEPAL, 2010: *CentroAmérica: Estadísticas del subsector electric, 2009*. United Nations, Comisión Económica para América Latina y el Caribe, Sede Subregional en México, 79 pp.

Fridleifsson, I.B., 2002: Energy requirements for the new millennium. In: *Human development and the environment: Challenges for the United Nations in the new millennium*, p. 220-233. United Nations University Press, Tokyo.

Fridleifsson, I.B., 2007: Geothermal energy and the Millennium Development Goals of the United Nations. *Proceedings of the European Geothermal Congress 2007, Unterhaching, Germany,* 30 May – 1 June, 2007.

Fridleifsson, I.B., 2010: Capacity building in renewable energy technologies in developing countries. Proceedings of the World Energy Congress 2010, Montreal, Canada, 12-16 september 2010, 11 pp.

Fridleifsson, I.B., Bertani, R., Huenges, E., Lund, J.W., Ragnarsson, A., and Rybach, L., 2008: The possible role and contribution of geothermal energy to the mitigation of climate change. In: Hohmeyer, O., and Trittin, T. (eds.), *IPCC Scoping Meeting on Renewable Energy Sources, Proceedings*. Luebeck, Germany, 20-25 January 2008, 59-80.

Gawell, K., Reed, M., and Wright, P.M., 1999: *Preliminary report: Geothermal energy, the potential for clean power from the Earth*. Geothermal Energy Association, Washington D.C., 15 pp.

Haraldsson, I.G., 2011: Geothermal activity and development in South America: Short overview of the status in Bolivia, Chile, Ecuador and Peru. *Proceedings of "Short Course on Geothermal Drilling, Resource Development and Power Plants"*, organized by UNU-GTP and LaGeo 16-22 January 2011, El Salvador, 15 pp. (Available on www.unugtp.is).

Lippmann, M.J., 2002: Geothermal and the electricity market in Central America. *Geothermal Resources Council, Transactions, 26,* 37-42.

Lund, J.W., Freeston, D.H., and Boyd, T.L., 2010: Direct utilization of geothermal energy 2010 worldwide review. *Proceedings World Geothermal Congress 2010, Bali, Indonesia*, 23 pp.

Nakicenovic, N., Grübler, A., and McDonald, A. (editors), 1998: *Global Energy Perspectives*. Cambridge Univ. Press, 299 pp.

Ragnarsson, A., 2010: Geothermal Development in Iceland 2005-2009. *Proceedings of the World Geothermal Congress 2010, Bali, Indonesia*, 12 pp.

WEA, 2000: *World Energy Assessment: energy and the challenge of sustainability*. Prepared by UNDP, UN-DESA and the World Energy Council**.** United Nations Development Programme, New York, 508 pp.

WEA, 2004: *World Energy Assessment: overview 2004 update*. Prepared by UNDP, UN-DESA and the World Energy Council**.** United Nations Development Programme, New York, 85 pp.

WEC, 1993: *Energy for Tomorrow's World*. St. Martin's Press, USA, 320 pp.

WEC, 2007: *2007 Survey of energy resources*. World Energy Council 2007, 427-437. (Available on www.worldenergy.org).