

Status of Geothermal Energy Amongst the World's Energy Sources

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Abstract

The world primary energy consumption is about 400 EJ/year, mostly provided by fossil fuels (80%). The renewables collectively provide 14% of the primary energy, in the form of traditional biomass (10%), large (>10MW) hydropower stations (2%), and the “new renewables” (2%). Nuclear energy provides 6%. The World Energy Council expects the world primary energy consumption to have grown by 50-275% in 2050 depending on different scenarios. The renewable energy sources are expected to provide 20-40% of the primary energy in 2050 and 30-80% in 2100. The technical potential of the renewables is estimated 7600 EJ/year, and thus certainly sufficiently large to meet future world energy requirements.

Of the total electricity production from renewables of 2826 TWh in 1998, 92% came from hydropower, 5.5% from biomass, 1.6% from geothermal and 0.6% from wind. Solar electricity contributed 0.05% and tidal 0.02%. The electricity cost is 2-10 US¢/kWh for geothermal and hydro, 5-13 US¢/kWh for wind, 5-15 US¢/kWh for biomass, 25-125 US¢/kWh for solar photovoltaic and 12-18 US¢/kWh for solar thermal electricity. Biomass constitutes 93% of the total direct heat production from renewables, geothermal 5%, and solar heating 2%. Heat production from renewables is commercially competitive with conventional energy sources. Direct heat from biomass costs 1-5 US¢/kWh, geothermal 0.5-5 US¢/kWh, and solar heating 3-20 US¢/kWh.

Keywords: geothermal, electricity, direct use, comparison of renewables, energy prices.

1. Introduction

With increasing awareness of the detrimental effects of the burning of fossil fuels on the environment, there has been an increasing interest world wide in the use of clean and renewable energy sources. It is important for the proponents of renewable energy sources to be aware of the outlines of the world energy use. The present paper starts with a description of recent energy forecasts for the world in the new century and the increasing role that renewable energy sources are expected to play in the world energy mix. The forecasts referred to here have been initiated by the World Energy Council. The present use of energy sources is summarised. A comparison is made of geothermal energy with other renewable energy sources based on data presented in the World Energy Assessment report [1] prepared by the United Nations Development Programme, the United Nations Department of Economic and Social Affairs, and the World Energy Council. The present paper is largely based on two review papers recently published by the author [2], [3].

2. World energy forecasts

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 one-quarter of that of W-Europe, and one-sixth of that of the USA [4]. 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 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. 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 [5].

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 constraints appear more likely to limit future development.

In all WEC's scenarios, the peak of the fossil fuel era has already passed. 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. The technical potential is the yearly availability of the renewable resources.

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 1: Technical potential of renewable energy sources

Source: World Energy Assessment [1]

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

3. World energy sources

Table 2 shows the world primary energy consumption in 1998. Fossil fuels provide 80% of the total, with oil (35%) in first place, followed by coal (23%) and natural gas (21%). The renewables collectively provide 14% of the primary energy, mostly in the form of traditional biomass (10%) and much less by large (>10MW) hydro power stations (2%) and the “new renewables” (2%). Nuclear energy provides 6% of the world primary energy.

Table 2: World Primary Energy Consumption in 1998

Source: World Energy Assessment [1]

Energy Source	Primary energy (exajoules)	Percentage
Fossil fuels	320	79,6
Oil	142	35,3
Natural gas	85	21,1
Coal	93	23,1
Renewables	56	13,9
Large hydro (>10 MW)	9	2,2
Traditional biomass	38	9,5
“New renewables” (biomass, geothermal,solar, small hydro (<10MW), tidal, wind)	9	2,2
Nuclear	26	6,5
Nuclear	26	6,5
Total	402	100

If we only look at the electricity production, the role of hydro power becomes much more significant. The world electricity production was about 14.000 TWh in 1998 as compared with 6.000 TWh in 1973 [6]. 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).

4. Geothermal energy

Although geothermal energy is categorised in international energy tables amongst the “new renewables”, it is not a new energy source at all. People have used hot springs for bathing and washing of clothes since the dawn of civilisation in many parts of the world. An excellent book was recently published with historical records and stories of geothermal utilisation from all over the world [7].

It was first in the 20th century that geothermal energy was harnessed on a large scale for space heating, industry, and electricity generation. Prince Piero Ginori Conti initiated electric power generation with geothermal steam at Larderello, Tuscany, in 1904. Commercial production of electricity started in Larderello in 1913. The first large scale municipal district heating service started in Iceland in 1930. Geothermal energy has been produced commercially for about ninety years, and for four decades on the scale of hundreds of MW both for electricity generation and direct use. The utilisation has increased rapidly during the last three decades. In 2000, geothermal resources have been identified in over 80 countries and there are quantified records of geothermal utilisation in 58 countries in the world.

In 1999, the worldwide use of geothermal energy amounted to about 49 TWh/a of electricity [8] and 53 TWh/a for direct use [9]. A recent estimate of the geothermal potential of the world [10], gives the total potential for the resources suitable for electricity generation (resource temperature in excess of 150°C) as $11,000 \pm 1,300$ TWh/a, and the total potential resources for direct use (resource temperature lower than 150°C) in excess of 1400 EJ/a (390,000 TWh/a heat). These figures for the potential cover both known and unidentified resources. Stefansson [10] estimates the identified geothermal resources to be 2000 ± 140 TWh/a for electricity generation, and in excess of 7000 TWh/a heat for direct use. It is clear that the present use of geothermal energy (49 TWh/a for electricity and 53 TWh/a for direct use) is a very small fraction of the identified geothermal potential. There is certainly space for an accelerated use of geothermal energy both for electricity generation and direct use in the near future. With both ample resources and a relatively mature technology at hand, the question of future development of geothermal utilisation boils down to economic and political competitiveness with other energy sources on the market in the different countries.

5. Comparison of geothermal with other renewables

The World Energy Assessment report [1], prepared by UNDP, UN-DESA and the World Energy Council, was written as a contribution of the United Nations Commission on Sustainable Development to the “Rio Plus Ten” conference in 2002. The report gives a very valuable and comprehensive description of the status of the world’s energy sources at the turn of the millennium. Chapter 7 of this voluminous report deals with the renewable energy technologies and includes a highly interesting table entitled “Current status and potential future costs of renewable energy technologies”. The data presented here in Tables 3, 4 and 5 is extracted from Table 7.25 of the World Energy Assessment [1].

Table 3: Status of electricity production from renewables
Modified from Table 7.25 of World Energy Assessment [1]

	Energy production in 1998		Installed capacity, end 1998		Capacity factor	Current energy cost	Potential future energy cost	Turnkey investment cost	Increase in inst. capac. last 5 years %/year
	TWh(e)	%	GWe	%	%	US¢/kWh	US¢/kWh	US\$/kW	
Hydro *	2600	92.00	663	91.80	20-70	2-10	2-8	1000-4000	2
Biomass	160	5.66	40	5.53	25-80	5-15	4-10	900-3000	3
Geothermal	46	1.63	8	1.11	45-90	2-10	1-8	800-3000	4
Wind	18	0.64	10	1.38	20-30	5-13	3-10	1100-1700	30
Solar photovoltaic	0.5		0.5		8-20	25-125	5-25	5000-10000	30
thermal electricity	1	0.05	0.4	0.12	20-35	12-18	4-10	3000-4000	5
Tidal	0.6	0.02	0.3	0.04	20-30	8-15	8-15	1700-2500	0
Total	2826.1		722.2						

* Large hydro stations produce 2510 TWh (capacity 640 GWe) and small 90 TWh (23 GWe).

Table 3 shows the status of electricity production from renewables. The total electricity production from renewables in 1998 was 2826 TWh. By far the largest contribution (92%) came from hydropower, but 5.7% from biomass, 1.6% from geothermal, and 0.6% from wind. The electricity production by solar energy constituted only 0.05% and from tidal energy 0.02%. The current energy cost is lowest for hydropower and geothermal, followed by biomass and wind. Solar photovoltaic electricity is by far the most expensive, but significant cost reductions are expected in the future. The annual % increase in installed capacity during the last 5 years is 2-4% for hydro, biomass and geothermal, but reported 30% for wind and solar photovoltaic.

Table 4: Electricity from four renewable energy resources in 1998
Compiled [2] from data in World Energy Assessment [1]

	Installed capacity		Production per year		Capacity factor
	Gwe	%	TWh/y	%	%
Geothermal	8	41.7	46	69.6	66
Wind	10	52.1	18	27.2	21
Solar	0.9	4.7	1.5	2.3	19
Tidal	0.3	1.5	0.6	0.9	23
Total	19.2	100	66.1	100	39

The capacity factor is variable for the different sources. Table 4 shows the installed capacity and the electricity production in 1998 for four “new and renewable” energy sources, namely geothermal, wind, solar and tidal energy. The data for the table is compiled from Table 7.25 of the World Energy Assessment [1]. It is apparent that in 1998, wind energy was in the leading position with regard to installed capacity (52.1%) followed by geothermal (41.7%). Geothermal was, however, the leading electricity producer with 69.6% of the total electricity production of the four, followed by wind energy with 27.2% of the production. The relatively high share in the electricity production reflects the reliability of geothermal plants which can

be operated at capacity factors in excess of 90%. Geothermal energy is independent of weather 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. However, in most cases, it is more economical to run the geothermal plants as base load suppliers.

Table 5 shows the status of direct heat production from renewables. Biomass constitutes at least 93% of the total, geothermal 5% and solar heating 2%. The biomass shown here is, of course, only a fraction of the total use of biomass in the world, as fuel wood etc. is not included. The biomass energy shown here is heat embodied in steam (or hot water in district heating), often produced by combined heat and power production using forest residues, black liquor, or bagasse. Each of these energy sources are site specific and have their respective restraints. As regards geothermal energy, it is widely used for municipal district heating systems, with the largest systems in Iceland, France, China and Turkey. Space heating of individual houses is also common (in many cases with heat pumps), not least in the USA, Sweden, and Switzerland.

Table 5: Status of direct heat production from renewables
Modified from Table 7.25 of World Energy Assessment [1]

	Energy production in 1998 TWh th	Installed capacity end 1998 GWth	Capacity factor %	Current energy cost US¢/kWh	Potential future energy cost US¢/kWh	Turnkey investment cost US\$/kW	Increase in inst. capac. last 5years %/year
Biomass*	>700	>200	25-80	1-5	1-5	250-750	3
Geothermal	40	11	20-70	0.5-5	0.5-5	200-2000	6
Solar heat Low temp.	14	18	8-20	3-20	2-10	500-1700	8

* Table 7.25 [1] also shows ethanol under biomass, with operating capacity (end 1998) 18 billion litres, energy production of 420 PJ, current energy cost 8-25 \$/GJ and future potential energy cost of 6-10 \$/GJ.

Heat production from renewables is competitive with conventional energy sources. The current cost of direct heat from biomass is 1-5 US¢/kWh, geothermal 0.5-5 US¢/kWh, and solar heating 3-20 US¢/kWh.

6. Discussion

Geothermal energy has until recently had a considerable economic potential only in areas where thermal water or steam is found concentrated at depths less than 3 km in restricted volumes, analogous to oil in commercial oil reservoirs. The use of ground source heat pumps has changed this. In this case, the earth is the heat source for the heating and/or the heat sink for cooling, depending on the season. This has made it possible for people in all countries to use the heat of the earth for heating and/or cooling, as appropriate. It should be stressed that the heat pumps can be used basically everywhere.

It is of interest to speculate on what political issues may encourage nations to increase markedly their use geothermal energy.

The significant fluctuations in oil prices caused by political unrest in key oil producing regions should encourage governments to focus more on indigenous energy sources to meet their basic energy requirements. Since 1973, four major disruptions in world oil supplies (>4 million barrels/day supply loss) have occurred and caused significant escalations of oil prices [11]. These were in 1973-1974 (Arab-Israeli War), 1978-1979 (Iranian Revolution), 1980-1981 (Iran-Iraq War), and 1990-1991 (Gulf Crisis). A new wave of oil price escalations came with the terrorist attacks in the USA on 11th September 2001. This has been prolonged by the war in Afghanistan and the anticipation of war in Iraq.

Recent developments in the deregulation of the electricity markets and integration of the electricity networks in Europe have unstabilised electricity prices to consumers. This makes e.g. ground source heat pumps a favourable alternative as base load heat source in countries where electrical heating is common.

Following the United Nations conferences on the environment in Rio (1991) and Kyoto (1997), the European Union has committed itself to reducing the overall emission of greenhouse gases by at least 8% below 1990 levels in the commitment period 2008-2012. According to a report of the European Commission [12], the contribution of renewables in the EU was 5,3% in 1996. The largest contributor was biomass (62,1%), followed by hydropower (33,0%), geothermal (3,7%) wind (0,6%), solar (0,3%), and others (0,3%). Stefansson [13] points out how the two energy sources, hydro and biomass, dominate the present contribution of renewables in Europe. The only other renewable source with more than 1% contribution is geothermal energy. He states that “there might be a possibility to increase the contribution from a given energy source several times during the next 10-15 years, but it is unrealistic to assume that the energy production for a given source can be increased by a factor of 100 or 1000 during this time”.

Only hydro, biomass, geothermal, and wind energy, appear technically ready to make a significant contribution towards an overall reduction in the CO₂ emissions in Europe by 2012. In spite of this, as yet, the role of geothermal energy is very limited in the energy strategy plans for Europe. In a few years, several countries richly endowed with geothermal resources will become members of the European Union. Amongst these are Hungary, Poland, Slovakia and Slovenia. This will hopefully strengthen the presently weak political support for the development of geothermal energy in Europe.

International forecasts expect the share of renewable energy sources in the world energy mix to increase very significantly in the new century (to 30-80% in 2100). How large the share of geothermal energy will be at the end of the new century is much dependant on the actions of the geothermal community and the countries leading geothermal development.

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