RENEWABLE ENERGY RESOURCES

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Contents

Summary

Natural energy resources are spread out almost all over the world, but some of them are restricted in certain regions. The total amount of energy possessed by these energies is enormous but the availability of the exploitable amount of these resources is limited. The majority of renewable energy resources have been explored and estimated for their form and amount of totally stored energy, for possible future utilization and those that are exploitable by the present technology. Some of them are already under exploitation in economical ways but others still need improvement to be economically usable for various purposes including desalination.

1. Introduction

Ninety-nine point nine per cent of the natural energy resources available on the earth's surface are or were generated, directly or indirectly, by the activities taking place in the sun's mass. The remaining 0.1 per cent is activated by the temperature at the earth's crust, and the lunar attractive forces. All conventional energy reserves, as oil, coal, and natural gas are indirect activities of the sun which took place hundreds of million years ago. These fuels are exploited in huge amounts without being replenished, therefore continuously and rapidly decreasing the existing reserves.

Renewable energies on the contrary, are transient sources which remain inexhaustible because they are continuously replenished, so that the amounts remain almost constant. Their reserves, when and where they are available, can be exploited, but their use depends mainly upon technological breakthroughs. The renewable energy technologies are not yet totally commercialized, thus the corresponding devices and equipment are still in many cases capital intensive, and the market depends partly on energy services demand. The growth of the population, the high economic growth, and the continuous increase in energy requirements lead to an acceleration in research on renewable energies, as a near future energy source of wide exploitation, in large amounts.

Over the centuries fossil fuels provided us with most of the energy needed, because usually this energy is cheap, convenient to handle and until recently there was no special concern about environmental pollution. Therefore little attention was paid to the wide or large scale applications of renewable energies until a few decades ago. World energy demand is estimated to increase by 30 per cent and at the same time electricity demand by about 265 per cent, between the years 1995 and 2050, when it is estimated that proven oil reserves will be exhausted. The estimations for renewables are, that for the same period their global consumption will be about 320 EJ y^{-1}.

The renewable energy sources are, at least to our scale of measures, inexhaustible and replaceable. They are generated mainly by natural forces and in some cases by human activities, e.g. the huge amounts of human waste. They are classified into two main categories according to the method of transformation to a usable energy form, and they comprise the following types of energies (as sun activities, wind, waves, tides):

(a) The renewable energies generated by natural forces, which can be converted into useful forms of energy by physical methods.

(b) Direct solar energy, coming from the sun in the form of solar radiation, as photon and heat energies.
(c) Geothermal energy, generated by the activities of the earth's magma, available as heat.
(d) Hydropower, generated by natural kinetic and gravitational forces and is available as kinetic energy.
(e) Wind energy, which is a kinetic energy generated by indirect activities of the sun.
(f) Tidal energy, a kinetic force activated by the lunar attractive forces and the forces generated by the earth's rotation.
(g) Wave energy, a kinetic energy which is generated by the indirect activities of the sun.
(h) The energy produced by the temperature differences between the sea surface and depth's >1000 m, in the tropical regions of the oceans. This energy is known as OTEC (Ocean Thermal Energy Conversion).

The second category of renewable energies refers to the energy sources that are transformed into usable energy by chemical and/or biological means. These sources consist of materials considered as inexhaustible and available easily on the earth's surface. They are:

(i) The renewable energies generated by natural and/or human activities.
(j) Biomass, which is a primary energy production resulting from the conversion of solar energy into chemical energy by photosynthesis, and stored as chemical energy.
(k) The refuse, produced by the human consumption wastes, increasing considerably every year, adding to the pollution problems.

All the above renewable energies are available either in the form of thermal energy and kinetic energy or stored as chemical energy. They can be transformed into heat, work or electricity, and utilized in the same way as the energy produced by the conventional energy sources. The theoretical heat and/or work available from the various natural energies are given in Table 1. The natural energies listed in the table are in part mature enough to be harvested because the corresponding technology is mature as well. It must be noted that the theoretical obtainable work, that is the work considered as a perfect Carnot engine, is less than the heat offered for conversion. The reason is that heat is lost during the conversion to mechanical energy.

Energy source, energy type	**kJ y^{-1}**	**kWh y^{-1}**	**MW**	**toe y^{-1} ***
Solar energy on earth's surface, *photon and heat energy*	$5.40 \cdot 10^{21}$	$1.5 \cdot 10^{18}$		$1.3 \cdot 10^{4}$
Geothermal, *thermal energy*				
near the core	$8.00 \cdot 10^{27}$	$2.22 \cdot 10^{24}$		$1.90 \cdot 10^{20}$
accessible base	$1.40 \cdot 10^{26}$	$3.90 \cdot 10^{22}$		$3.30 \cdot 10^{20}$
Hydropower, *kinetic energy*				
potential		$44.40 \cdot 10^{22}$		$3.80 \cdot 10^{9}$
feasible		$12.90 \cdot 10^{12}$		$1.11 \cdot 10^{9}$
Wind power, *kinetic energy*			$6.00 \cdot 10^{6}$	
Tidal power, *kinetic energy*			$3.00 \cdot 10^{3}$	

OTEC, *thermal energy*	$2.70 \cdot 10^{8}$		$2.70 \cdot 10^{8}$	
Biomass, *chemical energy*			$8.20 \cdot 10^{14}$	
Wave energy, *kinetic energy* as: P_w/m =Amplitude × 2 × frequency × g ×ρ in $W\ m^{-1}$				

***** toe = tones oil equivalent

Table 1. Estimated potential capacities of the main renewable energy sources world-wide.

Energy carrier	**Energy as heat, $kJ\ kg^{-1}$**	**Energy as work, $kJ\ kg^{-1}$**
Solar	Infinite	infinite
Dry biomass	16.88	9.495
Heat of ice fusion	$3.38 \cdot 10^{-1}$	$2.32 \cdot 10^{-2}$
Thermal energy of water	$4.22 \cdot 10^{-2}$	$1.48 \cdot 10^{2}$
Thermal energy of dry soil	$1.27 \cdot 10^{-2}$	$4.32 \cdot 10^{-4}$
Thermal energy of air	$1.16 \cdot 10^{-2}$	$4.01 \cdot 10^{-4}$
Osmotic pressure of waters	$2.21 \cdot 10^{-2}$	$2.22 \cdot 10^{-3}$
Water behind 100 m dam	$1.00 \cdot 10^{-3}$	$1.00 \cdot 10^{-3}$
Kinetic energy of air or water at velocities: 10.0 $m\ s^{-1}$	$4.85 \cdot 10^{-5}$	$4.85 \cdot 10^{-5}$
3.0 $m\ s^{-1}$	$4.54 \cdot 10^{-5}$	$4.54 \cdot 10^{-5}$

Table 2. Heat and theoretical mechanical energy potential of various natural carries of solar energy (Palz 1978).

All renewable energies are considered as an alternative solution to supply energy in the desalination plants. Their utilization depends upon a series of parameters connected mainly to the type of installation and the operation costs.

2. The Sun as an Energy Source

Solar power comes as electromagnetic radiation, due to thermo-nuclear processes within the mass of the sun. It is easily converted into heat, electricity or mechanical energy. It is a clean and silent energy, two characteristics that relate directly to the environment. Furthermore it is abundant and available everywhere, in the sense that the radiation quantity reaching the earth's surface is sufficiently large and can be converted into a useful form of energy. Its disadvantage is that as it reaches the earth's surface this energy is very dilute, i.e. the intensity of the radiation per square meter is very low, and variable, thus usually having to be multiple-concentrated.

2.1. The Availability of Solar Energy

The presently available primary energy sources, world-wide, are estimated to be 9.0×10^{9} t coal equivalent which amounts only the 0.005 per cent of the annual solar radiation (Mangal 1990). Solar radiation possesses an enormous amount of energy and it is estimated that it will provide humanity for generations with energy, without decreasing its power. Its diffuse nature needs large land areas for concentrating installations of the incident solar radiation, but not all places around the world are favored by intensive solar radiation.

The intensity of solar radiation on the surface of the earth varies from zero, for cloudy regions to about 1047 W m^{-2}. The maximum radiation is at the Equator where the highest reaches 1050 W m^{-2}. In latitudes 30 to 45° North or South to Equator a mean yearly value reaches 4.0 to 6.5 kWh d^{-1} m^{-2}. Meteorological stations provide solar radiation intensity data, and for solar radiation distribution maps have been formulated indicating the intensity by site (Lof 1966; SERI 1982).

2.2. Application of Solar Energy to Desalination

Desalination plants can be easily connected to solar energy conversion plants which can provide energy in the form of steam or electricity. There are some restrictions that may be considered: solar radiation is an energy that can be harvested only during daytime. This runs a solar energy plant and the connected desalination plant a discontinuous operation system except if storage is provided. Solar radiation at sea level is low and widespread. From the total solar extraterrestrial intensity of 1.367 kW m^{-2}, only a part, 51.7 per cent, and at the best 68.7 per cent (0.70-0.98 kW m^{-2}) is available for direct utilization. It has to be received by collectors, concentrators or solar cells to produce low or high temperature thermal energy and/or electricity. Solar plant's efficiency on the other hand is very low, about 15 per cent for solar heat engines and about 28 per cent for solar cells. As a consequence solar power plants need large surface areas to overcome the capacity selected for the energy produced. Thus though solar energy is free to harvest, storage and solar radiation collection systems are very capital-intensive enterprises.

In dual solar-desalination plants capital costs have a large share on the total cost of energy. The capital cost of direct solar energy systems to the initial unit solar energy cost can be calculated easily from the following general equation, which is based in real terms, inflation free (Mangal 1990).

$$C = 11.4 \cdot r\left(\frac{C_{pc}}{F}\right) = 11.4\left[\left(\frac{C_c}{H_a}\right) \cdot \eta_c\right] \qquad \text{in cents per kWh} \qquad (1)$$

The above symbols present: C, the capital cost contribution to the initial cost per unit output energy. C_{pc} is the capital cost per peak watt output, and C_c is the capital cost per m^2 of collector area, all in US \$. F is the load factor i.e. the annual average peak power, η_c is the efficiency of the collectors or concentrators and H_a is the annual average incident solar energy output as mean monthly radiation. r is the charge rate as per cent per year, of the capital costs. It can be increased for a 20-year-life solar installation, by an additional amount of 10 per cent per year. The value 11.4 represents a factor converting \$ per W per year to cents per year. For more information about solar energy conversion systems see Section 10.2. In Table 3 is presented the irradiance in various latitudes for summer, equinox, winter and yearly average as is given by the World

Energy Council (1994).

Horizontal global					Global 180° latitude			
Latitude	**Summer**	**Equinox**	**Winter**	**Year**	**Summer**	**Equinox**	**Winter**	**Year**
0.	0.303	0.344	0.324	0.330	0.303	0.344	0.324	0.330
15	0.351	0.331	0.251	0.317	0.317	0.345	0.306	0.330
30	0.378	0.292	0.166	0.283	0.328	0.341	0.271	0.321
45	0.380	0.230	0.078	0.231	0.336	0.327	0.202	0.300
60	0.366	0.152	0.022	0.174	0.341	0.298	0.078	0.257
75	0.364	0.091	0.002	0.141	0.345	0.260	0.003	0.211
90	0.449	0.071		0.151	0.495	0.115		0.198

Table 3a. Solar energy resource at sea level: Seasonal irradiance by clear sky and latitude, kW m^{-2} (WEC 1994).

Two axis tracking, global					Two axis tracking beam			
Latitude	**Summer**	**Equinox**	**Winter**	**Year**	**Summer**	**Equinox**	**Winter**	**Year**
0	0.462	0.483	0.493	0.481	0.379	0.399	0.405	0.397
15	0.504	0.479	0.444	0.479	0.418	0.396	0.362	0.3395
30	0.542	0.468	0.369	0.465	0.448	0.383	0.292	0.379
45	0.587	0.444	0.253	0.435	0.482	0.357	0.192	0.349
60	0.655	0.393	0.089	0.387	0.526	0.306	0.037	0.294
75	0.847	0.332	0.004	0.380	0.676	0.196		0.260
90	1.099	0.193		0.436	0.743	0.001		0.263

Table 3b. Continued solar energy resource at sea level, for tracking surfaces. Seasonal solar irradiance by clear sky and latitude, kW m^{-1} (WEC 1994).

3. The Geothermal Energy

3.1. Introduction

Geothermal energy in its broad sense refers to all thermal energy stored in the earth. In its practical sense it is the thermal and mechanical energy stored in the rocks and fluids contained in the upper part of the earth's crust and can be exploited economically. In geological terms geothermal energy is "the heat above the ambient solid core, earth's temperature".

The earth consists of a central core (composed 90 per cent of iron and 10 per cent of nickel), part of which is in liquid form, a central mantel and the crust on its surface. The crust in correspondence to the continents of the earth has an average thickness of 35 km. The upper 22.5 km consists mainly of granitic rocks, but the floors' at the base are made out of basaltic rocks. From the ocean's bottom the crust is only 5 km thick.

Temperature differences between the core of the earth and its upper surface generate a continuous heat flow which is know as "geothermal energy or geothermal heat". Inside the earth the existing temperatures fluctuate between 3000 and 10 000°C, producing vigorous heat flow to the earth's crust. In the core of the earth the existing energy is estimated to be about 8×10^{17} kJ. The temperature of the earth's crust increases with depth at varying rates depending on the location.

There is a constant heat flow from the earth's crust surface into the environment which has an average value of 0.063 W m^{-2} (63 kW m^{-2}). This heat flow is the result of the geothermal heat and the radioactivity of the crust, though the latter is very small. Granitic rocks are relatively rich in U^{238}, U^{235}, Th^{232} and K^{40}, long half-life radioactive elements, whose decay produces heat released at the surface of the earth.

Geothermal energy is a competitive energy source in areas with geothermal gradients. World-wide the installed power plants operated with geothermal energy are of a capacity of 6000 MWe. About 15 000 MW_{th} are extracted for process heat and space heating.

3.2. The Geothermal Resources System

The crust of the earth is divided into a number of plates, called "tectonic plates", which are moving in relation to one another, over the underlying mantel. This movement is caused by thermal processes in the core, involving enormous quantities of thermal energy which generates magmas inside the earth's mantel. The molten magmas coming from the mantel at temperatures 600-900°C intrude in the crust, at depths of about 7.0 to 15.0 km. Their heat is transferred by conduction upwards until reaches a wet permeable rock where it is stored. These rocks are called geothermal reservoirs. The hot water in the rocks form, over the rock reservoir, aquifers where hot water and/or steam under pressure are stored. In general, there exists a temperature gradient from the mantel to the crust which is estimated to be 30-35°C per km of depth. However, in some regions the temperature gradient is much greater reaching 1°C per meter. Thus the deeper the reservoir the higher the temperature of the geothermal fluids from the aquifer. The characteristics of the geothermal reservoirs and their individual technical features are highly site-specific (Palmerini 1993).

The exploitable wells are localized in reservoirs referred as geothermal systems. There are basically three types of geothermal reservoirs systems: The liquid and vapor dominated systems known as hydrothermal reservoirs, the hot dry rock system and the geopressurized system (Palmerini 1993). These types are characterized by their thermodynamic and hydrologic properties and comprise the following.

3.2.1. Hydrothermal Reservoirs

Which are permeable formations with natural fluid circulation. The hydrothermal reservoirs are fully developed, exploited and used in a commercial basis. They are divided into the following two types:

(A) Liquid-Dominated Geothermal Resources

This type of reservoir is controlled by the presence of circulating water or brine which transports the thermal energy of the deep region rock to the near surface region by natural circulation. It is estimated that the liquid-dominated geothermal systems are the most abundant geothermal sources world-wide. The temperatures varies from about ambient to as high as 360°C. In the best geothermal fields temperatures increase rapidly with depth, but at prevailing hydrostatic pressures seldom exceed the boiling point of the liquid.

(B) Vapor-Dominant Geothermal Resources

In this system, referred also as dry steam source, vapor is dominated, though in the deep regions there exist also small amounts of water. This type of geothermal reservoir is the most important source for geothermal power developments and proved successful world-wide for the production of electricity. The system temperatures are in the range of 150 to 220°C and the steam produced in the reservoirs is simple and easy to extract.

3.2.2. The Geopressurized Reservoirs

Which consist of confined reservoirs, with moderate temperatures. They are located in deep sedimentary geologic regions where effective shale had been formed. Under conditions of shale compression, an internal pressure greater than the ordinary hydrostatic pressure at that depth is imparted to the water. The temperatures of the geopressurized systems are as high as 237°C and the well head pressures can be as high as 7.6×10^4 kPa.

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