Desalination and Water Treatment
www.deswater.com

13 (2010) 1–12
January

doi: 10.5004/dwt.2010.831

Renewable Energies

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Received 21 July 2009; accepted 20 August 2009

ABSTRACT

At prevailing economic practice the alarming ''two degrees-limit'' of global warming will be reached long before the known fossil fuel reserves are gone. A future alternative energy economy relying on renewable energies will be more diverse yet more expensive than traditional combustion the new figure of merit is the cost of CO_2 avoidance. This communication surveys the relevant alternatives – solar energy in its various manifestations, geothermal and tidal energy – and assesses their current contribution to the over-all energy supply, revealing a deplorable lag between renewable capability and the needs of climate conservation. Nuclear energy is seen as low-CO_2 bridging technology between the fossil period and the age of renewables; being restrained in Germany in favor of subsidizing alternative energies, the German experience with renewables is drawn upon in this survey.

Thermodynamics teaches: Energy can be transferred from one system to another, as from sun to earth. It can be transformed from one form into another, as from light to electricity. Energy can not be produced nor destroyed nor renewed. The term ''Renewable Energy'' is applied to energy derived from our surrounding for human use. Renewable energies will have to replace fossil fuels – coal, oil and gas – for two reasons: If we continue to burn them, reserves will be exhausted before long; emission of carbon dioxide is about to change our climate by the so-called green house effect.

Keywords: Energy mix; Climate change; CO_2 avoidance

1. Global consumption of primary energy

As visualized in Fig. 1, between 1870 and 2000 the world population grew by nearly a factor of four (from 1.5 to 6 billion, currently 6.8 billion) whereas the global consumption of primary energy increased over twentyfold (from 20 to 430 EJ/a, now about 500 EJ/a). Thus, in the time span of 130 years the average energy consumption per person grew more than fivefold.

Since 1870 consumption of conventional biomass (mainly wood) has tripled. By comparison, fossil fuels, which in 1870 contributed a small fraction to the total energy consumed, have increased by a factor of 70 and now account for about 80% of the total energy consumption – and for the CO_2 problem at hand. Nuclear energy and renewable energies, the development of which (excepting water power) started in the middle of the last century and which operate without CO_2 emission, now add up to 20% of the total. In Fig. 2 the renewable energies are further itemized to show the

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Presented at the conference on Desalination for the Environment: Clean Water and Energy, 17–20 May 2009, Baden-Baden, Germany. Organized by the European Desalination Society.

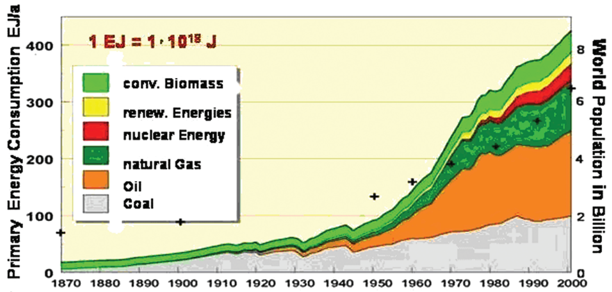

Fig. 1. World population (+; right scale) and annual consumption of primary energy from 1870–2000 (split into coal, oil, gas, nuclear energy, renewable energy and conventional biomass).

relative minor contribution of their modern forms: wind power, solar power, tidal power and geothermy.

When burned at present rate, reserves of coal, oil, gas and uranium, accessible at reasonable cost with today's technology will last not more than 200 years. Thereafter, secondary deposits (resources) will have to be exploited at appreciably higher cost.

2. Carbon dioxide endangers our climate

Continued emission of carbon dioxide associated with the consumption of fossil fuels is expected to lead to severe problems with the world's climate. As is known for more than hundred years already, radiation from the sun penetrates the atmosphere to be transformed into heat at the surface of the earth, however, the heat or infrared radiation emitted from the earth will not leave the atmosphere completely because of it's being absorbed by atmospheric carbon dioxide and other relevant gases, as recorded in Fig. 3. This causes

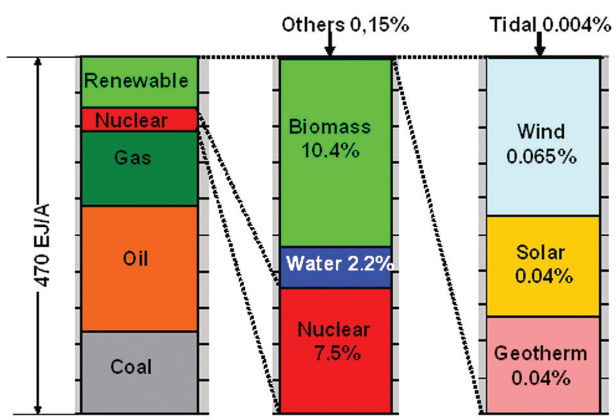

Fig. 2. Contribution of the renewable energies (in percent, middle and right column) to the global energy production (in EJ/a, left column; 2005).

the so-called green house effect, a net warming of the earth.

More than 100 years ago *John Tyndall* (Fig. 4), a prominent Irish/British scientist, already worried about the influence of atmospheric CO_2 on the temperature of the earth: ''With no carbon dioxide in the atmosphere the warmth of our fields and gardens will escape into the universe, and the sun will rise over an island which for ever is in the grip of eternal frost''. This was at the end of the 19th century. At about the same time *Svante Arrhenius* (Fig. 5) published a thorough investigation [1] ''On the influence of Carbonic Acid in the Air upon the Temperature of the Ground''.

Referring to the experiments of a great number of prominent physicists (Fourier, Tyndall, Pouillet, Röntgen, Ångström, Paschen and others) Arrhenius made estimates on the relationship between the CO_2 content of the atmosphere and the surface temperature of the earth, taking into account the yearly seasons and the geographic altitude. His data show clearly that an increase of the CO_2 concentration in the air will lead to an increase of the temperature on the earth.

Much later Arrhenius' and Tyndall's ideas were confirmed (Fig. 6): Analysis of air bubbles entrapped in Greenland ice during the past 150,000 years gave clear evidence for the parallelism of the CO_2 concentration in the air and the temperature of the earth, justifying Tyndall's fear of a world ''for ever in the grip of eternal frost''. In fact, this condition is expected to occur once the CO_2 concentration drops below 200 ppm.

From Arrhenius' many data we extract just one item which is of utmost relevance to our present situation: He predicts a global temperature increase of about one centigrade on increase of the atmospheric CO_2 concentration by 25%, which is from 300 ppm CO_2 at the time Arrhenius wrote his paper to 375 ppm one hundred years later (Fig. 7). Indeed, Fig. 8 demonstrates that during the last one hundred years the averaged global temperature increased by about 1 C.

Prior to the industrial revolution, i.e. before 1800, the atmospheric CO_2 concentration remained stable at 280 ppm for thousands of years. The increase since 1800, in all probability, is due to human action, is caused by burning fossil fuels. Fortunately, not all CO_2 we produce accumulates in the atmosphere. Between 2001 and 2007 the average worldwide CO_2 emission was $28{\cdot}10^9$ tons per year. When mixed with $5{\cdot}10^{15}$ tons of atmospheric air (global surface in cm^2 multiplied by 1 kg air per cm^2) this would yield an annual increase of 3.65 ppm of atmospheric CO_2, whereas actually the present value is 1.9 ppm (average 1995–2005). Thus, only about half of the man-made CO_2 is collected in the air, the other half is removed

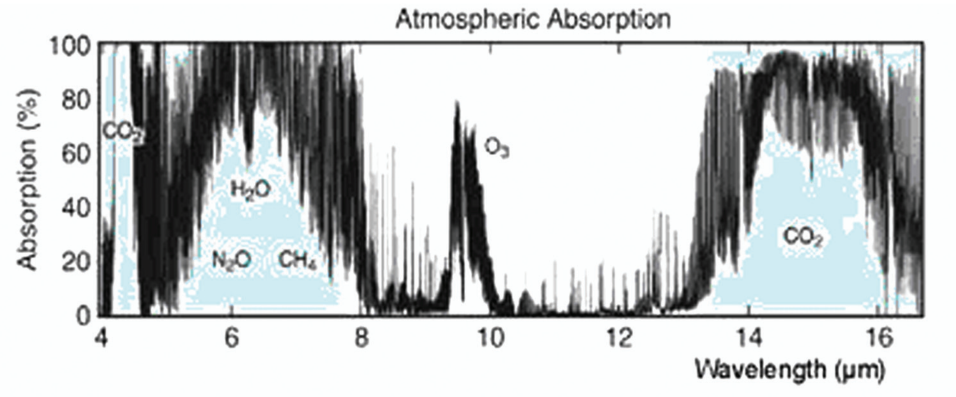

Fig. 3. Near-infrared absorption spectrum of the atmosphere with the absorption bands of CO_2, CH_4, H_2O and other ''green house gases''.

by nature itself, for example dissolved in the huge oceans.

For perspective: The world population of currently 6.8 billion people exhales more than $2{\cdot}10^9$ tons CO_2, which is about 7% of the global anthropogenic CO_2 emission. Decomposition of bio-organic material annually produces $550{\cdot}10^9$ tons CO_2, implying that biogenic CO_2 emission is 20 times larger than anthropogenic. As long as equilibrium conditions prevail, the same amount is extracted from the atmosphere by photosynthesis to form bio-organic material. By this cycle the atmospheric CO_2 concentration stayed constant for thousands of years before the industrial revolution.

On the basis of historic data climatologists warn that a global warming of the earth by 2 °C is the most nature will tolerate. Above that threshold ocean warming will noticeably increase the water vapor pressure and lower the solubility of CO_2 in the ocean ''sink''. As a consequence, the atmosphere will be further enriched with CO_2 and with water vapor, which both by their green house action (Fig. 3) will cause the temperature to rise progressively further etc. In other words, the warming effect is self-escalating.

3. Sources of renewable energy

The sun, of course, is our principal supplier of energy; but we also can tap the earth, making use of its thermal heat content or of its rotational energy.

3.1. The sun, the most reliable power source

For the next 2 billion years the sun will shine on the earth with an intensity of about 1 kW/m^2 (perpendicular incidence) which, when integrated over the earth's surface, amounts to $4{\cdot}10^{24}$ J/a, – almost 10,000 times more than our present annual global consumption of primary energy ($5{\cdot}10^{20}$ J/a). It derives this energy from the nuclear fusion reaction (4 ^{1}H ==> ^{4}He), by which

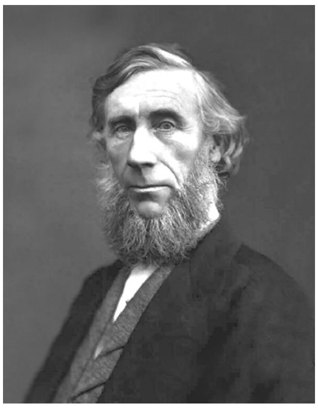

Fig. 4. John Tyndall (1820–1893), Physicist at the Royal Institution, London. Investigated light scattering in turbid media (Tyndall effect) and explained the blue colour of the sky.

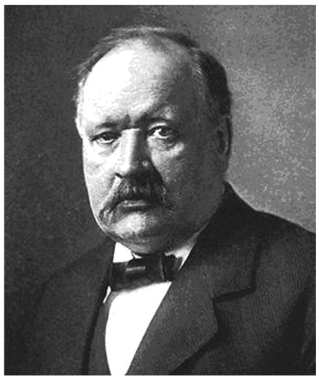

Fig. 5. Svante August Arrhenius (1859–1927), Swedish Physicist and Chemist. Nobel Price for Chemistry, 1903, ''for the services he has rendered to the advancement of chemistry by his electrolytic theory of dissociation''.

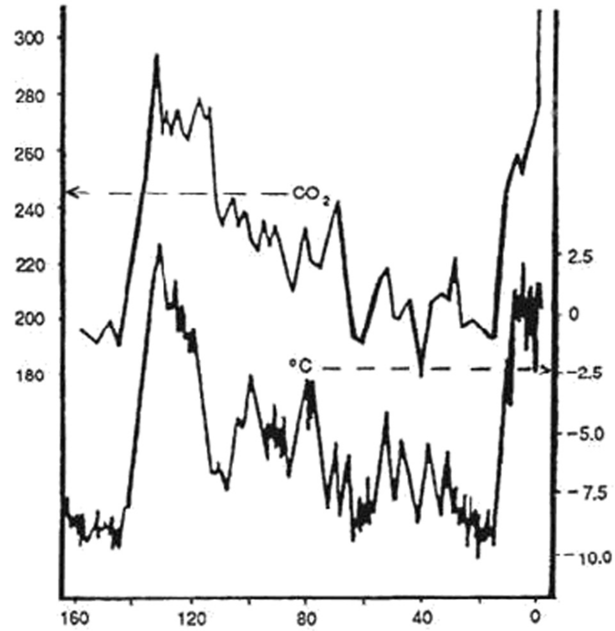

Fig. 6. Carbon dioxide concentration in the atmosphere (in ppm, left scale) and average temperature on the earth during the last 160,000 years (A. Gore [2]).

600 billion kg He are formed every second (mass difference $\Delta m = -0.0287$ g/mol, $\Delta H = \Delta m \cdot c^2 = -2.58 \cdot 10^{12}$ J/mol = 27 MeV).

Thus there is no need to worry about future energy supply, if only we learn how to make use of it. The sun's energy is available to us in the form of heat which we can use to warm houses and water; in the form of light, which nature converts into bioenergy or which we can transform into electric energy; and we can use the kinetic energy into which the sun's energy is transformed: Water power and wind power.

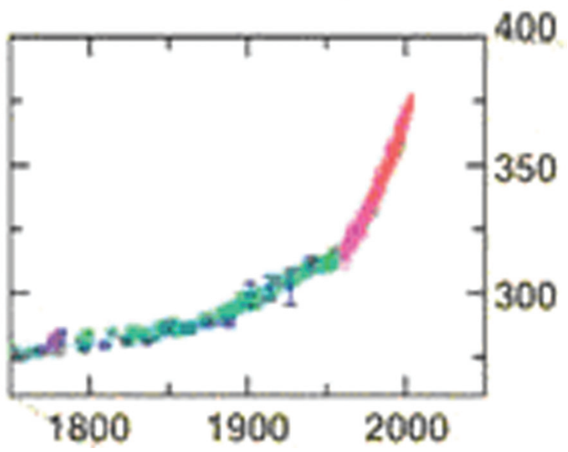

Fig. 7. CO_2 content of the atmosphere (in ppm) during the last two centuries.

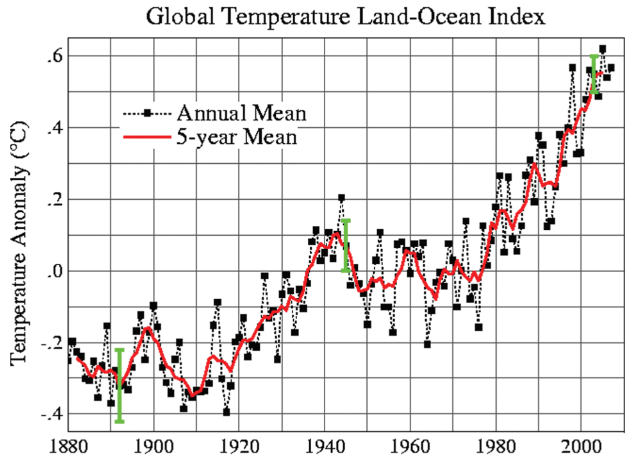

Fig. 8. Global temperature change during the last 130 years.

3.1.1. Solar domestic heating

Four decades ago when visiting Tel Aviv the author wondered about strange structures on the roofs of many houses there, until he learned that those constructions helped to supply warm water. Only since the steep increases of the oil price, and after becoming sensitized toward the CO_2 problem, Germans reluctantly started to make use of the sun to heat their homes and to warm water for domestic use. A small sun collector with a capacity of about 400 kWh/(a m^2) is shown in Fig. 9 which also describes the development in Germany since 1990: The installed collector area and the heat produced have up to now increased more than thirtyfold. In 2007 about 3.7 TWh heat were produced with collectors of 9.7 million m^2, distributed on more than one hundred thousand roofs all over Germany.

Thermal energy costs with these small units are rather high, oil heating definitely is cheaper. In larger installations however, e.g. for industrial use, competitive costs may be achieved.

3.1.2. Photovoltaic

Direct transformation of sun light into electric energy definitely is the most elegant way of using the sun's energy. For in photovoltaic installations no waste is produced nor noise, there is no danger connected with them. However we have to pay for these advantages. The reasons are: The transformation efficiency of even the most advanced photovoltaic cells is below 25%; along with the change from day and night and

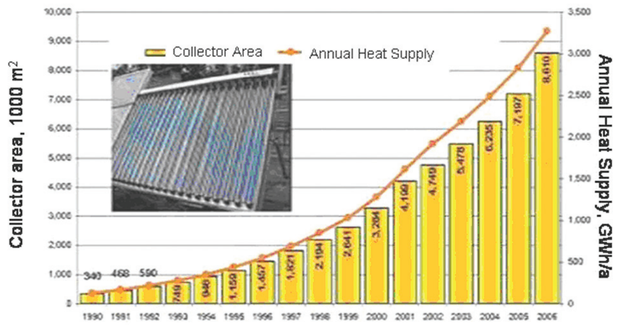

Fig. 9. Installed collector area and heat production with solar collectors in Germany 1990–2006. Insert: A small sun collector for domestic heating.

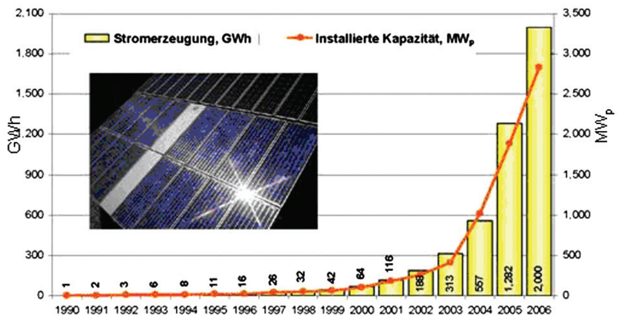

Fig. 10. Capacity and energy production of photovoltaic installations in Germany 1990–2006. Insert: View of a roof covered with photovoltaic modules.

from summer and winter sun shine intensity varies, the variations being amplified by clouds and fog. The output of a photovoltaic installation is not constant, and is predictable only in so far as we know they will not produce energy during nighttime.

The peak output in kW_P given on the specification label of the installations can be gained only during day time under ideal conditions, never for example in Middle or Northern Europe. A small installation of 1 kW_P, which has an area of roughly 10 m^2, in Germany will produce 800–1,000 kWh/a at best, implying that only 9–11% of the time it is in full power (or correspondingly longer at lower power).

More than half of the world's photovoltaic capacity is installed in Germany, adding up to 3.8 GW_P in 2007 (Fig. 10). Producing slightly above 3 billion kWh, it covers 0.5% of the annual German electric power consumption. As demonstrated in Fig. 10, an exponential growth in the installed capacity is observed, a trend which is expected to continue and which will lead to decreased installation costs and consequent reduction of the cost of photoelectric energy.

3.1.3. Bioenergy

The light of the sun inducing photosynthesis is the energy source of all living things. Wood and peat or, more generally, biomass for a long time was the only source of energy for mankind. As seen in Fig. 1, until 1970 biomass was used for one hundred years on a level of 10–15 EJ/a. Since then its use has increased to 50 EJ, reaching about 10% of the global energy consumption. In Germany biomass contributes only 4% to the total energy production, at slightly increasing rate.

On the other hand, conversion of crop biomass, foremost corn, wheat, sugar cane, rape, into automobile biofuel is growing fast: Between 1990 and 2007 it grew more than one thousandfold (Fig. 11) to about 50 billion kWh/a, used as pure diesel fuel or as additive to fossil gasoline. It represents about 7% of the current motor fuel consumption. This trend is expected to continue since, according to a European Union directive, by 2020 biofuel must be added to all fossil fuels to a concentration of 10%; now it is at 3%.

This development arouses mixed feelings. When food is transformed to fuel, food prices will rise. As example Fig. 12 shows the development of the wheat price, which has tripled during the past years. – In some parts of the world, for example in Brazil, it might be economically attractive to burn forests in order to grow biofuel plants. However, with the loss of forests we loose a CO_2 sink, to the net effect that rather than diminishing the CO_2 output by motoring with biofuels we are actually increasing it. Finally we have to keep in mind that the process chain of plowing, seeding, plant protection, fertilizing, harvesting and crop processing uses energy which has to be balanced against the energy gained in the form of biofuel. According to a recent study from California, burning biofuels in a power plant from whence to operate electrocars would

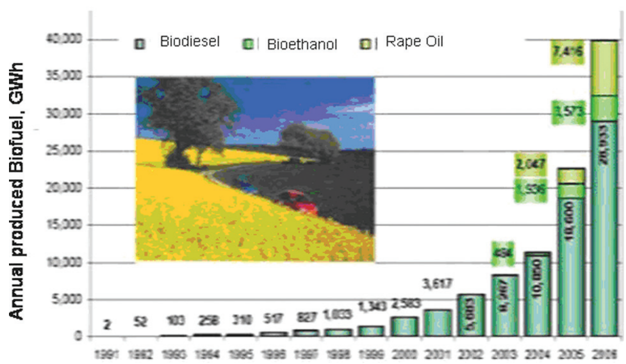

Fig. 11. Production of biofuel (diesel, ethanol and oil) in Germany from 1990–2006.

Fig. 12. Development of the wheat price at the commodity exchange in Chicago, 2003–2008.

give more mileage than fueling conventional cars with biofuels directly.

At present biofuels are hardly competitive with fossil fuels. But there is hope: it is expected that with genetically engineered plants harvest yields may double, which would cut production expenses.

3.1.4. Wind power

In 1895 some 20,000 wind mills were operating in Germany, mainly for milling grain. In 2008 some 20,000 wind turbines are operating in Germany to generate electric power. The first major wind energy plant, constructed in 1983, of 3 MW nominal capacity was a failure; it was dismantled 1987 after only 400 erratic operating hours. Nevertheless, based on the experience gained, advanced wind plants went into operation since 1990, steadily increasing in number and capacity to a total installed power of 23.5 GW in 2007 (Fig. 13). Average individual capacity now is 1.2 MW each, current maximum capacity is 5 MW. They produced nearly 40 billion kWh of electric energy in 2007; by implication, it follows that the plants were operating only 20% of the time at full capacity in 2007 (or correspondingly longer at lower capacity).

Wind power plants thus have about twice the efficiency of photovoltaic power plants; but they have another disadvantage: Winds are moody and definitely not as predictable as day and night. This is demonstrated in Fig. 14, showing the power supply of the

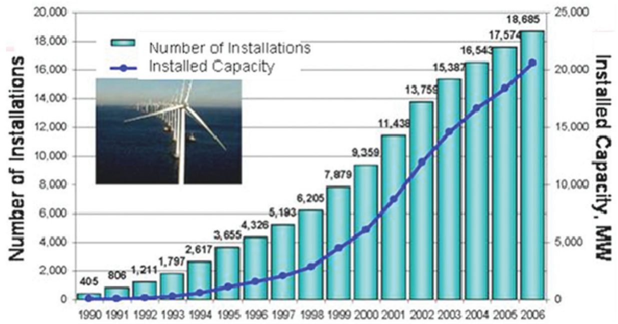

Fig. 13. Number of wind power stations and installed capacity in Germany from 1990–2006. (Insert an offshore wind power park).

wind power plants in northern Germany for a week's period at the turn of 2007–2008. The power varied between a few MW and 12,000 MW until, on January 4, it ceased completely. Such a breakdown is most problematic for the public power supply, requiring a dozen conventional power stations of 1 GW each to be activated from stand-by to full operation on short notice. This example shows that wind power – just as photovoltaic power – is not suited to cover the base load of the electric energy supply.

3.1.5. Hydroelectric power

Towards the end of the 19th century water turbines were developed capable of processing larger amounts of water at higher pressures than any of the hydraulic devices which were used for thousands of years in China and the Near East for agricultural irrigation.

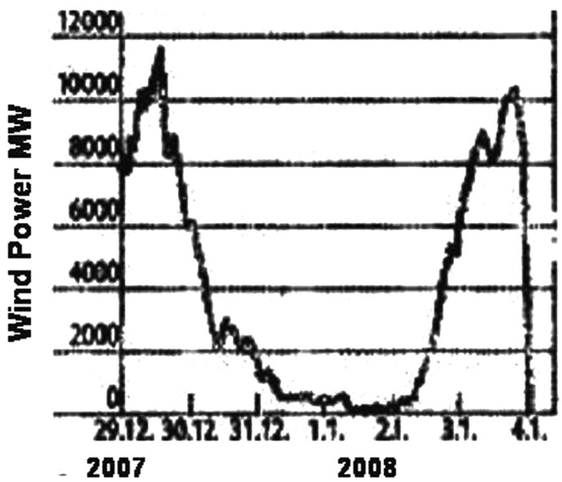

Fig. 14. Electric power supplied from the wind plants in northern Germany during the turn of 2007/2008.

Fig. 15. Archimedes focuses sun light with parabolic mirrors to set Roman ships on fire (Syracuse, 212 b.c.).

With these new machines the production of electric energy from water power became possible.

Worldwide about 17% of the electric power production of $18.1 \cdot 10^{12}$ kWh/a is contributed by water power. Yet its potential being about five times larger, water power worldwide has a good chance to expand. In Germany, on the other hand, practically all potential being utilized, the production of water power has remained constant for the last 30 years at around 20,000 GWh/a.

3.1.6. Solar power collectors

More than two thousand years ago Archimedes, a Greek mathematician, physicist and engineer, is told to have set fire to the Roman armada using parabolic mirrors to focus sunlight, in a vain attempt to end a yearlong beleaguering of Syracuse (Fig. 15).

The same principle now is used in thermal solar power stations. Hundreds of mirrors up to 100 m^2, each individually following the sun's course, focus sunlight to a receiver on top of a tower (Fig. 16). The working fluid in the receiver is heated and, via a turbine, drives a generator. With highly pressurized inert gas as working fluid heated up to 1000 °C it is possible to use the so-called combined gas and steam process (Fig. 17). The compressed gas is first fed into a gas turbine where it delivers its peak energy, and then its rest energy is converted to vapor for the steam turbine. By this combination the average yearly efficiency can be increased to 25%.

Using other working fluids, e.g. molten salts, which also can be heated up to 1000 °C, it is possible to store the excess heat of the day for power production during the night, which results in an appreciable reduction of the power costs.

Easier to control are linear parabolic collectors, 6–8 m wide and extending over 100 m and more in north-south direction (Fig. 18). The sunlight is concentrated on an absorber tube in the focal line through

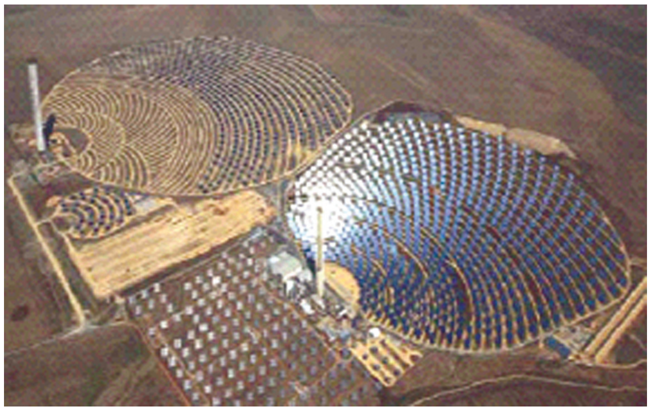

Fig. 16. Solar power station (11 MW) with hundreds of individually controlled mirrors near Sevilla, Spain.

which oil is pumped and heated up to 400 °C. In heat exchangers water vapor is generated to drive the turbine/generator. During the day the collectors follow the sun by east-west rotation around the long axis.

Power plants with linear collectors as described were realized already 1911 in Egypt, more were built or are under construction. In the US a plant of 350 MW and average efficiency of 15% produces more than 500 GWh/a. The acreage required is huge as seen in Fig. 18. At about 2 ha/MW it is 100 times more than that of a nuclear power plant. However, this is not seen as prohibitive since these plants are and will be set up mainly in sun rich areas with little inhabitation, – definitely not in Germany.

3.2. Geothermy, the energy under our feet

Only the earth's crust on which we live is ''cold''. But its temperature increases by 3–4 °C per 100 m going downwards. 99% of the globe has a temperature of around or above 1000 °C. The earth's heat content is of the order of $1 \cdot 10^{31}$ J (product of earth mass $\approx 6 \cdot 10^{27}$ g, averaged heat capacity ≈ 1.7 J/(g K) and

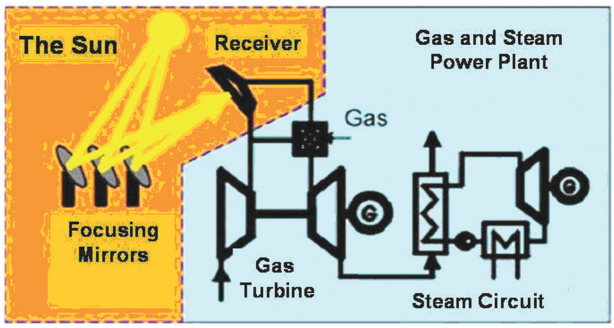

Fig. 17. Solar gas and steam power plant.

Fig. 18. This picture of a linear parabolic solar power station in California visualizes the extreme floor space required by solar power plants.

$\Delta T \approx 1000$ K), it could cover our primary energy needs for billions of years, if we could tap it.

Easily accessible geothermal sources are – just as the fossil fuels – very unevenly distributed on earth. Iceland is most favored: 53% of the primary energy and 20% of the electric energy is of geothermal origin. In 90% of all households the heat to warm rooms and water are taken from the earth. This country even can afford to heat streets and pavements to prevent ice formation. Fig. 19 shows the Svartsengi power station (76 MW) with the famous spa Bláa Lónio (Blue Laguna), which both are fed by geoheat.

In other countries, Germany as an example, one has to drill deep into the ground to extract some geoheat. For instance in Unterhaching, close to Munich, boreholes were drilled 3,000 m down to hit an aquifer which delivers water of 130 °C (Fig. 20). It is used to generate electric power (up to 3.5 MW) and to provide heating for 2,500 households. Furthermore, house heating can be effected with heat extracted from groundwater only 10–20 m below surface using a heat pump. Several hundred thousands of these systems are installed by now, even though they are rather uneconomical compared to oil or electric heating.

3.3. Even the moon helps

Ocean tides are caused by combined action of the attractive forces of the moon and the rotation of the earth. A tidal power station, in principle a hydropower plant, uses the kinetic energy of the sea water streaming forth and back in the rhythm of the tides. This kinetic energy is taken from the rotational energy of the earth which is $\approx 2.5{\cdot}10^{29}$ J ($= \mu\, \omega^2$, $\mu = 2/5\ m\ r^2$, moment of inertia with earth mass $m \approx 6{\cdot}10^{24}$ kg, earth radius $r \approx 6.3{\cdot}10^{6}$ m, and angular frequency $\omega = 2\ \pi/(24{\cdot}3{,}600)\ s^{-1}$).

The first tidal power station was installed in 1966 at the mouth of the Rance River on the North West coast of the Bretagne (Fig. 21), where the tidal range is 12–16 m. The mouth of the river is separated from the sea by a 750 m long dam thus forming a storage reservoir of 22 km^2. The seawater coming in with rising tide and going out with lowering tide drives 24 turbines of 10 MW each which are incorporated in the dam. This tidal power station produces about 600 million kWh/a, about 0.2% of the French consumption. Tidal power plants have also been constructed on the coasts of Canada, China, and Russia.

Diminishing the rotational energy of the earth by 600 million kWh per year – as the French do – leads

Fig. 19. Spa Blue Laguna with the power station Svartsengi in the background.

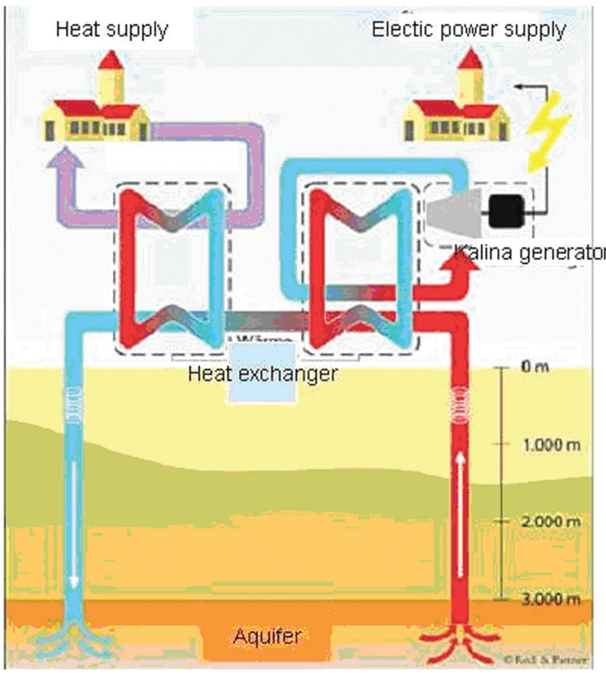

Fig. 20. Boiling water from 3,000 m below for power production and heating (Unterhaching near Munich).

Fig. 21. The tidal power station at the mouth of the Rance River at Saint Malo (Bretagne). The 750 m long dam separates the storage reservoir from the open sea.

to an increase of its rotational time (i.e. length of the day) by a few hundred picosec per year.

4. A summary account

Table 1 summarizes the contribution of the new energies in Germany for the year 2007, with particular attention to production costs and CO_2 avoidance. They are grouped into:

(a) Annual electrical energy produced by water power, wind power, biomass and photovoltaics, – together 14% of the total electrical energy production. (The contribution of geothermal energy to the production of electricity is <0.1% and is neglected here).
(b) The annual *heat energy* produced from biomass, geothermy and solar radiation, – about 8% of the total heat production.
(c) Annual energy as *biofuel* for motor vehicles produced from biomass, – about 7% of the total fuel consumption (biodiesel and bioethanol combined).

Column 3 lists the difference of the specific generation costs of the renewable energies and the conventional ones they replace (cts/kWh). They vary within wide limits, depending on the size and the location of the installations. For photovoltaic elements, for example, power production costs between 35 and 65 cts/kWh are reported, varying from large scale open access installations to small devices on the roof of little family homes. Wind power is listed between 5.5 and 16 cts/kWh for onshore and offshore generators. For hydropower plants on a great river or on a small creek the costs vary between 7 and 23 cts/kWh. The figures given in column 3 are weighed averages.

Renewable energies do not depend on classical fuels, and consequently the CO_2 emission associated with them is avoided (column 4): Ideally, water, wind, solar radiation, and geoheat are available free of CO_2 emission. Also, combustion of biomass to generate heat or when used as engine fuel in principle does not release more CO_2 into the atmosphere than is taken up by photosynthesis growing it. In reality, of course, engineering and operation of the supporting technology as well as the processing of biomass all require conventional energy and thus are associated with CO_2 emission.

Table 1
Renewable energy sources: the energy produced; specific cost difference; CO_2 avoidance; and costs for the avoidance: Germany 2007 (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, ''Erneuerbare Energien in Deutschland'', 15.12.2008)

	Produced energy	Diff. costs ren. energ.	Avoided CO_2 Emiss.	Costs of avoidance
	Billion kWh/a	cts/kWh	Million t/a	Billion €/a
Water power	21.3	5.63	23.1	1.20
Wind power	39.8	8.82	34.2	3.51
Bioenergy	22.9	11.0	19.5	2.52
Photovoltaik	3.0	55.3	2.1	1.60
ΣElec. Energy	**87.0**	**10.1**	**78.9**	**8.83**
Bioheat	94.0	2.0	21.9	1.88
Geoheat	2.3	2.2	0.5	0.05
Solar heat	3.7	20	0.9	0.74
ΣHeat Energy	**100.0**	**2.7**	**23.3**	**2.67**
ΣBiofuels	**46.1**	**8.3**	**15.0**	**3.81**
Total Σ			**117.2**	**15.3**

In summing up, by employing renewable energies the German economy avoided emission of 117 million tons of CO_2 in 2007; this is about 12% of the total emission of the reference year 1990, which is the year of highest CO_2 emission in the wake of Germany's reunification.

To be sure, we have to pay for the avoidance of CO_2 since the renewable energies are more expensive than the conventional ones they replace. The costs of avoidance are given as product of the energy produced (column 2) and the difference of the costs between the renewable and the conventional energies (column 3). They are listed in column 5.

Renewable energies may have avoided 117 million tons of CO_2, albeit at additional costs of 15.3 billion €, or 131 €/t (CO_2). This is the price we have to pay to reduce our CO_2 emission in order to counteract the climate catastrophe predicted. However, the damage caused by the climate change most certainly will be more costly than the measures to prevent it.

4.1. The personal incentive to invest in renewable energies

The Germans pride themselves to be pioneers in the supply of renewable energies. However, they are not. In summa, in Germany the contributions of renewable energies (biomass, water power, wind power, solar and geo-energy) to the primary energy production is 7.1%, compared to 12.7% world wide.

Only with respect to wind power, solar and geo-energy the figures are different: 1.3% in Germany versus 0.15% worldwide. Capacity for the production of these energies has increased exponentially during the last 20 years (Figs. 9, 10, and 13) and will continue to do so in the near future. But as shown in Table 1, column 3, production costs are high. Is the German citizen, who decorates his roof with photovoltaic cells or with a sun collector, motivated by such a pronounced ecological awareness that he is willing to pay the extra cost? Not at all – in fact, these new energies are heavily subsidized. Photovoltaic devices installed before 2008 are being supported with 20 billion € over the next 20 years; these installations are ''cash cows'' for their owners.

5. A perspective account

The nuclear option

There is universal agreement that continued combustion of fossil fuels at the present rate unequivocally will lead into a climate change, the consequences of which we are not fully aware of, let alone prepared for. There is also little doubt that the obvious remedy – to save energy on a global scale – has no realistic chance of being enforced, neither by administrative measures, nor by human insight. Substituting fossil fuels by renewable (CO_2 neutral) energies is a distinct and necessary possibility to ease the situation. However, in their present and near-future state of availability they are far from being capable of meeting the energy demands of mankind, as the following simple calculation may illustrate: Global emission of CO_2 at present is $28{\cdot}10^9$ tons per year. To slow down the climate change 30% of this should be avoided. By employing renewable energies at 131 € per ton of CO_2 avoided (Table 1) this would amount to thousand billion Euros per year. It would take decades of international haggling until agreement is reached on the distribution of this enormous sum among all countries of this globe.

One way out of the dilemma is nuclear energy. CO_2 emission per kWh of nuclear electric energy is below 20 g, compared to 1,100 g for lignite (brown coal), 800 g for anthracite (mineral coal), or 400 g for natural gas. At about 3 cts/kWh, production costs are on a par with any of the fossil fuels. In light of these figures, nuclear energy appears to be the only realistic alternative to replace fossil fuels, until the time renewable energies become affordable to society. In awareness of the problem 150 nuclear power plants currently are under construction or in the planning stage worldwide – in addition to the 440 nuclear power plants with a capacity of 393 GW which presently are in operation worldwide and which in 2008 produced 2,628 billion kWh.

It is not given to human wisdom to rationally weigh the consequences of a climate change against the burden of safeguarding nuclear waste, – obligating future generations both. We have to act now.

The German situation is unique: Here politics has self-imposed a ban on nuclear energy for ideological reasons, dreaming to jump from the fossil age directly to the age of renewables. The gap is to be bridged by still more fossil energy (even imported nuclear energy), and by heavily subsidizing the emerging industry of renewable energies.

6. A glance into the past

Tapping the sun for energy supply is neither an invention of our generation nor that of our fathers. ''One must not believe that the idea of using solar heat for mechanical operations is recent. On the contrary, this idea is very ancient; and it slowly developed across the centuries and has given birth to various curious devices'', so Augustine Mouchot (1821–1912), a French teacher for mathematics and physics, when he

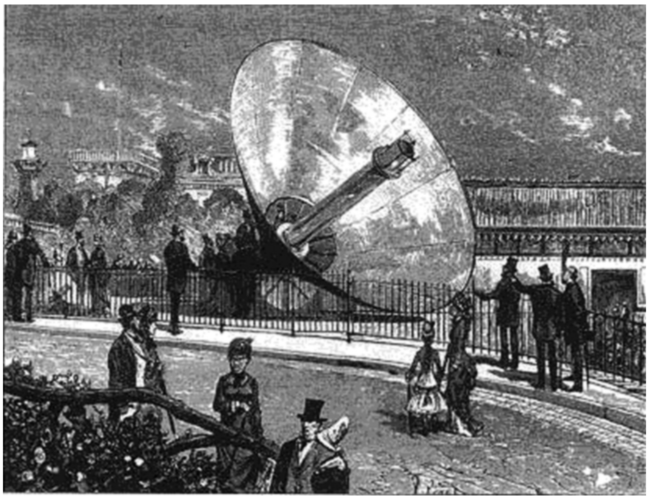

Fig. 22. The first solar generator, Universal Exhibition, Paris 1878.

demonstrated his solar generator at the Universal Exhibition 1878 in Paris (Fig. 22). He was drawn to the idea of finding new alternative energy sources, believing that the coal which fueled the industrial revolution would eventually run out. – The linear parabolic sun collector (Fig. 18) was patented 1907 in Germany and was for the first time realized in a small sun power plant in Egypt in 1912.

The next inventions served automobiles with renewable energies. An US inventor mounted 10,600 selenium photocells on top of a 1912 Baker Brougham car and thus started the idea of sun powered motion (Fig. 23). Biofuel to replace gasoline was commercialized in the US at the time of the great depression, as witnessed by a gas station in Lincoln, Nebraska, in 1933 (Fig. 24).

7. A glance into the future

Profitable and rewarding sources of renewable energies are distributed very unevenly all over Europe.

Fig. 24. The first biofuel filling station in the US (1933), ''corn alcohol''.

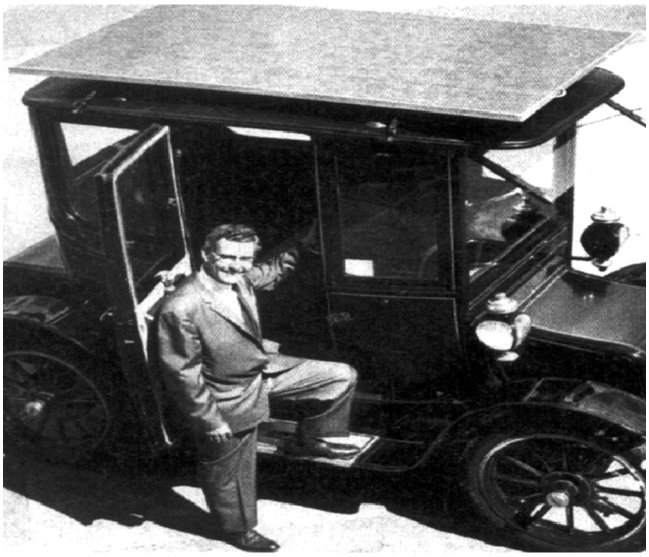

Fig. 23. Selenium photocells powering a 1912 car.

Geothermic energy is found mainly on Iceland, wind energy is abundant along the coasts of Europe, solar power is concentrated in northern Africa, water power is found in Norway, Sweden, Ausria, and Switzerland, perhaps some energy from biofuels might be contributed from Germany. Future electric power development will call for a European distribution network into which the various supplies are pooled and from which participants less favored by renewable energy might draw. Fig. 25 shows the vision of such a European-Mediterranean network.

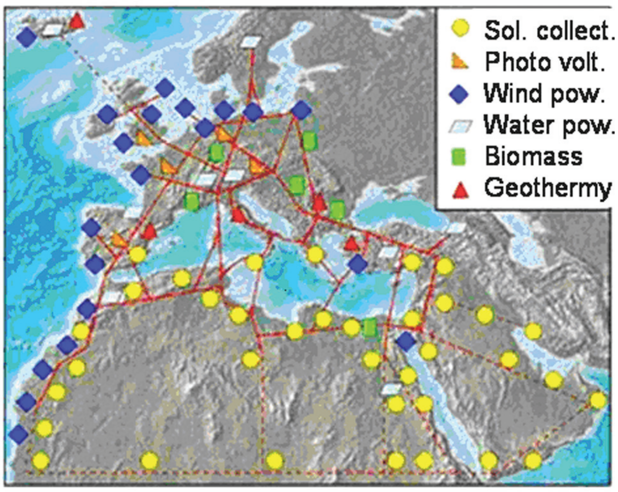

Fig. 25. Vision of an European-Mediterranean high voltage dc network to distribute electricity from the most efficient renewable energy sources.

Fig. 26. Positive proof of global warming.

It would have to be operated as high voltage DC grid to minimize transmission losses.

On a less serious note

If we do not succeed to control the CO_2 emission by developing an alternative energy economy based on clean energies, a fashion trend seemingly in evidence since the time of the Industrial Revolution may reach its climax, Fig. 26.

Acknowledgement

The article is based on the reports on the ''Manfred-Eigen-Nachwuchswissenschaftler-Gespräche'' der Deutschen Bunsengesellschaft, Herrenalb 2008, edited by Schindewolf; Bunsen-Magazin 2008/5, 180; 2008/6, 217; 2009/1, 14; 2009/3, 120.

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