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Environmental aspects of development of renewable power engineering

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Abstract
The authors consider the environmental aspects of development of power engineering, the problem of global climate mitigation and the prospects of improvement of renewable energy sources.

Keywords: energy, energy sources, environmental properties, additional heat, greenhouse effect.

Introduction

The vital functions of all living organisms require the energy which comes from exothermal reactions of oxidation of organic food with the oxygen coming from the atmosphere in the process of breathing. All the mechanisms of this process are compatible with the special features of organic substances and the content of oxygen in the atmosphere. That is why the formed organic life and the atmosphere are so important for the preservation of the Earth bio-variety and sustainable biological links and life conditions.

Besides the bio-chemical processes, the living organisms adapted themselves to "external" energy sources, e.g. to the solar radiation and the Earth internal heat as well as to the heat insulating capacities of some natural and artificial structures.

The appearance of human beings caused the discovery of many new energy sources which people learned to explore, to extract, to process, to transport and to transform into other energy forms which allowed people to warm themselves, to prepare food, to move themselves, to produce necessary goods, to erect buildings and structures, to share information, to generate new knowledge, to preserve health and to do many other things characteristic for the "modern way of life".

The man discovered many energy sources and learned to use them. Nowadays, it is expedient to divide these energy sources into two groups depending on their origin and availability. One group may be called "renewable energy sources", and the other one-"non-renewable energy sources". The human beings did not take part in the process of creation of the aforesaid energy sources, and people are only interested in their use.

The renewable energy sources (RES) include the energy produced by "eternal" natural sources: the solar radiation, the Moon gravitation, the Earth internal heat, the Earth magnetic flux, the atmospheric electricity, the Earth rotation centripetal foree and some others.

The solar energy may be primary (light radiation and heat radiation), secondary (wind) and tertiary (sea waves).

The non-renewable energy sources formed as a result of global processes which do not proceed anymore; these are fossil organic fuels: coal, oil and gas. The formation of these energy sources caused a considerable reduction in the carbon concentration in the Earth atmosphere and the accumulation of the carbon in the organic fuel mass.

Review

The history of development of "external" energy sources is very long. For hundreds thousands years the human beings used the wood combustion energy, the solar radiation energy, the wind energy, the heat insulating properties of natural and artificial structures. But small population of primitive people didn't use much organic fuel and practically didn't influence the environment.

However, the increase in population up to seven billions and the occupation of the land caused considerable landscape changes and a greater consumption of organic fuels. An "explosive" development of anthropogenic power engineering took place in the second half of the 19th century, and it was connected with two great events: invention of industrial power engineering and exploration of huge reserves of coal, oil and gas.

Since then, the humankind development has been based on the use of organic fuels: 95% of the energy was obtained from coal, oil and gas. The use of organic fuels, which are high-calorific, high-technological and transportable, made the science-and-technology revolution possible. This revolution started in the end of the 19th century; it changed the life of the human society on Earth, supported the population growth and

opened the prospects of new social and technological development.

Nowadays questions of using RES and reduction influence the environment have been a subject-matter for scientific studies for many years [3, 6-10].

The United Nations and other international organizations pay a considerable attention to this issue. Many from the EU funds are allocated to work in the field of using renewable energy sources. More and more international symposia, conferences and meetings are devoted to the analysis of the status and prospects of development of this field of energy use.

Leading experts in the field of the RES use are Bezrukikh P.P., Belyaev Yu., Devins D., Krasovsky N.P., Perminov E.M., Serebryakov R.A., Soloviev A. A. and others.

We should also note the following works in the field : the works by W. Duffy, Beckman W.A., Tande IOG, Hansen Y.C., etc.

In contrast to the traditional energy sources, the renewable energy sources are characterized by a lower density of energy flows and a higher power output variation, so the most preferred are the power plants working with different energy sources, but united in complex power plants.

The operation modes of combined hydraulic, solar and wind power plants were calculated by the scientists Arefiev N.V., Vasilev Yu.S., Vissarionov V.I., Elistratov V.V. and others.

The questions of economic efficiency and design of RES power plants in Russian are considered in works by Shpil'rain E.E., Makarov N.A. Nekrasov A.S., Malinin N.K., Strebkov D.M., Tarnizhevsky B.N., Meylanov A.Sh., etc.

We also should note some works on environmental economics, in particular those relating to the environmental component of RES done by Dunaevsky L.V., Novosselov A.L. Chepurnykh N.V. and others.

The analysis of the aforesaid research works has revealed that a predominant use of organic fuels lead to three global systematic environmental problems, which we consider further.

Main part

The first problem is connected with the exhaustion of reserves of non-renewable organic fuels because of their high consumption rate. The assumed average exhaustion periods are the following:

- for oil: 35 years;
- for gas: 70 years;
- for coal: 120-125 years.

After the exhaustion of these organic fuels, the mankind should replace the aforesaid energy sources by the other ones, and it will be a very difficult technological and economic problem.

The second problem is the emission of "additional" heat from combustion process into the atmosphere. The coal, oil and gas in their "natural" condition are located under the Earth surface and don't take part in the formation of the atmosphere heat balance (they conserve the carbon accumulated in them). In the process of combustion of organic fuels, all the heat produced comes into the atmosphere changing the atmosphere heat balance. The "additional" heat is proportional to the extracted organic fuels

The third problem, which is considered to be the environmental problem №1, is connected with the emission of so-called "greenhouse gases", mostly CO_2, into the atmosphere. The greenhouse gases flow into the upper atmosphere layers and form there a layer preventing the heat emission into the space. A higher heat concentration in the atmosphere causes the "global climate mitigation" which may have many environmental after-effects.

The world association worries about the aftereffects of the global climate mitigation; nowadays we are trying not to admit the increase in the average atmosphere temperature more than $2\,^0C$ by the end of the century. It is a very difficult problem, which has technological, economic and political aspects.

The most logical, natural and efficient way of solution to the global climate mitigation problem is a wide use of renewable energy sources. Their main advantages are the following:

1. The renewable energy sources always take part in the formation of the atmosphere heat balance. So the use of them doesn't cause any additional heat emissions.
2. The technologies of transformation of renewable energy sources don't provide for any harmful emissions, so they won't cause any greenhouse effect.
3. Either renewable energy sources exist everywhere on Earth, so the power supply of any consumer may be provided for without any transportation costs.
4. The use of local renewable energy sources will allow us to exclude the energy carrier transport expenses (oil-pipelines, gas-pipelines, heat supply lines).
5. The power resources of renewable energy sources in the world are quite sufficient for the power supply of the mankind for a boundless period of time.
6. The power equipment based on renewable energy sources has been developed and maintained for a long time, and it is quite acceptable for the modern level of engineering and technology. The economic parameters concerned approach the parameters of the most efficient heat and nuclear power plants.
7. The aforesaid power equipment is not absolutely ecological, but the damage is negligible in comparison with that from heat and nuclear power plants and transport engines using organic fuels.

The carbon concentration in natural reservoirs is measured in tons of equivalent fuel, that in the atmosphere is measured through the CO_2 concentration, in mln^{-1}. The equality (1) establishes the correlation between these units:

$$1000\ \text{mln}^{-1} \approx 2134\ \text{Gton C} \qquad (1)$$

The pre-industrial level of the CO_2 concentration (1860) is taken equal to 290 mln^{-1}. By 1976 the CO_2 concentration equaled 333 mln^{-1}, and by 2000 it equaled 370 mln^{-1}.

By the end of the XXI century the CO_2 concentration in the atmosphere may reach the value of 460 mln^{-1}, i.e. it may be 1.66 times higher than the pre-industrial level. The coefficient of the carbon emission in any country may be calculated through the formula (2):

$$C_c = \frac{0.733E_s + 0.586E_l + 0.398E_g}{E_c} \quad (2)$$

where

E_s -solid energy carriers, ton;

E_l -liquid energy carriers, ton of equivalent fuel;

E_g -gaseous energy carriers, ton of equivalent fuel;

E_c -total amount of consumed primary energy, ton of equivalent fuel.

TABLE 1.The carbon intensity coefficient*

Country	Consumption of primary energy, total, ton of equivalent fuel	Structure of consumption of energy carries, ton			Carbon emission coefficient, C_o (calculation through the formula (2))	Average consumption of primary energy per capita, kg/person* year	Average carbon emission per capita, ton/person* year
		Coal	Oil	Gas			
USA	2910974	675611	1274493	818100	0,539	9821	5289
Canada	347254	36341	129478	128152	0,442	10751	4753
Finland	36056	7107	16509	5773	0,477	6873	3275
Norway	39459	1110	14756	8220	0,323	8500	2743
Israel	29961	12267	15844	2049	0,637	4287	2732
Russia	**880869**	**124393**	**162517**	**555585**	**0,463**	5800	**2683**
German	415954	114737	146466	128471	0,531	5045	2681
Japan	621425	173947	286692	112109	0,547	4863	2662
Great Britain	307892	58869	101742	134895	0,508	5114	2599
Greece	44958	12827	27080	3739	0,595	4048	2410
Dania	23010	5345	9690	6990	0,538	4249	2285
Italy	261287	24279	112482	112256	0,491	4459	2191
Poland	125458	79188	27726	19439	0,654	3288	2150
Ukraine	186532	48358	19552	107193	0,480	3963	1903
France	249515	21908	107243	65138	0,420	4097	1721
Sweden	39248	3689	17153	1338	0,339	4337	1468
China	2008534	1542049	350848	61054	0,677	1537	1041

**The data are taken from UNITED NATIONS STATISTICAL YEARBOOK 2013.*

As it is seen from Table 1, Russia has a low carbon emission coefficient; it is due to the use of new technologies, which guarantee the valid environmental requirements concerned.

The carbon capacity is a parameter characterizing both the economy structure and the efficiency of the use of hydrocarbon fuels [6].

The GNP carbon capacity level in different countries and the rate of its change is characterized by the economic development of the countries and the availability of hydrocarbon fuels.

For the analysis of probable increase in the level of emission of greenhouse gases, the countries are divided into 6 groups, which differ in GNP carbon capacity and its dynamics. Russia is a carbon-non-intensive country with a transition economy. The correlation of the GNP per capita in carbon-non-intensive countries is shown in Fig.1.

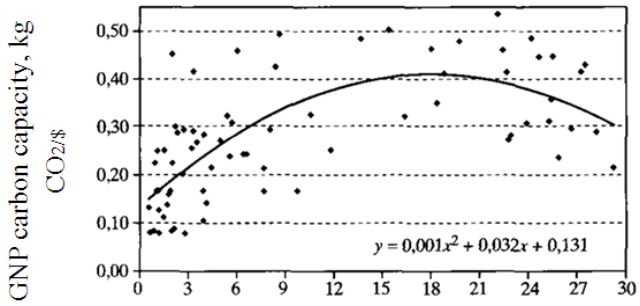

Fig.1. The level of economic development and the GNP carbon capacity in carbon-non-intensive countries with market economies [2, 5].

The economic development leads to an absolute increase in the volume of emissions of greenhouse gases, the dependence of these parameters is linear.

The environmental effects of power stations based on renewable energy sources may be reduced through the erection of their projects with consideration of some restrictions:

- to erect wind power stations at the distance not less than 250-300m from residential and office buildings; to avoid the bird migration routes and the nesting places;
- in the process of construction of small hydropower stations, to provide for the passage ways for fish in the main river-bed; not to use the rivers with the spawning-grounds;
- at the GeoPP and GeoThPP, to provide for the utilization of waste gases as well as the reverse separate pumping into the seam;
- to use only ecological technologies of the silicon production;
- to use the ecological technologies of production of the bio-ethanol from cellulose raw materials.

A considerable shortcoming of large wind power stations is the noise produced by the wind wheel. The studies in the field evaluate the noise at the tower base as 100-110 dB. However, observing the aforesaid distance of 250-300 m from WPP may guarantee an admissible noise level.

The infrasound spectrum of the noise and its influence on living organisms may be overcome through an appropriate selection of the wind wheel rotation velocity and the blade profile.

One more advantage of the use of renewable energy sources is that these power plants (wind power plants and photo power plants) do not require much water: the water loss for WPP is 100 limes less ($\approx 0{,}004l/kWh$) and for PHPP is 10 times less ($\approx 0{,}11l/kWh$) than for NPP (2.3 l/kwh) and HPP (0.95-1.9 l/kwh) [4].

The erection of WPP doesn't require much arable land as they are usually erected on the territories not suitable for the agriculture. A wind power station requires only about 25 m^2 for itself and a piece of land for the access road. The distance

between the wind power plants is equal to 5-10 wind wheel diameters (70-90m), i.e. from 0.5 to 1 km. the soil near the wind power plants may be used for growing vegetables, forage, rape, or for pastures.

The photo power plants require more land: 10-30 m^2/kW, while the heat power plants require only about 1 m^2/kW.

The aforesaid environmental restrictions for the use of renewable energy sources may be overcome; they have less influence than the use of hydrocarbon fuels or of nuclear power plants.

The present state of renewable energy sources and their development trends are shown in Table 2; the data demonstrate the scales and the prospects of the use for renewable energy sources in the world.

During the crisis period, the renewable power engineering has developed faster than the economies of the countries concerned. The development of photo and wind power engineering is very fast [1].

TABLE 2. The development rate of RES in the world [1]

Renewable energy indicators	Units	2009	2010	2011	2012	2013	2014
New investment (annual) in renewable power and fuels	Млрд. USD	178	237	279	256	232	270
Renewable power capacity (total, not including hydro)	*GW*	250	315	395	480	560	657
Renewable power capacity (total, including hydro)	*GW*	1170	1250	1355	1470	1578	1712
Hydropower capacity (total)	*GW*	915	935	960	990	1018	1055
Bio-power generation	*TWh*	-	313	335	350	396	433
Solar PV capacity (total)	*GW*	23	40	71	100	138	177
Concentrating solar thermal power (total)	*GW*	0, 7	1, 1	1, 6	2, 5	3, 4	4, 4
Wind power capacity (total)	*GW*	159	198	238	283	319	370
Solar hot water capacity (total)	GW_{th}	159	195	223	255	373	406
Ethanol production (annual)	Billion litres	71	85, 0	84, 2	83, 1	87, 8	94
Biodiesel production (annual)	Billion litres	17, 8	18, 5	22, 4	22, 5	26, 3	29, 7
Country with policy targets	#	89	109	118	138	144	164
States/ provinces/ countries with feed-in policies	#	82	88	94	99	106	108
States/ provinces/ countries with RSP/ quota policies	#	66	72	74	76	99	98
States/ provinces/ countries with biofuels mandates	#	57	71	72	76	63	64

The investment volume during the period from 2009 to 2014 became greater by 1.7 times; the total capacity of power plants using the renewable energy sources (without hydropower plants) became greater by 2.6 times, the capacity of photo power plants became greater by 7.8 times; the capacity of solar thermodynamics stations became greater by 6.3 times, the capacity of solar hot water supply systems became greater by 2.5 times. The production of bio-diesel fuel increased by 1.7 times.

More and more countries consider the development of renewable power engineering to be the priority question of the State policy. More than 160 countries established special state programmes for the use of renewable energy sources as a certain part in the total consumption of primary energy and/or the production of electric power. Some countries established the programmes of introduction of certain kinds of renewable energy sources and certain capacities. Fig.2 shows the information on the use of renewable energy sources in countries which are the leaders in the field.

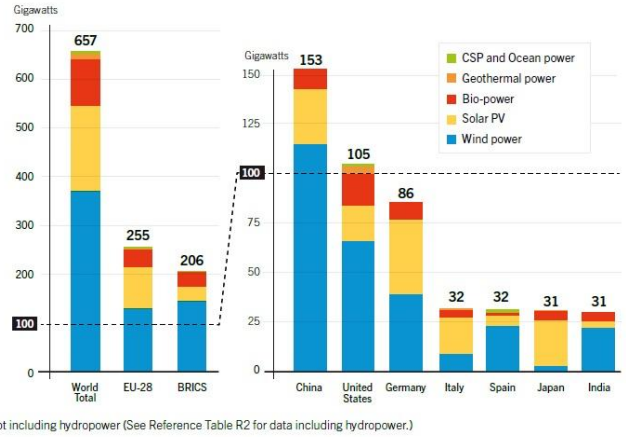

Fig.2.-Renewable Power Capacities* in World, EU-28, BRICS, and top Seven Countries, 2014 [1]

By the end of 2014, the total power capacity of renewable energy sources in the world became greater than 1700 GW, which is by 1.5 times greater in comparison with 2009 [1]. Now more than 5% of the world electric power is produced with the use of renewable energy sources. The total capacity of these power plants (without hydropower plants) became greater than 650GW.

The state programmes of development of renewable power engineering in many countries as well as the political pressure of some international documents may be a considerable reason for an optimistic prediction in the field. By 2050 the Denmark intends to produce 100% of electric power by renewable sources of energy, the Germany intends to produce 60% of that.

Conclusion

The analysis of programmes in the field testifies to the fact that by 2020 the share of renewable energy sources (with hydropower stations) will be equal to 20% of the total electric

power produced. In the process of achievement of these advances, a greater share of renewable power engineering will be guaranteed by its economic and environmental efficiency.

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