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Global Environmental Problems, Environmental Safety and Environmental Efficiency of the Power Industry.

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ABSTRACT

The connection between global and local environmental issues to the energetics has been shown. Global criteria for these relationships have been established. They are the amount of resources consumed and greenhouse gas emitted. The quantitative characteristics of the energy materials types have been given as regards these key indicators. A qualitative and quantitative evaluation of the environmental performance of various types of energy sources has been given, including alternative and renewable energy sources. It has been shown that the nuclear power had the greatest benefits in terms of solving global environmental problems.

Keywords: environmental problems, power generation, coal, gas, oil, solar, wind, nuclear, hydraulic power generation, qualitative and quantitative evaluation, environmental performance.

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INTRODUCTION

Environmentally caused threat to the existence of human civilization is officially recognized worldwide; scientific-and-technological advance has created a risk of environmental catastrophe, and the very notion of "development" is in question. There is an urgent need to review the scale of human values.

Consumer attitude towards nature has put it on the brink of survival. Prevailing production and consumption models cause environmental devastation, increase risk for human life and health due to the decreased quality of environment. Global security is put a risk.

According to the UNEP report, the prospects for human development to 2032 are unfavorable. As a result of human activity, irreversible changes will occur on the planet. More than 70% of the earth's surface will be misshaped, more than 1/4 of flora and fauna will be irretrievably lost, safe air, clean drinking water and undisturbed landscapes will be in heavy deficit, nature's ability to recover from human impact will be impaired. It is a high quality of natural environment that is the main wealth of mankind and absolute value, the essence of *global environmental interests*. According to WHO, today 80% of all diseases in the world arise from the consumption of low-quality drinking water, and the IAEA estimates that 5 million people die from diseases related to the consumption of contaminated and low-quality water. Water may well become the main cause of future armed conflicts, such as take place today because of oil.

Even the most superficial statistics related to the environmental state of the Russian territory is disappointing: today more than 1/3 of the Russian urban population inhabit areas where no air pollution monitoring is performed, and more than 1/2 of the Russian urban population live in cities with high and extremely high level of air pollution.

Russia, along with the entire planet, encounters serious environmental problems – increase in the average air temperature, retreat of permafrost, various signs of climatic instability. The problem of global warming is obviously accompanied by environmental footprint caused by the deterioration of climate conditions.

Depending on the scale of the human activities' impact on the environment, it is common practice to divide environmental problems into global and local. Global environmental problems are directly related to local environmental problems (Figure 1).

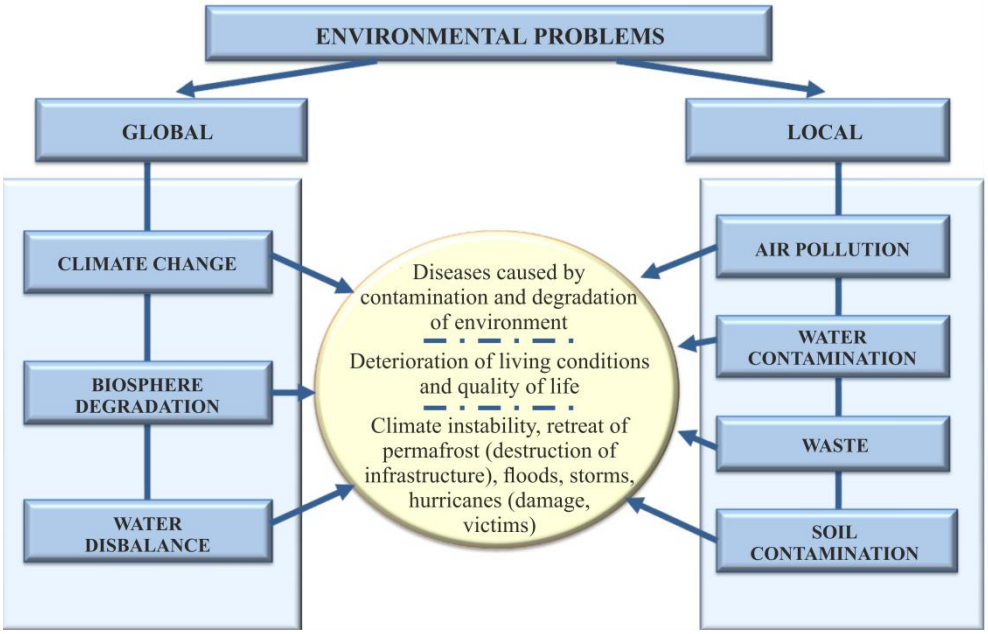

Figure 1. Interrelation between global and local environmental problems

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METHODOLOGY

The authors proposed a method of calculating the cumulative complex index of environmental impact. They measured seven most important environmental indicators using a 10-point scale: 10 points – the most negative impact (actual value), 0 points – no impact.

Environmental impacts of energy sources

To meet the energy demand there are renewable and non-renewable sources of energy. Sun, wind, hydro-, and tidal power are known as renewable, since their amount almost does not alter in course of their use by man. Coal, oil, gas, peat, uranium are known as non-renewable, their amount decreases in the course of their processing.

This classification is, however, quite arbitrary. For example, uranium in a closed fuel cycle can be regarded as a renewable energy source (RES).

Global environmental problems are closely related, above all, with the economic situation in certain countries, which main indicators are GDP per capita and energy production and consumption (Table 1).

Table 1. Main energy indicators of countries – main consumers of primary energy

Country	Population, mln people*	GDP per capita (PPP), USD**	Power plant capacity, GW (e)**	Electric energy consumption	
				Total, bln kWh*	Per capita, kWh per capita
The USA	311.6	49,800	1,025	4,380.1	14,057
China	1,344	9,100	1,146	3,684.5	2,742
Russia	143	17,700	223.1	1,020.6	7,137
Japan	127.8	36,200	284.5	1,079.8	8,450
India	1,193	3,900	189.3	909.4	762

* data as of 2010, except for electricity consumption in China and India (2009) (Statistical report, 2012).
** data as of 2012, except for power plant capacity in Japan and India (2009) and the USA (2010) (Central Intelligence Agency, 2012).

Table 1 demonstrates that energy consumption in the developed countries may be 11-18 times higher than in the developing countries (e.g., Japan vs India, the USA vs India).

If all countries in the world in the next 15-20 years reach the level of energy consumption in the USA or at least in the “economical” Japan, the total energy consumption will increase according to the population growth – that is almost 15-fold. The world energy production is not ready to face such a “great leap”. The planet does not have as much fossil fuel. Therefore, we can conclude the following: power industry should develop in the direction of using new high-power sources of energy not involving fossil fuels.

The tendency towards the use of electric energy is obvious. However, it is only an intermediate stage – in order to produce energy, one need to find a high-power primary source of energy.

Exhaustible energy resources (oil, coal and gas, as well as uranium in nuclear power) will remain the main sources of energy in the next decade (Figure 2), with the share of energy obtained from hydrocarbons to remain the largest. However, the reserves of oil and gas are apparently limited. The prospect for their active use after a few decades is unclear. It is obvious that during this time oil and gas power generating capacities should be replaced by others (International Energy Agency, 2008; Fortov and Makarov, 2009; Makarov, 2009).

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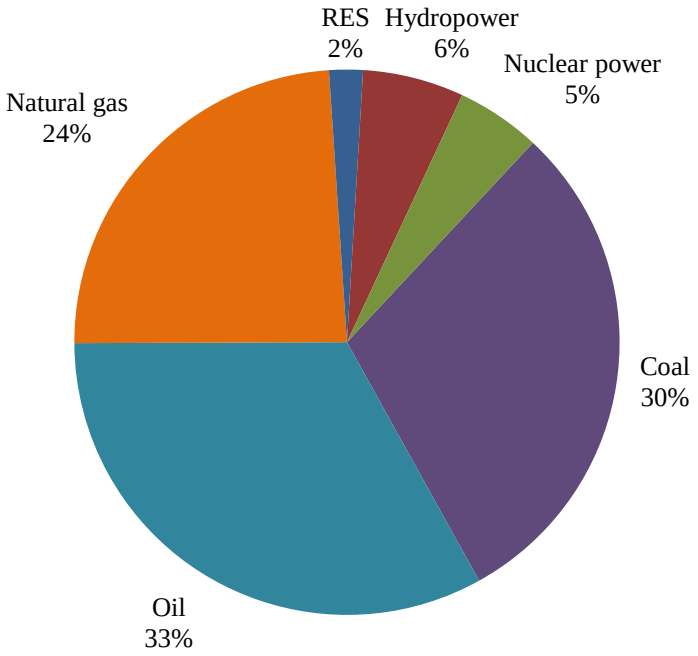

Figure 2. World electric power generation by energy source (BP Statistical Review of World Energy, 2012)

The main problem commanding attention of humanity is ensuring environmental security. The concept of "environmental security" is defined in the Law of the Russian Federation N 7-FZ On environmental protection (2016): "Environmental security is the state of protection of the environment and vital interests of a human from possible negative effects of economic and other activities, natural and man-made emergencies, and their consequences."

Threats to the environmental security:

- ozone layer depletion;
- climate change;
- transboundary impact on the environment;
- ecosystem degradation;
- biodiversity loss;
- reduction of forest cover;
- degradation of agricultural land;
- depletion and scarcity of natural resources;
- chemical, physical, and radiation pollution.

Global environmental problems are closely related to global energy problems (Figure 3). The link between global environmental and energy problems is particularly evident when comparing the two indicators: 1) required amount of the resource required to produce an energy unit; 2) global effect on the environment caused by the greenhouse gas emissions.

Table 2 summarizes the main characteristics of the different methods of electricity generation according to the two global indicators: greenhouse gas emissions and power generation per weight unit that demonstrates energy effectiveness of the matter's internal energy use, i.e. of the nuclear and thermonuclear energy. In fact, this is the basis of the Solar System's existence – the energy in the Solar System exists due to the two reactors: the nuclear one, inside the Earth, and the thermonuclear one, on the Sun.

Table 2. Global effectiveness of various methods of energy generation (Grachev and Zakhlebny, 2014)

Method of generation		Greenhouse gas emissions per 1 t of energy source, t	Energy per 1 kg of matter, kWh/kg
Combustion	Coal* (coal 1 kg of coal = cinder 567 g)	CO_2 = 2.76	7
	Natural gas	CO_2 = 1.62	14
Nuclear energy		CO_2 = 0	24,000,000
Thermonuclear energy		CO_2 = 0	60,000,000
Quark-gluon energy (Higgs boson)		CO_2 = 0	6,940,387,213,578,000

* As a result of combustion of 1 kg of coal, 567 g of cinder is left.

The solution to the problem of energy supply could be harnessing thermonuclear fusion energy. However, according to the recent studies, on the road to harnessing thermonuclear fusion energy today there are several technical problems, the solution to which has been sought for the last 50 years but in vain.

Among the existing alternatives to the conventional energy sources, only fuel and nuclear modern technologies are able to meet the growing energy needs of mankind for the next several hundred years.

Coal-fired and nuclear power industries are the most interesting in the context of their impact on the environment and human health, since coal and nuclear energy are the only two energy sources that have sufficient reserves in the long term. Thus, according to Rodionov (2010), the coal will last for 420 years, whereas only 1/5 of hydrocarbon available reserves will be left by 2030, that is, they can be largely exhausted in the next 30 years. At the same time, the uranium reserves (including the 238 isotope in fast reactors) will last for thousands of years.

The comparison of the environmental and health aspects of certain energy sources is given below.

Environmental performance of coal

Atmospheric emissions from coal-fired power plants cause the so-called acid rain that damage flora, soil, water reservoirs and, first of all, human health. To estimate the amount of acid rainfall, one should imagine a 1,000 MW TPP (thermal power plant) consuming coal with a sulfur content of approximately 3.5% (despite the use of cleaning agents) and emitting 140 thousand tons of sulfur dioxide into the atmosphere annually; thus, about 280 thousand tons of sulfuric acid is produced every year. Nowadays, the annual amount of the ash and slag waste from TPPs in the CIS exceeds 120 million tons. Wind raises ash from the surface of the ash disposal areas, thus causing dust storms.

Harmful emissions emitted into the environment as a result of coal combustion at coal-fired power plants and main environmental consequences are provided in Table 3, the potential adverse impact of the coal power plants' emissions on the human body is demonstrated in Figure 3.

Table 3. Harmful emissions as a result of coal combustion and main environmental consequences

Emissions	**Main environmental consequences**
Sulfur dioxide SO_2	Contributes to the formation of acid rain, respiratory and cardiovascular diseases.
Nitrogen oxides NO_X	Contribute to the formation of smog and respiratory diseases.
Particulate matter PM	Contributes to the formation of smog, haze, respiratory and lung diseases.
Carbon dioxide CO_2	Is a greenhouse gas; it absorbs infrared radiation, this leads to the accumulation of heat in the atmosphere and to the increase in temperature.
Mercury and other heavy metals	Cause developmental and neurological disorders in humans and animals. Once in the water, mercury can be converted to methylmercury – a highly toxic chemical that accumulates in fish, animals and humans.
Fly ash and slag	Are disposed into the groundwater aquifers, washed out from the disposal sites and sometimes break through the disposal sites, thus creating acute environmental problems.

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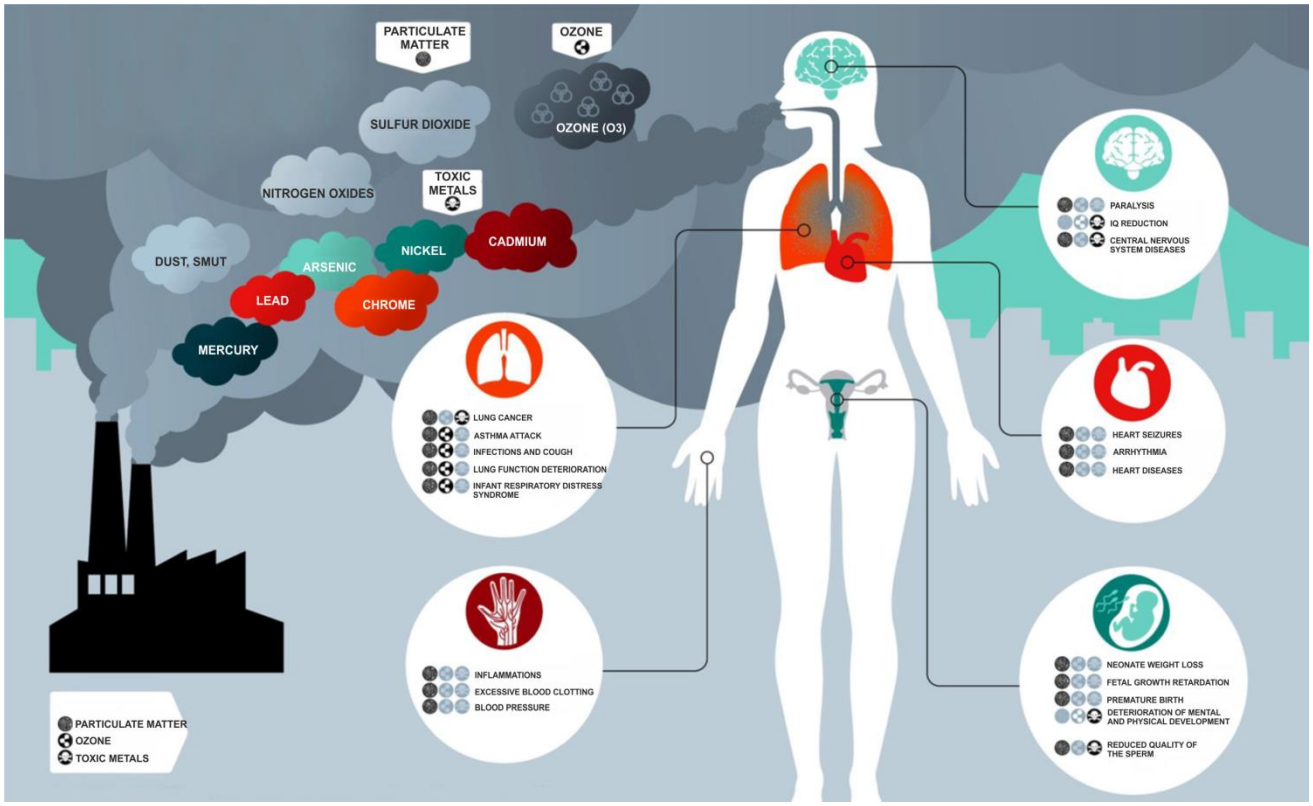

Figure 3. The impact of the coal-fired power plants' emissions on the human body

Coal combustion results in the radioactive contamination of the environment. During coal combustion, radionuclides that are contained in coal (^{238}U, ^{210}Pb, ^{40}K, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{230}Th, etc.) are emitted into the atmosphere and concentrated in the ash. The radioactive emission per energy unit produced by the coal-fired power plants exceeds that of the nuclear power plant.

Environmental performance of shale gas

The most "clean" fossil fuel is natural gas. Let us focus on the shale gas. According to the studies by Grachev and Lobkovsky (2015), there are 5 main environmental problems related to the shale gas production:

1. Pollution of the aquifers by highly toxic substances and of the surface water by waste water.
2. Methane emissions into the atmosphere.
3. Increase in the radioactive background in the areas of extraction.
4. Increased probability of induced earthquakes.
5. Withdrawal of considerable land and water resources.

Environmental performance of oil

The most significant environmental problems associated with the oil extraction and usage are the following:

1. Chemical pollution of the groundwater during oil extraction, chemical and thermal pollution of the surface waters, formation of the oil film.
2. Disturbance to fauna and flora habitats.
3. Soil pollution and degradation.
4. Significant water withdrawals.

Environmental performance of nuclear power

Nuclear power does not consume oxygen, does not emit hazardous chemicals into the atmosphere and water; it saves significant amounts of fossil fuel, which is scarce. Particularly, in five most developed countries of the world nuclear power saves up to 440 million tons of coal a year (in Russia – 65.3 million tons), 350 million tons of oil (in Russia – 40.3 million tons), up to 280 billion m^3 of gas (in Russia – 36.8 billion m^3), prevents combustion of over 450 million tons of oxygen (in Russia – 36 million tons), saves landscapes on the territory of 70 thousand hectares (in Russia – 11 thousand hectares). France, where nuclear power generation exceeds 70% of the total power generation, is said to be the pollution-free region of Europe (Boyko and Koshelev, 1998).

Environmental performance of hydropower

Nowadays, among all the types of RES, hydropower is the only one to make a significant contribution to the worldwide electric power production (17%). In most highly industrialized countries there are scarce hydropower resources that remain untapped. According to Bezrukikh et al. (Bezrukikh and Strebkov, 2005; Bezrukikh et al., 2002), adverse impact of hydropower on the environment mainly results in:

1. Flooding of the agricultural lands and settlements.
2. Water imbalance that alters flora and fauna.
3. Climatic impact (change of the heat balance, increase in the rainfall, wind velocity, cloudiness, etc.).
4. Reservoir siltation and shore erosion, deterioration of the flow waters' self-purification, reduction of the oxygen concentration, hindrance to the free migration of fish.
5. Hydropower facilities are potential accident source.

Environmental performance of wind energy

Wind energetics has a negative impact on the environment too (Bezrukikh and Strebkov, 2005; Bezrukikh et al., 2002):

1. Withdrawal of vast territories (in France, the current level of electricity production with the use of wind energy would require 20 thousand km^2, or 4% of the country)
2. Wind energy is an unstable source of energy.
3. Noise pollution (one wind power generator with 2-3 MW capacity makes such a noise that it must be disabled in the night time).
4. Interference in air communication, broad- and telecasting, violation of the bird migration routes (a wind power generator with 2-3 MW capacity must have rotor 100 m in diameter).
5. Violation of the natural air circulation causes local climate change.
6. Hazard to migratory birds and insects.
7. Alteration of conventional shipping, affection of marine life (wind power plants are installed in the offshore area in order to save land resources).
8. Landscape incompatibility, unattractiveness, visual aversion, discomfort.

Environmental performance of solar energy

Solar power plants (SPP) are effective only for areas with high level of insolation. For the midland of the European part of Russia, the solar radiation intensity is 150 W/m^2 – that is 1,000 times less than heat flux from thermal power plants (TPP). When using SPPs, a number of environmental problems arise:

1. Withdrawal of vast territories and their eventual degradation: an SPP with 1 GW capacity (el.) and 10% efficiency factor, being located in the midland of the European part of Russia, requires an area of 67 km^2.
2. Dim-out of vast territories because of the solar concentrators.
3. High material consumption (time and human resources costs are 500 times more than in conventional energetics).
4. Eventual leakage of working fluids containing chlorates and nitrites.
5. Overheating and inflammation of the systems, contamination of the production by toxic chemicals when using solar systems for agricultural purposes.

6. Change of the heat balance, humidity and wind rose within the SPP's site.
7. Climatic effect caused by the cosmic SPPs.
8. Transmission of the power from the space to the Earth in the form of microwave radiation, which is unsafe for the living organisms and humans.

Environmental performance of bioenergy

Adverse effects of the bioenergetics on the environment include (Review of modern biomass technologies, 2002):

1. Emissions of PM, carcinogens, toxic chemicals, carbon oxide, biogas and bioalcohol.
2. Heat emission, change of the heat balance.
3. Loss of the soil organic matter, soil depletion and erosion: production of 1,000 MW from biogas requires manure from 80 million pigs or 800 million birds and a territory of 80-100 km^2.
4. Explosibility: biogas plants must be duly verified and kept in order according to the instruction manual.
5. Great amount of waste by-products (flushing water, distillation residues).

RESULTS

Eco-efficiency evaluation of the power generation's impact on the environment, carried out by the authors on the basis of scoring the different methods of electricity generation, allowed a comparative analysis of the environmental performance of electricity generation by energy type on the basis of the seven key indicators: amount of greenhouse gas emissions, amount of harmful substances emissions into the atmosphere, disposal of harmful substances into water, generation of waste, land withdrawal, emission of the radioactive substances into the environment, and risk for humans (Table 4).

Table 4. Environmental performance of various methods of energy production

N	Indicator	Points					
		Coal	Gas, oil	Hydropower	Solar	Wind	Atomic energy
1.	Amount of greenhouse gas emissions	10	7.2	0.1	0.7	0.3	0.1
2.	Amount of harmful substances emissions into the atmosphere	10	4.3	0.1	5	0.1	0.1
3.	Disposal of harmful substances into water	5	0.4	0.1	0.1	0.1	0.1
4.	Generation of waste	10	1.7	0.1	3	3	0.1
5.	Land withdrawal	0.1	0.1	10	3.3	5	0.1
6.	Emission of the radioactive elements into the environment	10	0.4	0.1	0.1	0.1	5
7.	Risk for humans	10	0.3	0.9	2.9	0.2	0.5

The authors developed a cumulative complex index for the evaluation of the parameters' impact on the environment. These seven key environmental indicators were assessed using a 10-point scale: 10 points – the most negative impact (actual value), 0 points – no impact. The calculated values of the cumulative complex index of the impact on the environment are represented in Figures 4 and 5.

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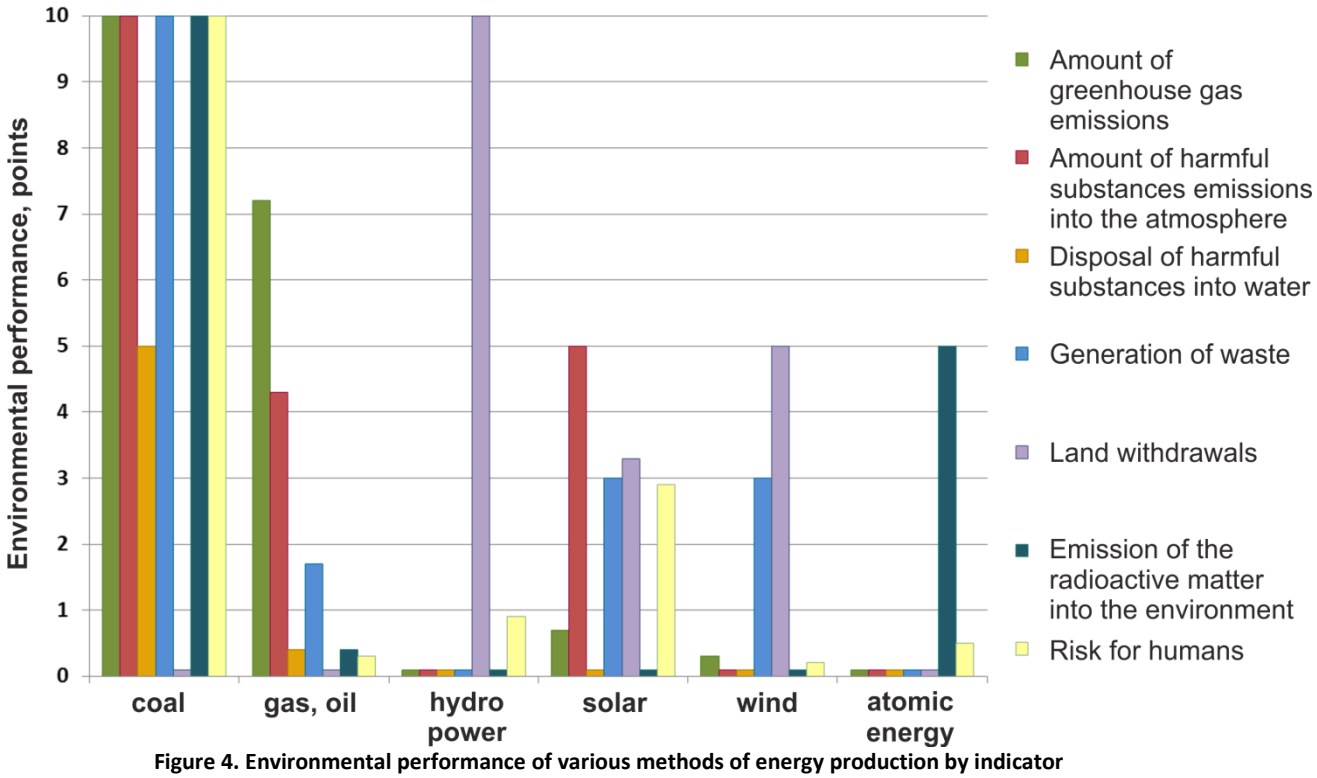

Figure 4. Environmental performance of various methods of energy production by indicator

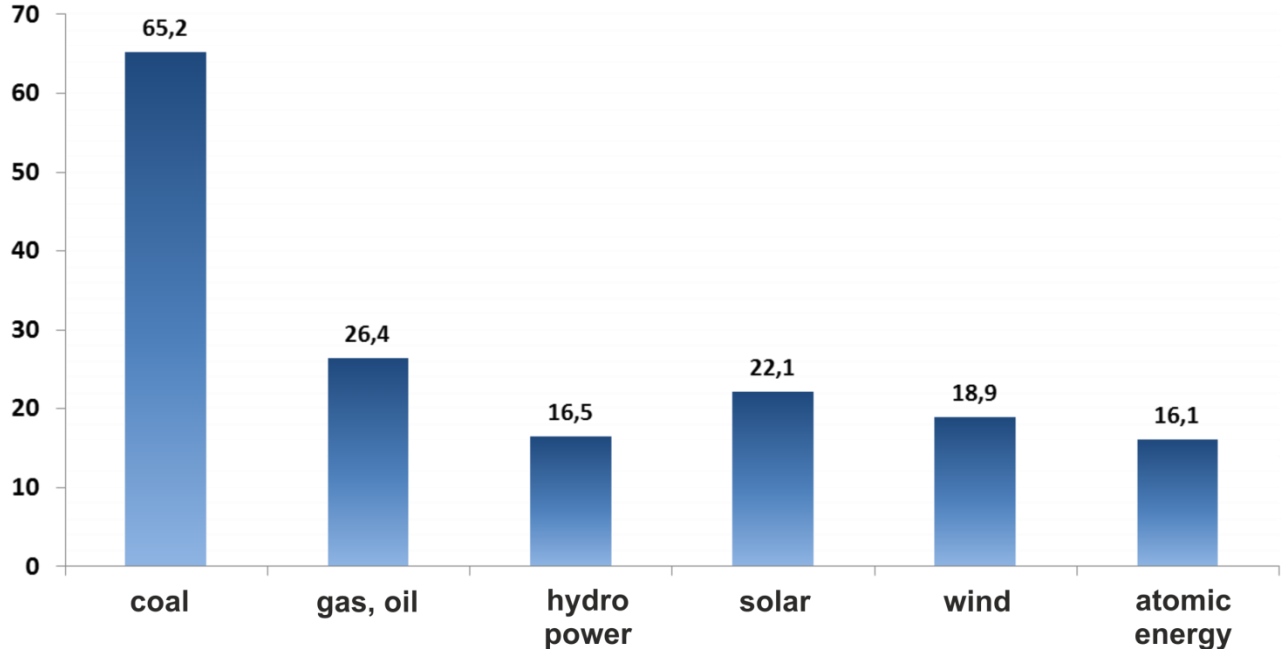

Figure 5. Cumulative complex index of the negative impact on the environment and humans by energy type

According to the calculation data, in terms of greenhouse gas emissions, the 1st place – the most "hazardous" – belongs to coal; gas and oil are by 28% less "hazardous"; hydro, solar, wind, and nuclear energy are insignificant indicators – there is only concomitant release of greenhouse gases during power generation. The same with the emissions of harmful substances: the highest point is for coal, half of that – for oil, gas and solar panels. The situation is similar for the waste.

When it comes to the withdrawal of land, hydropower and solar energetics are in the lead as "hazardous".

As for radioactive substances, one would think that nuclear energy is the leader, but it turns out that due to the perfectly designed operation, in the normal operation mode, actual emission of radioactive substances into the environment is twice lower than in the combustion of coal.

CONCLUSIONS

In the view of the above, several general conclusions may be drawn:

At the present stage, oil remains the dominant source of energy in the global economy, providing more than 1/3 of the total energy demand, first of all, of the transport sector. However, since the beginning of the 21st century, the global extraction of this energy source has increased at a rather low rate (less than 1% a year); in the new decade, the technological complexity (and financial cost) of oil production keeps on growing. Moreover, oil has become a destabilizing factor in the sustainable development

Technical advance in the sphere of renewable energy sources has achieved rather high growth rates in green power production (17-19% annually). However, because of the high initial capital intensity, wind, solar, geothermal and other renewable energy sources as yet provide less than 2% of the commercial energy supply. These renewable energy sources are harnessed only in few countries: half of the world renewable energy sources' capacity is owned by four countries – the USA, Germany, China and Spain.

Global environmental challenges are the climate, resource depletion, waste, and purity of the air and the global ocean. The impact and the amount of these challenges are increasing, while the compensatory capabilities are being impaired. Solution to these global issues requires a tremendous amount of energy, and the energy itself turns into a challenge due to the depletion of energy reserves and growing negative effect of energy generation.

Development of the renewable energy sources will be based on the innovation, not on the technology of yesterday. In the near future (current century prospect), renewable energy will remain the auxiliary energy source for solving local problems.

Comparison of the environmental performance in the context of global and local environmental problems gives evidence that nuclear energy use is the most promising, having the best cumulative complex index.

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