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ENVIRONMENTAL EFFECTIVENESS OF ENERGY TECHNOLOGIES

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ABSTRACT: The paper compares key energy technologies, such as coal, hydrocarbons, hydropower, solar, wind, and nuclear energy based on the following indicators of environmental effectiveness: specific energy per unit mass, carbon footprint, direct release of greenhouse gases, emission of harmful substances into atmosphere, discharge of harmful substances into water sources, waste generation, alienation of land, emission of radioactive substances, human health risk. The author analyzes specific values of environmental effectiveness indicators for different energy production technologies and introduces the term of the comprehensive cumulative indicator of energy technologies impact on the environment and humans (CII). It is proved that coal-fired power generation, with the highest greenhouse gas emissions and carbon footprint of all the energy technologies under consideration, has the most harmful effect on the environment, life and health of the population and personnel. Comparison of all indicators and CII among all types of energy technologies speaks volumes for advantages of nuclear energy, having the lowest carbon footprint in Europe comparable to the carbon footprints of hydro and wind power according to the global data.

Keywords: Power engineering, Environment, Environmental effectiveness

1. INTRODUCTION.

1.1 Relevance of the Problem

The environmental effectiveness of energy technologies depends on the source of initial energy used, and is determined by the impact of this technology on the environment, as well as by the environmental safety for staff and population.

Energy generation for human needs is always associated with certain global environmental issues, such as climate change, pollution of the atmosphere, hydrosphere, and lithosphere, etc.

It stands to reason that some energy technologies are not directly associated with release of greenhouse gases and therefore do not affect global climate change. However, to design devices to convert solar or wind energy, or to build a nuclear power plant, it is necessary to produce construction materials, equipment, carry out construction works, and use materials and means of transport for their operation, etc., that in turn, is associated with release of greenhouse gases, and therefore global climate change.

A composite index of such impact is the carbon footprint. And this is not the only indicator. Important environmental indicators include also mass, withdrawn from Nature per unit of produced energy, the release of harmful gases, dust, discharge of harmful substances into water sources, waste generation, alienation of land resources, emission of radioactive substances, and the risk to personnel and the population.

Analysis of all these indicators and selection on this basis the optimal energy sources is an important scientific problem.

1.2 Research Purpose and Objectives

The objective of this work is giving an unprejudiced, scientifically well-grounded analysis of all available data on ecological indices of energy technologies, as well as proposing a methodology for their assessment and comparing different energy technologies based on selected indicators.

1.3 Research Methodology

To compare, we have selected the following energy technologies, based on the use of coal, hydrocarbons, hydropower, solar, wind, and nuclear energy.

The following factors were considered as indicators of environmental effectiveness:

1. Specific energy per unit mass;
2. Carbon footprint;
3. Direct release of greenhouse gases;
4. Emission of harmful substances into atmosphere;
5. Discharge of harmful substances into water sources;
6. Waste generation;
7. Alienation of land;

8. Emission of radioactive substances;
9. Human health risk.

To conduct systemic analysis, we used generally accepted data sources available from International Energy Agency, the Parliamentary Office of Science and Technology of the UK (POST), etc.

2. RESEARCH RESULTS AND DISCUSSION

2.1 General Environmental Characteristics of Energy Technologies

2.1.1 Coal-fired power engineering

In recent years, the situation with the impact of coal energy on the condition of the air basin has become particularly acute. In countries, such as China and India, this has become a very serious problem. Emissions of harmful substances from coal combustion contain the following compounds:

- Sulphur dioxide SO2, causing the formation of acid rains, as well as respiratory and cardiovascular diseases.
- Nitrogen oxides NOX, causing the formation of smog and respiratory diseases.
- Particulate matter, causing the formation of smog, haze, respiratory diseases and damaging lungs.
- Carbon dioxide CO2, being a greenhouse gas, absorbs infrared radiation contributing to the accumulation of heat in the atmosphere that leads to temperature rise.
- Mercury and other heavy metals, causing developmental disorders and neurological impairment in humans and animals. Spilling mercury in water leads to the biological process of transformation of mercury into methyl mercury, a highly toxic chemical, which is accumulated in fish, animals, and humans.
- Fly ash and bottom ash; leaching out these chemicals from storage and dumping sites into the groundwater, as well as breakthrough of several major ash dumping sites have become acute environmental problems.

According to the data of the University of Stuttgart (Germany) for 2013 [1], the exposure of harmful emissions of coal-fired power engineering results in 22,100 premature deaths per year. This would amount to 2,700 additional deaths per year at the launch of 50 new coal-fired plants. This is exactly the number of coal-fired plants that are launched in China every year (that is, every week, a new coal-fired station becomes operational) [2].

In total, 237,000 lives are already lost. Besides, coal mining is characterized by the following negative consequences [3]:

- Change in topography and landscape;
- Water pollution;
- Diverting methane from the mines to the atmosphere;
- Subsidence over the ore mines;
- Leakage of acidic water from mines;
- Long-term occupation of large areas of land;
- Fine ash dusting;
- Pollution of the atmosphere, soil, and water by heavy radioactive metals.

According to 49 scientists, Nobel Prize laureates, the consequences of the enhanced greenhouse effect on the planet can be comparable only with the consequences of nuclear war [3].

2.1.2 Natural gas-fired power engineering

The use of hydrocarbon fuel sources is the most secure. It is well known that the converting power equipment to natural gas firing reduces harmful effects by several orders of magnitude. In foundries, the use of gas fired cupola furnaces instead of coke fired ones [4] reduces the dust emission by 300 times, while toxic carbon monoxide – by 100 times.

Fig. 1 shows the emissions of CO2 from different energy sources [5].

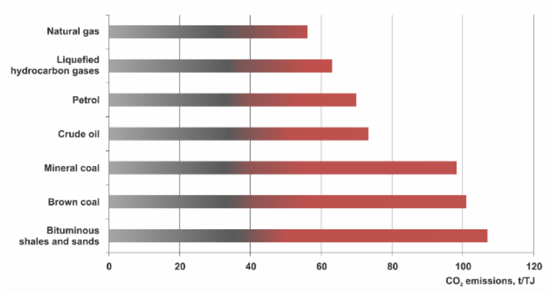

Fig. 1 Emissions of CO2 from different types of fuel, t/TJ.

At the same time, shale gas has significantly worse environmental performance than traditional natural gas. Shale gas has a negative impact on the environment, which is expressed as follows [6, 7]:

- disruption of ground and surface waters (including drinking water), change of their quantity and quality;
- the need for the disposal of water and hydraulic fracturing fluid (HFF); for example, Schlumberger recommends to dispose the wasted HFF as hazardous waste;

- the risk of HFF leakage, which may contain potentially hazardous chemicals (brines, heavy metals, radionuclides, and organic compounds);
- degradation of land resources, soil erosion, landslides, and reduction of fertility;
- microearthquakes caused by both fracturing process and re-injection of wastewater.

2.1.3 Oil

Oil reserves at the current production levels will last for 50 years (and for 60-100 years, taking into account the commissioning of new fields).

Adverse impact of oil on the environment is expressed as:

- formation of by-products from the combustion of petroleum products, such as carbon dioxide (CO2), carbon monoxide (CO), sulfur dioxide (SO2), nitrogen oxides (NOX), and volatile organic compounds, particulate matter, lead, and various toxic substances that pollute the air (benzene, formaldehyde, acetaldehyde, and 1.3-butadiene);
- chemical pollution of groundwater during extraction, chemical and thermal pollution of surface waters, formation of an oil film (the annual pollution of land and water area amounts to 15 mln tons);
- violation of the fauna and flora habitats;
- pollution and degradation of soil covering;
- significant water intake.

2.1.4 Hydropower energy

It would seem that this technology is free from emission of greenhouse gases, however, it is not. The emission of greenhouse gases by hydropower plants can exceed emissions from conventional oil fired thermal power plant, if the area of the reservoir is quite large relative to the hydropower plant capacity (100 W per 1 m2 of the surface), and deforestation in flooded areas have not been conducted [8].

Adverse effects on the environment are as follows:

- flooding of agricultural land and settlements;
- violation of the water balance upstream and downstream;
- the impact on flora and fauna;
- climate impacts (change in heat balance, an increase in precipitation, wind speed, cloud cover, etc.);
- siltation of the reservoir upstream and erosion downstream;
- deterioration of self-purification of flowing water and reduction of the oxygen content;
- obstruction of the free migration of fish;
- liberation of significant amounts of methane and CO2.

2.1.5 Solar energy

Solar power plants are only effective in areas with a high level of insolation. In the middle belt of the European part of Russia the intensity of solar irradiance is 150 W/m2, which is 1,000 times less than heat fluxes in boilers of thermal power plants. Using solar energy leads to the following environmental problems:

- alienation of large land areas and their possible degradation; for example, solar power plant of 1 GW in the middle belt of the European part of Russia at an efficiency of 10% requires minimum area of 67 km2;
- shading of large areas by solar concentrators;
- greater consumption of materials (costs of time and human resources are 500 times higher than in the traditional energy sector);
- possible leaks of fluids containing chlorates and nitrites;
- superheating and ignition of systems, product contamination with toxic substances during the use of solar systems in agriculture;
- change in heat balance, humidity, wind direction in the area of the station location;
- impact of space solar power plants on climate;
- transmission of energy to Earth in a form of microwave radiation, which is dangerous to living organisms and humans.

Fig. 2 shows that solar energy sector is not so inoffensive from the viewpoint of waste generation.

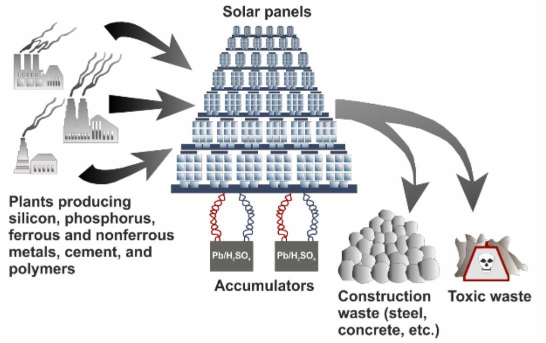

Fig. 2 Waste from solar energy

In addition, solar energy requires large areas (Fig. 3).

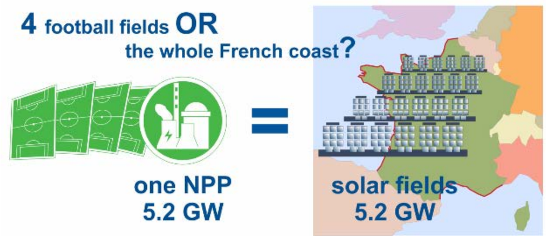

Fig. 3 Area required for solar power plant

2.1.6 Wind-power engineering

Wind-power engineering has the following adverse effects on the environment:

- alienation of large land areas (to ensure France with electricity generated by wind-power, it is necessary 20 thousand km2 of land that is 4% of the country's area);
- interference with air traffic and radio and television broadcasting;
- adverse effects on marine animals (in the case of offshore wind turbines);
- local climate change due to the disruption of the natural circulation of air flow;
- violation of migration routes of birds (installation with a capacity of 2.3 MW has a diameter of wind wheel equal to100 m);
- danger to migrating birds and insects;
- noise impact (a plant with a capacity of 2-3 MW should be stopped at night time due to noise);
- incompatibility in terms of landscape, unattractiveness, visual pollution;
- need to change the ways of traditional maritime transport in the region of offshore wind power plants.

Solar and wind power facility can be useful and relevant at local scales. Nevertheless, the growth of wind power engineering is observed from year to year [9].

2.1.7 Nuclear power engineering

Nuclear power engineering has the following characteristics:

- Nuclear power plants (NPP) neither consume oxygen, nor emit harmful chemicals into the atmosphere and waterways. They save consumption of fossil fuels, the reserves of which are very limited.
- Design solutions to ensure nuclear, radiation and ecological safety of nuclear power plants are based on the requirements of national standards, which are guided by recommendations of International Atomic Energy Agency (IAEA), International Commission on Radiological Protection (ICRP), as well as guided on the experience in the design, construction, and operation of civil nuclear power facilities, built according to Russian projects.
- Parameters of external effects adopted in the design of the contemporary Russian NPP correspond to the most rigid world requirements, such as the impact caused by the hit of a heavy aircraft, while on some parameters even surpass international standards (in particular, the pressure in the shock wave front that may occur as a result of explosion of combustible materials at the NPP site, exceeds the level taken in similar international projects by three times).
- Implementation of safety functions is provided by a set of equipment, which includes devices with active and passive principles of action.

However, there is a problem concerning radioactive waste disposal.

Problems related to spent nuclear fuel (SNF) and radioactive waste (RW). The basic principle of RW management is "concentration and isolation". However, the mere concentration is not sufficient; RW should be conditioned, i.e. transferred into a chemically stable, ecologically safe condition. Therefore, all liquid wastes are converted into a solid form (e.g. cement blocks). Solid RW, having sufficient chemical stability and mechanical strength, are loaded in special protective containers, and the containers are sent to special storage facilities or final disposal sites. Environmental safety in the disposal of RW is ensured by the principle of multibarrier protection.

This issue can be solved radically by transition to a closed fuel cycle in nuclear power engineering. Thom Blees, President of the Science Council for Global Initiatives, in his book [2] describes in detail the story of how he was blocked in the United States. The oil lobby won. But this is really a way out of all problems.

Energy generation in nuclear reactors is due to fission of uranium and plutonium. In thermal neutron reactors (TNR), radioactive isotopes of uranium-235 and plutonium-239 are exposed to fission. Uranium-238, the content of which in the source nuclear fuel (enriched uranium) amounts to 95%, is not subjected to fission. By absorbing neutrons, uranium-238 is converted, ultimately, into plutonium-239.

In fast neutron reactors (FNR), uranium-238 under the impact of fast neutrons also absorbs fast neutrons and forms plutonium-239. At that, formation of plutonium-239 from uranium-238 through absorption of fast neutrons is much more efficient. Therefore, FNR can generate plutonium-239 in much more quantities than thermal neutron reactors (breeding factor in FNR can be more than 1).

Since plutonium-239 is subjected to fission under the impact of thermal and fast neutrons, then due to its use as nuclear fuel, uranium-238, the proportion of which in natural uranium amounts to more than 99%, also becomes involved in nuclear fuel cycle.

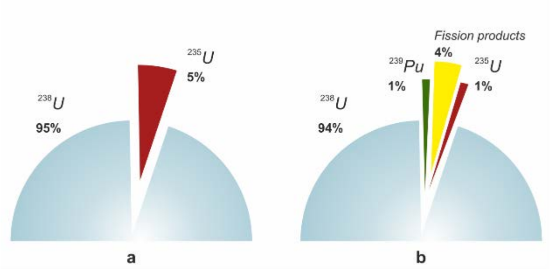

Fig. 4 The structure of enriched (a) and irradiated (b) uranium

The use of TNR in the open nuclear fuel cycle leads to high consumption of natural uranium. The open nuclear fuel cycle of TR is characterized by low utilization effectiveness of natural uranium (less than 1%) because only radioactive uranium-235 is used.

Radiochemical technologies enable to extract from the spent nuclear fuel (SNF) and generate for reuse more than 95% remaining uranium-238 and uranium-235, as well as formed plutonium-239 (from uranium-238).

Development of nuclear power engineering and any other high technology industry is to be based both on existing researches and innovative projects. Fast neutron reactors are an example of the innovative approach in power engineering, and Russia acts as an acknowledged leader in their construction and operation. FNRs allow to make nuclear power engineering more safety and to solve a number of environmental issues.

Closed nuclear fuel cycle is the cycle in which SNF unloaded from the reactor is reprocessed to extract uranium and plutonium for subsequent reproduction of nuclear fuel.

In closed fuel cycle, the SNF after aging in temporary storage is transported to the processing plant for reprocessing. After reprocessing, the plutonium accumulated in SNF, as well as remaining uranium, can be reused for the production of nuclear fuel. However, only a small portion of useful fissionable substance (about 1%) is lost in the course of reproduction and fabrication of nuclear fuel, and turns into RW. The use of SNF in fuel fabrication (recycling) promotes more effective use of natural uranium, reducing its costs per unit of installed nuclear capacity at NPP.

Other, less common energy sources are biomass, geothermal energy, tidal and marine energy, and hydrogen energy.

2.1.8 Biomass

Biomass has negative impacts on the environment, such as:

- negative effects on biodiversity (replacement of natural flora by energy crops);
- depletion of soil organic matter, soil depletion and erosion (generating biogas from manure to produce 1 GW of electricity requires 80 mln pigs or 800 mln poultry on the area of 80-100 km2);
- deterioration of drinking water quality and the acidification of soils resulting from the application of pesticides and fertilizers;
- emissions of particulate matter, carcinogenic and toxic substances, carbon and nitrogen oxides, biogas, and bioethanol;
- heat release and change of heat balance;
- explosiveness (biogas plant should be monitored and maintained in good condition);
- large amounts of waste in the form of byproducts (wash water, and distillation residues).

At a time when one million people on the planet are undernourished, it is unethical to consider food as fuel, not to mention the scope and capabilities of using this type of energy source.

2.1.9 Geothermal energy

Geothermal energy also has limitations in application and negative impacts on the environment:

- the alienation of land;
- change of groundwater level, land subsidence, and water logging;
- Earth's crust shifts, increase of seismic activity;
- emission of toxic gases (vapors of mercury, methane, hydrogen, sulfide, ammonia, carbon dioxide, and carbon monoxide);
- heat release into atmosphere or into surface waters;

- discharge of the poisoned water and condensate contaminated with ammonia, mercury, and silica;
- contamination of groundwater and aquifers, as well as salinization of soils;
- outflow of large amounts of brines in case of pipeline rupture.

2.1.10 Tidal and marine energy

Tidal and marine energy is not harmless as well. Adverse effects on the environment consist in the following:

Tidal energy:

- periodic flooding of coastal areas, changing land use, flora and fauna of the waters around the tidal power plant;
- construction turbidity of water, surface discharges of contaminated water;
- used turbines are dangerous to wildlife (birds and fish).
- Marine energy:
- coastal erosion, the change in the movement of coastal sands;
- water pollution in the course of construction, and surface discharges.

2.1.11 Hydrogen energy

Hydrogen energy is not an independent source at all. To produce hydrogen we must either decompose water or hydrocarbons. This is not the energy source that can replace the fuel in the vehicle and eliminate CO2 emissions. Despite the fact that hydrogen is environmentally friendly energy carrier, hydrogen production requires using so much energy that the question of the appropriateness of using hydrogen as a fuel does not arise at all. Another matter is, if people could discover a way to produce hydrogen without energy use. But this is kind of "perpetuum mobile", the practical implementation of which, as well known, is impossible.

2.2 Ecological Indicators of Energy Technologies

2.2.1 Consumption of mass of material resources, or energy output per unit of mass of used substance

Comparison of energy technologies based on mentioned indicator is given in Table 1. Fuel energy is the least effective, although the advantage of hydrocarbons is evident. Hydro, solar and wind energy are secondary sources of fusion reactor such as Sun. Unlike fuel power generation, generation of energy from hydro, solar and wind sources does not require any substance as fuel. Transforming directly substance into energy in accordance with the known law E = mc2 is the most effective way of energy generation.

Table 1 Comparison of energy technologies

Energy technology	Amount of energy produced from 1 kg of used substance, kWh
Coal technology	7
Hydrocarbon technology	14
Hydropower technology	No substance needed
Solar energy technology	No substance needed
Wind energy technology	No substance needed
Nuclear technology	
Nuclear	24 000 000
Fission	60 000 000
Quark-gluon plasma	6940387213578000

2.2.2 Carbon footprint

In recent years, carbon footprint has become the most popular indicator, although it is part of the ecological footprint [10]. There is also water footprint. Though, the contribution of ecological footprint is now the most relevant [11].

Carbon footprint is historically defined as the amount of greenhouse gases caused by particular technology or activities of organizations, i.e. actions related to manufacturing and transportation of products, or human activity.

The exact total amount of carbon constituting the "carbon footprint" cannot be calculated reliably due to the need of collecting a huge amount of accurate data for this purpose, as well as the fact that carbon dioxide can be produced also in the course of natural processes.

Greenhouse gases are formed when using transport vehicles, growing and harvesting crops, consuming products, fabricating goods, materials, logging, constructing roads and buildings, as well as rendering various services.

A large portion of the carbon footprint is formed by "indirect" sources. They include also fuel, consumed during production and delivery of goods produced far from the end consumer. However, this should be distinguished from the greenhouse gases produced due to fuel combustion in vehicles, furnaces or power plants, which are usually called "direct" sources of carbon footprint.

The term "carbon footprint" is a conditional reduction, which allows the best estimation of what the final impact can be caused by climate change with regard to something. This "something" can be anything – an activity, a way of life, a company, a country, or even the whole world.

Largely, the confusion around carbon footprint is reduced to the distinction between "direct" and "indirect" emissions. The carbon footprint of a plastic toy, for example, includes not only direct emissions from production and transportation of this toy to the shop: it also includes a number of indirect emissions, such as those, which are caused primarily by the extraction and processing of oil, used to produce plastic. And this is only part of all processes involved in formation of carbon footprint. Tracing the entire chain of events that could or could not happen when manufacturing this toy, leads to an infinite number of processes, most of which are insignificant. For example, the staff at the offices of the plastic factory uses staples made of steel. But steel also has its own carbon footprint, given the material of machinery and equipment used at the iron mine, where iron ore was originally extracted... and so on to infinity. The carbon footprint of the plastic toy includes a lot of factors, so that accurate determination of carbon footprint is not an easy task.

There are many articles devoted to the calculation of the carbon footprint [12–15]. Works on calculating the carbon footprint of nuclear power engineering are of particular interest [16–22]. The POST [23] studied in detail the carbon footprint of nuclear power engineering. It is shown that according to European data of 2004-2006, calculated carbon footprint for coal-fired power engineering amounts to 1,075 gCO2eq/kWh, while that for the nuclear power engineering ranges from 3.5 to 5 (Fig. 5).

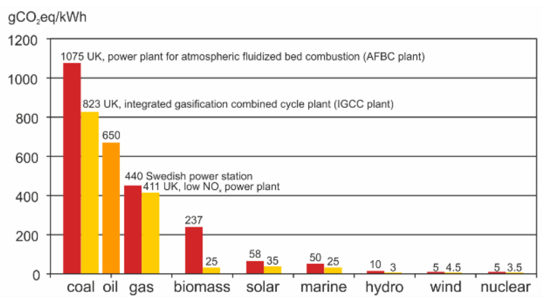

Fig. 5 Carbon footprints of electricity generating technologies, data for the UK and EU, 2004–2006. Source: POST

Global data, i.e. the data taken for the whole world, gives approximately the same results (Fig. 6).

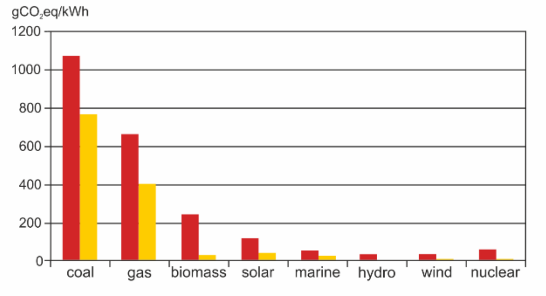

Fig. 6 Worldwide carbon footprint, global assessment. Source: POST

2.2.3 Human health risk

According to the Commission of the European Communities and the U.S. Department of Energy, the health damage of the population is the least in the case of wind and nuclear power engineering (Fig. 7).

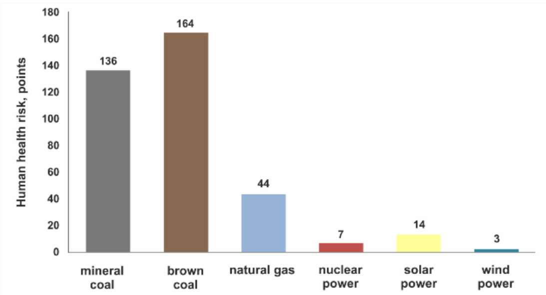

Fig. 7. Human health risk caused by different energy technologies

The reports on assessment and comparative analysis of "the external price" of different energy production types issued by the Commission of the European Communities (in cooperation with the U.S. Department of Energy) compare health damage to the whole European population (480 mln. people) at generating energy based on different energy carriers. Human health damage is shown in natural values – lost years of life per TWh – and presented in an averaged way. The results speak volumes for absolute advantages of the nuclear fuel cycle (NFC) as compared to hydrocarbon power engineering.

Besides, the studies have shown that coal and oil energy production cost will double, and energy production cost at gas burning will increase by 30%, if such "external costs" as environmental and human health damage are taken into account. It was calculated that such costs amount to 1-2% of EU GDP.

Although there are data proving high environmental safety of nuclear technologies, the state and the society view everything that is connected with nuclear technologies negatively. It can be explained by rather objective causes –

severe accidents at FGUP PO Mayak and Chernobyl Nuclear Power Plant – and results from exaggerated, amateurish assessments and politicization of the problem.

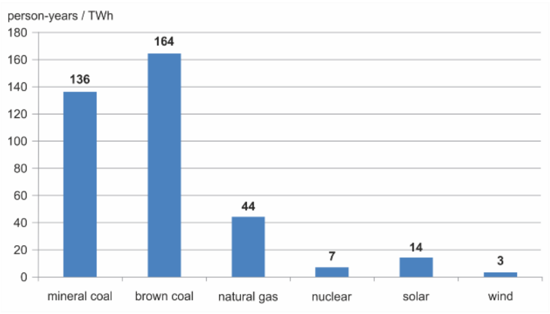

Fig. 8 Human health damage in Europe caused by different energy technologies, lost years of life per TWh

Another important cause for an inappropriate perception of NFC plants operation, nuclear power plants inclusive, is exaggerations in the applicable regulatory and legal framework related to radiation safety, and we think that it is marked out by excessive, groundless rigidity of standards and rules.

It is clearly seen at comparing existing radiation and chemical safety standards from a perspective of health risk assessment. Comparison of risks caused by ionizing radiation and some chemical carcinogens at the level of adopted standards has shown that the standard radiation risk is hundred times less than chemical carcinogenesis risks (Fig. 9). Number of chemicals, which impact creates unacceptable risks at the level of approved standards, is rather big.

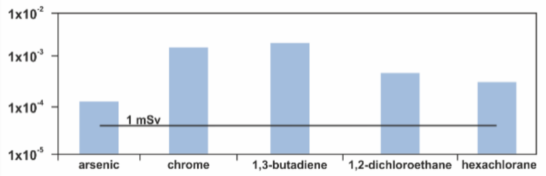

Fig. 9 Individual carcinogenic lethal risks of the yearly dose of human radiation (1 mSv/year) and some chemicals at community ambient air standards

Exaggerations in the regulatory and legal framework and lack of a statutory unitary criterion for qualitative comparative assessment of impact of different technogenic factors in the form a unitary health risk (damage) measure result in inconsistency of data on substance (radioactive, chemical, etc.) and process impact levels, and, thus, adoption of false managerial decisions on energy technology development priorities.

2.3 Rating of the Energy Technologies Impact

The author of the present article proposed a comprehensive point rating system of the impact of energy technologies on the environment. It allows conducting a comparative analysis of environmental effectiveness of electric energy production when using different energy resources based on seven major indicators: the amount of greenhouse gas emissions, the amount of harmful substances' emissions to atmosphere, the amount of harmful substances' discharge into water sources, waste generation, the alienation of land resources, emission of radioactive substances into the environment, and human health risk (Table 2).

Table 2 Comparative environmental effectiveness indicators for different energy production technologies

Indicator	Rating of various energy generation technologies					
	Coal	Gas, Oil	Hydro-power	Solar energy	Wind energy	Nuclear energy
Amount of greenhouse gas emissions	10	7.2	0.1	0.7	0.3	0.1
Amount of harmful substances' emissions to atmosphere	10	4.3	0.1	5	0.1	0.1
Amount of harmful substances' discharge into water sources	5	0.4	0.1	0.1	0.1	0.1
Waste generation	10	1.7	0.1	3	3	0.1
Alienation of land resources	0.1	0.1	10	3.3	5	0.1
Emission of radioactive substances into the environment	10	0.4	0.1	0.1	0.1	5
Human health risk	10	0.3	0.9	2.9	0.2	0.5

For a comprehensive evaluation of the impact of all considered factors on the environment, the author developed the comprehensive cumulative indicator of the impact on the environment and humans. When calculating cumulative indicator, seven most important environmental indicators were estimated on a 10-point scale: 10 points meant the most harmful impact (by actual value), while 0 points – no impact.

The calculated values of the comprehensive cumulative indicator of the impact on the environment and humans are shown in Fig. 10.

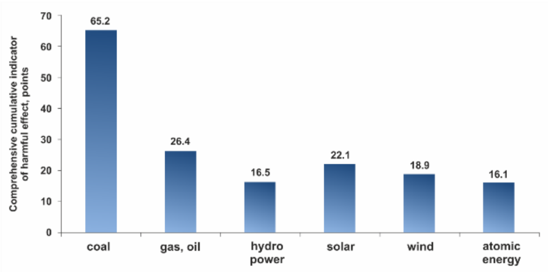

Fig. 10 The comprehensive cumulative indicator of harmful effects on the environment and humans

The calculations of the environmental impact indicators have revealed that in terms of greenhouse gas emissions, coal occupies the 1st place, whereas contribution of gas and oil are by approximately 28% lower than coal; hydropower, solar, wind, and nuclear energy have very small indices, i.e., they are characterized by only a concomitant release of greenhouse gases when generating energy.

When considering the impact of harmful substances' emission into environment, it was revealed that the greatest emission is peculiar to coal, while oil and gas emissions are twice lower, though roughly comparable emissions are associated with the production and disposal of solar panels. Similar situation was observed with regard to wastes. The impact on the environment in the context of land resources' alienation is typical to the greatest extent for hydro and solar energy.

It would seem that in the context of the radioactive substances' emission into the environment, nuclear power engineering would take leading position, though actually it turns out that due to the highest perfection of the processes in the nuclear power engineering, the actual emissions of radioactive substances into the environment in the nominal regime are half that of coal combustion. Thus, based on the comparison of environmental impacts of various power generation technologies, we can conclude that according to all indicators, nuclear power engineering looks more preferable from the viewpoint of both global and local environmental problems.

3. CONCLUSIONS

Comparison of energy technologies on specific energy per unit mass, carbon footprint and release of greenhouse gases, emission and discharge of harmful substances, waste generation (normal and radioactive), alienation of land and human health effect applying the term of the comprehensive cumulative indicator of energy technologies impact on the environment and humans, introduced by the author, allowed the following conclusions:

1. Coal-fired power engineering has the most harmful environmental and human health effect. Its emissions and discharges contain SO2, causing the formation of acid rains, mercury, heavy metals, ash and dust solids polluting air and water; radioactive substances, which quantity exceeds the ones from the nuclear station of equal capacity. Greenhouse gases emissions and carbon footprint are the highest of all energy technologies.
2. Natural gas-fired power engineering shows better values as compared to the coal one. Transition to the natural gas reduces emissions of dust 300 times, carbon monoxide –100 times, and greenhouse gases – 2 times. At the same time, shale gas has significantly worse environmental performance. Hydraulic fracture is highly dangerous – it has a negative impact on water resources.
3. Hydropower engineering requires alienation of large land areas (67 km2 per 1 GW). Wind and solar power engineering has permissible environmental indicators.
4. Nuclear power engineering has the best environmental indicators. Nuclear power plants do not consume oxygen and do not pollute the air and water resources with harmful chemicals; they highly save consumption of organic fuel, which supplies are rather tight. Its carbon footprint is the lowest in Europe and is almost the same as of hydro and wind power engineering based on data for the whole world.

4. REFERENCES

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