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ANALYSIS OF INDICATORS OF THE ELECTRICAL POWER PRODUCTION ENTERPRISES' POLLUTION AND HARM RISK DEGREE IN TERMS OF THE PARIS AGREEMENT

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Abstract:
In the current decade, electricity consumption will increase by more than 16%. The main resources for electricity generation are oil – 2.53%; gas – 22.9%; coal – 35.98%; nuclear industry – 9.84%; hydraulic power regeneration – 15.01%; renewable sources – 12.85%; other – 0.89%. This causes global warming of the planet due to greenhouse gases increased emissions into the atmosphere. A resource capable to cover the thermal energy field's balance is the nuclear energy. To compare the resources' polluting capacity, it is necessary to introduce a general indicator that takes into account their properties. This study proposes an integrated approach based on the formation of groups of indicators reflecting greenhouse gas emissions; power consumption; economic activity, air quality, etc. For comparison needs, all indicators are normalized in dimensionless form and compiled with reference to their specific weight. Calculations of the pollution index for fossil resources and nuclear energy, carried out using this algorithm proved that the nuclear power, with a careful consideration of all possible polluting radionuclides (11 components), exceeds this indicator for gas by 22%, but is lower than ciphers for coal and oil by 36 and 26%, respectively. For two latters only 3 specific components being taken into account. Therefore, it seems advisable to use the considered complex indicator of environmental pollution to assess the resource safety level for electricity generation.

Key words: electricity, resource, production, pollution, environment, indicator

INTRODUCTION

In the modern world, energy is the key stone for the development of basic industries that determine the progress of public production. In 2021, according to British Petroleum [1], 28,466.3 TWh of electricity was produced worldwide. Among the main sources of electricity generation by fuel type are: oil – 720.3 TWh (2.53%); gas – 6518.5 TWh (22.9%); coal – 10244.0 TWh (35.98%); nuclear industry – 2800.3 TWh (9.84%); hydraulic power – 4273.8 TWh (15.01%); renewable sources – 3657.2 TWh hour (12.85%); other – 252.2 TWh (0.89%).

By 2030, the demand for electricity may reach 33,275 TWh. At the same time, electricity generation is one of the main sources of climate change (global warming) on the planet. One of this change main reasons is the increase in greenhouse gas emissions into the atmosphere. To address climate issues, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted, which entered into force on March 21, 1994 [2]. In addition to UNFCCC in the Japanese city of Kyoto, on December 11, 1997, the Kyoto Protocol has been adopted, which entered into force on February 16, 2005 [3]. That agreement main goal is to stabilize the greenhouse gas concentrations index in the atmosphere at a level that would prevent dangerous anthropogenic impact on the planet's climate system [4]. The international treaty applies to the six greenhouse gases listed in Annex A to the Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) [5].

The next agreement of the UN Framework Convention on Climate Change became the Paris agreement (2016) [6, 7] which regulates measures to reduce the carbon dioxide content in the atmosphere since 2020. That agreement purpose (according to Article 2) is "to intensify implementation" of the UN Framework Convention on Climate Change, in particular, to keep the global average temperature rise "well below" 2°C and "make efforts" to limit the temperature rise to 1.5°C. The Paris Agreement signatory countries should take, using any available mechanisms, more intensive measures to reduce emissions. The main from among such mechanisms is a systematic reduction of greenhouse gas atmospheric emissions through the transition to new technologies and the production facilities' transfer [8, 9]. Achieving climate neutrality in the energy producing sector should ensure the abandonment of electricity production at coal and gas-fired power plants. At that, the focus is shifter on renewable energy sources, mainly wind and solar power plants. At the same time, the global balance of electricity generation should remain within the same volumes.

In 2021, thermal power plants (TPPs) generated 62% of the world's electrical power [10]. These powerplants run on fossil organic fuels such as natural gas, coal, fuel oil, peat, and oil shale. But when generating electricity at thermal power plants, large volumes of CO_2 and other greenhouse gases that cause climatic change are released into the atmosphere, as well as other harmful substances such as carbon monoxide, sulfur oxide, ash, sulfur dioxide.

In the areas designated by the Paris Agreement as these of the energy complex development without greenhouse gas emissions, the central focus belongs to the renewable energy sources (RES), which include: solar, wind, geothermal, hydraulic energy; the energy of sea currents, waves, tides, sea water temperature gradient, the temperature difference between the air mass and the ocean; biomass of animal, plant and household origin; low-potential heat of ventilation emissions, water from natural and artificial reservoirs, industrial and domestic effluents [11, 12]. However, many types of electricity generation are inappropriate for increasing the capacity of producing plants and for obtaining large amounts of electricity (hydroelectric power plants, wind farms, tidal power plants).

LITERATURE REVIEW

According to research [13, 14] any energy source is characterized by two parameters: the energy density and its transfer rate. Multiplying these values provides us the maximum power that can be obtained from a unit surface using energy of this given kind. For solar energy, this value in near-Earth space is greater than 1 kW/m^2, and at the sea level, taking into account its losses in the atmosphere, the flow value actually possible to use is 100...200 W/M^2. This flow is sufficient for life on the planet, but as the main source of energy for humanity it is extremely inefficient.

Similar problems limit the use of geothermal energy due to the thermal properties of rocks. Hydraulic power of the rivers flow and the use of sea tides never exceeds 5% and is profitable only in mountainous areas, when there is a large potential energy per unit area of the reservoir. The use of wind, energy is also economically unjustified, due to an insufficient energy flow density.

Sources specific with high energy density – fuel cells – are characterized by a low speed of energy transferring, so the actual energy collection does not exceed 200 W/M^2.

In addition, worth considering is such indicator as the installed power utilization rate (IPUR). It characterizes the efficiency of electric power generating enterprises. It is calculated as the ratio of the arithmetic mean power to the installed power of an electrical installation for a certain time period. So, if there are two different power plants: nuclear and solar, producing the same rated capacity (720.000 MWh/month), the solar power plant will produce only 15...30% of this value, since it directly depends on the sun. Just this indicator will be its IPUR.

An alternative source of generating the electric power free from atmospheric emissions and capable to cover the balance part of thermal energy is the nuclear energy industry. According to JRC report [15], the nuclear power plants produce emissions CO_2 on average, 28 g/kWh, which is comparable to the emissions from the hydro- and wind farms, and is even lower than that of solar panels, which average emission is about 85 g/kWh. The figures vary from source to source (for example, the ISRR 2014 report [16] indicates average emissions from nuclear power plants at 12 g/kWh level, and these from industrial photovoltaic cells at 48 g/kWh), but the ciphers' order and ratios are approximately the same. At the same time, the emissions from gas and coal plants are about 500 and 900 g/kWh, respectively. To mention here is that the nuclear generation is 6 times cheaper than the "green" one and 3 times cheaper than the thermal generation [17].

Currently, 31 countries operate the nuclear power plants. As of January 2022, there are 437 power reactors worldwide (not including those shut down for a long time) with a total capacity of about 391 GW, and 57 reactors are under construction [18]. The nuclear power industry can currently be considered as the most promising. This is due both to relatively large reserves of nuclear fuel and to a clearly gentle impact on the environment. This domain advantages also include the possibility of building nuclear power plants without being tied to resource deposits, since the usable resource transportation does not require significant costs due to the small volumes. It is enough to note that 0.5 kg of nuclear fuel shall allow getting the same amount of energy as from burning 1000 tons of hard coal.

Nuclear power plants are safe, reliable and do not emit greenhouse gases, therefore the nuclear power should be considered as the most attractive industry for investment. On the other hand, one can't escape to note the issues of the produced radioactive waste volume, cost of disposal and safety, these requiring a separate study. In addition, the article [19] discusses the risks of technogenic disasters on the example of the Three Mile Island nuclear power plant (1979), Chernobyl nuclear power plant (1986), Fukushima-1 (2011) accidents. Among the accidents' causes, first of all distinguished are errors and shortcomings in powerplants design and the human factor. However, it is noted that after these events, the nuclear power plants' designs were revised in a way ensuring a significant increase in their operation safety.

Taking into account the above, there exists a need to introduce a "General indicator of the energy industry enterprises' development taking into account the environmental component" according to the Paris Agreement. Contamination is the presence of undesirable components in the environment. In the natural environment, this phenomenon occurs in connection with human activity or natural disasters. Exposed to pollution are the atmosphere of the Earth, the waters of open and underground reservoirs, as well as soils. Polluting agents can be either individual substances or complex physical and chemical structures. The main types of environmental pollution are shown in Table 1 [20].

Table 1
Main types of environmental pollution

Physical	Chemical	Biological	Informational
(thermal, noise, electromagnetic, light, radioactive)	(heavy metals, pesticides, plastics and other chemical substances)	(biogenic, microbiological, genetic)	(Information noise, false or erroneous information, factors of concern)

Air is in direct contact with everything on Earth and is an easily vulnerable component of the natural environment. Air pollution occurs when substances are introduced into it that results in a negative effect to the condition of vegetation, animals and humans. These are organic compounds, gases, aerosols, and dust. Such substances can be both products of economic activity and natural disasters (fires, volcanoes, etc.). Natural waters are considered the second most polluted natural resource after air, due to harmful emissions into open and underground reservoirs. Land and soil pollution is mainly caused by economic activities through waste discharges and the use of physical and chemical reclamation. Noise, light, heat, and radiation pollution form a specific group of impacts that carry poorly predictable genetic changes in all three environmental resources [21]. Enterprises that produce thermal and electrical energy create a variety of products that are not typical of the natural environment and are capable of polluting it.

A comprehensive assessment of the state of the territories adjacent to the station is a time-consuming procedure due to the presence of a large number of indicators reflecting various aspects [22, 23]. There are many indexes designed to assess the ecological state of countries, regions and cities, the environmental safety of territories, and so on. Generally, methods for calculating integral indices are based on expert methods [24]. An integrated approach allows to form an objective assessment of the multidimensional parameters system [25].

The purpose of this article is to form a comprehensive pollution assessment for the territories where energy production facilities are located based on the analysis of the observed environmental indicators' values. To achieve the formulated goal, it is necessary to solve the following problems:

- creating a list of observed indicators;
- formation of limit or normalizing values for those observed indicators;
- sequential rationing based on acceptable values, the amounts of resources considered, and observed indicators.

RESEARCH METHODOLOGY

An integrated approach is based on the formation of groups of indicators that reflect certain aspects of the system state. Siemens Corporation, together with The Economist Intelligence Unit, developed an expert methodology for comprehensive urban assessment. Eight groups of indicators: greenhouse gas emissions; energy consumption; urban economy; transport; water use; waste and land use; air quality; environmental management provided a reflection of all aspects of the system's functioning.

For comparison convenience, all indicators are normalized in dimensionless form. The general index is constructed as a quantitative sum of all groups, taking into account their specific weights [25, 26].

Similar expert assessments of the international organizations Mercer Human Resource Consulting and the Blacksmith Institute are also known in urbanism [27]. Other cities' health assessment indexes are structured in the same way.

For example, in the environmental safety of cities are used: the atmospheric pollution index, the threshold mass index of hazardous substances, the total hazard index of individual components that pollute a particular biogeochemical environment (water, air, and soil), and so on.

Indicators are evaluated by rationing parameters' values. If the change intervals are known, the following ratio is used for normalization:

$$I_i = \frac{p_i - p_{i,min}}{p_{i,max} - p_{ii,min}}, \tag{1}$$

where:

p_i – value of the *i*-th parameter for a specific object;

$p_{i,\min}$, $p_{i,\max}$ – respectively, are the minimum and maximum values of this parameter in the group of objects under study;

I_i – corresponding indicator.

The water pollution index is often used to assess surface water pollution:

$$I_{pw} = \frac{1}{6} \cdot \sum_{i=1}^{6} \frac{C_i}{MPC_i}, \tag{2}$$

where:

C_i – values of the observed parameters;

MPC_i – maximum permissible concentrations of pollutants in water.

Integral indicators for evaluation are determined by the relation [23]:

$$I = \sum_{i=1}^{m} a_i \cdot I_i, \tag{3}$$

where:

I_i – indicators in the form of parameters' normalized values;

a_i – weighting factors.

The addition to relative indexes of multi-stage normalization used in [23] is effective. Based on expert assessments, a reliable comprehensive indicator for comparing the environmental load of the environment is obtained.

Analysis of the methods used has shown that there exists series of unresolved problems in the field of integrated assessment [23]:

- methods of comprehensive assessment based on expert approaches do not take into account the analyzed systems' regularities;
- many integral indexes are not adapted to the statistical data obtained from observations;

– equations for calculating indexes have weak resistance to data changes, causing the parameters' values unjustified fluctuations.

The methodology exposed below differs from that used in [27] by replacing expert assessments with monitoring control data or project documentation. To assess the territories pollution, 6 groups containing 33 indicators were used (Table 2).

Table 2
Groups and types of pollution indicators

1 technological		18	^{54}Mn,
1	productive performance,	19	^{51}Cr,
2	energy consumption,	20	thorium,
3	water consumption as a reagent,	21	Uranium
4	water consumption for cooling.	22	tritium in the atmosphere,
2 environmental (emission level)		23	suspensions,
5	heat,	24	tritium in the hydrosphere,
6	water vapor,	25	liquid waste.
7	CO_2 at TPES,	**3 reliability related**	
8	carbon monoxide *CO*),	26	duration of operation,
9	NO_x,	27	level of fixed assets renewal,
10	SO_x,	28	quality of supplied resources,
11	hydrocarbons (5-20%)	29	service security.
12	inert radioactive gases	**4 technical**	
13	^{131}I,	30	own energy consumption.
14	^{137}Cs	**5 institutional**	
15	^{60}With	31	management level.
16	^{90}Sr,	**6 dimensional**	
17	^{89}Sr,	32	territory that deals with the object,
		33	territory of the region.

The technology group contains indicators that characterize the capabilities and needs of the analyzed systems. The environmental group includes a list of all possible undesirable impurities and their emission levels. The third group combines system reliability indicators. In other groups, indicators of the systems' overall characteristics are concentrated.

All available limit values are used as normalizing parameters: the indicator acceptable limit values (R_{max}; R_{min}), maximum permissible emissions (MPE) and maximum permissible concentrations (MPC).

The current values of indicators are taken from the data of operational monitoring or systems' design technical documentation.

The current indicators' values are normalized in several stages.

The initial normalization of the indicators' current values is carried out in accordance with the ratio (1-3). If available data on the maximum permissible concentration (MPC), the normalization was performed according to the ratio:

$$I_i = \frac{C_i}{MPC_i}, \quad (4)$$

where:

C_i – current values *i*-indicators;

MPC_i – MPC value of *i*-th indicator.

After the initial rationing, individual values of indicators are normalized by their sums for the systems being compared.

The resulting normalized values of indicators are summed up for each system and the resulting amounts are normalized by their total amount.

RESULTS AND DISCUSSION

The comparison of the polluting capacity of power plants using fossil resources carried out according to the above exposed algorithm confirmed those powerplants distribution according to the degree of environment saturation with undesirable impurities (Fig. 1).

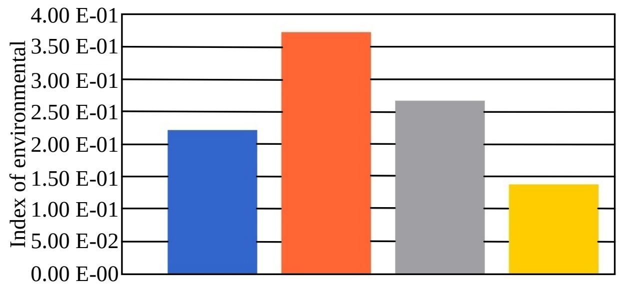

Fig. 1 Index of environmental pollution by power plants depending on the energy resource:
■ – NPP; ■ – coal; ■ – oil; ■ – gas

Analysis of the daily schedule (Fig. 1) shows that according to these conditions, the room heating time is quite long (from 0.00 to 8.00 hours), the system operates at the maximum thermal load for this time. The room temperature during the non-working period decreases from 20 to 10°C, respectively, the heat consumption for heating per day is very significant.

Essential to note is that the source data is general in nature without reference to specific objects. The calculations use weight coefficients in accordance with the recommendations [24, 29, 30, 31, 32]. The results obtained are characterized by high stability, which indicates the stability of the technique used. The maximum permissible value of the environmental pollution index by power plants is determined according to the given eigenvalue rationing scheme and is therefore equal to 1. The environmental pollution index obtained according to the above method is a measure of the maximum permissible relative pollution proportion.

The indicators of the environmental group, characteristic of the nuclear resource and are absent from the resources of the carbon group, by their number do neutralize the nuclear power plants' advantages (Fig. 2).

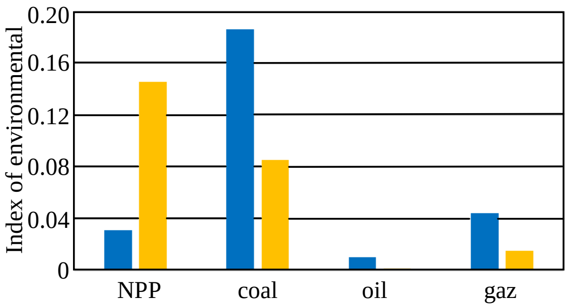

Fig. 2 Index of environmental pollution by power plants depending on the energy resource for production worldwide and in the Ukraine:
■ – global production; ■ – production in Ukraine

The predominant values are specific to the indicators of the technological group and part of the ecological group indicators, inherent in all types of resources. During the rationing process, the predicted pollution is reduced to a single productivity [33, 34, 35, 36, 37]. This allows extending the obtained patterns proportionally to the distribution of electricity production by resource type (Table 3).

Table 3
Electricity generation and pollution by region and resource (%)

Region	NPP	TPP		
		coal	oil	gas
World	10.3/3.1	36.7/18.6	2.8/1	23.5/4.4
Ukraine	55/14.5	19.3/8.5	0.5/0.16	9.3/1.5

CONCLUSIONS

The article reports on the research, within the framework of which a list of 33 observed indicators for a comprehensive assessment of environmental pollution in the production of electricity using fossil and manufactured energy resources has been established. In order to achieve the goals, a set of limit or normalization values of the observed indicators is formed and a sequence of transformation of the observed indicators into a dimensionless form and their rationing according to the permissible values and quantities of the considered resources is developed. Finally, the influence of the resource type and the production volume on the environmental impact of power plants is demonstrated.

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