The New Directions on Development of Renewable Energy Systems

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Abstract. In this article, the authors offer their assessment of the current state and ways of development of electricity and heat generation systems in the world and the Russian Federation, considering the development prospects of renewable energy systems. The results of neural prediction based on the correlation of a set of heterogeneous data inputs are presented. Forecasting and comparing of renewable energy sources and other energy sources makes it possible to identify their strengths and weaknesses and find their optimal combinations in the overall structure of the future energy sector.

1. Introduction
Today there is extraordinary growth in energy capacity using renewable energy sources (RES). This is due to a sharp drop in prices for equipment for solar energy, wind energy, and biomass technologies. Particularly striking is the decline in prices for silicon photovoltaic (PV) modules, which are the basis of most modern solar power plants (SPP). The cost of the first experimental PV, created in the USA in 1954, was about 250 US $ / W [1]. Since the start of production of the first series PV in 1977 - 1978, the cost has decreased by more than 100 times by now. High prices for PV up to 2010-2012 gave the reason for the heads of the power divisions of the federal and territorial levels to consider the construction of a solar power plant (SPP) entirely unpromising. It was deemed advisable to use solar power sources only for spacecraft or remote autonomous consumers - instead of diesel generator sets or in combination with them. Now, with a cost of PV modules of less than US $ 300/kW, they are the cheapest sources of electricity generation. And, according to many experts, the construction of nuclear power plants and thermal power plants is now becoming economically unprofitable, at least in the EU countries, in China, India, and the southern regions of Russia [2].

In 2020 renewable energy sources became the fastest growing and most-paying primary energy sector in the European Union's electric power industry. Twenty-seven countries of the European Union in 2020 received more electricity from renewable sources than from fossil fuels for the first time. Coal, gas, and oil share fell to 37%, while wind, solar, hydropower, and biomass accounted for 38% of total EU generation, increasing by 10%. Wind and sun provided a fifth of all power generation in the EU [3]. RES took the lead thanks to the continued rapid growth of wind and solar energy, which increased generation in 2020 by 9% and 15%, respectively, despite the economic crisis. Together, they provided 19% of all power generation in the EU last year: wind accounted for 14% and sun 5%. The volume of production in hydropower has remained unchanged, the development of bioenergy has stalled, the report
says. In Germany, the share of renewables last year exceeded 50% for the first time. The growth in power generation from renewables occurred in the EU last year amid a 4% decrease in electricity demand caused by the coronavirus pandemic and recession. At the same time, the rapid decline in electricity production at coal-fired power plants continued. In 2020 it fell by 20% and compared to 2015 it decreased by half. As a result, the share of hard coal and lignite in electricity generation in the EU dropped to 13%. The percentage of natural gas in the EU's electricity sector has reached 20%. Currently, the EU generates about the same amount of electricity from gas as from wind and solar sources.

China and India have become the main driving forces in implementing large-scale projects in solar energy [4]. The active development of renewable energy is carried out in Japan, systematically stopping the use of nuclear power plants after the accident in Fukushima; in the United States, where the goal is to preserve natural hydrocarbon reserves; in European countries where there are not enough fossil fuel resources, and modern economy requires vast amounts of energy.

In Russia, the share of renewable energy sources in the unified energy system is close to 1%. The installed capacity of solar and wind power plants (WPP) at the beginning of 2021 was 1440.00 MW and 1008.80 MW - 0.57% and 0.41% of the total capacity, respectively. The situation is better with hydroelectric power plants: their share is 20.24% [5]. For correcting the situation government RES support measures were developed. In Russia, an understanding of the relevance of renewable energy sources has not yet come in connection with the reliance on the vast available reserves of fossil hydrocarbons, especially coal: its proven deposits are sufficient for more than 300 years at the current rate of consumption [6]. But last few years have been characterized by a rapid increase in the volume of implementation in solar energy. In town, Novocheboksarsk, a plant for the large-scale production of high-performance PV modules with an efficiency of up to 22%, began to operate seven years ago. This plant has already ordered for its production several years in advance and is rapidly increasing the volume of production and reducing its cost. HEVEL and other companies use the plant's products to construct large-scale solar power plants in the southern regions of Russia. In addition, after the annexation of Crimea, Russia became the owner of the largest, even on a world scale, a complex of photovoltaic solar power plants (SPP) - more than 400 MW, built there by the Austrian company Activ Solar. Appropriately, the construction of the Crimean SPP was carried out in those years when the cost of PV was much higher than now [7]. This has led to the fact that for the payback of Austrian SPPs in at least 15 years, it is necessary to pay for the electricity supplied by these SPPs by 0.5 US $ for each kilowatt-hour - due to reasonably large budget subsidies.

At present, in more than 30 countries of the world, the energy from renewable energy sources has become cheaper than energy from thermal power plants and nuclear power plants. In these countries, the rejection of the use of nuclear energy, as well as the "decarbonization" of the energy sector - a gradual surrender of the use of lignite and hard coal at thermal power plants, which give the highest emissions of harmful and greenhouse gases into the atmosphere - is happening faster than in other regions. According to the forecasts published in the Global Report of the REN21 Center on the state of renewable energy [8], the use of brown coal will practically be phased out on Earth by 2035, coal - by 2045, oil, gas, nuclear fuel - by 2050 (figure 1). Even 4-5 years ago, it was impossible to imagine the current development rate of renewable energy. It was unlikely to persuade investors, including government agencies, to finance facilities with renewable energy sources, motivating them to solve environmental and social problems. When the economy has become the main factor in the spread of renewable energy systems, investors are lining up when conducting tender procedures to construct new SPP and WPP.
2. Development of a neural forecasting program based on the correlation of a variety of heterogeneous input data

The subject of the research is the medium-term and long-term forecasting of the development of energy markets and the share of various types of energy carriers, including renewable energy sources, in world electricity consumption based on the use of artificial neural networks. The purpose of this study was to create a computer program intended for neural network forecasting of non-stationary series describing the behavior of multi-connected systems. The calculations were carried out using the STATISTICA Neural Networks software package, which implements the entire set of neural network data analysis methods.

The program uses a neural network - a multilayer perceptron (MLP) with learning by the backpropagation method (figure 2) [9]. The algorithm of the program consists of seven consecutive steps.

**Figure 2.** Multilayer Perceptron (MLP) with error backpropagation training. Source: [10].

*Step 1.* The program iterates over the analyzed data (one value for each neuron) starting from the very first one ($x_0, ..., x_m$). The number of input neurons can vary in the direction of the expert user but cannot be more than the amount of data being examined.

*Step 2.* At the beginning of the work, the program randomly assigns weights to each synapse from the input neurons to the hidden layer's neurons and from the hidden layer's neurons to the output neuron. The value of each weight is in the range from 0 to 1.

*Step 3.* Next comes the calculation of the values in the neurons of the hidden layer. To find the value of one neuron in the hidden layer, you need to find the sum of the products of the importance of the input neurons by the weight of the synapse going to the desired neuron. By performing this operation, there is a possibility of getting a very different value from the initial value. To do this, we use...
the activation function in the program. An activation function is a way to normalize input data. This program uses an activation function called bipolar sigmoid.

**Step 4.** Then, the same calculations are made between the hidden layer's neurons and the neuron of the output layer. The sum of the products of neuron values with weights is calculated, and the value is normalized using the activation function.

**Step 5.** For the program to analyze the data offered to it, it needs training. Learning takes place using the backpropagation method.

**Step 6.** After training, the program re-fills the input neurons with data starting from the next value after the most recent value and repeats the whole cycle, but the weights are taken from the moment of the last training.

**Step 7.** This whole cycle occurs until it reaches the last value of the studied data $x_m$. Once the program has used all the data, it starts again from the first value $x_0$. Such a pass over all the data is repeated a specified number of times and is necessary for better analysis. As soon as the program has trained a sufficient number of times, the last values of the studied data are taken and go all the way from the input to the output neuron. At the output, we get the predicted value.

If it is necessary to form a forecast, taking into account the "mixing" of other input parameters of related phenomena (prices for traditional energy carriers, parameters of the world economy as the gross domestic product (GDP), the level of consumption of primary energy and electricity in the world, the level of greenhouse gas emissions, an increase in global temperature, solar activity, etc.), then for each parameter steps 1-7 are repeated. A forecast is formed "with admixture" of the given rows, with the neural network weights corresponding to each row separately. The basic algorithm of the neuro-prediction algorithm is discussed in detail in [10–12].

The novelty of this algorithm in the developed program lies in the calculation of joint weights in the formation of a forecast with "mixing" and, therefore, in more reasonable consideration of the mutual influence on each other or the correlation of a set of input parameters. For this, an additional point of the calculation algorithm has been developed in the program, namely, after repeating steps 1-7 for each input parameter from the set of input parameters, we find their average value and enter the total weight calculated in this way directly into the network neuron. Then, at each step of training, we apply these aggregate weights for all studied data. In this case, the task of forming a forecast "with mixing" is complicated by the fact that the predicted parameters can have different dimensions. Therefore, the program implements a procedure for preliminary normalization of all heterogeneous input data.

3. The prediction results of the RE systems developments direction

As a source of data for long-term use, open neural forecast statistics are presented in [13]. The first stage was to forecast the global GDP and global energy mix dynamics, which are shown in figure 3. At this stage, data on the cost of Brent oil, the level of greenhouse gas emissions (methane and carbon dioxide), the rise in global temperature, and solar activity were used as factors of "mixing".

![Figure 3. Retrospective and forecast dynamics of world GDP and the structure of world energy consumption (data are normalized to 1986 levels) Source: [13], authors' calculations.](image-url)
Despite significant fluctuations in economic parameters (world GDP), the dynamics of demand for various energy carriers appears to be a relatively smooth curve with growing trends for all carbon energy carriers (oil and gas), as well as the total consumption of fuel and energy resources and the production of energy carriers. Therefore, there is no particular reason to be scared of a sharp change in the world energy structure mention by many adherents of the "green world" and "energy transition," judging by the forecasts received until 2036.

At the second stage, a forecast of the share of various types of energy carriers (nuclear, hydropower, renewable energy sources) in the global consumption of primary energy (PE) was obtained. At this stage, the forecast data obtained at the first stage for the world GDP and the level of global, immediate energy consumption, as well as data on the cost of Brent oil, the level of greenhouse gas emissions (methane and carbon dioxide), the growth of global temperature and solar activity were partially used as "mixing" factors. The criteria for the selection of "mixing" factors were considered in more detail in [14].

Figure 4. Retrospective and forecast data (from 1985 to 2035) of the share of various energy carriers in the world consumption of primary energy, TWh. Source: [13], authors’ calculations.

Figure 4 and table 1 (with a step of 15 years from 1985 to 2035) show retrospective and forecast data of the share in the world consumption of primary energy of various types of energy carriers (nuclear, hydropower, renewable energy sources). The overall increase in the percentage of renewable energy sources brings it closer to other kinds of generation. Still, in total, it is no more than 20% of the total volume of electricity production. Consideration of the nuclear age requires special attention. Its fall will likely not be so impressive, and its new renaissance is possible if it is excluded from the non-ecological (carbon-containing) energy sources list. The forecast is based on limited current trends and may need additional analysis.

Table 1. A slightly more complex table with a narrow caption. Retrospective and forecast data (with a step of 15 years from 1985 to 2035) of the share of various energy carriers in world consumption of primary energy (TWh). Source: [13]; authors’ calculations.

| Year | Hydropower | Nuclear | Traditional biomass | Wind | Solar energy |
|------|------------|---------|---------------------|------|--------------|
| 1985 | 1980.0     | 1489.0  | 10541.0             | 0.0  | 0.0          |
| 1990 | 2159.0     | 2000.0  | 11111.0             | 4.0  | 0.0          |
| 1995 | 2486.0     | 2322.0  | 11785.0             | 8.0  | 1.0          |
| 2000 | 2652.0     | 2581.0  | 12500.0             | 31.0 | 1.0          |
| 2005 | 2916.0     | 2769.0  | 12076.0             | 104.0| 4.0          |
| 2010 | 3436.0     | 2769.0  | 11667.0             | 347.0| 34.0         |
| 2015 | 3885.0     | 2576.0  | 11111.0             | 832.0| 257.0        |
| 2020 | 4289.1     | 2862.9  | 10730.6             | 1518.3| 851.5       |
| 2025 | 4639.0     | 3104.4  | 10309.1             | 2298.4| 1413.5      |
| 2030 | 4988.8     | 3145.8  | 10087.5             | 2978.6| 1975.5      |
4. Conclusions

The use of renewable energy sources is already the norm almost all over the world. The presented results of the share participation of various energy sources, including RES in world consumption of primary energy, do not allow us to talk about a sharp change in the world energy structure until 2036 in the volume of electricity production.

It's necessary to recall that, by the decisions of the 2015 Paris Climate Conference [15], the world community has a goal: to limit the temperature rise on the planet by 2 °C. This goal can be achieved only if, by 2050, no more than 10% of the existing hydrocarbon reserves are used. Within the designated limits, approximately 80% of the world's coal reserves, 50% of natural gas, and 30% of oil will have to remain unused.

If these approaches are fair, then the costs of exploring and developing new deposits of fossil fuels are meaningless. It is necessary to finance not the exploration and development of new deposits of natural powers but research aimed at creating new methods of generating energy without using these fuels.

5. References

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