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THE COSTS COMPARISON OF PRODUCING, EXPLOITATION AND UTILIZATION OF RENEWABLE, NUCLEAR AND NON-RENEWABLE ENERGY

Об'єктом дослідження є методи порівняння вартості виробництва, експлуатації та утилізації відновлювальної, ядерної та невідновлювальної енергетики. Одним з найбільш проблемних місць у визначенні того, яка енергетика є найдешевшою є те, що різні автори зосереджуються на різних аспектах оцінки джерел енергії. Деякі вчені зосереджувалися виключно на вартості будівництва електростанції певного типу, інші на вартості утилізації або вартості експлуатації. Однак, не існує єдиного підходу, який дозволив би усунути недоліки попередніх досліджень, та оцінити вартість різних енергетичних ресурсів комплексно. Підхід до дослідження буде базуватися на методах аналізу, порівняння, спостереження та узагальнення, що дозволить усунути деякі недоліки, які були притаманні попереднім дослідженням, та розглядати питання вартості енергетичних ресурсів більш комплексно.

Отриманий у роботі результат дозволяє дивитися на проблему оцінки вартості енергетичних ресурсів ширше та краще розуміти, яка енергетична технологія є найдешевшою, з точки зору ціни, не тільки при створенні, користуванні та утилізації, але і загалом. Це пов'язано з тим, що запропонований метод оцінювання вартості має ряд особливостей, зокрема вартість ядерної, відновлювальної та невідновлювальної енергетики оцінюється з трьох точок зору: вартості створення технології, користування та утилізації. Завдяки цьому забезпечується можливість отримання значно ширшого погляду на дане питання та глибше розуміння переваг та недоліків кожного виду енергетичної технології на кожному етапі користування. За допомогою виділення слабких та сильних сторін, а також можливостей та загроз були проаналізовані отримані у роботі результати дослідження та узагальненні за допомогою SWOT-аналізу в таблицях. У порівнянні з аналогічними відомими дослідженнями, це дозволяє отримати глибше розуміння того, яка енергетична технологія є справді найкращою.

Ключові слова: *енергетична безпека, види виробництва електроенергії, ціна енергетики, енергетичні технології.*

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1. Introduction

Today it can be observed that there are many technologies for the production of electricity, such as traditional energy, renewable energy, nuclear energy and others. It can be observed that each type of power generation has its own advantages and disadvantages. For example, nuclear power is one of the cheapest to manufacture, but perhaps the most expensive when recycled. Also, renewable energy and energy from fossil fuels has similar issues. Today, there are various methods for estimating the cost of energy, but there is a lack of comprehensive research that would make this assessment common, and not only for certain aspects of the energy cost. Therefore, a study on a comprehensive assessment of the cost of energy production is relevant, which will allow us to determine which type of energy technology is the best and cheapest today.

2. The object of research and its technological audit

The object of research is methods for comparing the cost of production, operation and utilization of renewable, nuclear and non-renewable energy. One of the most problematic places in determining which energy technology is the cheapest is that different authors focus on various aspects of the assessment of energy sources. Some scientists focus solely on the cost of building a certain type of power plant, others on the cost of utilization or the cost of operation. However, there is no single approach that would eliminate the shortcomings of previous studies and estimate the cost of various energy resources in a comprehensive manner.

3. The aim and objectives of research

The aim of research is in determination which energy technology is the cheapest. To achieve this aim, the research will accomplish the following objectives:

1. To analyze the cost of production, use and disposal of renewable, nuclear and non-renewable energy.

2. To determine which technology is the cheapest and has more benefits.

4. Research of existing solutions of the problem

By reviewing the literature and exploring the approaches that different scientists use to analyze and compare different

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energy technologies, it can be said that there are many approaches to comparing different types of electricity production. For example, the authors of [1, 2] consider this issue from the point of view of comparing the cost of producing energy technologies, but do not pay attention to such important aspects of price formation as utilization and the cost of creating a technology. The authors of the studies [3] attempted to determine which technology is most effective with the help of the EROI (technology efficiency) indicator, but did not include the issue of price before their research. The authors of the study [4] didn't update 8 indicators tried to answer the question of what kind of energy is the best. Among these indicators was also the price criterion, but the issue of price in this work was not widely disclosed. The following authors of the study [5] believe that fluctuations in oil prices lead to an increase in the popularity of energy from renewable sources and may have different effects on exporting and oil-importing countries. The third authors in their works [6, 7] focus on certain aspects of energy production, for example, on utilization, and did not consider the whole process of price formation in a complex. It is also worth noting that a lot of information was taken from research and statistical data of such famous international organizations and companies as:

– IRENA [8, 9];
– British Petroleum [10];
– IEA;
– US Energy Information Agency (U.S. EIA) and others.

5. Methods of research

The following scientific methods are used:
– method of analysis – in the study of literature;
– method of observation – in the analysis of various energy technologies;
– method of comparison – when comparing different approaches to the assessment of the cost of energy;
– method of generalization – in the data analysis.

6. Research results

As the author of [11] rightly points out, an effective energy, technological strategy should balance between establishing a stable, long-term basis for innovation, and at the same time, should respond to more urgent changes in technology cost and efficiency.

Therefore, let's believe that to compare various technologies for the production of electricity, the comparison of energy technologies by just one criterion is not enough. In this section, it is proposed to compare energy technologies by three criteria based on price.

1. The cost of production technology.
2. The cost of fuel for a certain type of power plant.
3. The cost of recycling or recycling waste from the activities of the power plant.

This will help find the cheapest and most environmentally friendly technology for the production of electricity that is available today.

So, the first criterion by which let's evaluate various technologies is the cost of creating the technology itself. For comparison, the cost of creating a wind turbine (as an example of renewable energy), the construction of a thermal power plant running on coal or liquid fuel (traditional energy), the construction of nuclear power plants (nuclear energy) were chosen.

Currently, wind energy is one of the cheapest technologies for the production of energy from renewable sources, so this type of energy was chosen for comparison.

Over the past 30 years, the cost of wind energy has decreased significantly, thanks to reduced capital costs and improved performance. Various factors suggest that the low price of wind energy will continue to fall in the long run. According to most recent estimates, it is estimated that wind energy prices may drop another 20–30 % over the next two decades [11]. In particular, the report of the International Agency for Renewable Energy for 2017 [8] states that the prices of turbines and ground-based wind energy are decreasing every year. Over the past 30 years, the cost of ground-based wind energy has dropped significantly, according to the IRENA database on the costs of land wind energy projects from 1983 to 2016.

Based on these data, a graph is created (Fig. 1) in order to see and understand the dynamics of prices for wind energy and turbines.

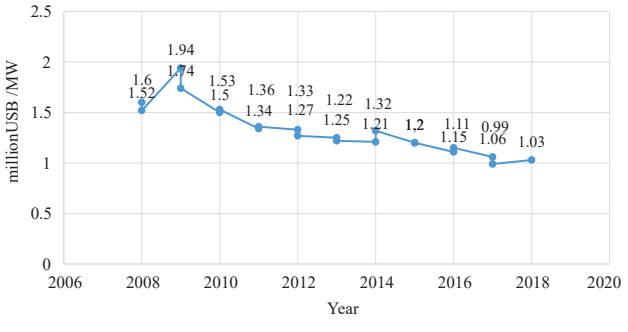

Fig. 1. Price of a turbine by delivery date (compiled by the author on the basis of [12])

Research [12] shows that the total weighted average cost of electricity or the levelized cost of electricity (LCOE) for land wind has decreased from 85 USD/MW in the first half of the year to 83 USD in the second half of the year. And for crystalline silicon photovoltaic, solar energy has dropped from 129 to 122 USD.

For example, let's propose to consider the dynamics of the price of fossil coal. For comparison, coal was chosen, since coal is one of the resources that are most often used to produce electricity. For example, in the structure of electricity production in countries such as Germany and the United States, energy produced from coal accounts for more than 50 % [13].

The future of fossil fuel combustion involves the use of carbon capture and sequestration (CCS) technology in order to meet the international goals of limiting global warming in the atmosphere. This will significantly increase the capital cost of such installations. The cheapest option is with modern technology with CCS, which is expected to cost 1,720 USD/kW. A coal-fired power plant with an internal cycle of coal combustion gasification, based on coal combustion, with CCS technology costs 3,427 USD/kW, almost twice as much as a gas-fired power station [10].

An important factor in the production of electricity in thermal power plants is also the price of coal. Therefore, the dynamics of coal prices at which thermal power plants (TPP) operate, are also given, Fig. 2.

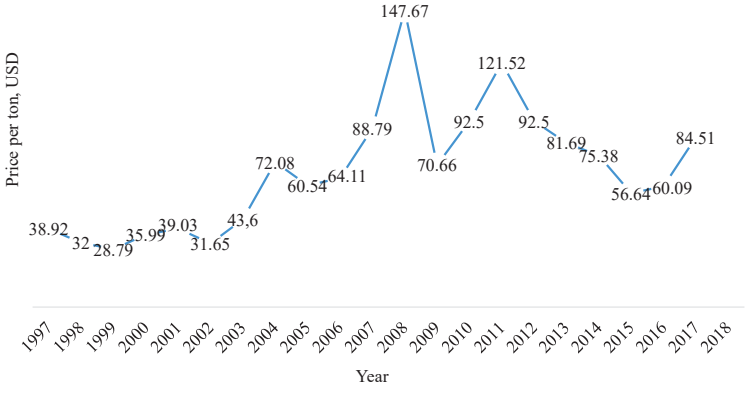

Fig. 2. Dynamics of prices for coal (compiled by the author according to [13])

It is sometimes noted that coal prices can have a significant impact on the price of uranium, since both resources are used to produce electricity, and the demand and price for one type of resource can also be displayed on the price and demand for another resource. Therefore, the next energy resource, for comparison, was chosen precisely nuclear energy.

An example is the construction of a new reactor in Finland – the Olkiluoto 3 reactor. The project was first introduced in 2000. In the Cabinet of Ministers of Finland, and construction began in 2005. It was originally supposed to complete the project by 2010 with a budget of approximately 2.8 billion EUR. However, the reactor has not yet been commissioned, and recent estimates of cost estimates exceed 85 billion EUR [1].

According to research conducted by the US Energy Information Administration, the construction cost for a modern nuclear power plant with a rated capacity of 2.234 MW is 5,945 USD/kW [14].

Also, for comparison with renewable energy and fossil fuels, it is advisable to present the dynamics of uranium prices, which is the basis for the operation of nuclear power plants (NPP), Fig. 3.

On the basis of the conducted research, it is possible to compare different types of energy resources by price criterion. For example, the average price of wind turbine production was 1,730 USD/kW in 2017 for coal-fired thermal power plants and equipped with conventional emission control systems, the cost would be 2,078 USD/kW. A more technological power station with carbon capture and storage will cost 3,427 USD/kW. The average cost of building capacity for the manufacture of 1 kW at nuclear power plants will average 5945 USD/kW. It should be added that there is a trend to reduce prices for wind turbines and to increase prices for the construction and commissioning of thermal power plants and nuclear power plants.

From the point of view of energy prices, renewable energy sources have a significant advantage over traditional ones, since they generally do not require fuel during operation.

When it comes to the costs associated with the use of a certain energy resource, it is also advisable to recall not only the cost of producing a certain technology and the cost of fuel that is necessary for energy production. It is also worth remembering the cost of disposal of waste generated during the production of electricity and the plant itself or the installation. Recycling also applies to renewable energy technologies. After all, solar panels and wind turbines have their own life.

As an example, it is possible to cite the utilization of solar panels, because, unlike wind installations, solar panels contain such a chemical element as silicon, which requires additional attention when disposing.

When it comes to recycling solar panels, various scientists have identified some excellent ways of dealing with solar panels after their shelf life.

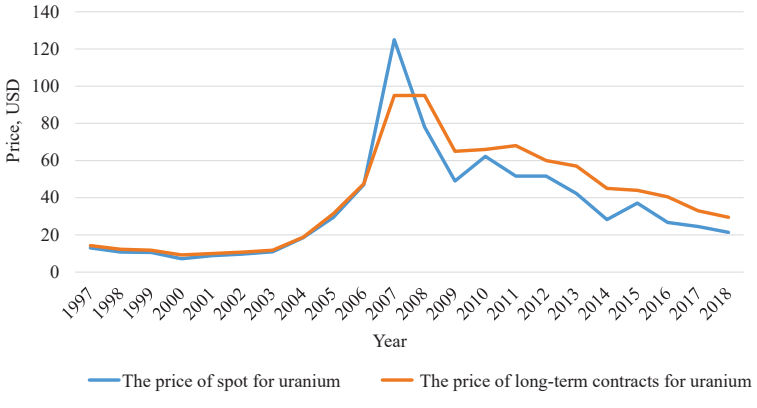

Fig. 3. The dynamics of uranium prices (compiled by the author according to [14])

For example, the authors of [15] call these 4 ways of handling solar panels:

1. Sending to landfill.
2. Burning.
3. Reuse.
4. Recycling.

Speaking of the processing of solar panels, the cost of processing has decreased significantly over the past 20 years. For example, in 2004, the cost of processing amounted to 0.12 USD/kW [16]. And in 2018, the cost of processing was estimated at 0.045 USD/kW according to the IEA data [17].

Other scientists estimate the cost of processing per ton of solar panels. For example, the author of the work estimates this cost at 200 EUR/t [17].

Many scientists believe that the processing of solar panels can turn into a fairly significant market. According to preliminary estimates, it is believed that raw materials that will be mined during processing can collectively reach values of 450 million USD until 2030 [18].

It is considered that, for comparison, it is advisable to compare the costs of utilization of waste from thermal power plants and nuclear energy as well.

Special attention should be paid to waste from thermal power plants, since approximately 63 % of the world's electricity is produced by thermal power plants, 19 % by hydroelectric stations and 17 % by nuclear power plants [19].

The authors of the work [19] state that during the processing of 100 thousand tons of waste, 10–12 thousand tons of secondary coal, 1.5–2 thousand tons of iron ore

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concentrate, 20–60 kg of gold, 60–80 thousand tons of building material (inert mass) can be obtained. This all creates a fairly significant market for recycling waste from thermal power plants.

The next analyzed waste group is nuclear waste. A special feature of radioactive waste is that, unlike TPP waste, this waste can't be recycled and it is not known that it can be recycled or used in some way in the future. Although some scientists suggest that plutonium can potentially be chemically immobilized (the two most likely materials are glass and ceramics) [20]. However, while there are no examples of such use.

The largest radioactive waste repository in Britain is Sellafield. The authors of the study [20] came to the conclusion that taxpayers spend more than 2.5 billion GBP annually on maintenance and maintenance of this vault. It is also worth mentioning the huge funds that were spent on the construction of this storage facility, as well as the costs that would be necessary to decommission it (after about 100 years). The National Audit and Finance Office of the United Kingdom and Ireland estimate these amounts at 49 and 670 billion GBP, respectively.

It is proposed to analyze the results of the study using a SWOT analysis (Tables 1–3).

Based on the processed data, it can be concluded that for each type of energy resources there are certain advantages and disadvantages. However, renewable energy has more advantages at the moment.

Table 1

SWOT analysis of renewable energy (RE)

Strengths	Weaknesses
1. The dynamics of reducing the price of energy produced. 2. Lack of fuel for energy production. 3. Low installation costs of renewable energy facilities compared to traditional and nuclear power. 4. Accessibility and ease of recycling or reuse. 5. Government support. 6. Environmental friendliness	1. High current cost of energy produced by renewable energy. 2. There is practically no infrastructure for processing waste installations of renewable energy (solar panels, wind turbines, etc.). 3. A small share in the overall structure of energy consumption
Opportunities	Threats
1. Establishment of new renewable energy facilities. 2. Large market for recycling of renewable energy installations	1. Great impact on the government subsidy sector. 2. The transition to renewable energy requires a certain time

Table 2

SWOT analysis of traditional energy

Strengths	Weaknesses
1. The low cost of energy produced. 2. Most of the total energy production. 3. Recycling of TPP waste	1. The high cost, support and decommissioning of power plants using traditional fuels. 2. Rising fuel prices for TPP. 3. Negative impact on the environment. 4. Dependence on energy suppliers
Opportunities	Threats
1. Diversification of import of energy resources for fuel at TPP	1. Pollution of the environment. 2. Greenhouse gas emissions. 3. The threat of being out of fuel for power plants

Table 3

SWOT analysis of nuclear power

Strengths	Weaknesses
1. A significant part in the overall structure of energy production. 2. Low cost of energy produced. 3. Environmentally friendly in the production process	1. Expensive technology for the construction, operation and termination of energy production. 2. Dependence on the supply of nuclear fuel. 3. The impossibility of recycling nuclear waste
Opportunities	Threats
1. Transition to low enriched uranium. 2. Development of new, safer energy production technologies using uranium	1. The threat of disasters at nuclear power plants

7. SWOT analysis of research results

Strengths. The strengths of the research are an integrated approach to the study of the problem, as well as the specific results obtained at the end of the research. Compared to peers, this helps look at the problem more broadly and better understand the price characteristics of energy technologies.

Weaknesses. The results require further refinements. It will be necessary to consider the issue of assessing energy resources, in more detail, by including more factors, which will provide even more accurate results.

Opportunities. The results obtained in the research will help professionals accurately assess the risks and prospects when choosing a specific energy technology. This will make it possible to make more correct decisions in projects embodying energy facilities.

Threats. To use the research results, there may be certain obstacles. First of all, it takes time and money to switch to renewable energy sources. Often, governments still choose old and inefficient technologies that may seem cheaper at first glance.

8. Conclusions

1. As a research result, the pros and cons of each of the above energy sources were identified and it was found out why one type of energy can be both effective in some indicators and less effective in others. For example, traditional energy has a low cost of energy production and a large part in the overall energy structure, but at the same time it has a negative impact on the environment and contributes to dependence on suppliers of energy resources. Nuclear power engineering has similar advantages and disadvantages.

2. On the basis of the conducted SWOT analysis, it can be seen that renewable energy has more advantages and prospects, and in particular, wind and solar. This in particular:

– dynamics of price reductions for restoration technologies;
– government support;
– lack of fuel for energy production;
– lower installation costs of renewable energy installations compared to traditional and nuclear power;
– availability and ease of recycling or reuse.

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