Assessment of the impact of the industrial enterprise on the environment by determining the integrated (generalized) energy efficiency performance indicator

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Abstract. The article summarizes the efficiency indicators. The authors have developed comprehensive efficiency indicators of the enterprise for a complete assessment of the efficiency of energy use. The comprehensive efficiency index of the enterprise is divided into three stages: generation of energy, energy transmission and energy consumption. In this case, the efficiency of using primary energy resources in the enterprise was accepted as a priority criterion. The integrated (generalized) energy efficiency indicator of the industrial enterprise was developed taking into account the participation of renewable energy sources in the energy consumption of the enterprise and the impact of energy consumption on the environment. The most effective way to green production and reduce carbon emissions per unit of product is through energy efficiency testing. Capturing and reducing carbon emissions per product can be achieved through energy efficiency research. It has good energy efficiency in terms of production quality and ease of production methods. The article describes in detail not only the evaluation methodology for evaluating the impact of production on the environment, but also the energy intensive in the production of unit of product and the coefficient of efficiency work in energy production and transmission in generalized indicators.

1 Introduction

Existing methodologies for assessing the energy efficiency of the enterprise do not allow comprehensive assessment of the energy sector of the enterprise in the market economy. This is one of the reasons for the low real energy efficiency of the enterprise. Currently, in order to increase the efficiency of energy use in the enterprise, the use of renewable energy sources in the energy supply system is increasing. These changes cause certain inaccuracies in the true assessment of the enterprise's energy efficiency. For example, even when the enterprise uses renewable energy sources, if the amount of energy consumed per product unit does not change, the energy efficiency indicator is considered unchanged. However, the use of renewable energy sources reduces the use of primary energy resources and the amount of environmental pollution, that is, increases the energy efficiency index. In order to eliminate

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this ambiguity, when evaluating the energy efficiency in the enterprise, it is appropriate to evaluate it by determining the efficiency of using primary energy resources in the enterprise, not by the coefficient of useful work of the energy devices in the enterprise [1]. In this case, all energy sources in the enterprise are considered as a single hybrid energy source, and the efficiency of energy use in the enterprise is evaluated with a single generalized energy efficiency indicator.

A.S. Krasnov and K.K. Kim stated in their research that "most of the existing methods for evaluating the energy efficiency indicators of heat supply systems are limited because they allow to evaluate only one or several indicators (for example, heat energy production for the specific consumption of conventional fuel, loss of heat energy during transportation through heat networks, etc.), emphasizes that not all indicators are generalized [2]". The generalized energy efficiency indicator of the enterprise is limited only to thermal energy, efficiency coefficient and relative consumption of energy were studied as energy efficiency indicators. Electricity efficiency and environmental performance are not discussed.

E.Evseev and T. Kisel studied energy efficiency indicators to ensure the integrity of the assessment of the activity of heat supply enterprises and summarized them in the section of the following indicators, i.e. technical efficiency, ecological efficiency, social efficiency, economic efficiency [3]. The system is complicated by dividing these indicators into several indicators for the state, managers and workers, enterprise owners and consumers. This methodology creates a number of difficulties for energy auditors when determining energy efficiency at the enterprise level.

I. Kozlov, V. Kovalchuk, O. Klymchuk in their scientific research analyzed the effect of the general efficiency indicator of the equipment on the energy efficiency indicator in the section of the centralized heat supply enterprise. The possibility of comprehensive assessment of heat supply efficiency by improving the efficiency index of the equipment was considered [4].

Thus, the main objectives of this study were:
1. Development of a comprehensive assessment methodology for the assessment of energy security, fuel efficiency and air emissions.
2. Per unit ($1) is determined by the amount of substances released into the environment during the production of the product.

2 Materials and methods

To achieve this goal, the comprehensive energy efficiency indicator of the enterprise is determined by dividing it into three stages: energy production, energy transmission and energy consumption stages (Figure 1).
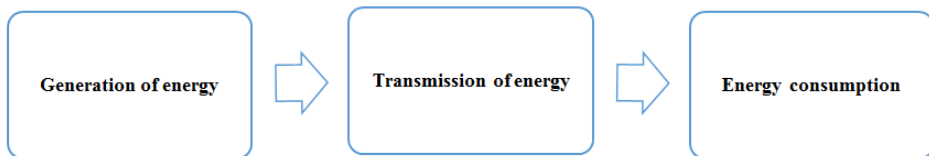

Fig. 1. Stages of the complex energy efficiency indicator of the enterprise.

The general energy efficiency indicator in the enterprise is determined by the efficiency of primary energy resource use in the general energy source, by the efficiency coefficient of the energy transmission system in energy transmission, and by the relative energy consumption per unit of energy consumption and environmental index.

An overview of the complex energy efficiency indicator of the enterprise will be as follows:

$$K_{ee} = \sum_{i=1}^{i} \alpha_i \cdot \eta_i = \alpha_1 \cdot \eta_{es} + \alpha_2 \cdot \eta_{et} + \alpha_3 \cdot \eta_{ec}, \tag{1}$$

Here: η_{es} − is the efficiency indicator the energy source of the enterprise; η_{et} − the indicator of efficiency in energy transmission in the enterprise; η_{ec} − the specified (standardized) efficiency indicator of the energy consumption process in the enterprises; α_i −weight coefficients of efficiency indicators.

When determining the efficiency of energy use of the enterprise, priority is given to the efficiency of primary energy resource use, not to the efficiency coefficient of energy sources. Because the efficiency of using renewable energy sources can be determined only through such an approach.

The total efficiency index of the generalized (hybrid) sources generating heat and electricity at the enterprise (efficiency coefficient) is determined from the following expression:

$$\eta_{es} = \frac{\eta_{th.e} \cdot W_{th.e} + \eta_e \cdot W_e}{W_{th.e} + W_e}, \tag{2}$$

Here: $\eta_{th.e}$ − the efficiency coefficient of the hybrid heat energy source; η_e −useful efficiency of the hybrid electricity source; $W_{th.e}$ − total thermal energy produced by the enterprise and received from abroad, kWh; W_e − total electricity produced by the enterprice and received from abroad, kWh.

Since many enterprises and organizations consume energy from several (centralized grid, renewable and non-renewable) energy sources in the enterprise territory, we consider 2 sources in the energy supply system: electricity and heat as a hybrid energy source [5]. The energy efficiency indicator of the hybrid energy source supplying electric energy is determined from the following expression:

$$\eta_{ee} = \frac{\sum_{i=1}^{i} W_{ee}}{\sum_{i=1}^{i} W_{ee} + \sum_{i=1}^{i} W_{p.n-r}} = \frac{W_{c.p.g} + W_{r.s} + W_{p.r}}{W_{r.s} + W_{o.n} + \Sigma W_{p.n-r}}, \tag{3}$$

Here: $\sum_{i=1}^{i} W_{ee}$ − total electricity received from various sources for enterprise consumption, kWh; ($W_{c.p.g}$ − from the centralized power grid; $W_{p.r}$ − from the company's own power plant operating in the primary energy resource; $W_{r.s}$ − from renewable sources); $W_{o.n}$ − energy used for its own needs (cooling, ventilation, control, etc.), kW; $W_{p.n-r}$ − primary (non-renewable) energy used for electricity generation, kW.

The expression of the generalized efficiency indicator (3) for the use of electric energy of the enterprise can be applied to individual sources. For example, if the enterprise consumes electricity only from the centralized power grid or primary energy resources, and the enterprise is supplied from its own power plant, expression (3) takes the following form:

$$\eta_{ee} = \frac{W_{c.p.g}}{W_{p.n-r}} = \frac{W_{c.p.g}}{\frac{W_{c.p.g}}{\eta_{g.g}}} = \eta_{g.g}, \tag{4}$$

Here: η_{es} − efficiency coefficient of the electric network supplying the enterprise or the power plant in the territory of the enterprise.

It can be seen from this expression that the efficiency indicator is equal to the efficiency coefficient of the power plant in the power grid or the enterprise. Depending on the type of network power plant and the amount of energy received by the enterprise, it is possible to calculate the primary energy resource and harmful substances released into the environment.

If the enterprise provides electricity using only renewable energy sources, since the electricity is obtained without using primary energy resources, $W_{er.i} = 0$ it will be in the expression (3), and the energy efficiency indicator is determined from the following expression:

$$\eta_{ee} = \frac{W_{r.s}}{W_{r.s} + W_{sn.qt}}, \tag{5}$$

Here: $W_{r.s}$ − It is electric energy obtained from renewable energy sources, and this energy is considered as a primary energy resource at the same time; $W_{sn.qt}$ − energy used for the use of renewable energy sources (cooling, ventilation, control, etc.) for its own needs, kWh.

In this way, we determine the efficiency of using primary energy resources in the production of thermal energy [6]. Since the consumption of heat energy in the enterprise is made from several (from the centralized network, renewable and non-renewable) energy sources in the territory of the enterprise, we will combine them into one source, that is, we will consider it as a hybrid heat energy source consisting of several energy sources [6]. To do this, we write the (3) expression in the following form:

$$\eta_{th.e} = \frac{\sum_{i=1}^{i} W_{th.e}}{\sum_{i=1}^{i} W_{th.e} + \sum_{i=1}^{i} W_{p.n-r}} = \frac{W_{d.h.n} + W_{r.s} + W_{o.b}}{(W_{d.h.n} + W_{r.s} + W_{o.b}) + (W_{o.n} + W_{p.n-r})} \quad (6)$$

Here: $\sum_{i=1}^{i} W_{th.e}$ − thermal energy obtained from various sources for enterprise consumption, kWh; ($W_{d.h.n}$ − from the district heating network, $W_{r.s}$ − from renewable sources, $W_{o.b}$ − from his own boiler room and others); $W_{o.n}$ − thermal energy used for own needs of heat energy sources, kWh; $W_{p.n-r}$ − primary (non-renewable) energy used for heat energy production resource combustion energy, kWh.

The next stage of energy movement in the enterprise is the stage of energy transfer, the efficiency of the energy transfer system in the enterprise (efficiency coefficient) is calculated from the following expression:

$$\eta_{e.t} = \frac{\eta_{th.t} \cdot W_{h.e} + \eta_{e.t} \cdot W_e}{W_{h.e} + W_e} \quad (7)$$

$W_{h.e}, W_e$- heat and electricity received from energy sources at the enterprise, kWh (or joule); $\eta_{th.e.t}$ and $\eta_{e.t}$ − the coefficient of efficiency in the transfer of heat and electricity from energy sources at the enterprise is determined from the following expressions:

$$\eta_{th.t} = \frac{W_{th.e}}{W_{th.e} + \Delta W_{th.t}} \quad (8)$$

$$\eta_{e.t} = \frac{W_e}{W_e + \Delta W_{e.t}} \quad (9)$$

Here: $W_{th.e}$ and W_e − respectively, heat and electricity consumed in the enterprise, kWh (or joule); $\Delta W_{ie.i}$ va $\Delta W_{ee.i}$ − accordingly, energy loses in heat and electricity transmission at the enterprise, kWh (or joule).

The main indicator of energy efficiency in production is the energy capacity of the product, since it has a unit of measurement and does not allow generalization [7]. Here, energy efficiency is explained by 2 indicators:

- the amount of energy costs used in the making of the product, which is proportional to the energy intensivity of the product and is ununit of measure ($1);
- a unit ($1) is determined by the amount of substances released into the environment during the production of a product.

The energy costs used in the production of a product of unit value are calculated from the following expression:

$$\gamma_{e.c} = \frac{S_{th.e} \cdot W_{h.e} + S_e \cdot W_e + U_{o.c}}{P_p} \quad (10)$$

$S_{th.e}$ va S_e- the price of unit heat and electricity consumed in the enterprise in a unit period (year, month, day), US dollars (or Uz S); P_p − the value of the product produced at the enterprise in a unit period (year, month, day), US dollars (or Uz S); U_{ex} − operating costs of energy farm, million UzS.

The smaller this indicator, the higher the efficiency. As efficiency increases in the summarization of indicators, the indicator should increase proportionally. Therefore, we get the inverse value of this indicator as an efficiency indicator:

$$\eta_{e.c} = 1 - \gamma_{e.c}. \quad (11)$$

One of the main indicators of energy efficiency is the indicator that determines the impact of energy use on the environment. Research on the impact of energy sources on the environment is aimed at creating a methodology for determining this indicator [8]. The environmental efficiency indicator, which is determined by the amount of substances released into the environment during the production of a unit ($1) product, is determined from the following expression:

$$\eta_{e.e} = \frac{m_{th.e} + m_e}{P_p} = \frac{m_{0.th} \cdot W_{th.e} + m_{0.e} \cdot W_e}{P_p}, \qquad (12)$$

$m_{th.e}$ *va* m_e- correspondingly, the amount of harmful substances released during the production of heat and electricity used in the enterprise, gram/US dollar (or UzS); $m_{0.i}$ *va* $m_{0.e}$ — accordingly, the amount of harmful substances released during the production of a unit amount of heat and electricity, gram/kWhour; P_p — the value of the product produced at the enterprise per unit period (year, month, day), US dollars (or UzS).

Since this indicator has a unit of measurement, we normalize it, that is, we bring it to a dimensionless unit by the following expression:

$$\eta_{e2} = \frac{\eta_{e.e}}{\eta_{e.n}} \qquad (13)$$

Here: $\eta_{e.n}$ —the value calculated by the amount of harmful substances released when producing heat or electricity using a primary energy resource (coal), gram/US dollar.

This indicator is equal to 1 if the energy is obtained from completely non-renewable energy resources according to expression (11) and equal to 0 if it is obtained from completely renewable energy resources.

This environmental index is taken into account with a negative sign when determining the overall efficiency indicator of the enterprise. Thus, the complex (generalized) energy efficiency indicator of the enterprise is determined from the following expression:

$$K_{ee} = \sum_{i=1}^{i} \alpha_i \cdot \eta_i = \alpha_1 \cdot \eta_{e.s} + \alpha_2 \cdot \eta_{e.t} + \alpha_3 \cdot \eta_{e.e} - \alpha_4 \cdot \eta_{e2} \qquad (14)$$

α_i —the weight coefficients in this expression were determined by the Fishbren method from the following expression:

$$\alpha_i = \frac{2(n-i+1)}{n(n+1)}, \qquad (15)$$

where: weight coefficient for a_i—indicator; i- indicator sequence number, n- total number of indicators.

$$K_{ee} = 0.4 \cdot \eta_{e.s} + 0.3 \cdot \eta_{e.s} + 0.2 \cdot \eta_{et} - 0.1 \cdot \eta_{e2} \qquad (16)$$

The values of the weighting coefficients may vary depending on the determination criterion and the field of production.

3 Results and discussion

In industry, energy efficiency is usually considered as the ratio of the amount of produced products and services to the unit of consumed energy. In this process, the coefficient of efficiency and the relative consumption of energy are taken into account. The methodology developed as a result of the research applies a comprehensive approach to energy efficiency assessment [9]. The general energy efficiency index in the enterprise was explained in detail by the efficiency of using primary energy resources in the general energy source, by the efficiency coefficient of the energy transmission system in energy transmission, and by the comparative energy consumption and environmental indicator spent per product unit in energy consumption [10].

The following conditions and limitations were applied in the formation of indicators for the energy source, energy transfer and consumption stages in the comprehensive assessment of the energy efficiency of enterprises:

- indicators were selected in the section of sources known in the energy system. The selection was made by the authors according to the requirement of distribution of the main outcome indicators.
- several indicators are proposed by the authors to help get a broader picture of the energy efficiency of the system and eliminate uncertainties;
- the novelty of the obtained results is based on the approach of the authors in the selection and classification of indicators. In general, all indicators of the system have the characteristics of necessity and sufficiency to evaluate the comprehensive energy efficiency of its operation and development in electricity and heat supply.

4 Conclusion

The developed comprehensive efficiency indicators in the energy research of industrial enterprises are the results of increasing the energy efficiency of the enterprise and the use of renewable energy sources in this process:

1. Determining the energy efficiency of an industrial enterprise through indicators of the efficiency of using primary energy resources allows to take into account the efficiency of the use of renewable energy sources in the energy consumption of the enterprise and its negative impact on the environment.
2. Summarizing the indicators that determine the energy efficiency of an industrial enterprise into a dimensionless unit makes it possible to evaluate energy efficiency based on a single indicator.

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