Requirements and conditions for ensuring sustainable energy-saving economic development of enterprises

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Abstract. The purpose of this study was to establish criteria and determine the conditions for sustainable energy-saving economic development of enterprises. The relative and absolute types of such development are distinguished. It is found that the absolute type of development occurs when the index of physical output of the enterprise falls within a certain range of values. The length of this interval determines the value of the indicator of the potential for sustainable energy-saving economic development of enterprises. In turn, this value is determined by the values of the four indices. This conclusion is obtained on the basis of building a model of decomposition of the indicator of potential of sustainable energy-saving economic development of enterprises. The theoretical and methodological developments obtained in this work were tested on a sample of 120 Ukrainian enterprises belonging to four industries. Among other things, the hypothesis was confirmed that there is a tendency to increase the share of enterprises in which there was an absolutely stable energy-saving economic development, while increasing the indicator of the potential of such development. It turned out that this dependence for the sample of the studied enterprises is linear.

1. Introduction

One of the key challenges facing the governments of many countries in recent decades is to ensure their sustainable economic development. This development should be reflected in long-term economic growth while taking into account restrictions on the use of many types of natural resources, including non-renewable energy sources. The solution to the problem of sustainable development should be considered, first of all, at the level of enterprises, as they have the greatest impact on the size of the national product, while consuming large amounts of natural resources [1]. At the same time, ensuring sustainable development for many companies is quite a challenge [2], due to the presence of various barriers that arise [3]. In particular, many enterprises, especially small ones, are characterized by a lack of adequate financial resources [4]. This factor causes insufficient rates of implementation of energy saving projects at enterprises. In addition, the high risk inherent in these projects has a negative impact on the volume of investments in energy saving [5]. However, the lack of sustainable energy-saving economic development in many enterprises may also be due to the fact that their owners and managers do not fully imagine the criteria and conditions for such development. In this regard, the establishment of formalized criteria and conditions for sustainable energy-saving economic development of enterprises can be useful in developing business strategies.
2. Literature review
The problem of ensuring sustainable energy-saving economic development of enterprises can be reduced to the question of how long enterprises can combine the growth of certain financial and economic results of their activities with a reduction in the consumption of certain types of energy resources. It should be noted that in the scientific literature this issue is considered mainly at the macro level. However, it is obvious that macro-level indicators are largely the average parameters of enterprises in the respective countries.

Consideration of the results obtained by various authors who have studied the relationship between economic growth and energy consumption indicates that these results are largely contradictory. Thus, in [6] it was shown that in both short-term and long-term periods, economic growth led to an increase in energy consumption of member countries of the Organization for Economic Cooperation and Development. At the same time, in [7], the study of the relationship between natural gas consumption and economic development revealed significant differences in the nature of this relationship for the economies of Japan and China. An inverse relationship between natural gas consumption and the dynamics of gross domestic product was also found for some Gulf countries [8]. However, in [9] for twelve European countries the impact of natural gas consumption on economic development has been proven only for the long term, and in [10] it is noted for a number of countries that are members of the Organization of Petroleum Exporting Countries.

It is also useful to point out the results of studies of the relationship between energy consumption and the index of sustainable economic prosperity for the G7 countries presented in [11]. These results show that this index is partly determined by energy consumption, however, in the long run there is an opportunity to reduce energy consumption without reducing the level of sustainable economic well-being. Also noteworthy is a study carried out in [12], which showed that for the economies of some African countries, energy consumption is inversely related to the parameters of the stock market and industrialization. An important way to reduce the consumption of fossil energy resources is to replace them with solar energy and other types of renewable energy sources [13]. However, regarding the impact of such substitution on economic growth, the results of relevant studies conducted by different scientists differ significantly. Thus, in [14] the positive impact of renewable energy consumption on economic growth was found for only 57% of the 38 countries considered. Similar results were obtained in [15] for the countries of the European Union. With regard to the Black Sea and Balkan regions, according to the results presented in [16], the impact of renewable energy consumption on economic growth was direct only for some countries, in particular for Ukraine.

It should be noted that one of the reasons that economic growth in some countries and in certain time periods is accompanied by a simultaneous increase in energy consumption is the insufficient pace of implementation of energy-saving technologies. The causes of this phenomenon have been considered in many scientific papers. In particular, scientists have identified economic [17], financial [18; 19], information [20] and other types of barriers to the implementation of energy saving measures in enterprises. At the same time, some authors point to the effect of a rebound in energy consumption, which may cause an increase in energy consumption in absolute terms due to a decrease in energy consumption of products [21]. Although, for example, in [22], it is noted that the impact of this effect on energy consumption is very limited, and in [23] the presence of this effect is not detected at all.

However, the scientific literature does not sufficiently consider the barrier to improving the energy efficiency of enterprises due to insufficient justification of their development strategies. In turn, the degree of this validity directly depends on how correctly the owners and managers of enterprises set the criteria and determine the conditions for sustainable energy-saving economic development of these enterprises.

3. Methodology and results of empirical analysis

3.1. Defining criteria for sustainable energy-saving economic development of enterprises
Considering the sustainable energy-saving economic development of enterprises, we should distinguish two types, namely: relative and absolute. The relative type of sustainable energy-saving economic development of enterprises is characterized by long-term and constant growth of certain financial and economic results of enterprises with a simultaneous reduction in their energy consumption per unit of these results. Regarding the absolute type of sustainable energy-saving economic development of enterprises, it is characterized by a long and steady growth of certain financial and economic results of enterprises with a simultaneous reduction in energy consumption in absolute terms.

To determine the formalized criteria of these two types of economic development of the enterprise, we introduce a system of the following vectors:

1) The vector of consumption by the enterprise of certain types of energy resources:

\[ E_t = (E_{it1}, \ldots, E_{itn}) ; \]  

2) The vector of values of certain financial and economic results of the enterprise:

\[ R_t = (R_{jt1}, \ldots, R_{jtn}) ; \]  

3) The vector of growth rates of consumption of certain types of energy resources in the reporting period compared to the previous period:

\[ I_{et} = \left( \frac{E_{it}}{E_{it-1}} \ldots, \frac{E_{nt}}{E_{nt-1}} \right) = (I_{et1}, \ldots, I_{eti} \ldots, I_{etn}) ; \]  

4) The vector of growth rates of certain financial and economic results of the enterprise in the reporting period compared to the previous period:

\[ I_{rt} = \left( \frac{R_{jt}}{R_{jt-1}} \ldots, \frac{R_{jtn}}{R_{jtn-1}} \right) = (I_{rt1}, \ldots, I_{rti} \ldots, I_{rtn}) , \]  

where \( E_{it} \) – natural volumes of consumption by the enterprise of the \( i \)-th type of energy resources in the \( t \)-th period of time; \( n \)-th the number of types of energy resources under consideration; \( R_{jt} \) – volumes of the \( j \)-th type of financial and economic results of economic activity of the enterprise in the \( t \)-period of time; \( m \)-th the number of types of financial and economic results of the enterprise, which are considered; \( I_{et} \) – the growth rate of enterprise consumption of the \( i \)-th type of energy resources in the \( t \)-period compared to the previous period; \( I_{rt} \) – the growth rate of the \( j \)-th type of financial and economic results of the enterprise in the \( t \)-period compared to the previous period.

It is also necessary to consider two matrices, namely:

1) A matrix of energy consumption values of financial and economic results of economic activity of the enterprise. Each element of this matrix will be the result of dividing the volume of consumption of a certain type of energy resources in the reporting period to the value of a certain financial and economic result of the enterprise in the same period;

2) The matrix of growth rates of energy intensity of financial and economic results of economic activity of the enterprise. Each element of this matrix will be determined by comparing the corresponding values of energy consumption of financial and economic results of the enterprise in the reporting and previous periods.

Given the above, the economic development of the enterprise for a certain period will be considered relatively sustainable energy-saving, if:

1. For all periods of this period, the values of all elements of vectors (4) are greater than one.
2. For all periods of this period are less than one unit value of all elements of the matrices of the
growth rate of energy consumption of the enterprise.
Regarding the criteria of absolute sustainable energy-saving economic development of the
enterprise, they can be formulated as follows:
1. For all time intervals of the period under consideration, the values of all elements of vectors (4)
are greater than one.
2. For all time intervals of the period under consideration, the values of all elements of vectors (3)
are less than one.
It is obvious that if during a certain period the absolutely stable energy-saving development of the
enterprise is recorded, then it a priori guarantees that it has a relative type of such development. At the
same time, in the general case, the opposite statement is not true. In this regard, in the future we will
consider only the case of absolutely sustainable energy-saving development of the enterprise. In order
to formalize the criteria for this type of development, we introduce the following parameters:

\[
I_{et}^{\text{max}} = \max(I_{et1}, \ldots, I_{eti}, \ldots, I_{etn});
\]
\[
I_{et}^{\text{min}} = \min(I_{et1}, \ldots, I_{eti}, \ldots, I_{etn}),
\]
where \(I_{et}^{\text{max}}\) is the maximum among the considered types of energy resources growth rate of their
consumption by the enterprise in the \(t\)-thperiod of time compared to the previous period of time; \(I_{et}^{\text{min}}\) is
the minimum among the considered types of financial and economic results of the enterprise growth
rate of their value in the \(t\)-thperiod of time compared to the previous period:

\[
I_{et}^{\text{max}} < 1;
\]
\[
I_{et}^{\text{min}} > 1.
\]
It should be noted that in the simplified case, the definition of the criteria of absolute sustainable
energy-saving type of enterprise development can be done without prior construction of vectors (3)
and (4). Then the company’s consumption of energy resources will be determined immediately by the
totality of these resources by expressing these volumes in the same units (in particular, in tons of oil
equivalent). Regarding the financial and economic results of the enterprise, in this case, only one type
is selected. In particular, this type of these results may be the net profit of the enterprise or its added
value.

3.2. Establishing conditions for ensuring the absolute type of sustainable energy-saving economic
development of enterprises
To establish the conditions of the absolute type of sustainable energy-saving economic development of
enterprises, we present the left parts of inequalities (7) and (8) as follows:

\[
I_{et}^{\text{max}} = I_{qt} \cdot I_{set};
\]
\[
I_{et}^{\text{min}} = I_{qt} \cdot I_{srt},
\]
where \(I_{qt}\) is the index of physical output of the enterprise in the \(t\)-thperiod compared to the previous
period; \(I_{set}\) - index of specific costs (costs per unit of output) of the type of energy resources, which
 corresponds to the maximum value of the elements of the vector (3), in the \(t\)-thperiod of time
compared to the previous period of time; \(I_{srt}\) is an index of the specific value of the type of financial
and economic result of the enterprise, which corresponds to the minimum value of the elements of the
vector (4), in the \(t\)-thperiod of time compared to the previous period. Then, taking into account the
need to comply with inequalities (7) and (8), the index \(I_{qt}\) must satisfy the following expression:
Taking into account expression (11), the conditions for ensuring the absolute type of sustainable energy-saving economic development of the enterprise will be the following:

1. The index of the specific value of the corresponding type of financial and economic result of the enterprise must exceed the index of the specific value of consumption of a certain type of energy resources.

2. The index of physical volumes of production must exceed the inverse of the index of the specific value of the corresponding type of financial and economic result of the enterprise.

3. The index of physical volumes of production should be less than the inverse of the index of specific consumption of a certain type of energy resources.

We will now consider an indicator of the potential of sustainable energy-saving economic development of enterprises. This indicator will be calculated by the following formula:

\[ I_{ed} = \frac{1}{I_{set}} - \frac{1}{I_{srt}}. \]  

Therefore, according to expression (11), the indicator (12) characterizes the length of the interval of those values of the index \( I_{qs} \), which provides a sustainable energy-saving development of the enterprise. Therefore, we can hypothesize that the probability of providing this type of development increases with increasing value of the indicator (12).

It is also advisable to identify the impact on the value of the indicator (12) of individual factors. To build a model for estimating such an impact, consider a simplified case in which expression (12) takes the following form:

\[ I'_{ed} = \frac{1}{I'_{set}} - \frac{1}{I'_{srt}}, \]  

where \( I'_{ed} \) – a modified indicator of the potential for sustainable energy-saving economic development of the enterprise; \( I'_{set} \) – index of specific costs of energy resources consumed by the enterprise; \( I'_{srt} \) – selected as a criterion for economic development indicator of a certain type of financial and economic performance of the enterprise (in the future as such an indicator we choose value added, because it directly determines the value of gross domestic product).

Then the expression \( 1/I_{srt} \) in formula (13) can be represented as:

\[ \frac{1}{I'_{srt}} = \frac{V_{t-1}}{V_t} \cdot I_{qt} = \left( \frac{I_{t-1} - C_{ot-1} - C_{et-1}}{I_t - C_{ot} - C_{et}} \right) \cdot I_{qt}, \]  

where \( V_{t,i} \), \( V_t \) – value added of the enterprise in time intervals, respectively, \( t-1 \) and \( t \); \( I_{t,i} \), \( I_t \) – operating income of the enterprise (excluding indirect taxes) in time intervals, respectively, \( t-1 \) and \( t \); \( I_{t,i} \), \( C_{ot,i} \), \( C_{or} \) – material costs of the enterprise (except for the cost of purchasing energy resources) in time intervals respectively \( t-1 \) and \( t \); \( C_{ot} \), \( C_{et} \) – the company's costs for the purchase of energy resources in time intervals, respectively, \( t-1 \) and \( t \).

Then, after performing certain mathematical transformations, expression (14) can be represented in the following equivalent form:

\[ \frac{1}{I'_{srt}} = \frac{1}{\alpha_1 \cdot I_{it}} - \frac{\alpha_2}{\alpha_1 \cdot I_{oct}} - \frac{\alpha_3}{\alpha_1 \cdot I'_{set} \cdot I_{pet}}, \]  

where \( \alpha_1 \) is the share of value added in the operating income of the enterprise in the \( t \)-time period; \( \alpha_2 \) – price index for the products of the enterprise \( (I_{q} = I_t/I_{qt}) \); \( \alpha_3 \) – the share of material costs (except
for the cost of purchasing energy resources) in the operating income of the enterprise in the t-time period; \( I_{oct} \) — index of specific material costs of the enterprise (except for the cost of purchasing energy resources) \( (I_{oct} = C_{oct}/(C_{oct} - I_{qt})) \); \( \alpha_3 \) — the share of costs for the purchase of energy resources in the operating income of the enterprise in the t-time period; \( I_{pet} \) — price index for energy resources purchased by the company \( (I_{pet} = C_{pet}/(C_{pet} - I'_{set})) \).

Taking into account expression (14), formula (13) can be presented as follows:

\[
I'_{ed} = \frac{1}{I'_{set}} \left( 1 + \frac{\alpha_3}{\alpha_1 \cdot I_{pet}} \right) - \frac{1}{\alpha_1} \left( \frac{1}{I_{if}} - \frac{\alpha_2}{I_{oct}} \right). \tag{15}
\]

Thus, the value of the indicator (13) depends on the values of the four indices, which are in the right part of expression (15). Accordingly, the process of assessing the impact of factors on the value of the indicator (13) will include the following stages of calculations: 1) calculation of the value of the indicator (13); 2) for each of the four factors, all indices, except for those that characterize its dynamics, are taken equal to one and the corresponding value of the indicator is determined (13); 3) the values obtained at the previous stage of calculations are divided by the value of the indicator (13).

3.3. The results of empirical analysis

In order to test the above methodological approaches to establishing criteria and conditions for sustainable energy-saving economic development of enterprises, the performance indicators of 120 enterprises of Ukraine were analyzed. These companies belong to four industries. At the same time, to reduce the impact of random factors, two-year time intervals were considered (the values of indicators for 2018–2019 were compared with their values for 2016–2017).

Table 1. Indicators characterizing the prevalence of the studied enterprises of sustainable energy-saving economic development

| Names of indicators                                                                 | Food Industry | Pulp and paper and printing industry | Woodworking industry | Textile and leather industry |
|------------------------------------------------------------------------------------|--------------|-------------------------------------|----------------------|-----------------------------|
| Number of enterprises surveyed                                                     | 44           | 21                                  | 35                   | 20                          |
| Number of enterprises that have undergone sustainable energy-saving economic development | 27           | 10                                  | 16                   | 8                           |
| Share of enterprises with sustainable energy-saving economic development, %        | 61.36        | 47.62                               | 45.71                | 40.00                       |
| Number of enterprises that have not undergone sustainable energy-saving economic development | 17           | 11                                  | 19                   | 12                          |
| Including due to the fact that:                                                   |              |                                     |                      |                             |
| 1) the index of specific value added did not exceed the index of specific consumption of energy resources | 12           | 6                                   | 10                   | 8                           |
| 2) the index of physical volumes of production was too low                          | 3            | 4                                   | 8                    | 3                           |
| 3) the index of physical volumes of production was too high                          | 2            | 1                                   | 1                    | 1                           |

Source: calculated by the authors on the basis of comparing indicators for 2018-2019 with their values for 2016-2017.
According to the data presented in Table 1, the share of surveyed enterprises that have undergone sustainable energy-saving economic development ranges from 40% for the textile and leather industries to about 61% for the food industry. However, for most enterprises in which this type of development was not observed, the reason for this was that the index of specific value added did not exceed the index of specific consumption of energy resources. Thus, in such enterprises, the indicator of the potential for sustainable energy-saving economic development was negative.

For those enterprises in which this indicator was positive, as shown in Table 2, there is a tendency to increase the share of enterprises that have undergone sustainable energy-saving economic development, while increasing the indicator of the potential of such development. The use of regression analysis showed that this dependence has the following form:

$$\beta = 0.092 + 3.786 \cdot I_{ed}' ,$$  \hspace{1cm} (16)

where $\beta$ is the share of enterprises in which there was an absolutely stable energy-saving economic development.

The dependence (16) is statistically significant with the following parameters: $R^2 = 0.709$; $F$-value $= 17.95$; $t$-value $= 5.23$.

**Table 2. Indicators of the share of enterprises that have undergone sustainable energy-saving economic development, depending on the value of the indicator of the potential of this development $I_{ed}'$**

| Intervals of indicator values $I_{ed}'$ | $0-0.03$ | $0.03-0.06$ | $0.06-0.09$ | $0.09-0.12$ | $0.12-0.15$ | $0.15-0.18$ | $0.18-0.21$ | $0.21-0.24$ | $0.24-0.27$ | $0.27-0.30$ | $0.30-0.33$ |
|----------------------------------------|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| The total number of enterprises with a positive indicator value $I_{ed}'$ | 3        | 4           | 7           | 6           | 12          | 16          | 11          | 10          | 5           | 6           | 4           |
| Number of enterprises where the corresponding type of development took place | 0        | 1           | 3           | 3           | 7           | 13          | 10          | 9           | 5           | 6           | 4           |
| The share of enterprises that have undergone the appropriate type of development in their total number | 0.00     | 0.25        | 0.43        | 0.50        | 0.58        | 0.81        | 0.91        | 0.90        | 1.00        | 1.00        | 1.00        |

Source: calculated by the authors on the basis of comparing indicators for 2018-2019 with their values for 2016-2017
It is also advisable to assess the impact of indices of individual indicators on the value of the indicator of the potential of sustainable energy-saving economic development in the studied enterprises according to the above sequence of such assessment (table 3).

According to the data presented in Table 3, the index of specific costs of energy resources had the greatest positive impact on the value of the indicator of the potential of sustainable energy-saving economic development in the studied enterprises. At the same time, the index of specific material costs of enterprises (except for the cost of purchasing energy resources) had a negative impact on all industries.

**Table 3.** The degree of influence of indices of individual indicators on the value of the indicator of the potential of sustainable energy-saving economic development in the studied enterprises (average data by industry), the share of the unit

| Names of indexes that have an impact | Food Industry | Pulp and paper and printing industry | Woodworking industry | Textile and leather industry |
|-------------------------------------|---------------|--------------------------------------|----------------------|-----------------------------|
| Price index for enterprise products | 0.31          | 0.28                                 | 0.26                 | 0.21                        |
| Index of specific material costs of enterprises (excluding costs for the purchase of energy resources) | -0.19         | -0.22                                | -0.14                | -0.17                       |
| Index of specific costs of energy resources consumed by enterprises | 0.64          | 0.71                                 | 0.59                 | 0.8                         |
| Energy price index | 0.24          | 0.23                                 | 0.29                 | 0.16                        |

Source: calculated by the authors on the basis of comparing indicators for 2018-2019 with their values for 2016-2017

4. Conclusions

Studies have shown the possibility of formalizing the criteria and conditions for sustainable energy-saving economic development of enterprises. In particular, it is necessary that the proposed potential indicator becomes positive. In turn, the value of this indicator depends on the values of the four indices. At the same time, the empirical analysis, among other things, showed that there is a linear trend towards an increase in the share of enterprises with absolutely stable energy-saving economic development, while increasing the indicator of the potential of such development.

Further research needs to take into account the environmental and social consequences of energy-saving economic development of enterprises and to clarify the limits of this development.

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