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Assessing energy efficiency factors in industrial companies

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Abstract. The relevance of the study is due to the fact that changes in the energy management policy at the national level, rising energy prices and increased state environmental control over production prompt industry to develop effective organizational and technical solutions in the field of energy management. The aim of the study is to identify energy management factors that determine the success or failure of the implementation of energy efficiency measures in industrial companies. In the empirical part of the study, the case-stage method was used to analyze the energy management practice of large metallurgical enterprises, where the problems of energy conservation are especially acute due to the high energy intensity of production. A promising direction in such an environment is the integration of structural components used to support decisions and social components represented by staff commitment and accumulated energy-efficient human capital. The main results can be applied in the practice of energy system management in the development of strategic planning processes, the adoption of sound investment decisions and the formation of energy-efficient human capital.

1. Introduction

Developing and implementing an effective energy policy aimed at reducing energy consumption, optimizing the energy balance structure and harmonious, safe use of the environment is a priority direction of development of countries in the current conditions. A number of global economic, political and environmental crises over the past fifty years have spurred the leadership of countries to seek domestic reserves to improve energy efficiency, as well as to develop cooperation in the field of improving technology to reduce the energy intensity of production. A number of researchers note that the oil crisis of 1973-1974, which exposed imperfections in the structure of energy consumption, as well as high dependence, played a significant role in increasing attention to energy efficiency issues. developed countries from oil prices [1-3]. As a result of this crisis, the Organization for Economic Co-operation and Development (OECD) has set up an International Energy Agency (IEA) that promotes the principles of safe energy consumption and conducts authoritative energy analysis and advice. Institutionalization of principles and approaches to energy efficiency management at the international level speaks to the strategic importance of energy consumption issues for all countries and industries and the need to develop and implement targeted, systemic resource-saving policies [4].

The problem of optimizing energy consumption is not new, but its relevance has not diminished for the last two hundred years [5]. In recent years, there have been major measurements in the factors that determine the success of energy management projects, and new barriers to the development of energy-saving technologies have emerged.

Recently, there has been a significant increase in the number of studies in the "energy economy" aimed at analyzing energy trends, structural changes and economic consequences. At first glance, by studying the problems of energy consumption, paradoxical results can be achieved, since, according to a number of empirical studies, the overall increase in energy consumption is a source of economic growth (as gross domestic product, GDP) and socio-economic development [6]. Consequently, on the one hand, energy resources are a significant source of economic growth, stimulating the development of industry. On the other hand, energy prices are increasing, causing a reduction in the marginal impact of energy intensity of GDP, so the overall contribution of this factor is also determined by the structure and nature of the energy sources that are involved in production. In developed countries, for example, economic growth is partly supported by an increase in the share of renewable energy in total consumption, including industrial consumption, despite the fact that alternative sources will be long overdue give way to traditional availability.

In general, it can be concluded that high energy intensity of GDP remains a significant factor of economic and environmental risk for a number of reasons.

First, higher energy costs reduce the competitiveness of national enterprises in local and international markets by increasing the overall cost of products and services and not being able to be accredited manufacturing technologies to enter international trading platforms. Secondly, low energy efficiency is associated with negative changes in environmental change in the regions of the presence of industrial enterprises.

In general, we note that the metallurgical industry, especially the steel industry, which also makes a significant contribution to greenhouse gas emissions, has significant energy-saving potential in developed countries. When developing energy-efficient technologies for metallurgy, many researchers take into account primarily technological factors [7]. The main producers in this sector are companies in China, Japan, the European Union, the United States and Russia, which produce about 70% of all black metals in the world. By 2050, the steel industry in the developed OECD countries will reduce carbon dioxide emissions by almost half (in a favorable scenario) precisely due to energy-efficient technologies. One of the most promising technologies in the steel industry in terms of energy efficiency is the electro-arc melting of steel, as well as direct iron recovery (DRI). A significant technical problem of energy efficiency is not only the direct implementation of the technology (for example, the use of outdated technology leading to losses), but also the lack of quality raw materials for processing, poor raw material base [8]. Both aluminum and copper industries are highly energy-intensive, with significant electrical energy costs in the production process.

IEA experts offer some promising technologies as part of energy-saving activities in the steel industry. These include the use of plastic waste in the smelting process, hydrogen smelting, FINEX heat exchange technology, the use of secondary waste gases, etc [9]. In the future, by 2030, the typical technology should be CCS (carbon capture and storage, carbon capture and storage), which would be associated with direct iron recovery processes. The total additional investment to achieve such technological breakthroughs in the steel sector will be between 300 and 400 billion. dollars in the period up to 2050.

Metallurgy is one of the most conservative industries in the field of technological development, on the other hand, it is characterized by one of the highest rates of unit energy consumption. All this suggests that the potential of energy conservation in the coming decades can be realized only through a flexible, focused management strategy focused on the intensive use of intellectual resources in planning, energy analysis and motivation of employees of enterprises [10]. Based on the previous analysis of literature, we can formulate a number of research questions for further analysis.

Question 1. What is the specificity of the production and organizational and economic conditions of the internal environment of industrial enterprises in modern Russia and how it determines the specifics of technologies and approaches to planning, organizing and controlling energy consumption as well as the motivation for energy saving?

Question 2. What factors in the internal and external environment of energy management determine the success or failure of the implementation of measures to improve energy efficiency in Russian industrial companies?

Question 3. What smart resources and technologies are companies using to compete in energy efficiency? What structural and social components of intellectual support for solutions are applied by enterprises in practice?

Question 4. How relevant are the issues of achieving energy efficiency for internal stakeholders and how deep is their awareness of energy saving issues?

2. Research methodology and data

To find answers to the research questions, we use the case-stage method, detailed analysis of a particular case, an example of a particular organization. Analysis of a particular object of research or case - case-stage - is one of the traditional methods of research in modern management. This method is usually associated exclusively with quality data, although it may include elements of quantitative analysis. The case-stage method involves the study of one or more cases involving a common research question, it differs in a detailed analysis of each object of the study in a given direction. In this section, we will present the main results of our analysis on a number of points, which will then allow us to answer the research questions posed at the beginning.

In our analysis, we will focus on some structural elements of management intellectualization that have been adapted in practice. Energy saving planning technologies based on regression models and subsequent targeting are used in practice at the surveyed enterprises. The models included specific parameters specific to each planning object, such as the temperature difference between the internal and external circuits, the volume of products produced, the cost of maintenance of the energy infrastructure, and so on. Climate conditions are compensated by entering the heating degree days (HDD) indicator, which reflects the duration of the period when the temperature in the region was higher than the baseline set at 15.5 degrees Celsius. In enterprise planning, external data is used to calculate HDD indicators, as well as data from weather stations located in the region of presence, published on the stations ' websites. In each case, the dependent variable was the final consumption of a specific energy resource, such as natural gas or electricity. The General view of the model used in enterprises is given below (equation 1):

$$E_t = \alpha_0 + \alpha_1 GP_t + \alpha_2 TE_t + \alpha_3 HDD_t + \varepsilon \quad (1)$$

E_t – Indicator of current energy consumption, kWh or Gcal;

α – Regression equation ratios;

GP_t – Production during the *t* period (e.g. steel output weight for one period);

TE_t – Technical parameters of the production process during the *t* period (e.g. temperature difference between two circuits of equipment, etc.);

HDD_t – Indicator of the degree-day of the heating season.

In particular, the following specific model was used for one of the production units for the process of electric arc smelting of steel at UMMC-Stal LLC (equation 2):

$$E_t = \alpha_0 + \alpha_1 ST + \alpha_2 GP^S_t + \alpha_3 SET + \alpha_4 CH_4 + \alpha_5 O_2 + \alpha_6 C + \varepsilon \quad (2)$$

ST – The total duration of melting in the oven, minutes;

GP^S_t – The weight of the release became for one smelting *t*, kg;

SET – The time of the metal under the current, minutes;

CH_4 – Natural gas consumption in terms of methane, m^3 per smelter;

O_2 – Oxygen consumption, m^3 per smelter;

C– Carbon consumption, m^3 per smelter.

In calculating regression equation ratios based on internal statistics, specific model parameters are determined, which are then used to calculate expected energy consumption. Descriptive variable statistics used to simulate expected energy consumption are shown in table 1.

Table 1. Descriptive statistics of the main variables used for modeling (compiled by the author on production reporting).

Production rate Process	Minimum	Maximum	Average	Rms deviation
Weight of steel output for smelting, kg	61400	121900	75556	3683
Melting time, min.	39.9	120.0	62.9	12.1
Time that metal is under current, min.	31.5	52.8	40.9	2.8
The amount of scrap scrap, t	55.2	465.6	89.4	6.6
Oxygen consumption for melting, m^3	1886.0	3615.0	2678.4	177.6
Carbon consumption for smelting, kg	10.0	1200.0	630.6	142.9
Natural gas consumption for melting. m^3	209.0	627.0	400.7	55.7
Power consumption actual, MWh	25.5	41.0	32.6	2.1
Electricity consumption per ton of steel, kWh per ton	252.3	540.4	431.5	29.0

In the first stage of the analysis, the regression ratios for Model 2 (table 2) are calculated. The calculated example provides data for all 5,138 smelting produced in 2019 at UMMC-Steel LLC, and other companies use models that use month-by-month data. Expected consumption, calculated on the basis of substitution of coefficient values back into the model based on the same technological parameters, is summed up by the increasing total, taking into account the coefficient of the finished savings set at 1%. For this model, the basis for energy conservation planning is the energy base, which reflects the benchmarks for setting regulatory indicators and becomes the basis for comparing the energy performance of different facilities. As our analysis shows, the main factor of energy consumption is one of the direct production factors - this time of the metal under the current, the other technological parameters also contribute to the change in the cost of electric Energy.

Table 2. Results of regression analysis on model 2 for the steelmaking of UMMC-Stal LLC in 2019 (calculated by the author based on production reporting)

	Model from Equation 2			Modified Model		
Variable	Coeff.	Standard deviation	t	Coeff.	Standard deviation	t
(Constant)	0.9184	0.230	3.991	5.2603	0.488	10.781
Weight of steel output in t	0.0096	0.003	3.678	0.0296	0.006	5.308
Smelting time in minutes	-0.0106	0.001	-12.303	0.0392	0.002	23.481
The time that the metal is under current	0.7054	0.005	135.623	-	-	-
The amount of scrap to be loaded. t	0.0021	0.002	1.392	0.0576	0.003	18.558
Oxygen consumption for melting, m^3	0.0011	0.000	15.288	0.0057	0.000	41.922
Carbon consumption for smelting, kg	-0.0002	0.000	-2.864	-0.0014	0.000	-9.195
Natural gas consumption for melting m^3	-0.0007	0.000	-3.821	-0.0031	0.000	-7.486
R^2 adjusted		0.907			0.573	
F-statistic		7145			1149	
The number of observations		5138			5138	
Darbin-Watson test		0.687			0.891	

Estimated regression ratios from table 3 are used to determine the expected energy consumption values, which are multiplied by a factor of 0.99 (laying additional savings within 1%). the level of savings at which the system is energy efficient. The considered tool, which is used in practice in the holding companies, allows to assess the effectiveness of energy-saving measures and to establish the degree of achievement of savings at each company of the holding.

3. Conclusions and recommendations on the results of the case-stage

In this section, we will provide answers to the main questions posed in the case-stage study and analyze the prospects for solving some of the problems that arose during the analysis.

Answer to question 1. All enterprises are in difficult socio-economic conditions of development, formed under the influence of the current crisis at the national level, only export-oriented enterprises have a financial advantage at the expense of exchange rates fluctuations in the national currency and the provision of its own resource bases. Many enterprises inherit energy infrastructure and technologies formed decades ago, which significantly determine the decline in energy efficiency. Approaches to market conditions involve a clearer link between current company performance indicators and energy management investment strategies. The staffing of enterprises is characterized by a high average age of employees, management technologies in such conditions are rather conservative, which leads to high resistance to change and the need for additional training. Businesses declare the use of a systematic approach to energy management, but in the conduct of energy audits not all items of the audit sheet are evaluated at a satisfactory fifty percent level. High results can be achieved with the introduction of energy management teams, which aim to improve compliance with internal business processes with the requirements of system energy management in the period from one to two years.

Answer to question 2. A major factor in success in improving the systemic approach to energy management is the achievement of a high level of commitment of employees to the values of energy-saving culture, which consists of awareness, documentary enshrining energy policy, as well as training different categories of staff. The key to success was the commitment of senior management, which planned to allocate additional human and administrative resources for the project. Companies were asked to develop several training programs for employees who indirectly influence energy conservation processes, technical staff and managers (in the field of energy responsibility). An important condition is also the compilation of an energy management team in the enterprise, which would be an internal agent of change, a source of activation of the mechanism of self-improvement. The best results in the work of teams are achieved by forming sustainable communication processes based on modern information technologies. Analyzing the process of teams in this case-stage it is important to note the factor of spent man-hours of work. Each of the main participants spent 3 to 10 hours of current working time per week, participating in supporting certain activities within the project. It is important that management understands the role of additional man-hours spent on the project and develops a system of staff motivation.

Answer to question 3. Businesses are actively using various structural and social components of the intellectual energy management mechanism, which was analyzed in the theoretical part of this study. Basically, the structural elements include ready-made technological and methodical solutions, which are formed on the basis of the best practices of energy management in the industry, the role of innovative components is insignificant. In addition, significant methodical updating in the enterprises was due to the joint work of the UNIDO team, which supported the analysis, planning and implementation of energy-saving projects. Structural components used in post-project enterprises include energy infrastructure monitoring automation systems, various optimization models used to set energy-saving targets, methods of conducting energy audits and internal current surveys, methods of planning current energy consumption based on the baseline. All the tools considered are a way to achieve a competitive advantage by reducing energy costs. The lack of a centralized information analysis system, as well as the lack of understanding by managers of the relationship between the structural and social components of the decision-making support models, are serious problems in this area.

Answer to question 4. In the course of qualitative analysis we have to conclude that enterprises do not use an approach to energy management based on taking into account the interests of stakeholders.

The main focus of current practical approaches lies in the analysis and planning of production processes, taking into account the only competitive strategy - reducing production costs. And in practice, the needs of each of the groups of internal and external stakeholders in the context of each business process are not always analyzed. The actions of the energy management team at the surveyed enterprises are aimed at finding current problems and implementing short-term projects to save energy and improve environmental efficiency. In this case, we recommend for each enlarged business process related to energy management, to single out a number of stakeholders and note the social, economic and environmental effects achieved. In a UNIDO-sponsored initiative, enterprises have been able to raise a significant level of awareness. The system approach aims to raise awareness of energy conservation processes only in the internal environment of the enterprise, reducing the importance of external stakeholders.

4. Limitations and conclusions

The empirical part of the study used the case-stage method to analyze the practice of energy management of four large steel enterprises in Russia, where energy conservation problems are particularly acute due to the high energy intensity of production. A case-stage survey has shown that in recent years the systemic approach to energy management has become more common, and the complexity of management practices increases over time through the use of better tools planning power supply, controlling energy consumption and motivating employees. The analysis showed that enterprises use intelligent methods to support management decisions, such as regression modeling and subsequent targeting.

Unfortunately, the systemic approach also provides only indirect answers to the question of the effectiveness of the impact of organizational culture and training on overall energy performance.

The integration of the social and structural components of smart energy management, which would provide the decision-making process with additional information about the internal energy environment, is a promising direction, taking into account the decision-making process. commitment and level of development of communications, knowledge management technologies within the organization. An important task in the intellectualization of management is not only the massive introduction of individual knowledge management tools and improvements into production process management models, but also to measure their effectiveness and, in ultimately, expediency.

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