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ANALYSIS OF THERMAL ENERGY CONSUMPTION MANAGEMENT OF ENERGY-INTENSIVE ENTERPRISES

Katarzyna WIDERA[1], Rafał GĄSIOR[2], Adam SMOLIŃSKI[3*]

[1] Opole University of Technology; k.widera@po.edu.pl, ORCID: 0000-0003-0651-8049
[2] Polish Mining Group S.A., Katowice; ra.gasior@pgg.pl, ORCID: 0000-0002-2032-1958
[3] Central Mining Institute, Katowice; asmolinski@gig.eu, ORCID: 0000-0002-4901-754
* Corresponding author

Purpose: The purpose of this study is to analyze and evaluate the consumption of thermal energy in a coal mining enterprise with separate business units, in the context of securing energy reserves and effectively managing the consumption of this energy.
Design/methodology/approach: Based on the aggregation and analysis of historical data of thermal energy consumption, the method of statistical analysis of aggregated data from individual business units of the coal mining company was applied.
Findings: The applied statistical analysis of the aggregate data made it possible to verify the planned short- and long-term activities for each group of facilities of the coal mining company.
Research limitations/implications: The further direction of the research requires verification of the obtained results of the statistical analysis, after completing the data of thermal energy consumption in the following years and correlating the obtained results with the introduced pro-efficiency measures in the enterprise so as to clarify the division of the enterprise's facilities into individual groups.
Practical implications: Statistical analysis of thermal energy consumption, can become an effective tool to support the process of managing pro-efficiency measures in mining enterprises with separate business units.
Social implications: The right approach of coal mining companies to thermal energy analysis and management can contribute to securing energy reserves for the local environment in which the company operates.
Originality/value: The presented classification of facilities into groups A, B and C and the use of statistical analysis to verify the introduced measures to reduce thermal energy consumption have not yet been introduced and tested in the Polish coal mining industry.
Keywords: energy efficiency, statistical analysis, energy consumption, enterprise.
Category of the paper: research paper, case study.

1. Introduction

Energy poverty in the current situation of a disrupted supply chain of energy resources, is a key challenge in the context of energy security of the European community society. It is also a demanding task for producers and energy distribution units in terms of managing the continuity of thermal energy supply. This article analyzes the characteristics of thermal energy consumption on the example of a coal mining company with a distributed organizational structure with regard to securing energy reserves for the local environment in which the company operates. For this purpose, the method of statistical analysis of aggregated data from individual organizational units of the coal mining enterprise was used. It allowed verification of the planned short- and long-term activities for the distinguished types of facilities. Thus, it is an effective tool to assist the management process in evaluating pro-efficiency measures for thermal energy consumption.

Over the course of 2022, there were an average of three changes in thermal energy price lists in the four operating regions of the company (consisting of fifteen business units). In the course of updating the price lists, it was estimated that price increases per 1 GJ ranged from 30% to 65%. Analyzing the aggregate annual consumption of the enterprise, the projected average price per 1 GJ from 2020 to the end of 2023 will increase by ≈153% (Figure 1.).

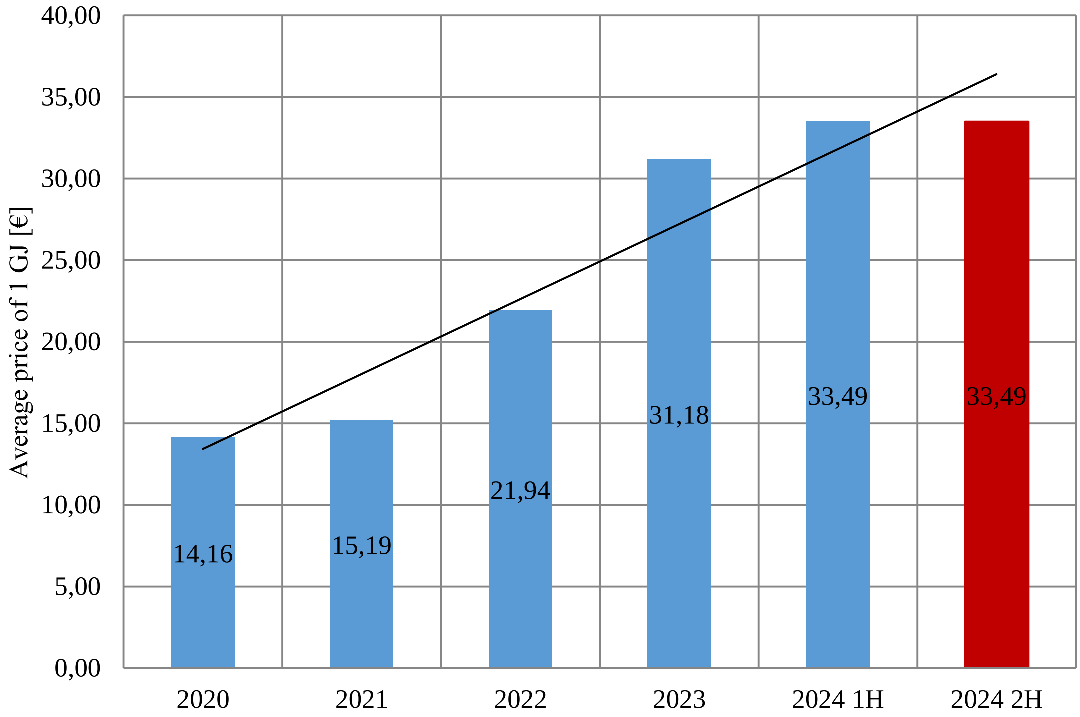

Figure1. Forecast of the increase in the average price of 1 GJ of thermal energy of the enterprise.
Source: own study.

2. State of the art review

One of the primary goals of implementing energy efficiency is to reduce primary energy consumption. In the literature, the concept of primary energy is understood as the sum of energy contained in primary energy carriers (Law of May 20, 2016 on Energy Efficiency, Journal of Laws. 2016 item 831). Achieving this goal for 2020 meant reducing the consumption of the aforementioned energy between 2010 and 2020 by 13.6 Mtoe (Skoczkowski et al., 2018).

According to current data from the Central Statistical Office, the increase in energy efficiency in 2021 was 0.5% higher than in 2020. The main area with the highest energy demand is industry (Leszczyńska et al. 2016). Energy consumption in industry increased by 2.3% in 2021 compared to 2020 and amounted to 17.3 Mtoe. It should be noted that between 2011 and 2021, total primary energy consumption increased from 96.6 Mtoe to 104.0 Mtoe, and for final energy the increase was 10.5 Mtoe from 64.7 to 75.2 Mtoe (GUS, 2023).

From 2006 to 2019, the level of total primary energy consumption ranged from 97 Mtoe - 103.5 Mtoe, indicating an average growth rate of 0.5%/year.

For final energy consumption, the rate was 0.7%, i.e. 61.6 - 70.7 Mtoe (Dołęga, 2022).

Considering the financial support instruments, it should be pointed out that the National Fund for Environmental Protection and Water Management allocated the amount of about €160, 355.00 to subsidize energy efficiency improvement projects, and granted loans with a total value of about €211, 057.00. This financing took place only in 2015-2018 (NIK, 2018). Nowadays, too, there are proposed programs to finance projects aimed at improving energy efficiency for both households and dal enterprises. Some of the most popular are:

- FENIKS Program - Energy efficiency improvement, high-efficiency cogeneration, RES installations,
- FENG Program - European Funds for Modern Economy Priority III "Greening of enterprises".

The problems of increasing energy efficiency, estimating future operating costs of an enterprise, as well as reducing the energy poverty of the community of the environment in which the enterprise operates, require reliable analysis of numerical data (Krawczyk et al., 2016; Tokarski et al., 2021; Howaniec et al., 2015). These issues imply the need to develop regulations for the rational management of thermal energy based on the substantive basis of both consumption and the amount of demand for it (Magdziarczyk et al., 2024a, 2024b).

Kanga (2007) used statistical analysis to evaluate the qualitative as well as quantitative difference in the effect of the temperature of the upper and lower heat sources and the power output to the upper source on the Coefficient of Performance. Szmechta et al. (2010) used statistical analysis as a tool to achieve improvements in wind power plant efficiency. In their study, they demonstrated the possibility of optimizing energy curve coefficients for wind energy and wind temperature, as well as the relationship between wind dynamics and improved controller performance for maximum speed. Ostanska (2016) used statistical analysis to assess the technical-energetic condition in the area of building insulation, performing a statistical evaluation of errors in the insulation performed. Kornatka (2022) demonstrated using statistical analysis the possibility of optimizing the selection of energy tariffs for a given customer based on reactive power consumption data from AMI (Advanced Metering Infrastructure) metering. Shaikh et al. (2016) evaluated the benefits of using high-efficiency electric motors compared to standard motors with similar ratings. Based on the collected data: annual energy savings, cost savings and payback period, a sadistic analysis was conducted using Student's t-distribution to determine the confidence limits of the indicated parameters. The determined confidence limits of the average annual cost savings and energy savings, as well as the average payback period, showed the advantage of using motors with higher efficiency, a concordance also demonstrated in the work of Memon et al. (2016). Sadeghifam et al. (2019) in their work addressed the issue of optimizing energy consumption in relation to the parameters of building materials considered in the design and construction of buildings. They used Taguchi's statistical method in their work to reduce the number of interfering factors and determine the main factors that can be controlled. The study adopted controlled factors floor (A), wall (B), window (C), ceiling (D) and roof (E), and uncontrolled factors temperature (F), airflow (G) and humidity (H). They showed that elements such as ceilings and then windows have a significant impact on the energy efficiency of buildings in effect pointing to the appropriate choice of materials for these elements of building construction. Sandu et al (2021) performed a statistical analysis of energy systems considering the areas of availability (e.g.: security of supply, import dependence, energy diversity), affordability (e.g.: energy prices and their stability, economic crises), acceptability (e.g.: greenhouse gas emissions, SOx emissions) and efficiency (e.g.: energy intensity, grid efficiency) based on the systems of 129 economies over the period 1990-2016 (Su et al., 2024; Magdziarczyk, 2024c). The paper uses the unit root test to determine whether the variables are non-stationary, principal component analysis (PCA) to determine the weights for the adopted performance indicators in a given area (Howaniec et al., 2011; Djaković-Sekulić et al., 2008). Causality of indicators was assessed based on Granger causality models and Dumitrescu and Hurlin causality models, and causality intensities were analyzed based on the least squares method (FMOLS) and dynamic ordinary least squares method (DOLS). It was found that in developed economies there is greater acceptability to environmental conditions, which is associated with increased use of renewable energy. Less developed economies were found to have an increasing reliance on fossil fuels for better access to energy. Cecinato et al. (2021) evaluated the energy performance of thermoactive micropiles using numerical modeling and Taguchi statistical analysis. It was observed that parameters such as pile length, concrete conductivity and pipe diameter play a major role in the energy evaluation of micropiles with the latter being particularly important. Mauleón in his work (2022) used statistical modeling based on historical data series to predict and simulate energy demand. Adilkhanova et al. (2023) addressed in their work the evaluation of the cooling effect by taking into account parameters that determine the reflectivity of a given surface. The paper used statistical analysis of actual energy consumption to develop a model for predicting energy consumption.

3. Hypothesis, materials and methods

Mining companies have the capacity to secure thermal energy for the local environment in which they operate. The research problem of this study is closely related to obtaining an answer to the question:

"How to make an effective assessment of the introduced measures to reduce thermal energy consumption in a mining enterprise?"

In order to obtain an answer to the research problem posed in this way, it was decided to use statistical methods to evaluate the planned measures for thermal energy consumption. The aggregated data were analyzed using adequate tools to assess both the average level of the phenomenon under study and the rate of change in real time.

The use of statistics in the analysis and interpretation of aggregated data, as a quantitative tool of the research method of industrial processes, can assist the management process of a mining enterprise. Statistical analysis begins with the aggregation of results, taking into account the completeness of the data, then grouping of individual information into subclasses is carried out adequately for the established characteristics. For the data (in this case, cross-sectional-temporal), statistical series, such as detailed ones, are obtained. Due to the fact that the study concerned the years 2021-2022, the following were used for statistical analysis: relative increments (determining the rate of change over time), geometric mean as a measure of location for dynamic data, relative frequencies as characteristics determining the structure of the data in terms of the studied characteristics. The results obtained were presented in the form of tables and graphs.

The data analyzed are the annual totals of thermal energy consumption in GJ for the facilities in the 15 studied units of the coal mining company. A division of the studied facilities into three types was made: the first in which it is not possible to reduce thermal energy consumption due to production activities, the second for which it is possible to reduce thermal energy consumption without affecting production activities, and the third where it is possible to reduce thermal energy consumption to the necessary minimum. Finally, the data was aggregated and the analysis looked at facilities in groups in terms of the three types mentioned. Among coal mining companies, no similar division and analysis was made in terms of effective thermal energy management.

The constantly rising prices in the energy market significantly affect the operating costs of mining enterprises. Taking into account the rational planning of thermal energy management as a package of solidarity responsibility of the enterprise, measures were carried out to increase energy efficiency.

The global consumption of thermal energy in the studied enterprise of 2021 was 1322340.92 GJ. Given the need to implement the above measures, a detailed response plan was developed:

Teams were established at the enterprise to analyze thermal energy consumption and propose measures to reduce its consumption. The teams' work included:

1. aggregating the level of thermal energy consumption historically in accordance with Table 1,
2. to divide the objects in accordance with Table 2:
   - type one objects are marked A - objects in which no heat energy consumption can be made,
   - type two objects are marked B - objects in which it is possible to reduce the consumption of thermal energy without affecting extraction,
   - type three objects are marked C - objects in which it is possible to reduce thermal energy consumption to the necessary minimum,
3. develop a plan to reduce thermal energy consumption by a minimum of 15% of facilities marked B and C according to Table 3, which will include, among other things, information on:
   - places of heat loss,
   - the state of thermal insulation of the objects,
   - the condition of the transmission network,
   - others not listed above.
4. development of short term and long term actions with particular attention to:
   - for short-term actions:
     - exclusion of unnecessary objects,
     - setting a minimum temperature in selected facilities (e.g., rarely used by employees),
     - use of heat regulators,
   - for long-term actions:
     - thermal modernization of facilities,
     - modernization of transmission networks,
     - replacing existing heat sources with more efficient, more effective ones,
     - application of thermal energy management systems,
     - implementation of other pro-saving investments,
     - implementation of investments enabling the acquisition of white certificates.

It has been assumed that the introduced measures in thermal energy consumption, once completed, will be globally evaluated during the analysis of subsequent plans, and the effects of the prepared plan will be verified through monthly monitoring of energy consumption. In addition, all actions related to improving energy efficiency must be in accordance with the Regulation of the Minister of Infrastructure on the technical conditions to be met by buildings and their location Law Journal 2002, No. 75, item 690, consolidated text Law Journal of 2022, item 1225, and the Ordinance of the Minister of Labor and Social Policy on general regulations of safety and hygiene at work Law Journal 1997, No. 129, item 844, unified text Law Journal 2003, No. 169, item 1650.

Table 1.
Aggregation of thermal energy consumption

Branch				Year
Object	**Power**	**Power**	**Power**	**Month**
	tariff 1	tariff 2	tariff n	Consumption
	[MW]	[MW]	[MW]	GJ
…				
TOTAL				
Total for tariff 1				
Total for tariff 2				
Total for tariff 3				

Source: own study.

Table 2.
Division of facilities

No	Name of the object	Object classification (A, B, C)	Condition of the facility/infrastructure	Comments
1.				
2.				
3.				
...				

Source: own study.

Table 3.
Measures to reduce thermal energy consumption

No	Name of the object to which the action relates	Name of operation /activity/investment	Type of action (long-term/short-term)	Estimated savings in thermal energy consumption in %	Comments
1.					
2.					
3.					
...					

Source: own study.

4. Results and discussion

Performing a statistical analysis of both the consumption of thermal energy and the improvement of efficiency in the use of thermal energy in the 15 surveyed units, a division (indications) was made into type A, B and C facilities. Figure 2 shows the thermal energy consumption of an enterprise located in the Upper Silesian Industrial District. The data was grouped into blocks by area, respectively: in blue the eastern area, in purple the Katowice area, in orange the central area, in green the western area.

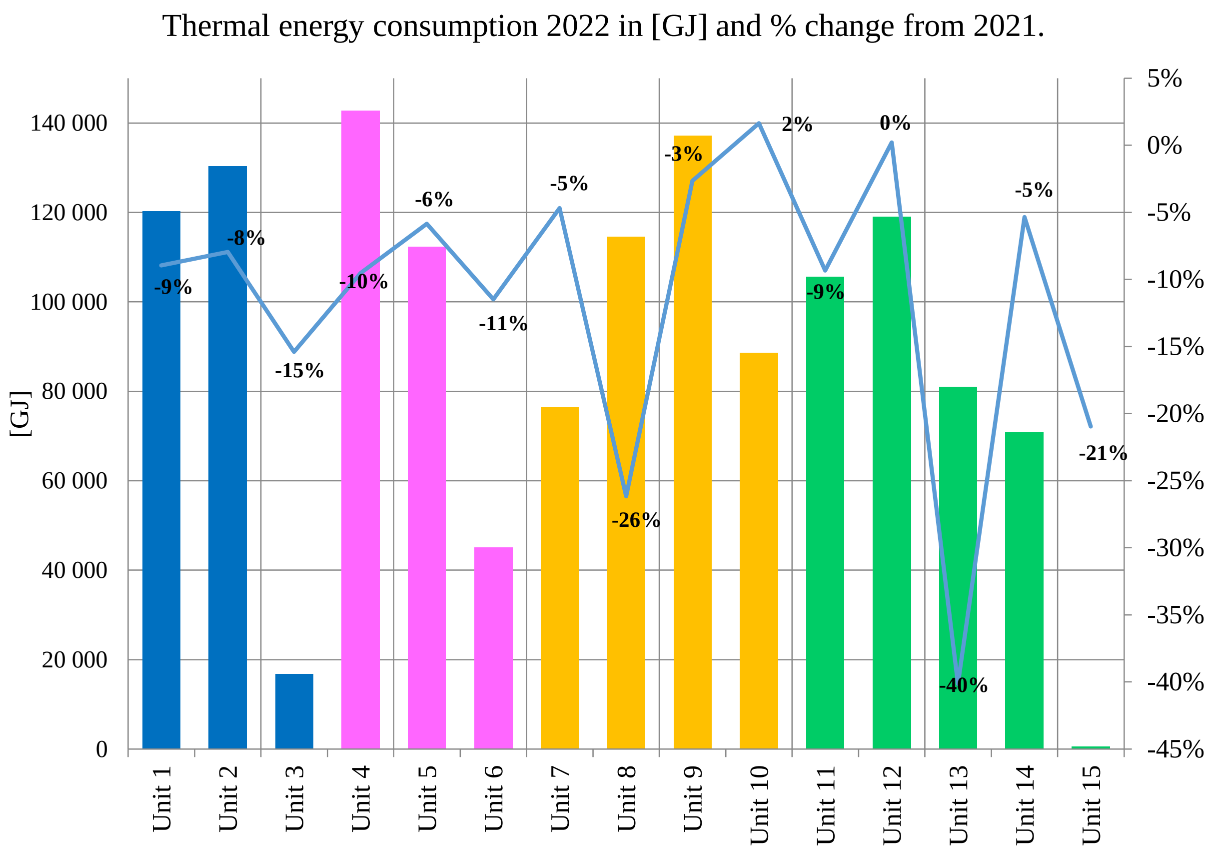

Figure 2. 2022 thermal energy consumption in GJ and % change from 2021 by 15 units.

Source: own study.

For each unit, a relative chain increment in energy consumption was calculated relative to the base year of 2021. The percentage of consumption for 2022 allowed the calculation of a geometric mean value, which shows an average 12% decrease in energy consumption in 2022 compared to 2021. Table 4 includes the % decrease by facility type A, B and C.

Table 4.
Percentage decrease in consumption in 2022 compared to 2021 by facility type

Facility type:		
A	**B**	**C**
7,60 %	13,53 %	18,44 %

Source: own study.

Table 5 provides information on projected savings after 2022 in terms of percentage frames by facility type.

Table 5.
Planned range of thermal energy savings after 2022 in facilities in [%]

Type of planned activities	Facility type:		
	A	**B**	**C**
short-term	3 - 15%	3 - 30%	15 - 30%
long-term	10 - 40%	10 - 40%	20%

Source: own study.

Based on the detailed information provided in the efficiency improvement plans for thermal energy use (the type of facility, type of planned measures and planned % savings were indicated), the overall structure of planned savings after 2022 shown in Figure 3 was determined.

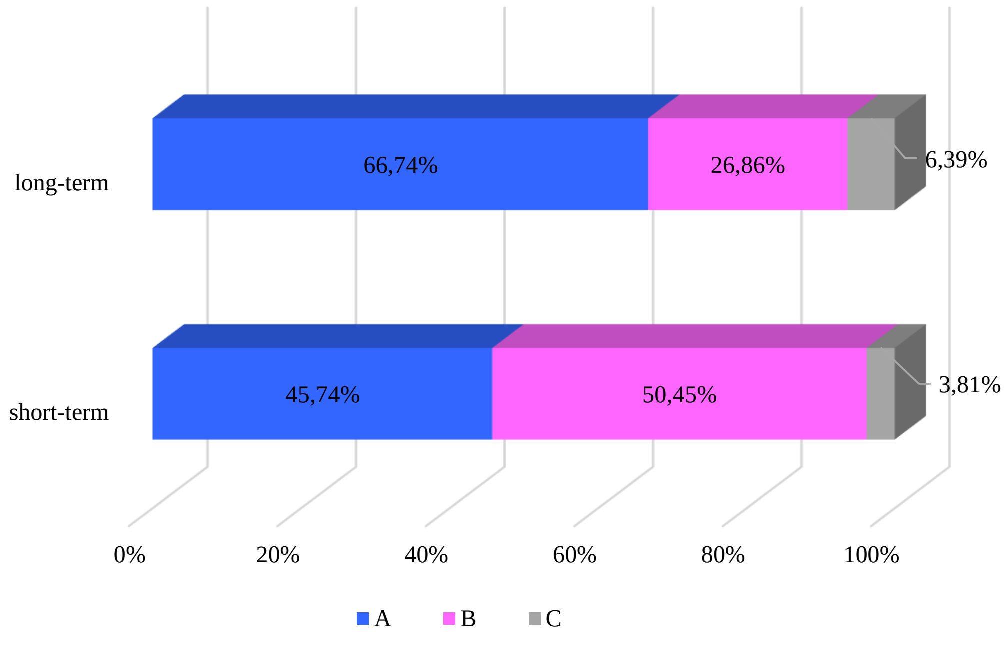

Figure 3. Structure of planned savings by type of activity and type of facilities in 15 units.

Source: own study.

The estimation of the average percentage decrease in consumption resulting from the planned savings was made on the basis of data on thermal energy consumption in 2022 by facility type. The obtained values of average decreases in thermal energy consumption are included in Table 6.

Table 6.
Przeciętny procent spadku zużycia wynikający z planowanych oszczędności w obiektach typu A, B, C w [%]

Type of planned activities	Facility type:		
	A	B	C
short-term	3,70 %	7,03 %	3,79 %
long-term	7,21 %	5,00 %	8,51%
total	10,91%	12,03%	12,30%

Source: own study.

The following assumptions were made in the analysis:

- The base year for the analysis of thermal energy consumption was 2021. And for the analysis of efficiency improvements in thermal energy use in the 15 surveyed units was 2022.
- The analysis of efficiency improvements after 2022 is for those type A, B, C facilities in the 15 units that had an indicated % of planned improvement in thermal energy use savings in their efficiency improvement plans.
- Units in their efficiency improvement plans for thermal energy use indicated a breakdown of facilities into A, B, C, but assigning a facility to a type was not tantamount to indicating planned measures: short or long-term, so it should be considered that if they were not indicated then the technical condition of the facility did not require such a plan.
- Units in the energy efficiency improvement plans indicated the nature of the actions by: short term and long term, and indicated the % of approximate improvement if implemented. In the situation where the unit indicated the nature of the planned actions without indicating the % of improvement, it was assumed that this would be in the case of short-term actions 5-10%, and long-term actions 10-20%.

The analysis carried out and the results obtained indicate that the average percentage of decrease in thermal energy consumption after 2022 for type A and B facilities of short-term measures is within the range of the planned range of thermal energy savings, indicating the correctness of the planning carried out by the enterprise's production units. With regard to C facilities of short-lived activities, the average percentage of decrease is 3.79% with planning assumptions of 15-30%, indicating the necessity of revisiting the planned short-lived activities for these facilities. With regard to long-term measures for facility types A, B and C, the average percentage of decrease in thermal energy consumption did not find coverage with planning sentences, in this particular case the proposed long-term measures should be verified for each case. Considering the average percentage of decline in thermal energy consumption after 2022 in relation to historical data (Table 4), progression occurs only in the case of type A facilities, it should be pointed out here that there is a clear structure of planned measures (Figure 3) long-term and short-term indicating the area of type A facilities as leading. The further direction of research on the issue will be the verification of the obtained results of the statistical analysis, after completing the data of thermal energy consumption in the enterprise for the year 2023, correlated with the introduced pro-efficiency measures.

5. Conclusions and evaluation

Taking into account EU legislation, and national resolutions and regulations on air emission requirements for large and medium-sized power plants, including: Directives on the limitation of emissions of certain pollutants into the air from medium-sized combustion plants (MCP), the Industrial Emissions Directive (IED) and the revision under the "Ready for 55" Energy Efficiency Directive (EED), and taking into account the fact that the Polish energy mix is mostly based on conventional fuels, it should be concluded that the rational use of thermal energy and the effectiveness and efficiency of thermal energy consumption management of e-extractive enterprises play an increasingly important role.

It was found that the use of statistical analysis is an effective tool in evaluating pro-efficiency measures. The statistical analysis performed showed the correctness of short-range planning for Type A facilities classified as facilities where there is no possibility of reducing thermal energy consumption due to production activities. Facilities with high production significance are subjected to a more reliable assessment (with a higher safety threshold) in estimating energy efficiency improvements. Despite the classification of Type A facilities as impossible to reduce thermal energy consumption, these facilities show their potential for energy efficiency improvements. Long-term planning is less precise, subject to greater error, as indicated in the comparison of planning and estimated results.

With regard to securing energy reserves for the local environment in which the enterprise operates, the potential for improving energy efficiency ergo reducing thermal energy consumption can be indicated, which implies securing thermal reserves for the local environment or reducing the level of use of energy carriers potentially limiting the increase in thermal energy sales prices. This approach of enterprises to thermal energy management can contribute to the impact on global thermal energy security in a given agglomeration of operation of a production unit.

So far, the division of the coal production enterprise into individual facilities (A, B, C) of thermal energy management and curtailment has not been carried out, and statistical analysis has not been used in such an approach. Nevertheless, the research has been carried out based on one enterprise, which requires further analysis in the indicated area, the research should be extended to other hard coal mining enterprises. Implementation of an identical system in other enterprises can make energy saving management more effective not only in the area of thermal efficiency but also in the efficiency of electricity consumption.

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