Management of Labour and Safety

DOI: https://doi.org/10.12958/1817-3772-2024-4(78)-155-163

UDC 339.9+331+338.24+338.23:338.585

D. Cherevatskyi,
DrHab (Economics),
Head of the Department of Fuel and Energy
Complex Prospective Development,
ORCID 0000-0003-4038-6393,
e-mail: cherevatskyi@nas.gov.ua,
Institute of Industrial Economics of NAS of Ukraine, Kyiv,

R. Smirnov,
PhD (Math.), Professor,
ORCID 0000-0001-5971-8541,
e-mail: roman.smirnov@dal.ca,
Dalhousie University,
Halifax, Nova Scotia, Canada,

O. Bojko,
Graduate Student,
ORCID 0000-0001-7301-724X,
e-mail: bojko-oksana@ukr.net,

V. Bash,
Graduate Student,
ORCID 0009-0008-1173-2174,
e-mail: bash.v@dch.com.ua,
Institute of Industrial Economics of NAS of Ukraine, Kyiv

THE CONTRIBUTION OF PERSONNEL TO THE OVERALL ENERGY INTENSITY OF LARGE MINING ENTERPRISES

1. Introduction

It is our contention that the actualization and activation of the analysis of material and energy costs in the production process fully align with Sustainable Development Goal (SDG) No. 12, which is formulated as "Sustainable consumption and production/Ensure sustainable consumption and production patterns. "Importantly, at the United Nations Summit "Transforming our world: the 2030 Agenda for Sustainable Development," held in September 2015 during the 70th session of the UN General Assembly, 17 SDGs were approved, further supporting our statement.

The cornerstone of major contemporary methodologies for assessing energy efficiency relates to human labor. To delve into the essence of the issue, it makes sense to begin with animal labor. Draft animals have been utilized since ancient times, even underground. For example, animals worked and lived in mines, where their stables were located.

Unlike horsepower, there is no official unit of measurement for human power. However, in work [1] the power of an adult male is recommended to be taken as 0.12 hp (90 W) and females as 0.08 hp (60 W). By the standard ratio of 50% men/women, the power level of the average worker is considered to be 75 W (~0.1 hp). This is the standard equivalent used in comparing human labor to agricultural machinery.

In what follows, we will discuss labor as both labor force and energy source.

With the 75-watt power of one person, for example, the combined power of all the regular workers in a mine where 5000 people work, a figure indicative of a very large enterprise, would amount to only 375 kW or 1.3% of the power consumption of the electricity consumers of the "Pokrovske" Colliery Group (Ukraine) at peak hours (30 MW).

The power of workers is at the level of engineering error compared to the power of the energy-mechanical system of the enterprise, which explains why "...exergy analysis also ignores important critical inputs, such as capital and labor" [2]. Exergy, a concept introduced by J. Szargut and R. Petela [3], denotes the maximum work that can be performed by a thermodynamic system. A recognized modification of exergy analysis is the concept of EROI (energy return on investment) or EROEI (energy returned on energy invested), which has become a commonly used synonym for energy profitability [4].

The principle that few people currently operate on the magnitude of human labor power, but the prevalence of specific rates of energy expenditure has been found. Ukrainian author, for example, determined energy labor standards based on waste management: according to his data, raw material collection requires 2.1 MJ per ton; transportation – 7.2; sorting + composting – 12.5; sorting + incineration – 15.5; integrated processing – 9.2 MJ/ton [5]. The drawback is that without knowledge of raw material processing standards, this approach cannot be used to address the problem as a whole, and it remains purely sectoral.

Another approach is presented in [6]. Based on the norms of the state standard (very light work – 0.60 MJ per person-hour; light – 0.90; medium – 1.26; heavy – 1.86; very heavy work – 2.50 MJ per person-hour), an analogy is made between a worker and a specific technological unit. According to this concept, after the end of the work shift, the worker transitions conditionally from a working mode to an idle mode, which is characterized by lower power consumption. There is reason to this: of course, a person's metabolism does not stop instantly. Thanks to this approach, it is possible to calculate the energy expenditure of a worker during sixteen non-working hours per day and during weekends and holidays, which amounts to 310 kg of CE per year.

The consideration or ignoring of energy aspects of living labor is not a tribute to theories, but, as a rule, a choice of practitioners. Perhaps it is precisely according to the logic of practitioners that this magnitude did not enter the inventory of the ecological backpack proposed in the context of the MIPS approach by Friedrich Schmidt-Bleek from Wuppertal [8]. Any further methodological developments by the Wuppertal Institute for Climate, Environment, and Energy at the Science Centre North Rhine-Westphalia regarding material flow analysis (MFA) also did not take into account the energy aspects of human labor. Experts agree that a single and universally accepted method of accounting for labor has not yet been developed [9].

Here we encounter a paradox. The direct energy costs associated with the muscular force of workers are decisively rejected by both theorists and practitioners, while the indirect costs associated with wages, etc., are exaggerated. This tendency is characteristic of both EROI adherents [10] and MIPS or LCA (Life Cycle Assessment) supporters [11].

Now let us discuss labor not as a producer of physical energy but as a consumer of energy resources.

However, if a pound was a pound yesterday, it remains a pound today, then referring to macro-level indicators produces significant discrepancies: for example, in India, energy expenditure per person-hour is 1.9 MJ (0.065 kg of CE), while in the USA, it's 30 MJ (0.251 kg of CE). Brazil's figure is 3.3; France's is 17; Germany's is 16 MJ per person-hour of working time [7].

In Ukraine, despite the fact that researchers in the field of measuring energy indicators of labor costs demonstrate active research activity – the most well-known is the work of the Institute of General Energy of the National Academy of Sciences of Ukraine [12-15] – economic approaches generally prevail. For instance, H. Panchenko, assuming the homogeneity of the income structure between all recipients of these incomes in the country, suggests calculating the full energy intensity of labor costs [12]. Full energy intensity of labor costs depends of the total energy costs for the production of own energy resources and the energy equivalent of imported energy resources used for energy purposes in Ukraine (in thousand tons of CE), total value of goods and services produced and final consumer spending, the wage fund of hired workers. The essence of the proposal stems from the premise that household expenditures constitute the main part of final consumption and characterize the structure of goods and services consumption by the population using their own funds. They include expenditures on purchasing consumer goods and services, as well as the consumption of goods and services obtained in natural form and produced for personal final consumption.

It would be pertinent to consider the amendment suggested by V. Bilodid regarding the inclusion of shadow sector indicators when determining the energy intensity of labor costs [14]. However, the reliability of estimates of informal sector activity itself poses a problem.

According to H. Panchenko, the final fuel consumption in Ukraine in 2017 (including the energy equivalent of nuclear energy) amounted to 77,249 million kg of CE. The total value of goods and services produced, final consumer spending, and payment for hired labor in the same year were respectively 8,381,846; 2,618,126 and 753,736 million hryvnias. Thus, the total energy intensity of labor costs in Ukraine in 2017 amounted to 32 kg of CE per thousand hryvnias [13].

In 2017, there were 248 working days. The average monthly working time was 165.3 hours. The average monthly salary in Ukraine in the same year was 6273.45 hryvnias. Under these conditions, the annual value of the full energy intensity of labor costs amounted to 1.21 kg of CE per person-hour. This again reveals the drift of indicators, particularly in time, due to the application of macroeconomic norms. In the USSR, for instance, the full energy intensity of labor costs was 1.9 kg of CE per person-hour, and in the history of Ukraine, there were times when this indicator reached 3.29 kg of CE per person-hour.

The improved methodology for determining the full energy intensity of products and services of multiproduct production by O. Malyarenko and V. Stanitsyna [15] contains a more advanced consideration of relevant indicators but does not address the energy intensity of labor costs. There have been no fundamental breakthroughs in this matter in the work of scientists from the National Technical University of Ukraine "Kyiv Polytechnic Institute named after Igor Sikorsky" [16].

The economic approach to assessing human labor energy consumption would be incomplete without its methodical implementation, which is appropriately defined institutionally. It is based on the provisions of the Mining Law of Ukraine[1] and was proposed in the work [17]. According to the legislative act, "... enterprises engaged in coal mining and coal mine construction enterprises provide coal for household needs free of charge, as determined by the collective agreement". According to the Sectoral Agreement between the Ministry of Coal Industry of Ukraine, other state bodies, owners (associations of owners) operating in the coal industry, and the all-Ukrainian trade unions of the coal industry on July 3, 2001, "free provision of coal to employees and pensioners of the coal industry is carried out at the rate of 5.9 tons per year (approximately 4.2 tons of CE, as commented by the authors) per household or apartment without central heating. Lists of coal recipients are compiled annually"[2]. For apartments with central heating, measures are taken to compensate utility bills from local budgets for the provision of benefits "based on the cost of 3.1 tons of coal for household needs per household" [ibid]. The system is currently in force, as evidenced by the collective agreement of DP "Dobropillyavuhillya-vidobutok" in 2022: "Free provision of coal to employees and pensioners who have earned this right by working at the mines "Dobropil'ska", "Almazna", "Bilits'ka", "Novodonets'ka", "Pioneer" and other units that are part of DP "Dobropillyavuhillya-vidobutok", regardless of the organizational and legal form of the previous enterprises, hired and elected employees of trade union bodies is carried out at the rate of 5.9 tons per year per household..."[3]. The mere presence of an employee on the staff of a coal enterprise entitles them to appropriate a share of the product produced, amounting to almost 4.2 tons of CE, which institutionally constitutes the definition of the annual energy equivalent of their labor.

Thus, the assessment of energy costs for workers of enterprises, primarily those using mining methods, allows for no less than three variants of cost standardization – physical, economic using macroeconomic indicators, and economic institutional.

The purpose of the study is to assess the energy costs of human labor using various approaches and to test the statistical significance of the impact of the obtained results on the overall energy intensity of the enterprise.

2. Materials and Methods

The task of the study is to assess the significance of the impact of the energy of live labor on the response function Y_i, which is the sum of the total energy costs of the enterprise – E_s (the annual electricity and fuel costs of the enterprise in thousands of tons of CE) and E_{pi} (the annual energy costs of live labor for the enterprise, in thousands of tons of CE (with E_{p1}, E_{p2}, and E_{p3} calculated using physical, economic methods with macroeconomic indicators, and economic institutional methods, respectively).

Along with general scientific methods (abstraction, analysis, and synthesis), the study used the Box-Wilson method of experimental research (multifactorial experiment) [18]. According to the Box-Wilson method:

$$Y = \lambda(x_1, x_2, \dots x_j), \tag{1}$$

where $\lambda(x_j)$ is the response function influenced by factors presented in standardized form (from -1 to +1, regardless of their nature). The standardization of factors is to be carried out using the formula:

$$x_j = \frac{X_j - X_0}{I_j}, \tag{2}$$

where x_j is the coded value of the factor;

X_j is the natural value of the factor;

X_0 is the natural value of the base level of the factor (zero level);

I_j is the interval of variation of the base level.

It is appropriate to consider a response function influenced by three factors: $X_1 = E_s$ – annual electricity and fuel costs of the enterprise; X_2 – specific energy costs of live labor; X_3 – size of the enterprise (a qualitative factor: large, small), which determines the volumes of energy resource expenditures and the number of employees according to the production capacity. Factor X_2 (t of CE) has modifications according to the method of determining the energy indicators of live labor, namely: X_{21} – specific annual energy costs of live labor per employee, in kg of CE; X_{22} – total energy intensity of labor costs, which depends on the state of the macroeconomy in year t, in kg of CE per 1000 UAH of the enterprise's wage fund; X_{23} – annual rate of free coal allocation per employee, in tons of CE.

According to the Box-Wilson method, each factor is subject to variation at two levels, upper and lower, so the number of experiments in a full factorial experiment is 2^n, where n is the number of factors. With three factors, the number of experiments equals 8. The

[1] Гірничий Закон України. *Відомості ВР України*. 1999. № 5. Ст. 433

[2] Галузева угода між Міністерством вугільної промисловості України, іншими державними органами, власниками (об'єднаннями власників), що діють у вугільній галузі, і всеукраїнськими профспілками вугільної промисловості від 3 липня 2001 року. URL: https://ips.ligazakon.net/document/FIN65437.

[3] Колективний договір ДП «Добропіллявугілля-видобуток» (2022 р.). URL: https://uszn-dobr.gov.ua/wp-content/uploads/2022/02/Колективний-договір-Добропіллявугілля-видобуток_compressed.pdf.

variation of factors should be carried out according to a specific plan-matrix of the multifactorial experiment. Each modification of factor X_2 is separately subject to statistical significance testing regarding its influence on the response function. The study adopts the following data characterizing the enterprises (Table 1).

For the "Large Enterprise" category, the "Pivdennodonbaska" coal mine No. 1 was selected, and for the "Small Enterprise" category, the "Rodinska" coal mine of the "Myrnohradvuhillia" State Enterprise (both from the Donetsk region of Ukraine) was chosen.

Table 1

Data Characterizing Enterprises and Energy Intensity of Labor Costs

Indicator	Large Enterprise	Small Enterprise	Source of Information
Annual coal production capacity, thousand tons	1,150	380	[19]
Annual electricity consumption, thousand tons of CE	6	2	[19]
Annual fuel consumption, thousand tons of CE	6	2	[19]
Total annual energy resource consumption, thousand tons of CE	12	4	
Number of employees, persons	4,700	1,960	According to enterprise data in 2017
Average monthly salary, UAH	8,376	7,045	According to enterprise data in 2017
Wage fund, thousand UAH	39,367	13,808	
Annual energy intensity of labor costs per physical measurement, kgce/person	310		[6]
Total energy intensity of labor costs, kgce/1000 UAH of the wage fund (according to 2017 indicators)	32		[13]
Annual rate of free coal allocation per employee, tons of CE/person	4.2		[17]

Coal mines are not only large consumers of electricity but also of thermal energy and motor fuel. Overall, the total fuel consumption (coal in boilers, natural gas, gasoline, and diesel fuel) is equal to the consumption of electricity.

3. Results

Data on factor levels are provided in Table 2.

A full factorial experiment with three factors corresponds to a $2^{(3-0)}$ matrix (Table 3).

Table 2

Factor Level Values

Factor	Unit of Measurement	Lower Level	Base Level	Upper Level	Interval
X_1	thousand tce	10 2	12 4	14 6	2 2
X_2	kgce/person kgce/₴ thousand tce/person	300 30 2	320 32 3	340 34 4	20 2 1
X_3		Small enterprise		Large enterprise	

Table 3

Experiment Plan and Calculation Results for Energy Intensity of Labor Costs and Response Function

Experiment No.	x_1	x_2	x_3	E_{p1}	E_{p2}	E_{p3}	Y_1	Y_2	Y_3
1	-1	-1	-1	0.6	5.0	3.9	2.6	7.0	5.9
2	1	-1	-1	0.6	5.0	3.9	6.6	11.0	9.9
3	-1	1	-1	0.7	5.6	7.8	2.7	7.6	9.8
4	1	1	-1	0.7	5.6	7.8	6.7	11.6	13.8
5	-1	-1	1	1.4	14.2	9.4	11.4	24.2	19.4
6	1	-1	1	1.4	14.2	9.4	15.4	28.2	23.4
7	-1	1	1	1.6	16.1	18.8	11.6	26.1	28.8
8	1	1	1	1.6	16.1	18.8	15.6	30.1	32.8

The conditions of the second experiment, for example, mean that the first factor (total energy consumption of electricity and fuel) should be taken at the upper level, the second factor, according to any method of calculating the energy costs of labor, should be taken at the lower level, and all calculations regarding the energy intensity of labor costs should be implemented for a small enterprise.

Processing the data from Table 3 using methods of mathematical statistics (regression analysis) allows for the assessment of the significance of the factors and the strength of their influence on the response function.

Now let us consider the dependence $Y_1(x_1, x_2, x_3)$.

Indeed, the Pareto chart (Fig. 1) provides insight into the overall energy intensity of the enterprise and the impact of each factor, particularly the energy intensity of labor in physical terms.

As can be seen from the chart, the greatest effect is from the qualitative factor x_3, which characterizes the size of the enterprise. The next most influential factor is x_1, which is not directly related to labor – the total energy resource expenditures (sum of electricity and fuel costs). The energy intensity of labor ranks (x_2) third in terms of its influence on the response function. All three factors are statistically significant, but the significance of the second factor is borderline. None of the interaction effects have a statistically significant impact.

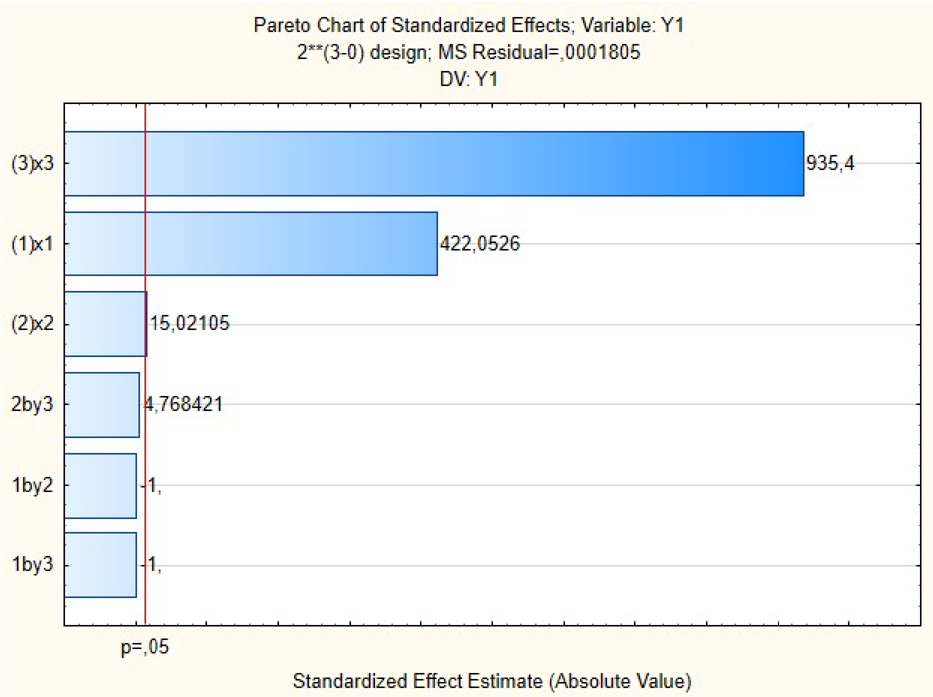

Fig. 1. Pareto chart characterizing the influence of factors on the response function Y$_1$

The regression model has the form:

$$Y_1 = 9{,}061 + 2{,}005x_1 + 0{,}071x_2 + 4{,}443x_3. \quad (3)$$

Since the factors are presented in standardized measurements, the coefficient value in front of each factor characterizes its influence. As demonstrated above using Figure 1, the strongest influence on the response function Y_1 is exerted by factor x_3.

It should be noted that the energy intensity of labor costs in industrial enterprises, as represented by physical evaluation methods, has a weak impact on the overall consumption of energy resources, although not without a statistically significant effect.

Next, we consider the dependence $Y_2(x_1, x_2, x_3)$.

The corresponding diagram is shown in Fig. 2.

When determining the energy intensity of labor costs using the economic method, which accounts for macroeconomic parameters, there is no fundamental difference in the order of factor influence on the response function: third, first, second. However, the effect of pairwise interactions between the second and third factors has become statistically significant. The factor of pairwise interactions is the product of the factors $x_{23}=x_2*x_3$. If the variables are of the same sign, the product is positive; if they are of different signs, the product is negative. This means that when these variables are at the same levels (both at the upper level or vice versa), they enhance each other's effect; if they are at different levels (one at the upper level, the other at the lower), they weaken each other's effect.

The regression model for statistically significant factors is described by the equation:

$$Y_2 = 18{,}212 + 1{,}998x_1 + 0{,}636x_2 + \\ + 8{,}905x_3 + 0{,}309x_{23}, \quad (4)$$

where x_{23} is the interaction factor between the second and third factors.

Now we consider the dependence $Y_3(x_1, x_2, x_3)$.

Fig. 3 shows the Pareto chart for this function.

The regression model for statistically significant factors is as follows:

$$Y_3 = 17{,}986 + 2{,}004x_1 + 3{,}333x_2 + \\ + 8{,}114x_3 + 1{,}366x_{23}. \quad (5)$$

A phenomenon of the institutional economic method for determining the energy intensity of labor costs is the transition of factor x_2 to the second place in terms of influence: third, second, first. This means that according to these calculations, the energy intensity of labor becomes more influential than electricity and fuel. Additionally, the influence of the interaction effect between the second and third factors has increased. This is a paradox, but "Dura lex, sed lex.

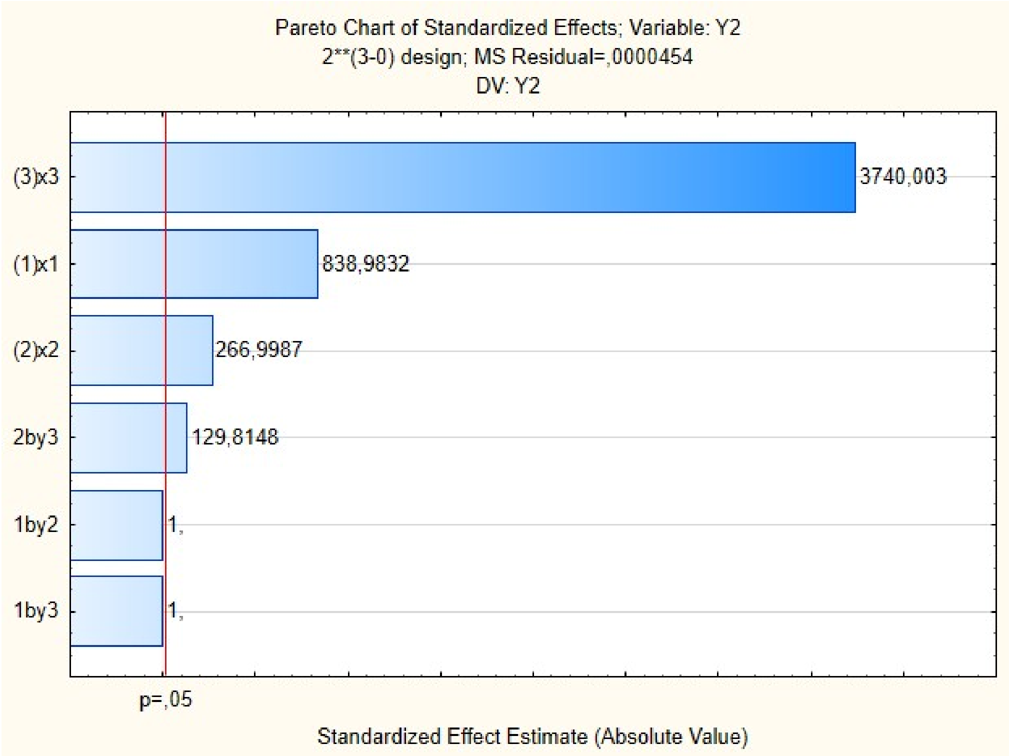

Fig. 2. Pareto chart characterizing the influence of factors on the response function Y_2

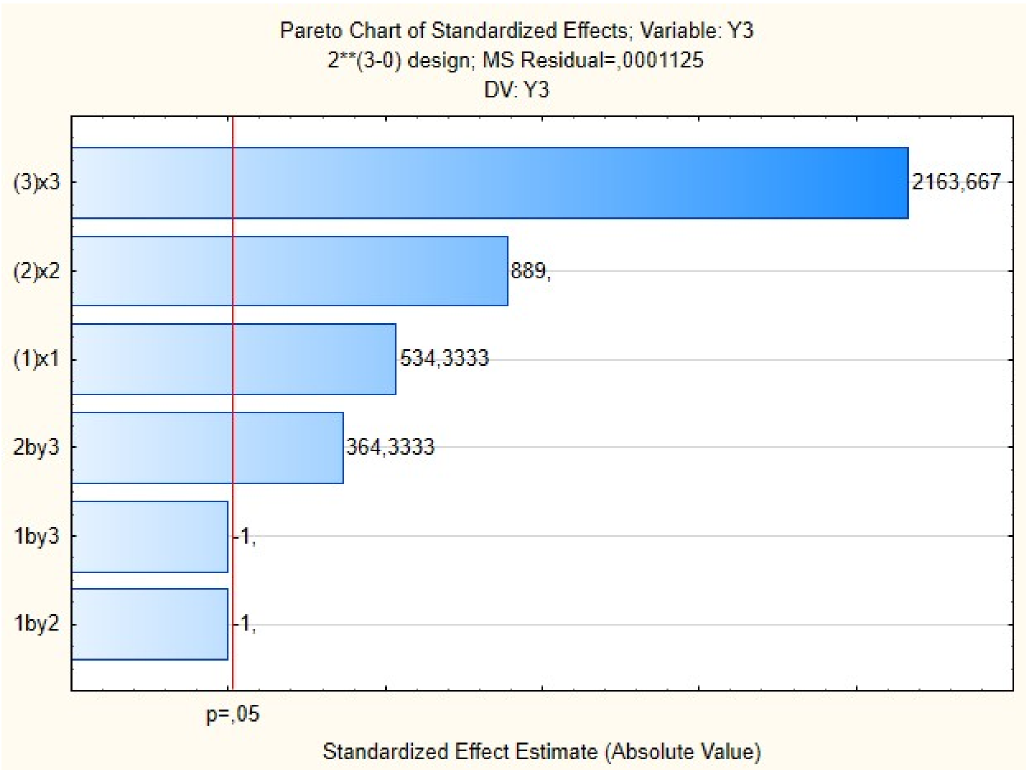

Fig. 3. Pareto chart characterizing the influence of factors on the response function Y_3

This ancient Latin saying means "The law is harsh, but it is the law." The conducted study demonstrates that the provisions of the Mining Law of Ukraine, which grant free coal to a wide range of coal industry workers, make the workforce the most influential factor in the energy consumption of mines, even more so than the powerful technological consumers in mining operations.

Therefore, regardless of the method used to determine the energy aspect of labor costs, experiments with data from large and small coal enterprises have led to the conclusion that the energy intensity of human labor has a statistically significant impact on the overall energy consumption of enterprises.

However, it should be noted that only E_{p1} can be considered a certain analog of the mechanical work of the physical force of the enterprise's workers, meaning that personnel act as carriers (sources) of energy. In cases of E_{p2} and E_{p3}, according to the logic of measurement, workers at the enterprise act not as carriers of energy but as consumers of it. By the way, one does not negate the other. In principle, the total energy intensity of the enterprise's production can be considered as a sum, for example, $E_{p1} + E_{p2}$, since workers are both carriers and consumers of energy. As for the institutional method of economic determination of energy labor metrics, it is characteristic only of coal enterprises, not any other mining enterprises.

4. Conclusions

The conducted research has successfully achieved its goal: determining the significance of the energy aspects of labor costs using various measurement approaches and proving the statistical significance of these indicators on the enterprise's energy resource consumption function.

The article begins with an example of horse-drawn transport application in mines. The existence of a physical unit, namely horsepower, allows for an objective assessment of the power of horse-drawn transport in the coal industry and the energy expenditure in the process.

Measuring the power of human labor does not rely on officially defined physical units, leaving any attempts to do so open to discussion. According to some methodologies, the power of an adult is considered to be 75 watts and is used as a benchmark in comparison with the power of mechanized tools. For instance, the power of the workforce of a large mine with a staff of 5,000 people, measured in such units, slightly exceeds 1% of the total power of the enterprise's technological electric energy consumers. Such an assessment of the muscle power of personnel, where the result aligns with the level of engineering error, has practically led to the omission of this factor in many cases. Consequently, the energy expenditures of human labor are not included in the nomenclature of the ecological footprint according to the widely known MIPS methodology.

Instead, the concept of the worker as a consumer of energy resources prevails over the notion of the worker as a carrier of physical energy, with a trend towards defining the energy norms of live labor using macro-level indicators, either purely energy-related or energy-economic (through the wage fund). The use of macro indicators leads to a wide dispersion of specific data across countries and over time.

In Ukraine, macroeconomic methods of assessing the energy of labor costs prevail. The most significant are the developments of the scientific school of the Institute of General Energy of the National Academy of Sciences of Ukraine. However, in the studies of the Institute of Industrial Economics of the National Academy of Sciences of Ukraine concerning the EROI of Ukrainian coal, a modification of the macroeconomic method, called the institutional method, has been noted. According to the norms of the Mining Law of Ukraine, every employee of a coal mining, coal processing, or coal construction enterprise is entitled to free coal for personal household needs. According to a multi-party agreement, the norm is 5.9 tons (approximately 4.2 tons of CE) per worker (per household).

The article considers the total energy resource consumption function of an enterprise as the sum of the expenditures of technological sector consumers and the energy costs of personnel. Three norms of human labor energy expenditure have been applied (physical, economic using macroeconomic indicators, and economics of an institutional nature), resulting in three types of response functions. The physical approach to determining the energy norm of labor costs is based on comparing a worker with a technological unit that switches from operational mode to idle mode with lower energy consumption after a shift. This allows for the consideration of human energy expenditures around the clock, as well as on weekends and holidays.

Using the Box-Wilson multifactorial experimental method, we conducted a study on both large and small coal mining enterprises. It has been proven that the size of the enterprise is the most influential factor; labor costs in the energy aspect, determined by any method, even by the physical method, statistically significantly affect the overall energy costs of the enterprise. Furthermore, we discovered the following paradox: energy costs related to personnel, determined by institutional norms, have a greater impact on the response function than energy costs by technological consumers.

The energy aspects of labor costs obtained by physical and macroeconomic methods differ significantly from each other. By the way, one does not negate the other. In principle, the total energy intensity of the enterprise's production can be considered as their sum, since workers are both carriers and consumers of energy. As for the institutional method of economic determination of energy labor metrics, it is characteristic only of Ukrainian coal enterprises, not any other mining enterprises.

Literature

1. Giampietro M., Pimentel D. Assessment of the energetics of human labor. *Agriculture, ecosystems & environment*. 1990. Vol. 32. Iss. 3-4. P. 257-272. DOI: https://doi.org/10.1016/0167-8809(90)90164-9.

2. Hau J. L., Bakshi B. R. Expanding exergy analysis to account for ecosystem products and services. *Environ. Sci. Technol.* 2004. Vol. 38. P. 3768-3777. DOI: https://doi.org/10.1021/es034513s.

3. Szargut J., Petela R. Exergy. Warsaw: WNT, 1965.
4. Hall C. A., Balogh S., Murphy D. J. What is the minimum EROI that a sustainable society must have? *Energies*. 2009. Vol. 2. Iss. 1. P. 25-47. DOI: https://doi.org/10.3390/en20100025.
5. Самойлік М. С. Біоенергетична оцінка сфери поводження з твердими відходами на регіональному рівні. *Вісник Житомирського національного агроекологічного університету*. 2013. Вип. 1-2 (2). С. 340-349.
6. Temukuyev T. B., Temukuyev, B. B. The use of an automated information system for monitoring and metering electricity in resolving disputes between economic entities. *Journal of Physics: Conference Series*. 2021. Vol. 1889. Art. 042003. DOI: https://doi.org/10.1088/1742-6596/1889/4/042003.
7. Zhang T. W., Dornfeld D. A. Energy use per worker-hour: Evaluating the contribution of labor to manufacturing energy use. *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses:* Proceedings of the 14th CIRP Conference on Life Cycle Engineering (June 11th-13th, 2007). Tokyo: Waseda University, 2007. P. 189-193. DOI: https://doi.org/10.1007/978-1-84628-935-4_33.
8. Schmidt-Bleek F. MIPS and ecological rucksacks in designing the future. *Proceedings Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing*. 2001. December. P. 1-8. *IEEE.* DOI: https://doi.org/10.1109/ECODIM.2001.992306.
9. Ayres R. U. (2004). On the life cycle metaphor: where ecology and economics diverge. *Ecological economics*. 2004. Vol. 48. Iss. 4. P. 425-438. DOI: https://doi.org/10.1016/j.ecolecon.2003.10.018.
10. Murphy D. J., Hall C. A., Dale M., Cleveland C. Order from chaos: a preliminary protocol for determining the EROI of fuels. *Sustainability*. 2011. Vol. 3. Iss. 10. P. 1888-1907. DOI: https://doi.org/10.3390/su3101888.
11. Rocco M. V. Accounting for human labour in LCA: a novel Input-Output approach. *V Convegno dell'Associazione Rete Italiana LCA – Life Cycle Thinking, sostenibilità ed economia circolare* (Ravenna-23-24, 2016). P. 466-474.
12. Панченко Г. Г. Огляд стану і перспектив розвитку енергетичного аналізу. *Енергетика: економіка, технології, екологія.* 2019. Вип. 4. С. 48-56. URL: http://energy.kpi.ua/issue/view/12162.
13. Панченко Г. Г. Повна енергоємність трудовитрат. *Актуальні питання розвитку сучасної економіки, управління та адміністрування:* Матеріали міжнародної науково-практичної конференції. Київ: Таврійський національний університет імені В. І. Вернадського. 2019. Ч. 2. С. 43–46.
14. Білодід В. Д. Оцінювання ефективності енергетичних технологій за методологією визначення повних енергетичних витрат. *Проблеми загальної енергетики*. 2012. Вип. 3. С. 12-18. URL: http://nbuv.gov.ua/UJRN/PZE_2012_3_5.
15. Маляренко О. Є., Станиціна В. В. Удосконалена методика визначення повної енергоємності продукції для багатопродуктових виробництв. *Проблеми загальної енергетики*. 2021. Вип. 2(65). С. 12–20. DOI: https://doi.org/10.15407/pge2021.02.012.
16. Бендюг В. І., Комариста Б. М. Життєвий цикл продукту та оцінювання енергетичних витрат. *Вісник Національного технічного університету "ХПІ". Сер.: Хімія, хімічна технологія та екологія*: *зб. наук. пр.* 2018. Вип. 35 (1311). С. 5-12. DOI: https://doi.org/10.20998/2079-0821.2018.35.01.
17. Cherevatskyi D., Atabyekov O. EROI of the Ukrainian coal. *Економічний вісник Донбасу*. 2017. Вип. 4 (50). С. 20-31.
18. Draper N. R. Introduction to Box and Wilson (1951) on the experimental attainment of optimum conditions. *Breakthroughs in Statistics: Methodology and Distribution*. New York: Springer, 1992. P. 267-269. DOI: https://doi.org/10.1007/978-1-4612-4380-9_22.
19. Череватський Д. Ю., Бойко О. В. Регресійна модель екологічного рюкзака українського вугілля. *Вісник економічної науки України.* 2022. № 2 (43). С. 41-45. DOI: https://doi.org/10.37405/1729-7206.2022.2(43).41-45.

References

1. Giampietro, M., Pimentel, D. (1990). Assessment of the energetics of human labor. *Agriculture, ecosystems & environment*, Vol. 32, Iss. 3-4, pp. 257-272. DOI: https://doi.org/10.1016/0167-8809(90)90164-9.
2. Hau, J. L., Bakshi, B. R. (2004). Expanding exergy analysis to account for ecosystem products and services. *Environ. Sci. Technol.*, Vol. 38, pp. 3768-3777. DOI: https://doi.org/10.1021/es034513s.
3. Szargut, J., Petela, R. (1965). Exergy. Warsaw, WNT.
4. Hall, C. A., Balogh, S., Murphy, D. J. R. (2009). What is the Minimum EROI that a Sustainable Society Must Have? *Energies*, Vol. 2, Iss. 1, pp. 25-47. DOI: https://doi.org/10.3390/en20100025.
5. Samoilik, M. S. (2013). Bioenerhetychna otsinka sfery povodzhennia z tverdymy vidkhodamy na rehionalnomu rivni [Bioenergy assessment of the sphere of solid waste management at the regional level]. *Visnyk Zhytomyrskoho natsionalnoho ahroekolohichnoho universytetu – Bulletin of the Zhytomyr National Agroecological University*, Issue 1-2 (2), pp. 340-349 [In Ukrainian].
6. Temukuyev, T. B., Temukuyev, B. B. (2021). The use of an automated information system for monitoring and metering electricity in resolving disputes between economic entities. *Journal of Physics: Conference Series*, 1889, 042003. DOI: https://doi.org/10.1088/1742-6596/1889/4/042003.
7. Zhang, T. W., Dornfeld, D. A. (2007). Energy use per worker-hour: Evaluating the contribution of labor to manufacturing energy use. *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses:* Proceedings of the 14th CIRP Conference on Life Cycle Engineering. (pp. 189-193). Tokyo, Waseda University. DOI: https://doi.org/10.1007/978-1-84628-935-4_33.
8. Schmidt-Bleek, F. (2001). MIPS and ecological rucksacks in designing the future. *Proceedings of the Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing*. (pp. 1-8). *IEEE*. DOI: https://doi.org/10.1109/ECODIM.2001.992306.
9. Ayres, R. U. (2004). On the life cycle metaphor: where ecology and economics diverge. *Ecological economics*, Vol. 48, Iss. 4, pp. 425–438. DOI: https://doi.org/10.1016/j.ecolecon.2003.10.018.
10. Murphy, D. J., Hall, C. A., Dale, M., Cleveland, C. (2011). Order from Chaos: A Preliminary Protocol for Determining the EROI of Fuels. *Sustainability,* Vol. 3, Iss. 10, pp. 1888-1907. DOI: https://doi.org/10.3390/su3101888.
11. Rocco, M. V. (2016). Accounting for human labour in LCA: a novel Input-Output approach. *Proceedings of the V Convegno dell'Associazione Rete Italiana LCA – Life Cycle Thinking, sostenibilità ed economia circolare.* (pp. 466-474). Ravenna, Italia.

12. Panchenko, H. H. (2019a). Ohliad stanu i perspektyv rozvytku enerhetychnoho analizu [Review of the state and prospects of energy analysis development]. *Enerhetyka: ekonomika, tekhnolohii, ekolohiia – Energy: economics, technologies, ecology*, 4, pp. 48-54 [in Ukrainian].

13. Panchenko, H. H. (2019b). Povna enerhoiemnist trudovytrat [Full energy intensity of labor costs]. *Aktualni pytannia rozvytku suchasnoi ekonomiky, upravlinnia ta administruvannia* [*Current issues of the development of modern economy, management and administration*]: Proceedings of the International Scientific and Practical Conference. (part 2, pp. 43–46). Kyiv, Tavrichesky National University named after V. I. Vernadsky [in Ukrainian].

14. Bilodid, V. D. (2012). Otsiniuvannia efektyvnosti enerhetychnykh tekhnolohii za metodolohiieiu vyznachennia povnykh enerhetychnykh vytrat [Evaluation of the effectiveness of energy technologies by the methodology of determination of total energy costs]. *Problemy zahalnoi enerhetyky –Problems of General Energy,* 3(30), pp. 12-18 [in Ukrainian].

15. Maliarenko, O. Ye., Stanytsina, V. V. (2021). Udoskonalena metodyka vyznachennia povnoi enerhoiemnosti produktsii dlia bahatoproduktovykh vyrobnytstv [An improved method for determining the total energy intensity of goods for multi-product productions]. *Problemy zahalnoi enerhetyky – Problems of General Energy,* 2 (65), pp. 12-20. DOI: https://doi.org/10.15407/pge2021.02.012 [in Ukrainian].

16. Bendiuh, V. I., Komarysta, B. M. (2018). Zhyttievyi tsykl produktu ta otsiniuvannia enerhetychnykh vytrat [Product lifecikl and estimation of energy consumption]. *Visnyk Natsionalnoho tekhnichnoho universytetu "KhPI". Ser.: Khimiia, khimichna tekhnolohiia ta ekolohiia – Bulletin of the National Technical University "KhPI". Ser.: Chemistry, chemical technology and ecology: collection of scientific works*, Issue 35 (1311), pp. 5-12. DOI: https://doi.org/10.20998/2079-0821.2018.35.01 [in Ukrainian].

17. Cherevatskyi, D., Atabyekov, O. (2017). EROI of the Ukrainian coal. *Ekonomichnyi visnyk Donbasu – Economic Herald of the Donbas*, 4(50), pp. 20-31.

18. Draper, N. R. (1992). Introduction to Box and Wilson (1951) on the Experimental Attainment of Optimum Conditions. *Breakthroughs in Statistics, Springer Series in Statistics (Perspectives in Statistics)*. (pp. 267-269). New York, Springer. DOI: https://doi.org/10.1007/978-1-4612-4380-9_22.

19. Cherevatskyi, D. Yu., Bojko, O. V. (2022). Rehresiina model ekolohichnoho riukzaka ukrainskoho vuhillia [Regression Model of Ecological Backpack Ukrainian Coal]. *Visnyk ekonomichnoi nauky Ukrainy,* 2 (43), pp. 41-45. DOI: https://doi.org/10.37405/1729-7206.2022.2(43).41-45 [in Ukrainian].

Черевацький Д., Смирнов Р., Бойко О., Баш В. Внесок персоналу в загальну енергоємність великих гірничодобувних підприємств

Потужність м’язів персоналу підприємства у порівнянні із загальними енерговитратами відповідає рівню інженерної помилки, що призвело до повної відмови від цього фактору на практиці. У цій статті загальна функція енергоспоживання підприємства розглядається як сума витрат технологічного сектора та енерговитрат персоналу. Застосовуються три норми енергоємності людської праці: фізична, економічна з використанням макроекономічних показників та економічна інституціонального характеру. Основною метою нашого дослідження є оцінка енерговитрат людської праці за допомогою різних підходів та перевірка статистичної значущості впливу отриманих результатів на загальну енергоємність підприємства. За допомогою методу багатофакторного експерименту Бокса-Вілсона проведено дослідження впливу факторів на сумарне споживання енергоресурсів. Доведено, що витрати праці в енергетичному аспекті, навіть виміряні фізичним методом, мають статистично значущий ефект. Фізичний метод слід рекомендувати як основний підхід для промислових підприємств. Недооцінка енергетичних параметрів живої праці створює ризик безвідповідального споживання і виробництва.

Ключові слова: промислові підприємства, персонал, жива праця, енергетичний аспект, статистична значущість.

Cherevatskyi D., Smirnov R., Bojko O., Bash V. The Contribution of Personnel to the Overall Energy Intensity of Large Mining Enterprises

The muscle power of a company's personnel, when compared to the total energy expenditure, corresponds to the level of engineering error, which has led to the complete rejection of this factor in practice. In this article, the general function of energy consumption by the enterprise is considered to be the sum of technological sector costs and the energy costs of personnel. Three norms of energy consumption of human labor are applied: physical, economic using macroeconomic indicators, and economic of an institutional nature. The main goal of our study is to assess the energy costs of human labor using various approaches and to test the statistical significance of the impact of the obtained results on the overall energy intensity of a given enterprise. Using the method of the Box-Wilson multifactorial experiment, a study of the influence of factors on the total consumption of energy resources was carried out. It is proven that labor costs in the energy aspect, even when measured by the physical method, have a statistically significant effect. The physical method should be recommended as the primary approach for industrial enterprises. Underestimation of the energy parameters of living labor creates the risk of irresponsible consumption and production.

Keywords: industrial enterprises, personnel, living labor, energy aspect, statistical significance.

Received by the editors: 22.11.2024
Reviewed: 03.12.2024