

SELECTION OF POWER LINE PARAMETERS

Pylyp HOVOROV,

Doctor of Technical Sciences, Professor,
Professor of the Department of Lighting Technology and Light Sources,
O. M. Beketov National University of Urban Economy in Kharkiv,
Kharkiv, Ukraine,

ORCID ID: 0000-0002-0379-1448

Roman TRISHCH,

Doctor of Technical Sciences, Professor,
Head of the Department of Mechatronics and Electrical Engineering,
M. E. Zhukovsky National Aerospace University "Kharkiv Aviation Institute",
Kharkiv, Ukraine,

ORCID ID: 0000-0002-9503-8428

Vladlen ZORIN,

Doctor of Technical Sciences, Professor,
Professor of National Technical University of Ukraine "Igor Sikorsky Kyiv
Polytechnic Institute";
Kyiv, Ukraine,

ORCID ID:

Vladlen HOVOROV,

Candidate of Technical Sciences,
Docent of Ukrainian Engineering Pedagogical Academy,
Kharkiv, Ukraine,

ORCID ID:

Anastasiia KINDINOVA,

PhD student,
Assistant of the Department of Lighting Technology and Light Sources,
O.M. Beketov National University of Urban Economy in Kharkiv,
Kharkiv, Ukraine,

ORCID ID: 0000-0003-2575-0767

DOI: 10.51587/3068-3580/US-2025-05-1

Hovorov, P., Trishch, R., Zorin, V., Hovorov, V. & Kindinova, A. (2025).
Selection of power line parameters / *University Science*, 1(1), 36–45.
<https://doi.org/DOI: 10.51587/3068-3580/US-2025-05-1-36-45>

Received: April 1, 2025
Accepted: April 18, 2025

ABSTRACT

In the current context of increasing loads on power grids and the urgent need for energy-saving solutions, the selection of conductor cross-sections for transmission lines is highly relevant. The article aims to investigate approaches to selecting the cross-section of power transmission lines, considering both technical and economic aspects; to assess the impact of this choice on energy losses, economic efficiency and reliability of the network, taking into account modern trends in the design and reconstruction of power transmission lines and the requirements of energy conservation and improving the quality of power supply. The study analyzes methods for determining the optimal cross-section, particularly the economic current density method and the method of economic intervals. Comparative calculations of energy losses for different cross-sections are performed, along with an evaluation of each method's efficiency both with and without discounting. The results confirm the appropriateness of applying the economic interval method during the design process, especially in the context of network reconstruction. Conclusions emphasize the influence of the selected method on operational costs and the overall energy efficiency of the system. This research provides a foundation for further development in the field of power transmission parameter optimization, considering modern requirements for reliability and sustainable energy development.

Key words

Conductor cross-section, economic current density, electricity losses, energy efficiency, power grids, reconstruction, power supply, cost optimization.

INTRODUCTION

Since the invention of electric energy, the following issues have been regularly addressed: methods and means of transmission, parameters, and modes. The first power transmission of significant (at that time) power was carried out by the scientist Dolivo-Dobrovolsky in 1891. It was a three-phase alternating current line (Laufen-Frankfurt am Main) 175 km long at 35 kV. The works of Dolivo-Dobrovolsky are one of the foundations of the creation of electrical networks and alternating current systems on which modern electrification is built in all countries of the world. In developing power transmission lines, lines of increasingly higher nominal voltages were subsequently mastered. Currently, monitoring and cable power transmission lines with voltages from 0.38 to 1150 kV are being monitored. The total length of power transmission lines in Ukraine is about 1 million km, part of which has spent its useful life and requires serious reconstruction and replacement.

The unsatisfactory condition of electrical networks, especially distribution networks, is the cause of a noticeable increase in electrical energy losses and a decrease in its quality, a reduction in the reliability of power supply and safety of operation of power transmission lines. Market conditions in the electric power industry require a guaranteed high-quality power supply to consumers. In this regard, in the coming years, a sharp increase in the volume of work on the replacement and reconstruction of all voltage processes should be expected, as well as changes in trends in power transmission. An essential part is solving the problem of choosing wire sections and residential computers, considering modern conditions. As experience shows, selecting cross-sections is the most noticeable; there-

fore, insufficient justification and even a slight inaccuracy can lead to significant, unjustified external costs (Alazazmeh & Asif, 2021; Argyroudis, Mitoulis, Chatzi et al., 2021; Dagtekin, Kaya & Besli, 2022; Dasović & Klanšek, 2022; Fei, Opoku, Agyekum, Oppon, et al., 2021; Fonseca, Commenge, Camargo, Falk & Gil, 2020).

LITERATURE REVIEW

The selection of the cross-section of the wires of the power transmission line in the devices is carried out by the principle of the device of electrical installations (Pravyla vlashtuvannia elektroustanovok, 2017); they prescribe the selection of wire cross-sections and cross-sections operating in the network with a voltage of up to 220 kV, exclusively according to economic parameters by the norms of financial stability of the current. At the same time, in several publications and guidance documents (Costa, Silva, Faia, Gomes, Faria & Vale, 2024; Galychyn, Fath, Shah, Buonocore & Franzese, 2022; Haddad, Hammad, Castro, Vasco & Soares, 2021; Hovorov, Kindinova & Hovorov, 2021; Hovorov, Khvorost & Kindinova, 2023; Khoshnava, Rostami, Zin et al., 2019; Kupriyanov, Trishch, Dichev & Kupriianova, 2022; Picot & Guillaume, 2024; Pravyla vlashtuvannia elektroustanovok, 2017; Qiu, Wang & Zhang, 2021; Seyrfar, Ataei, Movahedi & Derrible, 2020; Sharifhosseini, Niknam, Taabodi et al., 2024; Trishch, Cherniak, Zdenek & Petraskevicius, 2024; Tripathi, Sindhvani, Anand & Dahiya, 2022; Um-E-Habiba, Ahmed, Alqah-tani, Asif & Khalid, 2024; Utrilla & Górecki, 2023; Zech, Plörer, Pfluger & Breu, 2024; Zhu, Zhang, Gong & Li, 2023), wire cross-sections are selected according to the permissible currents that result from heating the wires in normal modes. Such recommendations cannot be recognized in reality because, in this case, the minimum possible, not the econom-

ic cross-section, will be selected, and at the same time, there will be significant losses in productivity. In table. 1 (based on the author's research) lead to a multiplicity of increase in

power losses $\delta\Delta P$ (i.e., lines in addition to the economically justified power on the overhead line with aluminum wires at $j_{ek}=1A/mm^2$ and $T_{ib}=5000$ h.

Table 1. Multiplicity of excess power losses

Source: Authors

Cross-sections, F, mm ²	35	50	70	95	120
I_{dop}, A	175	210	265	330	390
$\delta\Delta P, (o.s.)$	25.0	17.6	14.4	12.3	10.9

As is evident from Table 1, selecting wire cross-sections according to heating conditions in normal mode compared to economy leads to increased losses (11+25) times, which contradicts modern energy-saving requirements. Normal mode is a long-term mode in which the criteria for reliability and quality of electricity are met at the highest economic rates. After the cross-section is selected according to economic conditions, it is necessary to check the technical heating conditions in normal mode and some post-war and repair modes.

The simplest method is the selection of cross-sections of economic current density.

$$F = \frac{I_p}{j_{ek}}, \quad (1)$$

Where F is the economic cross-section of the cable core, mm; I_p is the calculated current value, A; j_{ek} is the normalized value of the economic current density, A/mm².

The values of economic current density are normalized depending on the conductor material and design and the number of hours of use of the maximum load given in the (Pravyla vlashtuvannia elektroustanovok, 2017).

GOALS

The study analyzes approaches to choosing the cross-section of power transmission lines, considering both technical and economic aspects. The primary attention is paid to assessing the impact of this choice on energy losses, economic efficiency, and network

operation reliability. An important aspect is to consider modern trends in the design and reconstruction of power transmission lines based on energy-saving requirements and improving the quality of power supply.

METHODOLOGY

The research methodology includes a theoretical analysis of scientific publications, regulatory documents, and modern standards that determine the optimal parameters of power transmission lines. Mathematical modeling allows you to estimate economic costs and energy losses depending on the selected cross-section and compare the effectiveness of different methods for its determination. Experimental research is based on analyzing actual operating indicators of existing networks, which allows you to check the correctness of the calculation models. In addition, comparative analysis helps to assess the advantages and disadvantages of different approaches, which, in the future, will allow you to formulate recommendations for optimizing the selection of parameters of power transmission lines.

RESULTS AND DISCUSSION

Despite its extreme simplicity, the method of selecting wire cross-sections and calculating the economic current density has several serious drawbacks:

- ▷ The standards given in (Pravyla vlashtuvannia elektroustanovok, 2017) were established back in the 1950s and have not undergone any changes. By now, the cost ratios (electrical equipment, electricity costs) have changed;

The scale of standard cross-sections is responsible. When considering cross-sections, the costs were regarded as a continuous function of the wire cross-section, and this requires that the found cross-sections be rounded to standard cross-sections, i.e., the method does not give unambiguous solutions;

- ▷ A linear dependence of the cost of building a line of one kilometer on the cross-section is provided. It is inconvenient to do this, especially when using unified supports;

The essence of the economic interval method is to analyze the change in costs for a series cross-section F_i depending on the current I and is based on the following assumptions (Dagtekin, Kaya & Besli, 2022; Dasović & Klanšek, 2022; Fei, Opoku, Agyekum, Oppon, et al., 2021; Fonseca, Commenge, Camargo, Falk & Gil, 2020):

- ▷ The power transmission line is constructed in the first year of the settlement period ($T_c = 1$ year), and the one-time capital investment is $K_{ot} = K_0$, after which its regular operation begins, for some time T until the end of the settlement period ($T_e = T_p - T_c$);
- ▷ annual deductions from capital investments for maintenance of the AOBSL, repair, and renovation of arenas, as well as the price of electricity C_0 during the calculation period remains constant $AOBSL = \text{const}$, $\text{arena} = \text{const}$, $C_0 = \text{const}$;
- ▷ Part of the load schedule along the line during the calculation period remains the same ($T_{nb} = \text{const}$);

- ▷ losses from interruptions in the power supply of consumers and the quality of electricity are not considered in the cost functions.

When making assumptions, the expression leads to the total discounted costs for the construction and operation of 1 km of line will be as follows:

Specific construction costs:

$$Z_{\text{соор.oi}} = K_{0\text{баз.i}} \cdot (1+E)^{-1} \quad (2)$$

Specific maintenance and repair costs for the period of operation until the end of the billing period:

$$Z_{\text{обсл.oi}} = \sum_{t=2}^{T_p} K_{0i} \cdot a_{\text{обсл}} \cdot (1+E)^{-t} = \quad (3)$$

$$= K_{0\text{баз.i}} \cdot a_{\text{обсл}} \cdot D_{p,e}$$

Specific costs for compensation of electricity losses at a constant design load for the period of operation $I_{pt} = I_p$

$$Z_{\text{пот.oi}} = \sum_{t=2}^{T_p} C_0 \cdot \Delta W_{it} \cdot (1+E)^{-t} = \quad (4)$$

$$= C_0 \cdot I_p^2 \cdot r_{oi} \cdot 10^{-3} \cdot \tau \cdot D_{p,e}$$

Specific costs, proportional liquidation costs

$$Z_{\text{ликв.oi}} = K_{0\text{баз.i}} \cdot (1 - a_{\text{рех}} T_e) \cdot (1+E)^{-T_p} \quad (5)$$

where t is the dimension of time; $Z_{\text{ликв.oi}}$ is the conditional discounted period of operation, is the availability

$$D_{p,e} = \sum_{t=2}^{T_p} (1+E)^{-t}$$

E – discount rate during sensitivity analysis of optimal solutions at the level of changes can be taken as 0.05%1.5

K_0 base – the base cost of line construction.

Thus, the expression of individual discounted costs (per 1 km of single-circuit line) can be presented in the following video.

$$Z_{0i} = Z_{\text{соор.oi}} + Z_{\text{обсл.oi}} - Z_{\text{ликв.oi}} + Z_{\text{пот.oi}} =$$

$$= K_{0\text{баз.i}} \cdot (1+E)^{-1} + K_{0\text{баз.i}} \cdot K_{\text{леф}} \cdot a_{\text{обсл}} \cdot D_{p,e} -$$

$$- K_{0\text{баз.i}} \cdot (1 - a_{\text{рех}} T_e) \cdot (1+E)^{-T_p} + \quad (6)$$

$$+ C_0 \cdot 3 \cdot I_p^2 \cdot r_{oi} \cdot 10^{-3} \cdot \tau \cdot D_{p,e}$$

The last expression (6) can be written in the form of two examples, the first of which is proportional to the value of the line stability

cost, and the second characterizes the specific expenses of electricity losses.

$$3_{oi} = 3_{к.oi} + 3_{пот.oi} = A \cdot K_{06a3.i} + B \cdot I_p^2 \cdot r_{oi} \quad (7)$$

Where

$$A = [(1 + E)^{-1} + a_{обсл} \cdot D_{p,e} - (1 - a_{пех} T_e)] \quad (8)$$

$$B = 3 \cdot C_0 \cdot \tau \cdot D_{p,e} \cdot 10^{-6} \quad (9)$$

The expression in square brackets is some equivalent discount factor Dec.

$$D_{екв} = (1 + E)^{-1} + a_{обсл} \cdot D_{p,e} - (1 - a_{пех} T_e) \cdot (1 + E)^{-T_p} \quad (10)$$

If and to ensure this location, the value of the limiting current is determined under conditions of equal flows

$$3_{oi} = 3_{oi+1} \quad (11)$$

When the expression is balanced, the costs per section are obtained as F_i and F_{i+1} .

$$A \cdot (K_{06a3.i+1} - K_{06a3.i}) = B \cdot (r_{oi} - r_{oi+1}) \cdot I_p^2 \quad (12)$$

Apply the limiting current for the sections F_i and F_{i+1} will be equal to

$$I_{рп i,j+1} = \sqrt{\frac{A \cdot (K_{06a3.i+1} - K_{06a3.i})}{B \cdot (r_{oi} - r_{oi+1})}} = \sqrt{\frac{A}{B}} \cdot \sqrt{\frac{\delta K_{i+1,j}}{\delta r_{oi,i+1}}} \quad (13)$$

A graphical representation of economic intervals is shown in Fig. 1.

Source: Authors

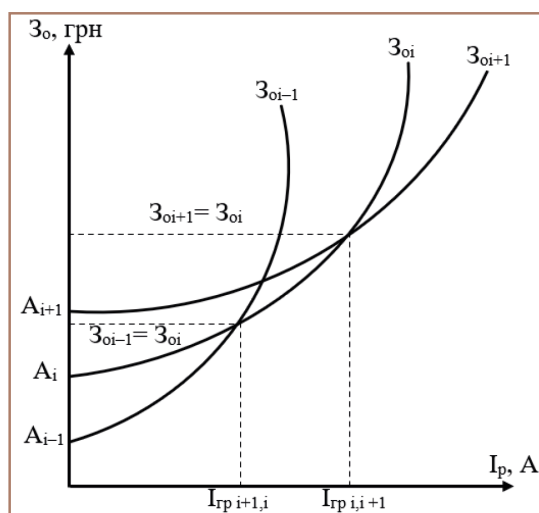


Figure 1. Dependence of costs on the design current I_r for three corresponding cross-sections $F_{i-1} < F_i < F_{i+1}$

Applying the time factor accounting method using the compound interest formula (discounting) does not raise any fundamental objections. However, it is not a recovery in the most straightforward cases when annual operating costs remain unchanged throughout the entire service life of the facility, and additional capital investments in the facility are not made since they are made once during the first year. In these cases, methods for estimating savings using the payback method at average full costs $Z = (En + Ra) \sum K + I$ give the same result as calculations of discounted costs based on reducing the sum of capital investments and current costs to one year (Pravyla vlashtuvannia elektroustanovok, 2017). It can be assumed that the payback or cost method sufficiently considers the timeliness of capital and current expenses (Kupriyanov, Trishch, Dichev & Kupriianova, 2022).

It should be remembered that with the parliament of options for total costs over the entire service life of the object (discounting), it is necessary to deduct the depreciation of instability from the composition of current expenses. At the same time, it must be considered when using the cost-based depreciation deduction method.

The standard payback period is T_n . In this case, three possible cases exist: $T < T_n$, $T > T_n$ and $T = T_n$. If the actual payback period T is less than the standard T_n , the option with significant capital investments is more economical. If T is more critical than T_n , then it will be more economical to consider capital investments. If $T = T_n$, then the compared options are equally economical.

The payback period is 8 years. For new technical equipment (computers, microprocessor devices, etc.), the standard payback period is equal to 3 years. The reciprocal value

$E_H=1/T_H=1/8=0.12$ is called the standard coefficient of comparative efficiency. In a modern market economy, the standard payback period and the corresponding standard coefficient of efficiency, depending on the existing conditions and requirements of the investor, the values T_H and E_H can prevent changes both in the more significant and in the lesser direction.

In addition to the above costs, other criteria for the economic efficiency of capital investments can be used in Ukraine. The final decision is made considering the analysis of the calculation results of one or more cases, depending on the nature of the problem being solved (Picot & Guillaume, 2024). The criteria include the integral discounted profit, which characterizes the excess of income over expenses. The profitability of investments is about revenue and costs. The payback period is the time during which investments are returned through income.

In this example, we will calculate the interval of economic cable lines of 10 kV with and without discounting. The fourth cable line $l = 1$ km of the AASHv type is laid in a trench in urban conditions with the following initial data: $T_p = 10$ years. $T_s = 1$ year.

$T_m = 3000$ hours, $E = 0.1$, $C_0 = 0.65$, $a_{obsl} = 0.008$ e./hour.

Calculation considering discounting.

According to formula (5), the estimated discounted period of operation during the term is calculated.

$$T_c = 10 - 1 = 9 \text{ років}$$

$$D_{pe} = \sum_2^{10} (1 + 0,1)^{-1} = \frac{1}{1,1^2} + \dots + \dots + \frac{1}{1,1^{10}} = 5,235 \text{ років}$$

Then the equivalent discounting factor, according to formula (11) without considering the liquid value, will be equal to

$$D_{екв} = A_{jl} (1 + 0,1)^{-1} + 0,008 \cdot 5,235 = 0,952$$

We find the number of hours of maximum losses τ

$$\tau = \left(0,124 + \frac{T_m}{10^4} \right)^2 \cdot 8760 = \left(0,124 + \frac{3000}{10^4} \right)^2 \cdot 8760 = 1576 \text{ год}$$

And considering τ , the value of the coefficient B_l is determined by the formula (9)

$$B_l = 3 \cdot 0,65 \cdot 1575 \cdot 5,235 \cdot 10^{-6} = 0,0162 \text{ тис. грн./A}^2\text{Ом}$$

We find the boundary points $I_{gr\ i,i+1}$ of the economic intervals using formula (13) and the values of the CL parameters (Table 2 - based on the author's research).

Table 2. CL parameters and intervals

Source: Authors.

Fi, mm2	35	50	70	95	120	150	185	240	Characteristic
C0, thousand UAH.	38	44	51	62	71	89	103	125	Association "Promkabel"
r0, Ohm/km	0.89	0.62	0.44	0.326	0.258	0.206	0.167	0.129	
Irp i,i+1, A	0-36.1	36.1-47.8	47.8-75.3	75.3-88.2	88.2-142.6	142.6-144.9	144.9-182.0	182.0 and above	Economic intervals
jek, A/mm2	1.03	1.03-0.96	0.96-1.08	1.08-0.93	0.93-1.19	1.19-0.96	0.96-0.98	0.98 and above	Estimated energy-saving lamp current

Calculation based on the cost criterion without discounting

The expression for the cost of constructing 1 km of cable line, in this case, has the form

$$3 = (E_H + P_a) \cdot K + 3 \cdot I^2 \cdot r \cdot C_0 \cdot \tau \cdot 10^{-6} \quad (14)$$

where E_H is the standard efficiency coefficient equal to $E_H = 0.12$ oe, P_a is the depreciation deduction $P_a = 0.063$ oe

Then, the formula for determining the value of the limiting current $I_{rp,i,i+1}$ will be the same

$$I_{rp,i,j+1} = \sqrt{\frac{E_H + P_a}{3 \cdot C_0 \cdot \tau \cdot 10^{-6}}} \cdot \sqrt{\frac{K_{i+1} - K_i}{r_{0i} - r_{0i+1}}} = \Delta \sqrt{\frac{\delta K_{i,i+1}}{\delta r_{i,i+1}}} \quad (15)$$

The calculation results are given in Table 3 (based on the author's research).

Table 3. Economic intervals and current density

Source: Authors.

Fi, mm2	35	50	70	95	120	150	185	240	Characteristic
$I_{rp,i,i+1}$, A	0-36.1	36.1-48.1	48.1-75.8	75.8-88.8	88.8-143.6	143.6-145.9	145.9-183.3	183.3 and above	Economic intervals
jek, A/mm2	1.04	1.04-0.96	0.96-1.08	1.08-0.93	0.93-1.2	1.2-0.97	0.97-0.99	0.99 and above	Estimated energy-saving lamp current

Analyzing the calculated values of economic current intervals with and without discounting (Table 2 and Table 3), they coincide. This is confirmed by the premise that in the case of one-time capital investments during the first year of construction of the power transmission line and fixed costs during the service life, calculations can be made using the cost criterion without discounting.

The obtained values of economic current density (Table 2 and Table 3) are 1.5+1.7 times lower than those of normalized economic current densities given in (Pravyla vlashtuvannia elektroustanovok, 2017) . The choice of wire cross-section and measurements at dynamic intervals allow the reduction of active power losses in lines by 2-3 times, contributing to the solution of energy-saving problems.

CONCLUSIONS

1. Due to their originality and mass, The economically justified choice of parameters of power transmission lines, pri-

marily wire cross-sections and structures, can be changed to solve the most critical tasks. Insufficient scientific substantiation of the task's technical and economic model and the model's inadequacy of actual conditions can lead to significant calculation errors and damage.

2. The normalized values of current density in the (Pravyla vlashtuvannia elektroustanovok, 2017) do not have sufficient scientific and methodological justification. The recommended values of current density were established in the 50s of the last century, and the initial conditions adopted during the calculations have now changed. Therefore, using normalized current density results when choosing economic wire cross-sections and measurements cannot be better.
3. The method of economic intervals allows you to determine the accuracy of standard wire cross-sections and residential

measurements and obtain unambiguous solutions manually. In this case, you can use the calculations not to average specific indicators but to essential values of basic costs (K, CT, E. R., etc.). The method makes it possible to analyze and obtain more reliable and economically justified solutions individually for each calculation, thereby solving the problems of resource and energy conservation in market conditions.

4. Calculations show that the values of current densities corresponding to the obtained economic intervals are 1.5+1.7 times lower than those normalized by the (Pravyla vlashtuvannia elektroustanovok, 2017) . Thus, the choice of wire cross-section

and calculations based on economic intervals allow for reducing power losses in power transmission lines with a voltage of 10-220 kV by 2-3 times.

5. Power transmission lines in distribution networks are usually constructed with one-time capital investments during the year, and additional costs during the service life are assumed to be unchanged. Therefore, the choice of economic processing of wire cross-section data and measurement can be made according to the criterion of costs without considering their discounting. Lines with economic changes in operation provide maximum profit regardless of the forms of ownership in the industry.

BIBLIOGRAPHIC REFERENCES

1. Alazazmeh, A., & Asif, M. (2021). Commercial building retrofitting: Assessment of improvements in energy performance and indoor air quality. *Case Studies in Thermal Engineering*, 26, 100946. <https://doi.org/10.1016/j.csite.2021.100946>
2. Argyroudis, S. A., Mitoulis, S. A., Chatzi, E., et al. (2021). Digital technologies can enhance climate resilience of critical infrastructure. *Climate Risk Management*, 35, 100387. <https://doi.org/10.1016/j.crm.2021.100387>
3. Costa, R., Silva, R., Faia, R., Gomes, L., Faria, P., & Vale, Z. (2024). Empowering energy management in smart buildings: A comprehensive study on distributed energy storage systems for sustainable consumption. *Energy and Buildings*, 114953. <https://doi.org/10.1016/j.enbuild.2024.114953>
4. Dagtekin, Y., Kaya, S., & Besli, N. (2022). Distributed energy system selection for a commercial building by using Multi Criteria Decision Making methods. *International Journal of Hydrogen Energy*, 47(86), 36672–36692. <https://doi.org/10.1016/j.ijhydene.2022.08.208>
5. Dasović, B., & Klanšek, U. (2022). A review of energy-efficient and sustainable construction scheduling supported with optimization tools. *Energies*, 15, 2330. <https://doi.org/10.3390/en15072330>
6. Fei, W., Opoku, A., Agyekum, K., Oppon, J. A., et al. (2021). The critical role of the construction industry in achieving the Sustainable Development Goals (SDGs): Delivering projects for the common good. *Sustainability*, 13(16), 9112. <https://doi.org/10.3390/su13169112>
7. Fonseca, J. D., Commenge, J., Camargo, M., Falk, L., & Gil, I. D. (2020). Multi-criteria optimization for the design and operation of distributed energy systems considering sustainability dimensions. *Energy*, 214, 118989. <https://doi.org/10.1016/j.energy.2020.118989>
8. Galychyn, O., Fath, B., Shah, I. H., Buonocore, E., & Franzese, P. P. (2022). A multi-criteria framework for assessing urban socio-ecological systems: The energy nexus of the urban economy and environment. *Cleaner Environmental Systems*, 5, 100080. <https://doi.org/10.1016/j.cesys.2022.100080>
9. Haddad, A., Hammad, A., Castro, D., Vasco, D., & Soares, C. A. P. (2021). Framework for assessing urban energy sustainability. *Sustainability*, 13(16), 9306. <https://doi.org/10.3390/su13169306>

10. Hovorov, P., Kindinova, A., & Hovorov, V. (2021). Mode control of urban electrical networks based on the Smart Grid concept. *2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek)*, 88–93. <https://doi.org/10.1109/KhPI-Week53812.2021.9570000>
11. Hovorov, P., Khvorost, M., & Kindinova, A. (2023). Increasing the efficiency of lighting objects in the urban environment. *2023 Eight Junior Conference on Lighting (Lighting)*, 1–5. <https://doi.org/10.1109/Lighting59819.2023.10299451>
12. Khoshnava, S. M., Rostami, R., Zin, R. M., et al. (2019). Green efforts to link the economy and infrastructure strategies in the context of sustainable development. *Energy*, *193*, 116759. <https://doi.org/10.1016/j.energy.2019.116759>
13. Kupriyanov, O., Trishch, R., Dichev, D., & Kupriianova, K. (2022). A general approach for tolerance control in quality assessment for technology quality analysis. *Lecture Notes in Mechanical Engineering*, 330–339. https://doi.org/10.1007/978-3-031-16651-8_31
14. Picot, P., & Guillaume, B. (2024). The controllability of the Technosphere, an impossible question. *The Anthropocene Review*, *11(1)*, 91–109. <https://doi.org/10.1177/20530196231187242>
15. Pravyla vlashtuvannia elektroustanovok (2017). Kyiv: Minenergovyhillia Ukrainy.
16. Qiu, Y., Wang, H., & Zhang, Q. (2021). Energy-efficient and sustainable construction technologies and simulation optimisation methods. *2021 International Conference on E-Commerce and E-Management (ICECEM)*, 334–351. <https://doi.org/10.1109/icecem54757.2021.00075>
17. Seyrfar, A., Ataei, H., Movahedi, A., & Derrible, S. (2020). Data-driven approach for evaluating the energy efficiency in multifamily residential buildings. *Practice Periodical on Structural Design and Construction*, *26(2)*. [https://doi.org/10.1061/\(asce\)sc.1943-5576.0000555](https://doi.org/10.1061/(asce)sc.1943-5576.0000555)
18. Sharifhosseini, S. M., Niknam, T., Taabodi, M. H., et al. (2024). Investigating intelligent forecasting and optimization in electrical power systems: A comprehensive review of techniques and applications. *Energies*, *17*, 5385. <https://doi.org/10.3390/en17215385>
19. Trishch, R., Cherniak, O., Zdenek, D., & Petraskevicius, V. (2024). Assessment of the occupational health and safety management system by qualimetric methods. *Engineering Management in Production and Services*, *16(2)*, 118–127. <https://doi.org/10.2478/emj-2024-0017>
20. Tripathi, A., Sindhwani, N., Anand, R., & Dahiya, A. (2022). Role of IoT in smart homes and smart cities: Challenges, benefits, and applications. *EAI/Springer Innovations in Communication and Computing*, 199–217. https://doi.org/10.1007/978-3-031-04524-0_12
21. Um-E-Habiba, N., Ahmed, I., Alqahtani, M., Asif, M., & Khalid, M. (2024). The role of energy management technologies for cyber resilient smart homes in sustainable urban development. *Energy Strategy Reviews*, *56*, 101602. <https://doi.org/10.1016/j.esr.2024.101602>
22. Utrilla, P. N., & Górecki, J. (2023). Decision-making in construction project management: Integrating smart city concepts and principles of sustainable development. *2022 IEEE International Smart Cities Conference (ISC2)*, 1–12. <https://doi.org/10.1109/isc257844.2023.10293708>
23. Zech, P., Plörer, D., Pfluger, R., & Breu, R. (2024). Scalable building energy efficiency balancing. *2024 Annual Modeling and Simulation Conference (ANNSIM)*, 1–13. <https://doi.org/10.23919/ANNSIM61499.2024.10732099>
24. Zhu, X., Zhang, X., Gong, P., & Li, Y. (2023). A review of distributed energy system optimization for building decarbonization. *Journal of Building Engineering*, *73*, 106735. <https://doi.org/10.1016/j.jobee.2023.106735>