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## **INNOVATION IN HOUSEHOLD ELECTRICITY CONSUMPTION: ANALYSIS OF LED LIGHTING AND HEATING ELEMENT TECHNOLOGY EFFICIENCY**

**Introduction.** *This research examines the potential for improving energy efficiency in Ukraine’s household and institutional sectors through the large-scale replacement of incandescent bulbs with LED lighting and the adoption of modern heating element technologies. It evaluates expected electricity savings and provides evidence-based recommendations for state support of these initiatives.*

**Problem Statement.** *Excessive electricity consumption in Ukraine’s household and institutional sectors persists due to outdated lighting and heating technologies, low overall energy efficiency, degradation of energy infrastructure, and the absence of a systematic state policy to promote widespread adoption of innovative energy-saving solutions.*

**Purpose.** *The purpose of this study is to analyze the effectiveness of implementing innovative technologies in Ukraine’s household electricity consumption sector — particularly LED lighting and modern heating element systems — to assess their energy-saving potential and to develop scientifically grounded recommendations for scaling state energy-efficiency programs under post-war recovery conditions.*

**Materials and Methods.** *Statistical data from the State Statistics Service of Ukraine, the International Energy Agency (IEA), and official government program reports, including the “Together We Bring Light!” initiative, have been used. Methods of analysis and synthesis, comparative analysis, techno-economic justification, and linear and logistic modeling have been applied.*

**Results.** *The replacement of 33 million incandescent bulbs with LED ones under the “Together We Bring Light!” program has yielded annual electricity savings of approximately 2.35 billion kWh, totaling more than 11.7 billion kWh over five years. A logistic model has predicted that cumulative savings will reach 22.5 billion kWh by 2030. The introduction of heating element technologies in public catering establishments has reduced electricity consumption by 11–22.5 million kWh per month, depending on*

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the scale of adoption. The use of innovative electric heaters — particularly those based on carbon fibers — has provided energy-efficiency levels of 80—95% and has enabled reductions in electricity consumption in the catering and heating sectors by 15—30%.

**Conclusions.** A logistic model for forecasting electricity savings from the LED transition has been proposed, accounting for program saturation limits and user-adoption dynamics. For the first time, the need to extend the energy-saving experimental program to the heating-element technology sector, supported by targeted state interventions, has been substantiated.

*Keywords:* energy efficiency, electric power industry, innovations, LED lighting, heating element technologies, energy saving, energy intensity, modernization.

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Ukraine's electric power industry is in a difficult situation, caused not only by the consequences of Russian aggression but also by chronic structural problems that have accumulated over decades. Outdated infrastructure, the high energy intensity of the economy, and dependence on imported energy resources require deep modernization. Under these conditions, and considering the country's European integration aspirations, innovative technologies are becoming not merely desirable but critically necessary to ensure Ukraine's competitiveness and sustainable development.

This article is dedicated to analyzing key innovative directions in the field of energy efficiency for household electricity consumption in Ukraine. It examines technologies aimed at reducing energy intensity in the residential and communal sectors (including public catering establishments). The main focus is on the implementation of “off-grid” and “net-zero energy” technologies, modernization of lighting (through LED lamps), application of heating element technologies for water and space heating, and the replacement of traditional appliances in public catering facilities. The article presents the authors' analysis of potential energy savings, cost assessments for technology implementation, examples of state initiatives, and recommendations for their scaling.

The relevance of the topic stems from the urgent need to increase energy efficiency in Ukraine's household and institutional sectors, especially amid an escalating energy crisis caused in part by military aggression and the destruction of energy infrastructure. The adoption of innovative tech-

nologies, such as LED lighting and modern heating element-based systems, contributes to a significant reduction in electricity consumption, cost savings, and improved national energy security — factors that are crucial for sustainable development and the post-war recovery of Ukraine.

There is considerable interest in this issue among the Ukrainian scientific community. In a collective monograph edited by I. M. Sotnyk, the theoretical and methodological foundations for motivational mechanisms driving dematerialization and energy-efficient transformation of the national economy were developed [1]. Theoretical approaches to dematerialization and the enhancement of energy efficiency in both production and consumption have been refined. For example, Dzyadykevych Yu., Sokhatska O. M., and Lyubezna I. V. analyzed strategies for energy efficiency and innovative technologies in the EU's energy sector, providing recommendations on how Ukraine could adopt European experience in this field [2]. Pyrih H., Faifura V., and Krupka A. proposed a brief analysis of the financial support mechanisms for energy-saving initiatives [3]. In their study, Pulin T., Teslenok I., and Nesterenko A. offered proposals for more efficient electricity usage in industry, public utilities, and households based on an analysis of the Zaporizhzhia region's energy efficiency strategy [4]. Shvedun V. classified various types of state policy in the field of energy efficiency, including: energy-saving policy, energy efficiency policy, and policies related to the efficient use of fuel and energy resources [5].

Foreign researchers are also active in promoting the transition to LED lighting. For instance,

Onuma H., Matsumoto S., and Arimura H. T. analyzed global experiences of LED adoption. Their empirical results have indicated that households can reduce electricity consumption by an additional 6.99% after completing a comprehensive “LED campaign” [6]. Heidari M., Majcen D., Nicoline van der Lans, Floret I., and Patel M. K. developed a dynamic model to assess energy efficiency potential in household lighting, taking into account the evolving mix of lighting technologies over time [7]. Research by Hossain A., Sawon M. H., and Talukder M. B. focused on assessing the socio-economic and environmental benefits of energy-efficient heating element technologies [8]. These scholars proposed a practical strategic action plan for implementing such technologies to enhance food quality and sustainability.

Currently, Ukraine’s economy is characterized by high energy intensity, as compared with advanced economies, which severely limits its competitiveness. This issue is further exacerbated by outdated electricity infrastructure that requires modernization to meet European standards. These challenges hinder the implementation of innovations, particularly due to financial limitations and regulatory barriers. Therefore, there is a pressing need to integrate “off-grid” and “net-zero energy” technologies in building construction and retrofitting, along with innovative approaches to energy saving in industry, public utilities, and the residential sector. Such efforts are essential to improve the overall efficiency of Ukraine’s energy system.

According to the latest available data from the International Energy Agency (IEA), in 2022, the residential sector accounted for approximately 21% of final energy consumption worldwide. Despite significant differences in energy use between countries, on average households spend approximately 50–60% of energy on space heating, while lighting consumes a relatively small share — only 2–5% with a tendency to decrease due to the transition to LED lighting [9].

Although the share of lighting in total household energy consumption is relatively minor, many countries worldwide are making significant ef-

forts to further reduce it. One of the first steps was the gradual phase-out of inefficient incandescent bulbs. Governments of many countries have introduced regulatory restrictions on their use, and in some states their sale has been completely banned. In addition to priority measures (for example, 2007 — USA adopted the Energy Independence and Security Act [6], 2008 — European Commission Regulation on phasing out inefficient household non-directional light bulbs from the market [10]), additional measures are being actively implemented worldwide to reduce energy consumption for lighting:

- ◆ Global initiative United for Efficiency (U4E) — UNEP, which describes U4E as a partnership promoting the transition of over 60 countries to energy-efficient lighting and other appliances with potential savings of up to 20% of electricity [11];
- ◆ IEA report “Targeting 100% LED lighting sales by 2025” establishes strategies for achieving digital lighting in buildings by 2030 [12];
- ◆ in 2025, China renewed its LED lamp subsidy program with a budget of approximately \$300 million [13]. Historical research has shown that during 2008–2013, China implemented over 780 million efficient lighting devices with subsidies of 30–50% [14];
- ◆ The US Department of Energy announced new standards for household lamps in April 2024: a minimum of 120 lumens/W by 2028, replacing the previous level of 45 lumens/W [15].

Against the backdrop of such global trends in reducing energy consumption for lighting, it is worth examining the situation in Ukraine. In 2020, households in Ukraine consumed 37.7 billion kWh of electricity, of which lighting accounted for 68.5% or over 24.5 billion kWh, space heating 5.7% — 2.0463 billion kWh, water heating 10.4% — 3.7336 billion kWh, cooking 12.1% — 3.7336 billion kWh [16]. These data indicate that lighting in Ukrainian households represents an extremely large share of electricity consumption, significantly exceeding global average indicators (2–5%). This situation may be due to the significant presence

of outdated or non-energy-efficient light sources in the housing stock.

In 2020, Ukraine produced 148.85 billion kWh of electricity, of which 37.7 billion kWh (25.32%) was consumed by households. Under conditions of growing load on the energy system, the issue of improving energy efficiency in the household sector is acquiring strategic importance. As international practice shows, the transition from incandescent bulbs to LED light sources reduces electricity consumption for lighting by up to 80%. In the case of Ukraine, where the share of lighting in the structure of household electricity consumption is over 68.5% (i.e., over 24.5 billion kWh annually), even partial upgrading of lighting equipment can provide savings within 10–15 billion kWh per year.

Considering that lighting is the largest consumer of electricity in Ukrainian households, it is advisable to begin the analysis of energy-saving opportunities with this element. Various types of lighting devices are traditionally used in households, among which the most common remain:

- ◆ incandescent bulbs, in which light is generated by heating a tungsten filament,
- ◆ halogen lamps as a modified version of incandescent bulbs with somewhat higher efficiency,

- ◆ fluorescent tube lamps based on electrical discharge in mercury vapor,
- ◆ high-pressure sodium lamps that are usually used in street or industrial lighting.

However, both in Ukraine and internationally, there is a clearly expressed trend toward gradual abandonment of outdated, energy-intensive light sources in favor of light-emitting diode (LED) lamps that provide significantly higher energy efficiency, longer service life, and less environmental impact. To scientifically substantiate the advantages of LED lighting, it is advisable to conduct a comparative analysis of the main types of light sources, particularly conventional incandescent bulbs and LED lamps, which is presented in Table 1.

Overall, LED lamps are significantly more efficient, durable, and economical in operation, although they have a higher initial cost. Therefore, the Cabinet of Ministers of Ukraine, with the aim of promoting efficient electricity consumption among the population, adopted on January 10, 2023, the Resolution “On the implementation of an experimental project to create favorable conditions for ensuring efficient electricity consumption in Ukraine” [17].

**Table 1. Comparative Characteristics of Incandescent and LED Bulbs**

Indicator	Incandescent bulbs	LED bulbs
Energy efficiency	Very low (about 5% of energy is converted to light)	High (up to 90% of energy is converted to light)
Service life	1000–2000 h	25000–50000 h
Energy consumption (at equivalent brightness)	60 W	8–10 W
Heat generation	High	Low
Resistance to mechanical impacts	Low	High
Cost	Low initial cost	Higher initial cost, but lower in the long term
Environmental friendliness	Do not contain harmful substances	Do not contain mercury, easily recycled
Switching speed	Instantaneous	Instantaneous
Light spectrum	Warm, close to natural	Diverse, depending on model
Brightness adjustment capability	Easily adjustable	Most modern models are adjustable

Source: created by the authors.

Within the pilot project, the opportunity to replace incandescent bulbs with energy-efficient LED lamps is provided not only to households but also to a wider range of institutions, namely: social protection, healthcare, education, culture and sports institutions under communal ownership; companies providing services for managing multi-apartment buildings; associations of co-owners of multi-apartment buildings (condominiums) and other relevant legal entities. An important condition for participation is the mandatory transfer of old incandescent bulbs in a quantity equal to the number of energy-saving lamps received [18]. At the same time, under the conditions of this experimental lamp exchange project, about 40 million lamps have already been transferred (30 million LED lamps will be purchased with EU funds, 5 million from France, 15 million from additional partners) [19; 20]. If we take the average price of an LED lamp at \$1.5–2, then the total grant amount of the “Together We Bring Light!” program is \$60–80 million. This amount covers only the purchase of lamps. Additional expenses — logistics, administration and disposal — are provided separately from state resources and local budgets. As of January 2024, 6.5 million Ukrainians participated in the experiment, exchanging 33 million lamps [21].

If 33 million incandescent bulbs (75 W) were replaced with LED lamps (10 W) and each lamp operates on average 3 hours per day throughout the year (365 days), then the annual electricity consumption would be: incandescent bulbs  $\approx 2.71$  billion kWh; LED lamps:  $\approx 0.36$  billion kWh. That is, the total electricity savings per year after replacement will be approximately 2.35 billion kWh. Accordingly, it can be predicted that over 5 years of LED lamp operation (the average service life of such lamps), the savings will amount to about 11.74 billion kWh (without considering brightness degradation or replacement). This is equivalent to over 7.9% of Ukraine’s total annual electricity production in 2020 (148.85 billion kWh), indicating the high effectiveness of the government initiative.

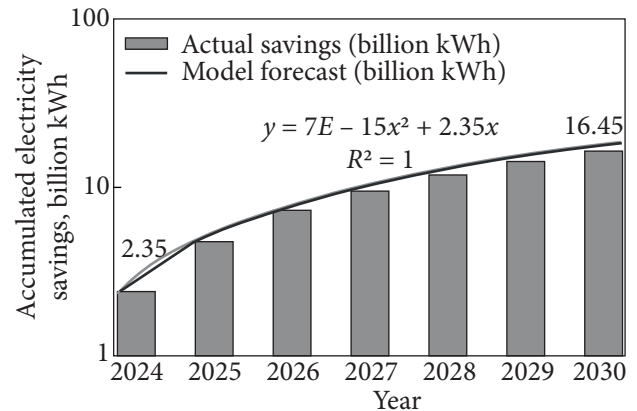
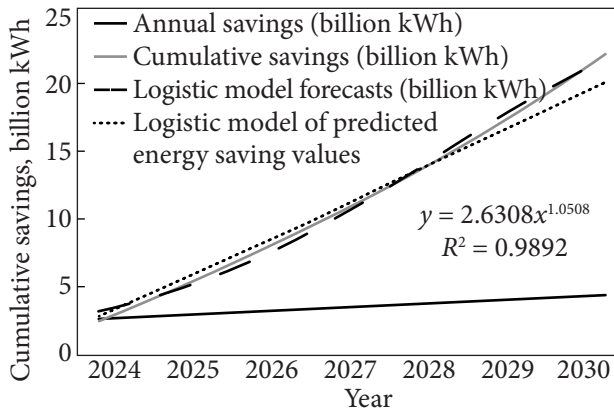


Fig. 1. Quadratic regression of predicted energy savings  
Source: created by the authors

Let us build a parabolic model (Fig. 1), which is nearly linear due to the almost zero coefficient at  $x^2$ . It is used to describe the accumulated electricity savings, where:  $x$  — time (year of LED program implementation, counted from the start — 2024),  $y$  — accumulated electricity savings (in billion kWh).

The quadratic term  $7 \cdot 10^{-15}x^2$  is very small — it can be considered insignificant in a practical sense. The model has essentially confirmed that electricity savings accumulate linearly over time:  $y \approx 2.35 \cdot x$ .  $R^2 = 1$  indicates that the data fits perfectly on the curve, meaning the model perfectly matches the available data (as expected, since the data is synthetic).

This model requires refinement, since under the conditions of the experimental lamp exchange project, it is expected to replace about 40 million lamps. Taking into account user growth (10% per year), the savings do not grow linearly but instead approach a limit of  $\approx 30.4$  billion kWh. A logistic model forecast (Fig. 2) is proposed:  $y = 2.6308x^{1.0508}$ ,  $R^2 = 0.9892$ , where  $y$  — cumulative savings (billion kWh),  $x$  — year of implementation (2024 = 1, ..., 2030 = 7), 2.6308 — saturation limit (maximum savings), 1.0508 — rate of approach to the limit. According to this model, the program is expected to achieve approximately 22.56 billion kWh of cumulative savings by 2030. The model better reflects a realistic scenario, accounting for slower



**Fig. 2.** Logistic model of predicted energy savings values  
 Source: created by the authors

growth in population coverage under the LED replacement program.

That is, the pilot program for exchanging incandescent bulbs for LED lamps in Ukraine demonstrates high energy efficiency and economic feasibility. Initial estimates based on the linear (parabolic) model provide an approximate savings of 2.35 billion kWh per year or over 11.74 billion kWh over 5 years, which is about 7.9% of Ukraine’s total annual electricity production in 2020. However, for a more accurate forecast of savings at the national level, it is more appropriate to use a logistic growth model that takes into account limitations in the number of participants, program resources, and the dynamics of its expansion. It predicts gradual saturation of the program and the achievement of cumulative savings of over 22 billion kWh by 2030. Thus, the “Together We Bring Light!” project not only allows for significant reduction of the load on the country’s energy system but also provides a strategic contribution to improving energy efficiency and energy security of Ukraine in the context of post-war recovery.

The substantial results achieved through the incandescent-to-LED lamp replacement program clearly demonstrate the potential of energy-efficient technologies for large-scale reductions in electricity consumption. This creates the foundation for extending similar approaches to other areas of household and institutional energy use.

One such key area is electricity consumption for heating purposes — both in households and across a wider range of institutions and organizations. In particular, a significant reduction in energy intensity can be achieved by transitioning to advanced technologies in heating devices used for food preparation in catering facilities, space heating systems in residential and industrial premises, hot water boilers, electric water heaters, radiators, and more. Rationalization of these systems is the next step toward improving energy efficiency and reducing the strain on Ukraine’s energy infrastructure.

In this case, “carbon cord” is used as a heating element — this is an innovative type of heating element that uses carbon fibers or threads. It consists of thin carbon fibers woven into a cord or ribbon. When electric current passes through, the carbon fibers heat up, releasing heat. This heater has significant advantages over traditional ones, namely: high efficiency of converting electrical energy into heat, rapid heating and cooling, uniform heat distribution, flexibility and ability to take various shapes, durability and resistance to mechanical damage, environmental friendliness (absence of harmful emissions).

Carbon cord technology is used in underfloor heating systems, heating panels for walls and ceilings, heated car seats, industrial heaters, specialized medical equipment. It has higher efficiency compared to traditional resistive heaters and higher fire safety, is easily adjustable, and is often used with thermostats. Due to these properties, this technology is considered a promising element of innovative heating systems in residential, industrial and public sectors.

The use of electricity in restaurants, cafes, canteens and catering services covers a significant share of the establishment’s total energy consumption, focused mainly on cooking, water heating, maintaining room temperature and food storage. According to the Energy Star for Commercial Kitchens project (USA), over 60% of electricity in public catering establishments is consumed by kitchen equipment that is often outdated and inefficient [22]. According to research by Ukrainian

experts, the nominal power of technological equipment averages 30–50 kW for an establishment with 100–150 seats [23]. At the same time, heating and refrigeration systems often function inefficiently. Because of this, up to 10% of the establishment's profit is spent on utility payments, which significantly increases the cost of dishes. According to official statistics from Interfax-Ukraine, during the heating season (winter), monthly costs for electricity and gas can reach 500–800 thousand UAH even for establishments with an area of over 1,000 m<sup>2</sup> — twice as much as pre-war levels [24].

These data indicate both the high potential for improving energy efficiency and the additional economic pressure on business in the absence of equipment modernization and technology optimization. Thus, the introduction of energy-efficient technologies in the food sector is critical: reducing the nominal power of systems (use of heating elements); smart temperature regulation; energy audit to identify irrational losses; investment in modern professional equipment with higher efficiency. This will reduce energy costs, lower utility payments (up to tens of percent savings) and increase the competitiveness of public catering establishments.

Modern heating element technologies demonstrate significant energy efficiency of up to 80–95%, speed and quality of heating. This opens up prospects for their widespread implementation in the food industry, particularly at public catering enterprises, where precision and safety in food processing are crucial [25]. Heating elements are used in professional kitchen equipment due to their reliability, relative cheapness and ease of replacement in case of breakdown. They are a standard solution for many types of electric stoves used in public catering establishments and households.

According to the State Statistics Service, as of 2023, about 15,000 public catering establishments were registered in Ukraine [26]. The average electricity consumption of one restaurant: 3,000–7,000 kWh per month (according to industry reports), thus these enterprises use: minimum — 45 million kWh per month; maximum — 105 million kWh per month; average approximate con-

sumption — 75 million kWh per month. The use of energy-efficient electric heaters allows saving 15–30% of electricity compared to traditional resistive burners and boilers [27]. Thus, with a conservative estimate, savings will amount to more than 11 million kWh per month, and with an optimistic scenario — 22.5 million kWh per month.

Therefore, heating element technologies — particularly innovative carbon heating systems — are one of the most effective solutions for reducing energy costs in public catering establishments and households. They provide fast, safe and controlled heating, save up to a third of energy and significantly reduce operating costs of heating and cooking systems. In the long term, this is one of the key directions for modernizing energy consumption in Ukraine.

In our opinion, to scale up the energy-saving experience developed in Ukraine and create favorable conditions for efficient electricity use, the Cabinet of Ministers of Ukraine should adopt a resolution “On the continuation of the experimental project to ensure efficient electricity consumption through heating element technologies”, with provisions for attracting resources from the EU and international financial institutions. Launching such a government program — backed by grants and loans from the EU, World Bank, EBRD, and others — will create financial incentives for modernizing heating equipment in households and enterprises, accelerate the achievement of national energy security goals, and enhance the competitiveness of the Ukrainian economy during the post-war reconstruction period.

The conducted research has shown that the transition to LED lighting in Ukraine has significant potential for energy savings — over 11.7 billion kWh over 5 years, equivalent to almost 8% of the country's annual electricity production. The successful implementation of the government project “Together We Bring Light!” demonstrates the high effectiveness of such programs, especially in the context of post-war recovery, when it is extremely important to reduce the load on the energy system. Similar potential has been identified in

the thermal consumption sector, particularly in food service units and public catering establishments. Innovative carbon-based heating element systems allow for electricity consumption reductions of up to 30% compared to traditional solutions. According to estimates, modernization of this segment alone could lead to savings of 11 to 22.5 million kWh per month. This confirms the feasibility of extending state incentive programs not only for lighting but also for heating systems in household and institutional sectors.

At the same time, the implementation of energy-efficient innovations in Ukraine faces a number of barriers. Among the key ones are the high initial investment costs, limited access to financing, institutional weakness in program implementation, and a lack of adequate information support and consumer awareness. Also hindering progress are insufficient localization of production of relevant technologies and uneven infrastructure development across regions. Overcoming these barriers requires a systematic policy at the national level, including the adoption of new regulatory acts, attracting international technical assistance, and launching long-term modernization programs with guaranteed financial resources.

The scientific novelty of the research lies in the development of a quantitative model for as-

sessing the effect of replacing incandescent bulbs with LED lamps at the national level, taking into account the dynamics of population coverage and resource constraints. A logistic model is proposed as a more accurate tool for forecasting long-term cumulative energy savings. In addition, for the first time, the feasibility of extending the experimental energy-saving project to the electric heating sector using modern heating element technologies as a strategic direction of energy modernization is substantiated. Accordingly, it is proposed to adopt a Cabinet of Ministers of Ukraine resolution “On the continuation of the experimental project for ensuring efficient electricity consumption using heating element technologies.”

Prospects for further research include developing detailed mechanisms for financing energy-efficient projects, exploring the possibilities for localizing the production of energy-efficient equipment in Ukraine, and researching the potential of using artificial intelligence to optimize energy consumption. Successful implementation of the proposed innovative solutions requires synergy among the state, business, and the scientific community, which allows not only reducing the energy intensity of the national economy but also enhancing Ukraine’s energy security.

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## ІННОВАЦІЇ У СФЕРІ ПОБУТОВОГО ЕЛЕКТРОСПОЖИВАННЯ: АНАЛІЗ ЕФЕКТИВНОСТІ LED-ОСВІТЛЕННЯ ТА ТЕН-ТЕХНОЛОГІЙ

**Вступ.** Надмірне побутове та інституційне електроспоживання в Україні, спричинене застарілими технологіями та низьким рівнем енергоефективності, вимагає впровадження інноваційних енергозберігаючих рішень і державної підтримки.

**Проблематика.** Актуальним є вивчення потенціалу підвищення енергоефективності через заміну ламп розжарювання на LED-освітлення та впровадження сучасних ТЕН-технологій для нагріву, що призведе до економії електроенергії, а також розробка рекомендацій щодо державної підтримки цих ініціатив.

**Мета.** Проаналізувати ефективність LED-освітлення та сучасних ТЕН-нагрівачів у побутовому електроспоживанні України, оцінити потенціал енергозбереження та розробити рекомендації для масштабування державних програм з енергоефективності у повоєнний період.

**Матеріали й методи.** Використано статистику Держстату України, ІЕА та урядових програм (зокрема «*Together We Bring Light!*»), застосовано методи аналізу, синтезу, порівняння, техніко-економічне обґрунтування, лінійне та логістичне моделювання.

**Результати.** Встановлено, що замінення 33 млн ламп розжарювання на LED за програмою «*Together We Bring Light!*» забезпечує щорічну економію близько 2,35 млрд кВт·год (понад 11,7 млрд за 5 років), а логістична модель прогнозує до 2030 року кумулятивні заощадження у 22,5 млрд кВт·год. Впровадження ТЕН-технологій у закладах харчування дозволяє зменшити споживання на 11—22,5 млн кВт·год щомісяця, а інноваційні вуглецеві нагрівачі з ефективністю 80—95 % скорочують витрати електроенергії на 15—30 %.

**Висновки.** Запропоновано логістичну модель прогнозу економічної вигоди від переходу на LED-лампи та обґрунтовано необхідність поширення енергозберігаючого проекту на сектор ТЕН-технологій із державною підтримкою.

**Ключові слова:** енергоефективність, електроенергетика, інновації, LED-освітлення, ТЕН-технології, енергозбереження, енергоємність, модернізація.