Economic Efficiency of City External Lighting Systems: Methodological Research Toolkit

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Abstract: The article reveals the methodological tools for research and assessment of the economic efficiency of the functioning and development of outdoor lighting systems in cities. The purpose of the research in the work is to substantiate approaches and methods for assessing efficiency, establishing types and groups of efficiency criteria, as well as developing a system of performance indicators for outdoor lighting systems. Taking into account the nature and purpose of the research object, the authors propose to make a comprehensive assessment of its effectiveness based on three groups of criteria through indicators of socio-economic, technical-economic and financial efficiency. In order to ensure comparability of efficiency indicators assessment of heterogeneous outdoor lighting systems, the work substantiates the new concept of "conditional luminaire". The methodological research tools proposed in the work can be used by owners in making decisions on the expansion, reconstruction, and modernization of outdoor lighting systems.

1 INTRODUCTION AND METHODOLOGY

Depending on the nature of vital activity objects and the spheres of their possible socially significant application, which predetermine the types of results and benefits they create, it is necessary to distinguish between the corresponding types of efficiency acceptable to them, which have a practical need to evaluate them. The types of efficiency, taking into account the nature-determined features of the forms and expressions of results and benefits created by various objects, respectively include economic (commercial), general economic, social, budgetary, investment, technical, environmental and other types of efficiency [1, 2]. It should be noted that any socially significant object usually carries several types of efficiency and is always endowed with economic efficiency, because economics is the basis for the functioning and development of any human community and everything that has value for people is certainly an economic good that has an economic significance and, accordingly, economic efficiency.

The city's outdoor lighting system belongs at least to the list of socially, technically, environmentally, budgetarily, politically, commercially, financially and general economically (the last three are types of economic results) significant objects [3-7]. Therefore, all of the listed types of efficiency are applicable to it, among which the most important and primary are the social, technical and economic components. The first - due to the main purpose of the facility - involves ensuring favorable conditions for the life and activities of the population, including business workers and employees of public administration bodies, the second - due to the nature of the management object - ensuring reliability, safety, energy efficiency, continuity and sustainability of the functions performed, the third -

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due to the presence of utility as an economic good, - ensuring maximization of the ratio of benefits and costs of its functioning and development. Therefore, taking into account the priority of these components, in this work the main emphasis is on the study of the content and justification of the key criteria for assessing the socio-economic, technical-economic, as well as financial-economic efficiency of external lighting systems of municipalities. At the same time, the assessment of the social and technical components in this work is carried out through the prism of approaches and categories of economic efficiency.

All approaches to assessing economic efficiency should be divided into simply economic, based on the study of costs and results, accounting, associated with the study of income and expenses, and financial, associated with the assessment of receipts and payments, - totally may be three groups of categories and their corresponding indicators, acceptable in relation to a specific object of research and assessment [8]. In our case, the first and third approaches are important.

The first approach in relation to an outdoor lighting system allows one to study and evaluate the economic parameters of a functioning facility, allowing one to judge its economic condition (the degree of individual elements suitability and the system as a whole), economic potential (the degree of elements use), economic returns (economic results from individual elements - effect in the form of savings or an increase in total benefit or utility), economic risks (losses in value terms caused by imbalances in the parameters of the object's economy, leading to the object as a whole not meeting the requirements of its external environment or disturbing its internal balance as a balanced system), etc. As a result of applying this approach, it is important to understand the economics of the system from the inside and establish its viability and consistency within the framework of existing and possible operating concepts.

The third approach is based on the cash flows assessment determined by budget limits and obligations arising in connection with contracts (agreements) for the maintenance, repair and operation of an external lighting system as a single object that creates a minimum set of economic results (socio-economic in our case), approved by the customer and satisfying the needs of direct consumers (primarily the population, as well as other categories - business, government agencies, etc.). In the context of this approach, the emphasis is on assessing the compliance of the payments volume (in our case, unless the contractor violates the contract terms, we are dealing primarily with a unidirectional cash flow) with the volume and quality of the socio-economic good (service) provided in a comparable monetary value, that is, taking into account the factors of the money time value theory. The economic content of the functioning processes of the external lighting system (hereinafter referred to as the System), the state of its elements, the use of potential, etc., if this does not directly violate the special terms of the contract, is entirely within the jurisdiction and responsibility of the contractor, that is, how he organizes the work on service provider, whether he uses energy-efficient technologies, whether he makes investments in modernization, etc., except in cases specifically stipulated by the contract or under additional agreements - all this does not in any way affect the assessment of the System efficiency level. In simple terms, the less money the customer (municipal entity) pays for a service of a certain volume and required quality, the more effective the model (concept) of the outdoor lighting system.

Considering the fact that the target result of the System functioning (as, in general, any other socially significant object) is to satisfy the specific consumer needs, and the consumer of the System work results in our case is the population, including employees of organizations and public authorities, then the choice of the most cost-effective option for the future state and functioning of the outdoor lighting system should be based primarily on considerations of socio-economic efficiency. Understanding that the System by its nature is a technical object that ensures the achievement of the target goods result, then when choosing a solution in conditions of identical socio-economic efficiency of the System development options, the criteria of technical-economic efficiency come into the background. And given the structure of costs in the System, energy efficiency criteria come first. In third place in importance may be the criteria and indicators of ordinary economic, commercial and financial efficiency.

2 RESEARCH RESULTS AND DISCUSSION

As criteria for the socio-economic efficiency of the Systems, two groups of indicators (two criteria) can be used: 1) the number (volume) of social results available (or created) by the external lighting system per resident (per unit territory area, per unit length of roads, sidewalks, per unit of transport or pedestrian flow, etc.) on average for a certain period of time (static method), for example, per year, or in the dynamics of time calendar periods (dynamic method), for example, monthly; 2) cost (volume of financial payments) of available (created) social good per inhabitant (also, possibly, by other divisors, as well as in statics or dynamics). As an additional criterion of socio-economic efficiency, the criterion of cost (financial burden) per unit of social good provided can be used [9-11]. Both quantitative and qualitative indicators can be considered as social goods (results) indicators. The latter can be assessed in points, percentage of the target audience satisfaction, by indirect indicators, for example, traffic safety, as a social good, can be assessed by the percentage reduction in accidents, crimes, the number of harm cases to health (from falls, collisions) or days of disability. The main social goods (results), in our opinion, in modern populated areas are the number of light points and the volume of luminous flux. Qualitative indicators should be specially developed and assessed for specific territories (sections) of the city (village, other populated area), such as roads, parks, squares, etc. [12-14].

The criteria of socio-economic efficiency must be followed when expanding outdoor lighting systems, as well as bringing their condition to the minimum regulatory requirements for the provision of the population and the territories where they are located in terms of the illuminated places number (area), by the level and quality of illumination, therefore these criteria are the main ones.

Let's consider an example of a comparative assessment of the socio-economic efficiency of the lighting system in the Izhevsk city and a potential outdoor lighting project for one of the new city microdistricts (table 1).

The data in table 1 shows that the level of socio-economic efficiency of the project under consideration is significantly inferior in efficiency to the City System. In particular, the annual current costs by the project per one resident of the microdistrict are more than 4 times higher than such costs in the city. The number of light points according to the project and, obviously, the luminous flux volume per resident are also several times higher than the provision of city citizens. An additional criterion is the annual current costs for one light point - it is not the main one, but it also indicates the inefficiency of the project.

Taking into account the above, priority should be given to solutions to expand the System to a size that provides the required coverage of territories (sections) of a populated area with a minimum number of light points and illumination level, creating conditions for fairly comfortable and safe movement in the conditions of a populated area at night, by roads and pedestrian routes of citizens in the territory municipality. Therefore, preference should be given to projects for installing additional light points in the most densely populated, most pedestrian-, passenger- and transport-loaded, least light-provided microdistricts (territories, sections) of a settlement. For this purpose, in the conditions of a municipality or individual settlements, in our opinion, minimum standards for the provision of light points can be established per resident of the territory (district, microdistrict, zone, etc.) and per unit area of the territory, as well as cost standards lighting also per inhabitant and per unit area, which can also be ranked according to the importance of the territory.

Table 1: Comparative assessment of the socio-economic efficiency of the city's outdoor lighting system and a potential outdoor lighting project for one of its new neighborhoods.

Indicator name	Project indicator value	Indicator value for the city
Full initial (replacement) luminaires cost, million rubles	55	292
Annual current costs, million rubles:		
- maintenance costs	2,2	35
- electricity costs	7,4	118
- depreciation costs	5,5	29
Total	15,1	182
- including current annual costs excluding depreciation	9,6	153
Light points number, pcs.	3000	37583
Annual current costs for 1 light point, rub./piece	5033	4840
Maintenance and electricity costs for 1 light point, rub./piece	3200	4071
Number of inhabitants, thousand people	12000	623000
Annual current costs per 1 inhabitant, rub./person	1258	292
Maintenance and electricity costs per 1 inhabitant, rub./person.	800	246
Light points number per 1 thousand inhabitants, pcs./thousand people	250	60
Effective light points number for the project (maximum), pcs.	724	-
Effective light points number for the project (minimum), pcs.	696	-

The technical-economic criteria used to evaluate the System can also be represented by two groups of indicators: 1) indicators of the functionality of the System and 2) indicators of the cost of the System. At the same time, you need to understand that the technical-economic criteria of the System largely determine both the values of individual indicators and the level of socio-economic efficiency of the System as a whole, and affect other types of efficiency - environmental, aesthetic, political, general economic, commercial, etc. One of the most important problems in the technical-economic assessment of existing Systems is the heterogeneity of their main elements - primarily the types of luminaires used [15].

As part of future research, in order to ensure uniformity and comparability of assessments of the functionality and cost of the System technical component, we propose to introduce the concept of a "conditional luminaire". A conditional luminaire is a luminaire rated at 100 W (thus consuming 100 Wh), emitting 15,000 lumens and having an effective average life of 10 years (or approximately 50,000 hours). The conditional luminaire generally corresponds to the key effective average technical parameters of modern LED luminaires of the mid-price segment used in outdoor lighting systems of municipalities. In this case, a luminaire (light point) should be understood as a light source in combination - the luminaire itself with a lamp. Thus, using the category "conditional luminaire", each System luminaire and the System as a whole can be converted into conditional luminaires - by dividing the luminous flux of each luminaire by a luminous flux of 15,000 lumens.

Table 2: Comparative assessment fragment of the technical-economic efficiency of options for an external city lighting system with gas-discharge (mercury) and LED lamps.

Indicator name	Replacement luminaires				Replaceable luminaires			
Luminaire type	LED			Total	gas-discharge		mercury	Total
Luminaire brand	Groza 80	Groza 100	Groza 150		YCS 100	YCS 150	MCS 250	
Luminaires number, pcs.	4217	10943	229	15389	4217	10943	229	15389
Average price including VAT, rub.	9900	15900	20700	14327	3690	5850	2700	5211
Luminous flux, lumen	12000	16500	22400	-	9000	15000	13000	-
Initial cost of lamps, million rubles	41,7	174,0	4,7	220,5	15,6	64,0	0,6	80,2
Total luminous flux, million lumens	50,6	180,6	5,1	236,3	38,0	164,1	3,0	205,1
Total power, kW	337	1094	34	1466	422	1642	57	2120
Electricity consumption, MW*hour/year	933	3026	95	4054	1166	4539	158	5863
Annual electricity costs, thousand rubles/year	8022	26021	817	34860	10028	39032	1361	50421
Conditional luminaires number in one luminaire, con. lm./pcs.	0,80	1,10	1,49	-	0,60	1,00	0,87	-
Conditional luminaires total number, con. lm.	3374	12037	342	15753	2530	10943	198	13672
Annual electricity consumption by one conditional luminaire, kW*h/con. lm.	276,5	251,4	277,7	257,3	460,8	414,8	797,6	428,8
Annual electricity costs per one conditional luminaire, rub./con. lm.	2378	2162	2389	2213	3963	3567	6859	3688
Conditional luminaire average price, rub./con. lm.	12375	14455	13862	13996	6150	5850	3115	5866
Average price of lamps for lighting fixtures, rub./piece	0	0	0	0	1020	950	1100	971
Average lamp life, years	0	0	0	0	3,9	3,9	3,9	3,9
Annual costs for replacing lamps, thousand rubles	0	0	0	0	1033	2680	56	3769
Annual amount of lamp depreciation, thousand rubles	0	0	0	0	1109	2680	65	3854
Annual amount of lighting fixtures depreciation, thousand rubles	4036	16821	458	21315	1556	6402	96	8053
Reduced annual current costs total, thousand rubles	12058	42842	1275	56175	13725	50794	1578	66097
Reduced annual current costs per one conditional luminaire, rub./con. lm.	3574	3559	3729	3566	5425	4642	7951	4835

Subsequently, we can reduce all the indicators of functionality and cost of existing light points of different types known to us to a common denominator - a conditional luminaire, and judge their functionality, energy efficiency, and maintenance costs in one single comparable estimate. But, with one caveat, that a conditional luminaire as a universal unit is not suitable for assessing the technical-economic efficiency of unique luminaire (those having a special aesthetic or ergonomic application, color spectrum, etc.).

Technical-economic efficiency criteria should be applied when making decisions on modernization, restoration, and reconstruction of Systems.

Let's consider an example of a comparative assessment fragment of the technical-economic efficiency of System options with traditional gas-discharge and modern LED lamps of the middle price segment (table 2).

The data in table 2 indicate that obsolete gas-discharge (and especially mercury) lamps are significantly inferior to their LED counterparts in terms of technical-economic characteristics.

It is believed that the criteria of ordinary economic (commercial, financial) efficiency are usually not applicable to assessing the effectiveness of social objects, which include the System. However, it is known that commercial efficiency is defined as the difference between the results (income, receipts) obtained and the costs (expenses, payments) incurred to obtain them [16-18]. At the same time, one of the types of economic results (income, receipts) can be the “savings” on costs (expenses, payments), which is applicable for any objects (projects) of assessment, both commercial and social, environmental and others. In order to obtain the savings (reduction of costs, expenses, payments) in one or another part of the System, it is necessary to incur costs (expenses, payments) to improve the condition of the elements of this System part or the processes occurring in it. In our case, the possibility of savings in the outdoor lighting system may be associated with a reduction in electricity costs for lighting, labor costs, machines and mechanisms for maintenance, reduction in electricity losses, reduction in restoration costs, etc. Typically, the possibility of savings is determined by investments in modernization, automation, robotization, digitalization, expenses in improving discipline and labor organization, expenses in improving control, standardization, regulation, planning, etc. Savings in each specific case require the development (or at least clarification) of a methodology for its measurement and evaluation.

For example, savings may represent the expected economic outcome of gas-discharge to LED lighting upgrade projects and associated improvements to the System during its subsequent operation. The benefit (in this case, financial-economic effect) will come down to savings in budget costs and minimization of budget payments to the municipality during the service life of the System improvements caused by the lighting fixture modernization projects. Savings within the framework of these projects can be expressed primarily by a reduction in the amount of costs for electricity consumed by the System and a reduction in the amount of costs for servicing lamps in terms of the cost of replacing gas-discharge lamps. In addition, it may also be necessary to estimate the savings or cost overruns (plus or minus) in the costs of major repairs of fixtures, as well as additional income (receipts) from recycling or costs (payments) for recycling old fixtures [19-21].

Table 3: Financial-economic efficiency of replacing gas-discharge YCS 150 with LED luminaires Groza 100, million rubles.

Indicator name	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Investments	-174									
Saving on electricity	13	13	13	13	13	13	13	13	13	13
Savings on lamp replacement	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4	5,4
Saving on repairs	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7
Total savings	20,1	20,1	20,1	20,1	20,1	20,1	20,1	20,1	20,1	20,1
Receipts from gas-discharge luminaires sales	6,4	-	-	-	-	-	-	-	-	-
Net cash flow	-147,5	20,1	20,1	20,1	20,1	20,1	20,1	20,1	20,1	20,1
Cumulative net cash flow	-147,5	-127,4	-107,3	-87,2	-67,1	-47	-26,9	-6,8	13,3	33,4
Cash flow (at a rate of 6%)	-148	19	18	17	16	15	14	13	13	12
Cumulative cash flow (at a rate of 6%)	-148	-129	-111	-94	-78	-63	-49	-35	-23	-11
Luminaires wear (service life 10.3 years)	17	17	17	17	17	17	17	17	17	17
Luminaires residual value	157	140	123	106	90	73	56	39	22	5

The costs (payments) aimed at obtaining these savings and which need to be estimated represent capital investments (investments) in replacing gas-discharge lamps with LED lamps, which include the purchase price (including acquisition and delivery costs) and the cost of their installation. The financial-economic effect from the modernization and subsequent operation of lighting systems can be expected to be obtained only in the long term. It represents the difference between the total savings achieved over the life of new luminaires and the one-time investment in upgrading them. The system as a social object can create other types of economic (financial) results, which requires the implementation of appropriate projects (events).

Let us give an example of assessing the financial-economic efficiency of a project fragment for upgrading gas-discharge to LED luminaires (table 3). Initial data are presented in table 2.

The data in table 3 indicates that the financial-economic efficiency of the lighting fixtures modernization project is quite attractive for the System we are considering as an object classified as social. Without taking into account the time factor, the investment profit on the project will be 33.4 million rubles in 10 years, and the payback period is 8.3 years. When discounted at a rate of 6% per annum, the project during the service life of the improvements (10 years) generates losses of 11 million rubles, that is, it almost pays for itself, which nevertheless indicates its low investment attractiveness for private investors.

3 CONCLUSIONS

The methodological approaches, methods, criteria and indicators for studying and assessing the economic efficiency of outdoor lighting systems proposed in the work allow us to comprehensively judge the advantages and disadvantages of the System as a whole and its individual elements, identify and rank social, technical and financial-economic problems of its functioning, as well as develop and justify projects for its improvement and development strategies.

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