

LIGHT POLLUTION. LIGHT AND ENERGY CULTURE OF LIGHTING AND LIGHTING DESIGN

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***Abstract:** The quantification of the impact of light pollution is presented by a 10 point scale (incl. 5 impact groups and 11 impact subgroups). It is proposed to evaluate the light pollution by 3 groups of outdoor lighting systems: street, architectural and advertising lighting. The energy aspect of the light pollution is represented by: obtrusive light (directed and reflected to the sky); energy losses by obtrusive light; carbon dioxide emission. Light pollution is evaluated on the basis of the actual amount of energy used for outdoor artificial lighting. A methodological approach for the management of light pollution has been developed.*

***Keywords:** Light pollution; Light; Lighting; Luminaire; Environment; Obtrusive light, Directed and reflected light, Street lighting; Architectural lighting; Advertising lighting, Methodological approach; Management of light pollution.*

INTRODUCTION

Light suggests, first and foremost, democracy with equal access without restriction to all individuals. Lighting in regard to the quantity and the quality is aiming to ensure adequate quality of life (Kyuchukov T., 2015, 2017). There is an unsatisfactory energy and lighting culture in many fields related to the lighting management processes. For the time being, the present philosophy refers to the acceptance that electricity is a product of free, unrestricted and uncontrolled access.

Light pollution is a relatively new phenomenon and has not yet been linked to the climate change. At the same time, limiting of the light pollution has taken place in a number of acts of global, European and national regulation (CIE 150 2017; IES TM-15-11; Giacomelli A. C. Nardi, F. Giussani, L. Massetti, 2017). The level of intellectual development in the way the artificial lighting is used dictates the evolutionary course of the human civilization.

Pope Francis estimates that the world techno-economic system, based on the “Culture of Waste”, puts products, not people, at the core. The Pope notes that human ecology and the environmental ecology must work together and calls for "End to the Culture of Waste" in his Easter message "Urbi et orbi" (To the city and to the World), dated 01.04.2018.

Light pollution is the focal point of the national community of energy engineers, lighting technicians and lighting designers.

EXPOSITION

A. Impacts of light pollution

Exterior lighting that is used during the dark part of the day (especially if it is overdosed, dynamic, improperly controlled and directed, with inadequate light color) results in negative (harmful and even dangerous) impact towards disturbed functions, conditions and activities. The sources of light pollution are as it follows (Kyuchukov T. 2015, 2019): external natural light sources; outdoor artificial lighting (street, architectural, decorative, advertising, information, transport lighting, lighting of outdoor areas, etc.); outdoor holiday lighting; indoor lighting, which emits light outside the premises).

At the same time, the scattered light has a harmful effect on (Kyuchukov T. 2015 a, 2019): living nature (biological rhythm of humans, animals, plants); road safety; air traffic safety; astronomical observations; the comfort of the external environment (incoming light); tourist activity.

The effects of light pollution are numerous leading to specific consequences. They are classified according to 14 classification criteria systematized in the block diagram of Fig. 1 in three impact groups (Kyuchukov T., 2015 c). This systematization makes it possible to assess the nature and severity of the of light pollution's effects.

B. Quantitative assessment system for the impact of light pollution

Table 1 presents a 10-point scale system for the effects of the light pollution (IES TM-15-11, Kyuchukov T., 2015). The systematization is based on the effects of light pollution according to the caused consequences. The system contains:

- "Impact groups" - 5 groups according to the degree of light pollution, formed by the ascending degree of negative impacts;
- Impact subgroups - 11 subgroups formed subsystememly according to the content of the light pollution impact.
- Nature of impacts

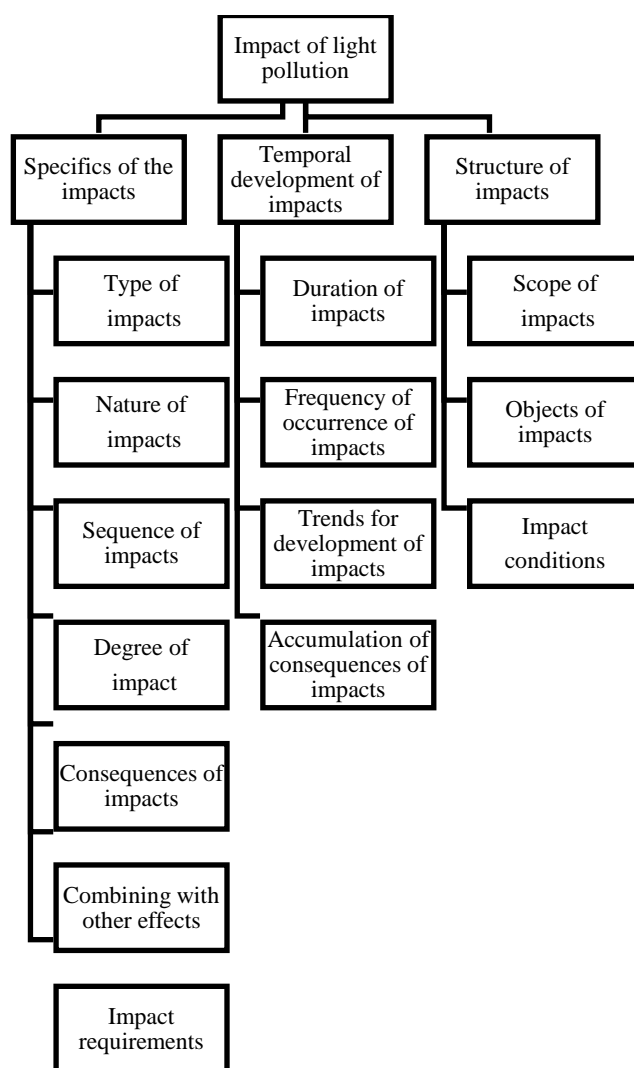


Fig. 1. Classification of the effects of light pollution

The assessment is based on: availability and characteristics of lighting systems; characteristic of light effects (specificity, time development, structure - according to *Figure 1*); development trends; prevention.

Group "0". It refers to places absolutely unaffected by artificial light and located at a great distance from sources of light pollution. The purpose is absolute inadmissibility of violating this area.

Group "1". It applies to locations with low negative impacts. These are places where, there is a slight, still unacceptable, presence of light pollution, which should be eliminated unconditionally and immediately. These are for instance nature reserves with unique animal and plant species, which over time have received artificial lighting to provide easy access for humans, but which cause them irreparable damage.

Group "2". It covers the average negative effects of light pollution that it is advisable to avoid, for instance through the application of good lighting practices.

Group "3" refers to the strong negative effects, which should be limited by mitigating or compensatory measures, but subject to the normal performance of the relevant lighting systems.

Group "4" refers to dangerous negative impacts and requires measures to eliminate these impacts through radical measures.

Approaches to managing the effects of light pollution are specified. The proposed system can be applied for the assessment of light pollution of both existing and forthcoming lighting systems.

Table 1. Systematization of the impact of light pollution

Scale Assessment of The Impact of Light Pollution				
Impact of the light	Impact group	Subgroup of impacts	Assessment	Specific lighting organization and management measures
There are no existing lighting systems.	0 There is no impacts	0-1	0	Assess the extent to which artificial lighting is permissible in the future.
Minor impacts.	1 Weak impacts	1-1	1	Prevention only for preservation of the existing state.
Tendency to maintain or reduce light effects.		1-2	2	
Accidental effects.		1-3	3	Control over the nature and severity of incidental light effects.
Tendency to maintain or reduce the appearance of light effects.	2 Medium impacts	2-1	4	Prevention to prevent future development and transition to a higher group and subgroup.
Short-term impacts. Regular effects. Tendency to maintain or reduce the duration and appearance of light effects.		2-2	5	Control and application of mitigation and compensation measures.
Secondary, medium-term effects.		2-3	6	Control and application of mitigation and compensation measures.
Cumulative, medium-term impacts.	3 Strong impacts	3-1	7	Control and application of mitigation and compensation measures.
Synergistic, medium-term effects.		3-2	8	Control and implementation of special effective mitigation and compensation measures.
Combined (secondary + cumulative + synergistic) effects - long-lasting, permanent, irreversible.		3-3	9	Prevention of future increase.
Significant secondary, cumulative and synergistic effects - long-lasting, permanent, irreversible.	4 Dangerous impacts	4-1	10	Control and application of special effective mitigating and compensatory measures.

C. Assessment of light pollution generated by outdoor artificial lighting systems

Based on the systematization of the quantitative assessment of the impact of light pollution (Table 1), there has been made a recommended assessment of the light pollution by different external light systems and situations and under different conditions. In this case, the following external artificial lighting systems have been evaluated:

- street lighting (Table 2);
- architectural and decorative lighting (Table 3);
- advertising lighting (Table 4).

D. Energy aspect of the light pollution

Outdoor artificial lighting (including street and architectural lighting) is one of the main sources of the light pollution.

The values of the energy and economic indicators related to the light pollution generated from the light emission directed to the sky from the street and architectural lighting in Bulgaria are determined on the basis of representative expertise (Kyuchukov R., T. Kyuchukov, 2012), data from national statistics (Kyuchukov R., T. Kyuchukov, 2012) normalization of the cost of the ecological equivalent of electricity (Ordinance № E-ПД-04-3) and own information.

The assessment is based on the electricity consumed by the outdoor artificial lighting systems. The street lighting and architectural lighting account for 1.62% and 0.27% respectively of the total annual electrical consumption in the Republic of Bulgaria. This amount of electricity consumed by luminaires from outdoor artificial lighting systems generates the actual radiated luminous flux from these luminaires.

Table 4 presents the values of indicators characterizing the light pollution from outdoor artificial lighting (street lighting and architectural lighting) in the Republic of Bulgaria.

The relative annual amount of the light emitted to the sky (directly generated to the sky and reflected) by the street and architectural lighting per inhabitant of the Republic of Bulgaria is q inhabitant - RB = 1.643 Mlm.h / inhabitant.

The explanation for this large scattering of light is mainly found in:

- the application of luminaires with inadequate light distribution and positioning;
- the presence of many settlements with a heavily reduced population but with a relatively large street lighting network.

The type of white spherical unshielded luminaire, which have a uniformly distributed luminous flux in the upper and lower hemispheres, is practically widely used, without any determined light distribution.

Table 2. Exemplary assessment of light pollution from street lighting

Assessment - Outdoor Light. Street Lighting	
0	Without street lighting. Possibly only with light marking of road and pedestrian areas.
1	Very well designed lighting system with very low brightness.
2	Portable temporary lighting (eg on street or road sections under repair).
3	Festive or seasonal street lighting
4	Penetration of light from street lighting through windows or in a private property.
5	Cumulation of the lighting effect of several lighting systems (to the normal street lighting is added the impact of other outdoor lighting systems - festive, architectural and artistic, advertising lighting, vehicle lights, etc.).
6	Simultaneous impact of several outdoor lighting systems (street, architectural, artistic, advertising and other lighting), where the overall effect exceeds the individual impact of lighting systems - light is scattered to the sky, the surrounding space, private property, penetrates through the windows.
7	Street lighting with a combined effect in the simultaneous presence of secondary, cumulative and synergistic effects (in the above three rows) and scattering of light to the sky, the surrounding space, private property, penetrates through the windows.
8	Overdose of street lighting, with independent negative impact or in combined presence of secondary, cumulative and synergistic impact. Light scatter light to the sky, the surrounding space, private property, penetrates through the windows. Unlimited. The impact covers large areas and large masses of people.
9	Highly overdosed street lighting on a large number of streets in large areas with a large number of inhabitants. Joint action of street lighting with other outdoor lighting systems (architectural and advertising lighting, illuminated shop windows, exposure of car headlights in the range of windows, etc. Uncontrolled emission of light to light to the sky, the surrounding area, private property, light penetration disturbance of the normal rhythm of "day / night" of a large number of people, in large areas and areas. There is no prospect for future changes in the light regime and to reduce the significant negative impact.
10	Street, road, path in a special or nature protection site, in which the artificial light creates inadmissible and dangerous (irreversible harmful impact on the natural inhabitants).

Table 3. Exemplary assessment of light pollution from architectural and artistic lighting

Assessment - Outdoor Light. Architectural And Artistic Lighting	
0	Without architectural and artistic lighting. Only with the site's own interior lighting and possibly street lighting.
1	Very well designed and dosed architectural and artistic lighting (with very low brightness, eg light edging of the building).
2	Portable temporary lighting of a building (eg during repairs).
3	Festive or seasonal architectural and artistic lighting.
4	Penetration of light from the architectural and artistic lighting inside the premises of the building or in the surrounding private properties.
5	Cumulation of the lighting impact of several lighting systems (to the architectural and artistic lighting is added the impact of other outdoor lighting systems - festive, street, advertising lighting, vehicle lights, etc.).
6	Simultaneous impact of several outdoor lighting systems (street, architectural, advertising, etc. lighting), where the overall effect exceeds the individual impact of lighting systems - light is scattered to the sky, the surrounding space, private property, penetrates through the windows.
7	Architectural and artistic lighting with a combined effect in the simultaneous presence of secondary, cumulative and synergistic effects (in the above three rows) and the scattering of light to the sky, the surrounding space, private property, penetrates through the windows.
8	Overdose of architectural and artistic lighting of a large number of buildings, with independent negative impact (including dynamic and colored light) or in the combined presence of secondary, cumulative and synergistic effects. Light scatter light to the sky, the surrounding space, private property, penetrates through the windows. Unlimited. The impact covers large areas and large masses of people.
9	Highly overdosed architectural and artistic lighting of a large number of buildings in large areas with a large number of inhabitants, incl. with dynamic and color lighting effects. Joint action of the architectural lighting with other external lighting systems (street and advertising lighting, illuminated shop windows, lighting effects, falling of the headlights in the range of windows, etc. Uncontrolled emission of light to light to the sky , the surrounding area, private property, light penetration through the windows.
10	Disturbance of the normal rhythm "day / night" of a large number of people, in large areas and areas.

Table 4. Exemplary assessment of light pollution from advertising lighting

Assessment - Outdoor Light. Advertising Lighting	
0	Advertising medium without its own lighting system. It affects only during the light part of the day, and during the dark part it is perceived only under the influence of street lighting or the lights of vehicles.
1	Advertising light with very low brightness.
2	Portable temporary lighting (eg during the installation of the advertising medium).
3	Festive or seasonal light advertising medium.
4	Penetration of light from advertising lighting into surrounding buildings or private properties.
5	Cumulation of the lighting impact of several lighting systems (to advertising lighting is added the impact of other outdoor lighting systems - festive, architectural and artistic, street lighting, vehicle lights, etc.).
6	Simultaneous impact of several outdoor lighting systems (street, architectural, advertising, etc. lighting), where the overall effect exceeds the individual impact of lighting systems - light is scattered to the sky, the surrounding space, private property, penetrates through the windows.
7	Advertising lighting with a combined effect in the simultaneous presence of secondary, cumulative and synergistic effects (in the above three rows) and the scattering of light to the sky, the surrounding space, private property, penetrates through the windows.
8	Overdose advertising lighting of a large number of objects, with independent negative impact (including dynamic and colored light) or in a combined presence of secondary, cumulative and synergistic impact. Light scatters light to the sky, the surrounding space, private property, penetrates through the windows. Unlimited. The impact covers large areas and large masses of people.
9	Highly overdose advertising lighting of a large number of buildings in large areas with a large number of inhabitants. Joint action of advertising lighting with other outdoor lighting systems (street and architectural lighting, illuminated shop windows, lighting effects, falling of car headlights in the range of windows, etc. Uncontrolled emission of light to light to the sky, the surrounding area, private property, penetration of light through the windows. Violation of the normal rhythm of "day / night" of a large number of people, in large areas and areas. There is no prospect for future changes in the lighting regime and to reduce the significant negative impact.
10	Advertising or similar lighting in a special or a site in which artificial light creates an unacceptable and dangerous (irreversible harmful effect on natural inhabitants) (eg in reserves in proximity to resort areas).

The total annual consumption of lighting in the Republic of Bulgaria is 14.03% of the total national electricity consumption - 5550.1277.106MWh (5.550 billion kWh/year).

The total annual consumption of street lighting in the Republic of Bulgaria is 11.57% of the total electricity consumption for lighting (1.62% of the total annual electricity consumption in the Republic of Bulgaria) - 642.149.103MWh/year.

The total annual consumption for architectural and artistic lighting in the Republic of Bulgaria is 1.24% of the total electricity consumption for lighting (0.27% of the total annual electricity consumption in the Republic of Bulgaria) - 107.672.103 MWh/year. Table 4 and Fig.5 show values of light pollution indicators from outdoor artificial lighting.

Table 5. Indicators characterizing light pollution from outdoor artificial lighting in the Republic of Bulgaria (street lighting; architectural and decorative lighting)

Light Pollution			
Indicator	Street Lighting	Architectural	Total
Annual net amount of light emitted by street lighting luminaires, T lm.h / year	28.19519	5.370164	33.565354
Emitted net amount of light directed directly to the sky, T lm.h / year, including:	7.229247	1.376910	8.606157
• reflected from the terrain (street lane) to the sky - from the street lighting, Tlm.h / year	2.096594	-	2.096594
• reflected from the surfaces of the illuminated objects to the sky - from the architectural and artistic lighting, T lm.h / year	-	0.798651	0.798651
Annual amount of electricity lost from scattered light (emitted to the sky and creating light pollution), MWh / year	164.6472.10 ³	27.607221.10 ³	192.25442.10 ³
Annual amount of greenhouse gas emissions released into the atmosphere - from lost electricity to create light pollution, t CO ² / year.	134.84605	22.610313	157.45636
Relative annual amount of light emitted to the sky (directly directed to the sky + reflected) from the street and architectural-artistic lighting - per inhabitant of the Republic of Bulgaria, Mlm.h / inhabitant. year	-	-	1,643
Relative annual amount of electricity lost from scattered light from street and architectural and artistic lighting (emitted to the sky and creating light pollution) - per inhabitant of the Republic of Bulgaria, kWh / inhabitant. year	-	-	27.465
Relative annual amount of CO ² emissions that are released into the atmosphere in accordance with the lost electricity for the scattered light to the sky - from street lighting and architectural and artistic lighting - per inhabitant of the Republic of Bulgaria, g CO ² / inhabitant. year.	-	-	22.494

E. Management of the light pollution generated by external artificial lighting systems

As a parametric factor, the impact of the light pollution is evaluated by parameters such as brightness, color, dynamics, direction, duration of impact, coverage of certain area, etc. In order to limit the harmful effects, the measures for limiting light pollution shall also be specified. Measures to limit light pollution are also practical measures to improve the energy efficiency of outdoor lighting.

The block diagram of (Fig.2) presents the methodological approach for managing of the light pollution. In a closed cycle of logically sequential and parallel connected elements (objects, features, conditions, stages, documents, etc.) as the basic elements closing the contour are "Environment", "Man", "Living nature" (Kyuchukov T. 2012 b, 2015 b.).

As the light pollution has recently come to the attention of the scientific and professional community and of society as a whole, it is practically not evaluated, both in the design and operation of outdoor artificial lighting systems. When designing and implementing outdoor lighting projects, no environmental impact assessment (so-called EIA) is made.

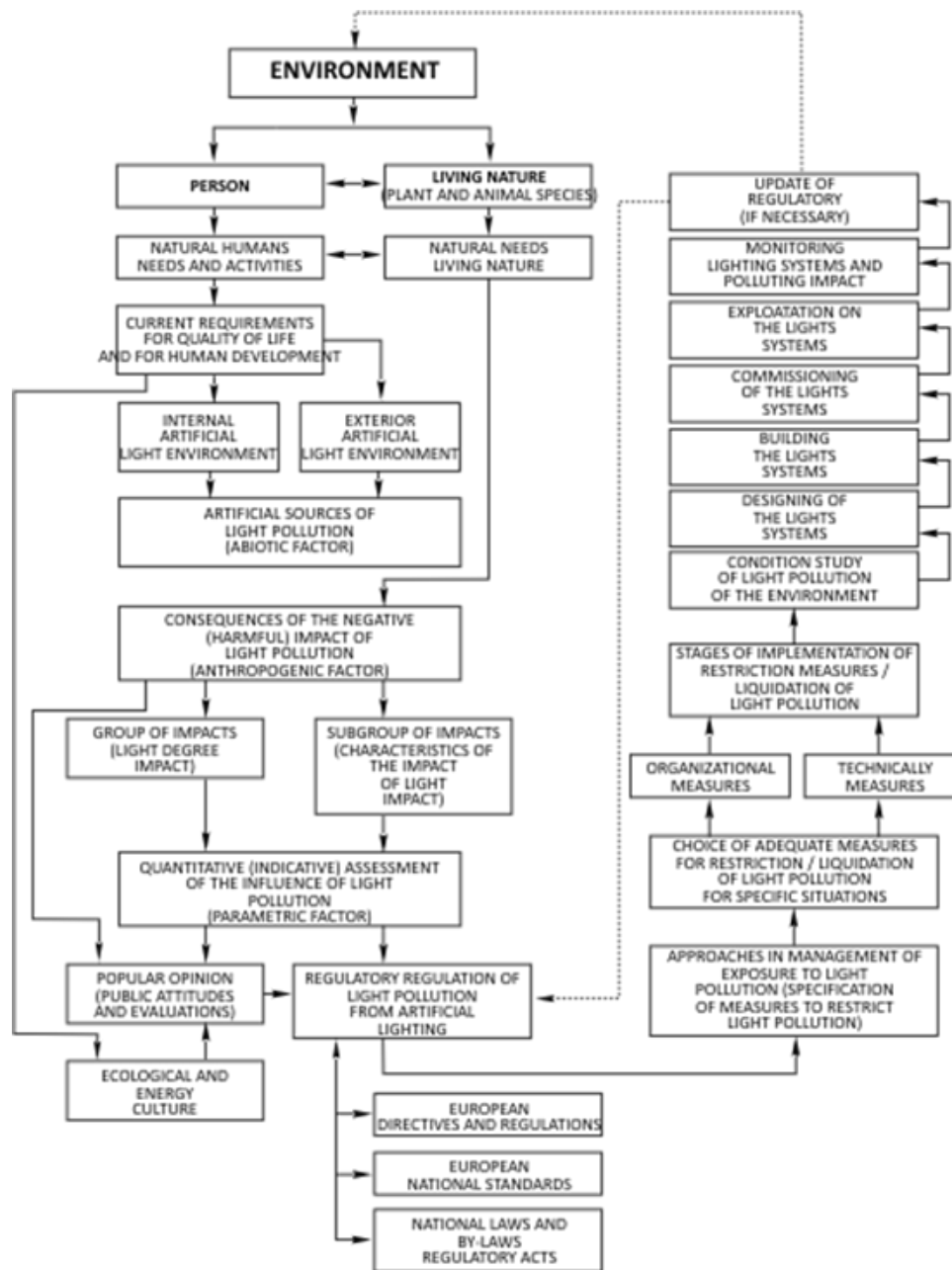


Fig. 2. Block diagram presenting the methodological approach for light pollution management

Light scattering, on the other hand, is associated with electrical consumption and should consider the energy dissipation and associated greenhouse gas emissions assessed in the Energy Efficiency projects of outdoor lighting. There has been specified 12 groups of recommended organizational and technical measures for limiting light pollution, specifying their implementation (Kyuchukov T. 2012 a, 2018):

- Rational regulation of street lighting;
- Application of energy efficient light sources;
- Application of luminaires with adequate light distribution and high efficiency ratio;
- Application of luminaires with adequate IP protection;
- Application of modern street lighting management systems;
- Application of energy efficient starting and regulating devices;
- Application of an adequate positioning system for external (including street) luminaires;
- Application of multifunctional and multicomponent street lighting;
- Implementation of high quality power supply to street lighting;
- Implementation of an adequate system for the repair and maintenance of street lighting;

- Improving the quality of design and construction control in the construction of the new lighting systems and in the reconstruction and modernization of existing street lighting;
- Other measures.

The implementation of adequate measures to limit light pollution is an element of the visual, energy and environmental culture of the quality of light systems.

CONCLUSION

In order to systematize the quantitative assessment of the impact of light pollution, an indicative assessment of the light pollution by three fields of external lighting systems (street lighting; architectural lighting; advertising lighting) has been made, under different situations and conditions.

The values of the indicators characterizing in general the light pollution from the street and architectural lighting in the Republic of Bulgaria are:

- Net light amount of artificial light emitted directly to the sky - 8.606157 T lm.h/year.
- Annual amount of electricity lost from scattered light (radiated to the sky and creating light pollution) - 192.25442.103 MWh/year.
- Annual amount of greenhouse gas emissions into the atmosphere - from lost electricity to create light pollution - 157.45636 t CO₂ / year.

The methodological approach for managing of the light pollution is presented as a closed cycle of logically sequential and parallel connected elements (objects, features, conditions, stages, documents, etc.). The basic elements that close the outline are "Environment", "Man", "Living nature".

Light pollution, with the scattering of light and energy, is an example of the Culture of Waste. Any scattering is an irrational act. Specifically, in lighting and lighting design, a new culture should be cultivated - the "*Culture of Rationality*", the core of which is the limitation of light pollution.

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