Romanian Journal of Civil Engineering, Volume 16 (2025), Number 4

Analysis of the Global Impact of Light Polution. Ecological Environment Perspectives

Analiza impactului global al poluării luminoase. Perspectivă ecologică și de mediu

Anca MANOLESCU [1], Ionuț STĂNESCU [1]

[1] Technical University of Civil Engineering of Bucharest
122-124 Bvd Lacul Tei, Bucharest, Sector 2, Romania

E-mail: anca.manolescu@utcb.ro, ionut-mihail.stanescu@phd.utcb.ro

DOI: 10.37789/rjce.2025.16.4.5

Abstract. *Light pollution is intensifying globally, affecting around 80% of the world's population, a figure that rises to 99% in Europe and North America. The use of artificial light at night increases annually by at least 10% due to urbanization, industrialization, and population growth. Efforts to enhance energy efficiency and reduce energy costs are leading to technological advancements and changes in consumer behavior that help mitigate light pollution. Annually, about $50 billion is spent on energy for lighting that ultimately leaks into space, impacting nocturnal environments and various species. This pollution disrupts human sleep, circadian rhythms, and melatonin production, and alters the natural behaviors of wildlife, trees, and insects. Despite its extensive impact on health, biodiversity, and ecosystems, a unified legal framework to regulate light pollution is lacking in the EU. Effective strategies to minimize ecological impacts while maintaining city illumination are crucial.*

Key words: *light pollution, energy efficiency, human health*

Rezumat. *Poluarea luminoasă este în creștere la scară globală, expunând circa 80% din populația lumii - și până la 99% în Europa și America de Nord - unor niveluri excesive de lumină artificială nocturnă. Suprafața și intensitatea iluminatului pe timp de noapte cresc cu cel puțin 10% anual, impulsionate de urbanizare, industrializare și dinamica demografică. Inițiativele orientate spre eficiență energetică și reducerea costurilor stimulează inovația tehnologică și schimbă comportamentele de consum, contribuind la limitarea emisiilor luminoase inutile. Se estimează că, anual, aproximativ 50 de miliarde USD sunt irosite pe energie pentru iluminat care se disipă în atmosferă, degradând peisajele nocturne și afectând o gamă largă de specii. Consecințele includ perturbarea somnului, dereglarea ritmurilor circadiene și a secreției de melatonină la oameni, precum și alterarea comportamentelor naturale ale faunei sălbatice, arborilor și insectelor. În pofida amprentei semnificative asupra sănătății, biodiversității și funcționării ecosistemelor, Uniunea Europeană nu dispune încă de un cadru normativ coerent și unitar pentru gestionarea poluării luminoase. Sunt necesare strategii integrate*

The article was received on 24.10.2025, accepted on 27.10.2025 and published on 27.11.2025

care să reducă impactul ecologic al iluminatului menținând, în același timp, siguranța și funcționalitatea spațiului urban.
Cuvinte cheie: *poluare luminoasă; eficiență energetică; sănătate umană; biodiversitate; politici publice*

1. Introducere

The majority of the global and particularly the U.S. and European populations live under light-polluted skies, obscuring views of the night sky and affecting natural light levels. Over 80% of the world experiences light-polluted nights, which not only diminishes human experience with the night sky but also has broader ecological impacts.

Economic and energy concerns are highlighted by the significant energy consumption of artificial lighting, which contributes to carbon emissions and financial costs. The adoption of energy-efficient lighting technologies offers a dual benefit of reducing expenses and minimizing environmental impact. Also, light pollution disrupts ecosystems by altering animal behaviors and affecting plant phenology. It also impacts human health by disrupting circadian rhythms and sleep patterns, with potential long-term health consequences.

Astronomical effects of increased skyglow from artificial lighting significantly hinder astronomical observations and diminish the visibility of celestial phenomena, which have historically played crucial roles in navigation and scientific discovery. Fig.1 illustrates a series of impacts caused by light pollution.

Fig. 1. Light pollution impact

2. Content of the paper

2.1 Overview of lighting pollution problem

Statistics on global exposure to artificial light reveal significant global and regional impacts, affecting the visibility of the Milky Way and extending geographically across vast areas. Over 80% of the world's population lives under light-polluted skies, where the natural darkness of the night is significantly altered by artificial lighting. This percentage rises to more than 99% for the U.S. and European populations, illustrating a profound loss of natural night environments in these regions. [1]

Light pollution obscures the visibility of the Milky Way for over one-third of humanity, including 60% of Europeans and nearly 80% of North Americans, representing a substantial cultural and natural loss as many are deprived of viewing this essential astronomical feature from their locations. Approximately 23% of the world's land areas between latitudes 75°N and 60°S suffer from light-polluted nights. This includes 88% of Europe and nearly half of the United States, demonstrating extensive environmental impact across large and diverse geographic areas.[1] These statistics underscore the extensive reach and growing problem of light pollution globally, affecting not just human health and energy consumption but also the ecological and atmospheric quality of our environment.

Light emitted from the Earth's surface into space is quantified as radiance, which is a measure of the intensity of brightness observed from a specific angle per unit area (nW/cm^2*sr). Such measurements are used in remote sensing and astronomical observations to assess the brightness and light pollution of areas on Earth. This can include monitoring city lights, tracking changes in light emission over time, and studying ecological impacts of artificial light. Instruments like the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite are commonly used to gather this type of data, allowing researchers to map and analyze how human activities light up the night on a global scale.

The images below illustrate the changes in radiance around the world from 2014 to 2023 [2].

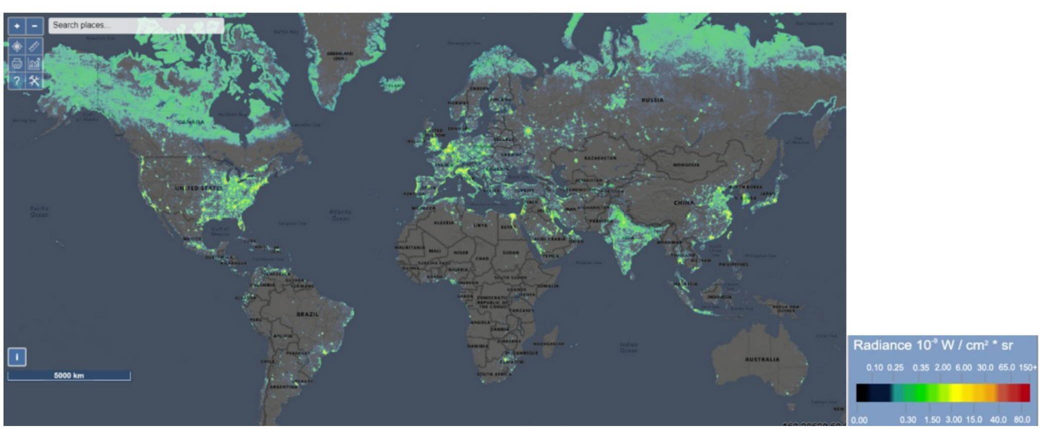

Fig. 2. World map light pollution 2014 [2]

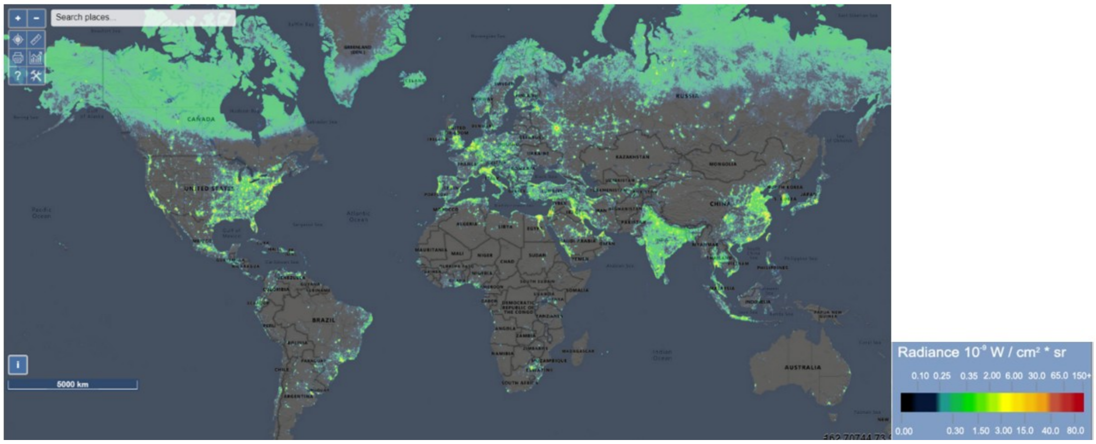

Fig. 3. World map light pollution 2023 [2]

In the following pictures we can see the numbers of observatories and sky dark cameras in 2023.

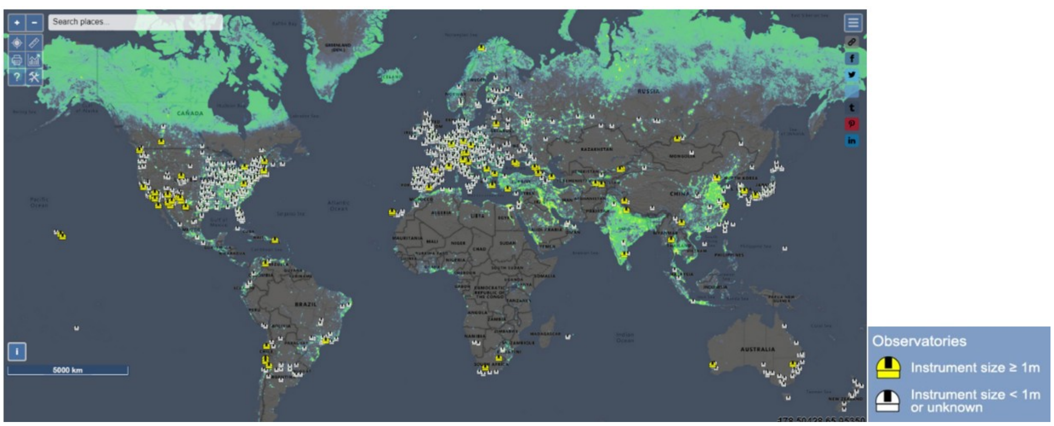

Fig. 4. World map observatories 2023 [2]

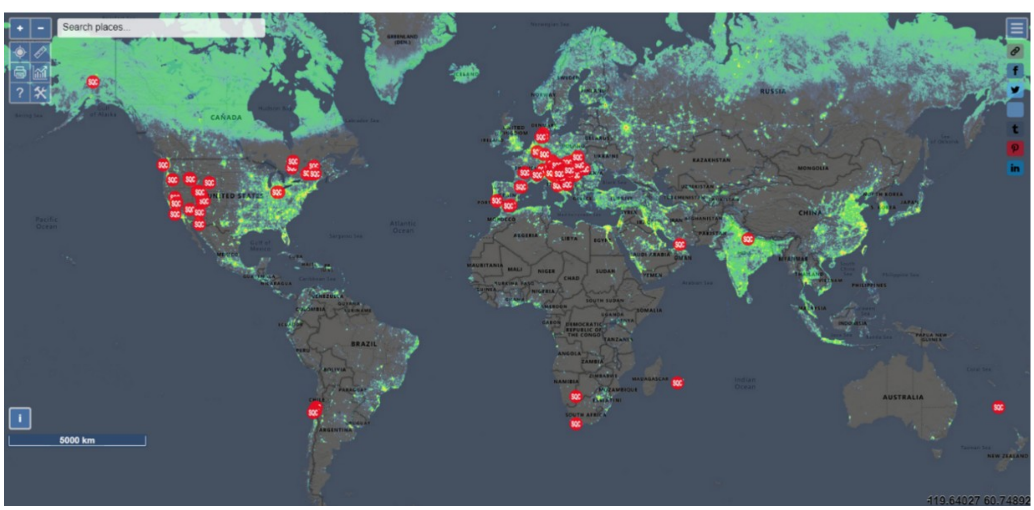

Fig. 5. World map sky quality cameras 2023 [2]

The images below illustrate the changes in radiance in Europe from 2014 to 2023.

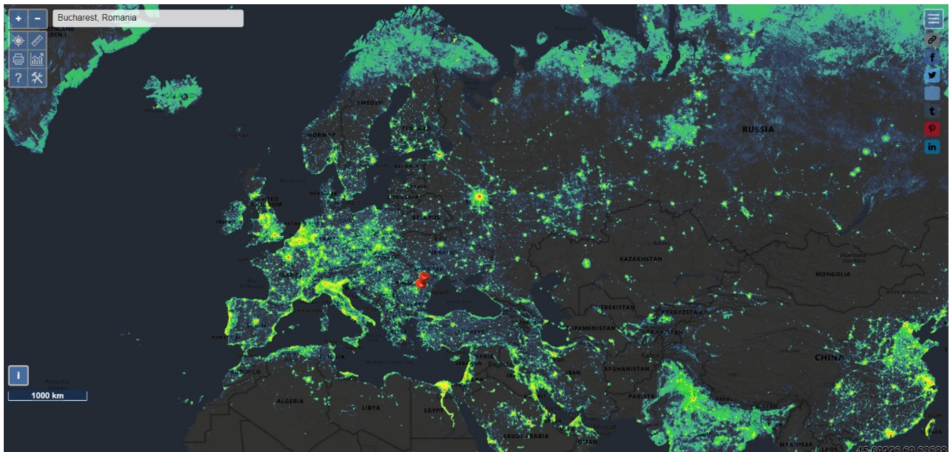

Fig. 6. Europe map light pollution 2014 [2]

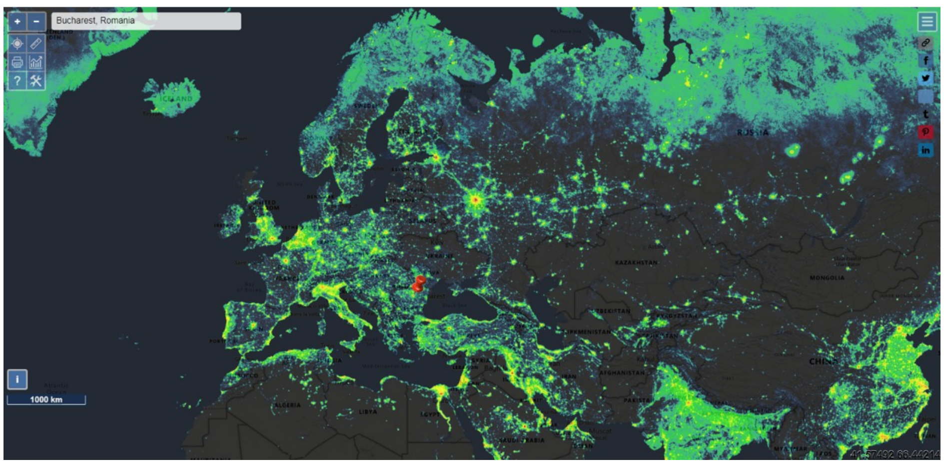

Fig. 7. Europe map light pollution 2023 [2]

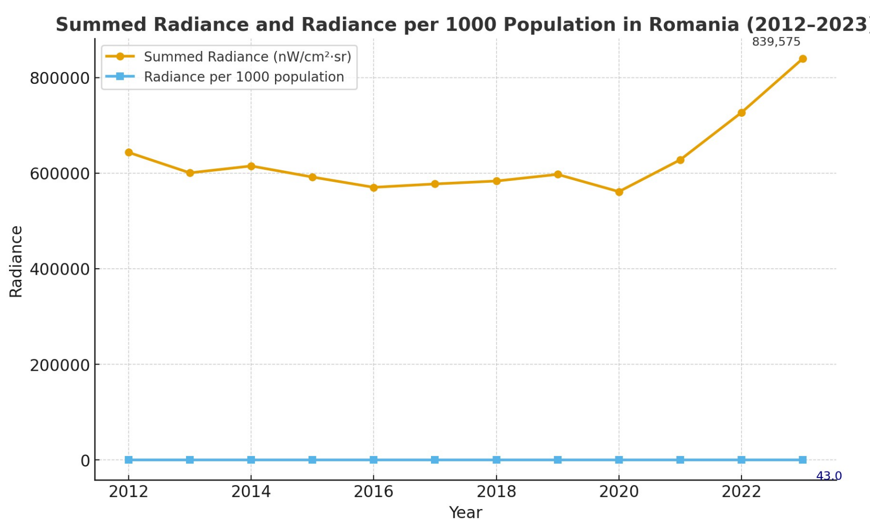

Fig. 8. Summed radiance for Romania 2012 – 2023 [2]

Table 1

Summed radiance for Romania 2012 – 2023 [2]

Year	Pixel count	Sum	Rad. / 1000 pop.	Mean
2012	1,591,881	643,413	33.0	0.5801
2013	1,591,881	600,621	30.8	0.5416
2014	1,591,881	615,013	31.5	0.5545
2015	1,591,881	591,867	30.3	0.5337
2016	1,591,881	570,367	29.2	0.5143
2017	1,591,881	577,425	29.6	0.5206
2018	1,591,881	583,535	29.9	0.5261
2019	1,591,881	597,434	30.6	0.5387
2020	1,591,881	561,326	28.8	0.5061
2021	1,591,881	627,882	32.2	0.5661
2022	1,591,881	726,855	37.2	0.6554
2023	1,591,881	839,575	43.0	0.7570

This study examined the evolution of artificial light at night (ALAN) in Romania using VIIRS satellite radiance data between 2012–2023. Our analysis confirmed the research hypothesis: radiance values show a measurable and consistent increase over the past decade, both in absolute terms and relative to population. These findings reflect the combined effects of urbanization, industrialization, and gaps in regulatory enforcement.

To ensure comparability across years, we relied on the VIIRS Annual V2 dataset, which has recently been validated and extended through global simulations by Tang et al. [5] and Chen et al. [6].

By integrating satellite-derived datasets with demographic normalization, the methodology provided both quantitative and comparative insights into light pollution trends. The results highlight that energy-efficient technologies alone do not necessarily reduce light pollution when urban expansion and increased consumption offset efficiency gains.

From a policy perspective, the evidence underscores the urgent need for harmonized European legislation, as well as local interventions such as stricter lighting codes, curfews for non-essential lighting, and adaptive smart lighting systems. Future research should expand this framework by incorporating cross-country comparisons, ecological impact assessments, and scenario-based modeling of mitigation strategies.

Overall, the findings strengthen the argument that light pollution must be treated not only as an energy or aesthetic issue, but as a measurable environmental pressure with direct consequences for biodiversity, human health, and cultural heritage.

2.2. Light pollution drivers

The main drivers of light pollution are industrialization and urbanization, complemented by population growth which escalates the use of artificial lighting. Meanwhile, the shift toward energy-efficient technologies seeks to lower energy expenses and mitigate climate change impacts. Industrialization and urbanization are significant drivers of increasing light pollution. As cities expand and industrial activities intensify, there is a corresponding rise in the use of artificial lighting. This increased lighting is not only a product of growth but also a facilitator for extended commercial hours and enhanced public safety. However, the side effects include disrupted ecosystems and altered human and wildlife circadian rhythms.

Urbanization leads to denser living spaces and more illuminated public areas, contributing significantly to "skyglow," which obscures the visibility of stars. The materials point out that as urban areas grow, there is a need for policies that address the balance between necessary illumination for safety and the prevention of excessive light that can be harmful to both environmental and human health. The challenge lies in implementing lighting that is effective yet minimizes the negative impacts of light pollution, urging a shift towards more strategic and lower impact lighting solutions in urban planning.

Population growth is a significant driver of increased artificial light use, leading to more widespread light pollution. As urban populations expand, there is a corresponding rise in the demand for lighting to support extended hours of activity and improved safety. This increase often leads to excessive night lighting in urban centers, which not only affects energy consumption but also disrupts ecosystems and human health. The challenge lies in balancing the benefits of artificial lighting for urban development and security with the need to minimize its ecological and health impacts. The documents suggest strategies like using energy-efficient lighting technologies and implementing better lighting designs that focus on limiting unnecessary light exposure to the environment.

The transition towards energy-efficient technologies, aimed at reducing energy costs and addressing climate change, is a critical response to the escalating impacts of light pollution. This shift is evident in the adoption of LED lighting and the implementation of energy-efficient fixtures that not only reduce power consumption but also minimize environmental impacts. For instance, the integration of LED technology is noted for its superior energy efficiency compared to traditional lighting solutions, reducing both energy costs and carbon emissions. This move towards LEDs and other energy-efficient lighting systems reflects a broader commitment to sustainability, particularly in urban settings where light pollution is most concentrated.

Light pollution extends beyond visual disturbance, influencing ecological and social well-being, as recent studies demonstrate [7].

Moreover, strategic approaches like the use of shielded fixtures to direct light precisely where it is needed and the implementation of smart lighting systems that adjust brightness based on real-time needs are being emphasized. These measures not only conserve energy but also help in preserving the natural night environment, reducing the adverse effects on both human health and wildlife. These transitions are supported by policies and guidelines encouraging the adoption of green technologies and practices that align with broader environmental goals, demonstrating a concerted effort to tackle the dual challenges of energy efficiency and environmental sustainability.

2.3. Economic and environmental costs

Annual global expenditure on energy for lighting not only impacts financial resources but also contributes to light pollution, which significantly degrades the quality of nocturnal skies and atmospheric conditions and have several effects on health and biodiversity.

Global spending on energy for artificial lighting is estimated at $50–70 billion annually, with street lighting alone accounting for approximately 19% of global electricity use [1]. This expenditure is particularly stark considering that much of this light is wasted, shining upwards or outwards rather than illuminating the intended areas, thereby adding unnecessary costs and environmental impacts. These wasteful practices not only result in financial loss but also exacerbate ecological disruptions by affecting nocturnal wildlife and contributing to energy inefficiency. It is important to adopt more efficient lighting practices, including the use of technologies that reduce light scatter and improve the directionality of lighting to minimize sky glow and light trespass. This shift towards more sustainable lighting practices is highlighted as a crucial step in reducing both the economic and environmental costs associated with light pollution.

Light pollution significantly degrades the quality of nocturnal skies and impacts atmospheric conditions. This form of pollution caused by the overuse and poor design of artificial lighting results in several environmental disturbances:

- Glare - bright, direct light that impairs human vision, making it difficult to see in the surrounding darkness. This can pose safety risks, particularly for drivers and pedestrians at night.
- Sky Glow - the excessive brightness that illuminates the sky overpopulated areas, obscuring the view of stars and planets. This glow extends far beyond the light sources, affecting even remote areas.
- Light trespass - light that spills into areas where it is not needed or wanted, such as residential windows, causing disruptions and reducing the quality of sleep for inhabitants.

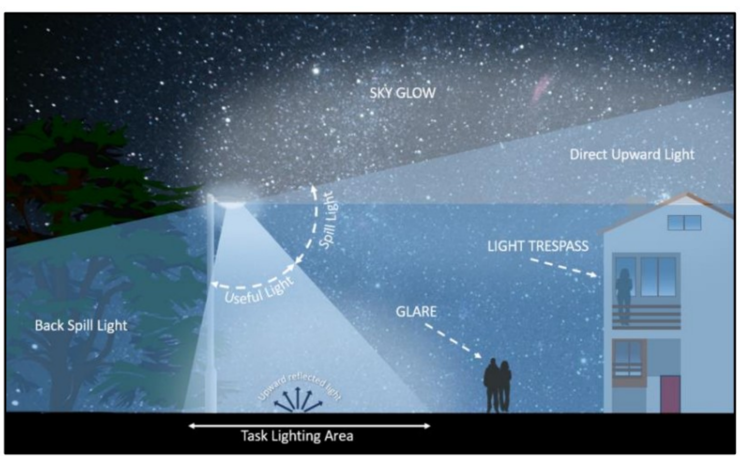

Fig. 9. Reduced sources of Light Pollution. The residual impacts of the lighting [3]

The impact of these aspects of light pollution is profound, affecting human health by disrupting circadian rhythms and suppressing melatonin production, which can lead to sleep disorders and other health issues.

At the global level, citizen science projects reveal a ~10% annual increase in sky brightness, underscoring that the problem is accelerating faster than satellite data alone suggests. [8]

In terms of biodiversity, light pollution has significant negative impacts on various species across different ecosystems. Nocturnal animals, which rely on the darkness for their natural behaviors such as feeding and reproduction, are especially affected. The altered light conditions can confuse animal navigation, alter predator-prey relationships, and disrupt the reproductive patterns of many species. This ecological imbalance extends to affecting plants and insects, fundamentally altering habitats and food chains.

Efforts to manage and mitigate these impacts are crucial, and they include designing lighting that minimizes sky glow, glare, and light trespass. Such designs involve using fully shielded fixtures, implementing lower light levels, and using lights only when necessary. These strategies not only improve the quality of the night environment but also save energy and reduce associated costs.

2.4. Light pollution in legal and policy frameworks

Despite various national and local initiatives to mitigate light pollution effects, there is no comprehensive EU-wide regulation to consistently address this issue. The lack of a cohesive legal structure leads to varied approaches and standards among EU countries, which can hinder effective regional strategies for reducing light pollution.

For instance, France has implemented detailed national laws that regulate lighting intensities, schedules, and specific requirements for various areas, with penalties for non-compliance (for example, from July 1, 2018, illuminated advertisements must be turned off between 1:00 AM and 6:00 AM). Italy and Spain have more regional approaches, with some areas lacking comprehensive legislation. Liechtenstein is an example of a country that has already defined artificial light as source of potentially harmful radiation in the Environment Protection Act, which is a national binding document Meanwhile, in Belgium, private light sources are regulated, but public lighting remains uncontrolled. Around the world, the Australian government was one of the first officially recognizing artificial light as a source of pollution in the Environment Protection Act in 1997 and therefore defining it as a threat to the human and environmental health.

The metropolitan government of Seoul adopted a national law called the ordinance on the prevention and management of light pollution in 2010. Over the last few decades Chile has established its status as astronomical capital of the world due to strong political efforts protecting the night sky. As early as the 1990s, the astronomical community was critical of the increasing light pollution. In Supreme Decree No. 686 by the Ministry of Economy in 1998 are included regulations on the features of outdoor lights mitigating upward light emissions and additionally the Office of Sky Quality in North Chile (OPCC) was founded.

Hong Kong is considered the most polluted city in the world due to its high population density, thriving economy, and more than 1000 skyscrapers. A study states that a night here is a thousand times brighter than the normal limit.

While LEDs are widely promoted, their effectiveness depends on implementation. In France, the introduction of curfews and shielded LED fixtures reduced skyglow by ~7% between 2012–2019 [4]. In contrast, regions of Spain where lighting policy is fragmented have shown little improvement. Chile provides a strong example outside Europe: strict astronomical protection laws since the 1990s have successfully reduced upward light emissions around observatories [2]. These examples suggest that technology alone is insufficient - effectiveness depends on strong regulatory frameworks and enforcement.

In the next table (1) ✓ means that there is a designated legislative act (on local/regional/national level) addressing light pollution; (✓) means that there is no designated legislative act addressing light pollution, but provisions from other legislative acts can be used; X means that there is no legislation addressing light pollution; (2) ✓ means that a guidebook/manual for correct lighting has been issued in the country; (✓) means that a guidebook/manual is underway; X means that n manual/guidebook is existing or in preparation; (3) Others means the country e.g. Dark Sky Area, specific projects, dedicated to light pollution [4].

The European Ecodesign Directive and the Energy Labelling and Repealing Directive focus on energy-efficient installations but do not directly address the adverse impacts of light pollution. Additionally, light pollution is recognized under the EU Green Public Procurement (GPP), which recommends reducing light pollution levels, but adherence remains voluntary.

Table 2

Overview of the European actions to reduce light pollution [4]

Country	Legislation[1]	Standard	Manual[2]	Other[3]
Austria	X	✓	✓	✓
Belgium	X	✓	✓	✓
Bulgaria	X	✓	X	X
Croatia	✓	X	X	✓
Cyprus	X	X	X	✓
Czech Republic	(✓)	(✓)	✓	✓
Denmark	(✓)	X	✓	✓
Estonia	X	X	X	✓
Finland	(✓)	X	(✓)	X
France	✓	X	X	✓
Germany	✓	X	✓	✓
Greece	✓	X	X	✓

Hungary	(✓)	X	✓	✓
Iceland	X	X	X	✓
Ireland	X	X	✓	✓
Italy	✓	✓	X	X
Latvia	(✓)	X	X	✓
Liechtenstein	X	X	X	✓
Lithuania	X	X	X	X
Luxembourg	X	X	✓	✓
Malta	✓	✓	(✓)	✓
Netherlands	(✓)	X	✓	✓
Norway	X	X	✓	X
Poland	X	X	X	✓
Portugal	X	X	✓	✓
Romania	X	X	X	✓
Slovakia	(✓)	X	X	✓
Slovenia	(✓)	X	✓	✓
Spain	✓	X	✓	✓
Sweden	✓	(✓)	✓	X
Switzerland	(✓)	✓	✓	✓
United Kingdom	✓	X	✓	✓

Establishing more standardized regulations could better address the ecological impacts of artificial lighting and align with broader environmental goals. The need for an integrated policy approach is evident, aiming to harmonize light pollution measures across member states while considering local environmental conditions and urban development patterns, to better manage light pollution's ecological, health, and astronomical impacts.

2.5. Mitigation strategies

There are several strategies for mitigating light pollution while maintaining essential urban illumination:

- ✓ Implementing energy-efficient lights such as LEDs, which can be dimmed and directed more precisely, reduces overall light pollution without compromising safety or aesthetic lighting needs.
- ✓ Encouraging the installation of fully shielded fixtures ensures that light is directed downwards where it is needed, preventing unnecessary sky glow and light trespassing into natural areas or neighboring properties.
- ✓ Integrating advanced technologies, including motion sensors and adaptive lighting systems, can dynamically adjust lighting levels based on actual conditions, such as pedestrian or vehicular presence. This approach minimizes light waste during time of low activity.
- ✓ Developing policies that require or incentivize the adoption of low-impact lighting technologies can help scale these practices. Urban planning that

integrates light pollution reduction into broader environmental and public health strategies is also crucial.

- ✓ Educating and involving community members and stakeholders in light pollution reduction efforts can enhance the acceptance and effectiveness of these strategies. Collaborative approaches can lead to more sustainable practices that are supported by both public and private sectors.

These mitigation strategies, coupled with an understanding of the benefits of reducing light pollution - such as energy savings, improved public health, and better environmental outcomes - underscore the importance of concerted efforts at various levels of governance and society.

3. Conclusions

This study analyzed the evolution of artificial light at night (ALAN) using VIIRS satellite data from 2012 to 2023, with a specific focus on Romania. The findings support the initial hypothesis: radiance values have increased steadily over the last decade, both in absolute terms and normalized per population, reflecting the combined influence of urbanization, industrialization, and insufficient policy enforcement.

Beyond confirming these trends, the results highlight the limitations of technology-only approaches. While LEDs and smart lighting systems reduce energy consumption, they do not automatically mitigate light pollution without complementary policies. Comparative evidence from countries such as France, Germany, and Chile suggests that legally enforced curfews and shielding requirements are more effective than technology alone.

Future research should expand this framework in three directions:

1. Cross-country analysis - extending the comparative dataset beyond Romania, France, and Germany to other EU countries with different governance approaches.
2. Ecological monitoring - linking satellite-derived radiance trends with biodiversity indicators (e.g., insect decline, bird migration, plant phenology).
3. Policy evaluation - scenario-based modeling to test the impact of specific regulatory measures (curfews, zoning rules, adaptive lighting systems) on radiance trends.

Concrete collaboration between remote sensing experts, ecologists, and policymakers will be essential to translate radiance data into actionable strategies. Ultimately, addressing light pollution requires treating it as an environmental pressure comparable to air and noise pollution - with robust monitoring, enforcement, and community engagement.

ACKNOWLEDGEMENT

This research was supported by $\boldsymbol{GNaC_{2024}^{ARUST} - UTCB\ 25}$ project from Technical University of Civil Engineering, Bucharest, project number 1401/07.02.2025

References

[1] F. Falchi, P. Cinzano, D. Duriscoe, C. C. M. Kyba, C. D. Elvidge, K. Baugh, B. A. Portnov, N. A. Rybnikova, R. Furgoni, The new world atlas of artificial night sky brightness. Sci. Adv. 2, e1600377 (2016).

[2] darksky.org, https://www.lightpollutionmap.info

[3] Darkscape Consulting. Dedham Vale National Landscape & Coast & Heaths National Landscape 2023. LIGHTING DESIGN GUIDE. Guidance to reduce light pollution and protect our dark skies. https://dedhamvale-nl.org.uk/

[4] Widmer, K., Beloconi, A., Marnane, I., Vounatsou, P., (2022). Review and Assessment of Available Information on Light Pollution in Europe (Eionet Report – ETC HE 2022/8), ISBN 978-82-93970-08-8, ETC HE c/o NILU, Kjeller, Norway.

Science for Environment Policy (2023) *Light Pollution: Mitigation measures for environmental protection*. Future Brief 28. Brief produced for the European Commission DG Environment by the Science Communication Unit, UWE Bristol. Available at: https://ec.europa.eu/science-environment-policy.

Welch, D., Dick, R., Trevino, K., Longcore, T., Rich, C., Hearnshaw, J., Ruggles, C., Dalton, A., Barentine, J. & Gyarmathy, I. (2024). *The world at night: Preserving natural darkness for heritage conservation and night sky appreciation*. IUCN WCPA Good Practice Guidelines Series No. 33, Gland, Switzerland: IUCN.

[5] H. Tang, J. Liu, Z. Zhang, et al., “Global annual simulated VIIRS nighttime light dataset from 1992 to 2023,” Scientific Data, vol. 12, no. 143, pp. 1–15, 2025. doi: 10.1038/s41597-025-05246-8.

[6] X. Chen, S. Xu, Q. Zhang, et al., “Global annual simulated VIIRS nighttime light dataset (SVNL) from 1992 to 2023,” Scientific Data, vol. 11, no. 567, pp. 1–14, 2024. doi: 10.1038/s41597-024-04228-6.

[7] T. Balafoutis, “Light Pollution Beyond the Visible: Insights from People’s Perceptions,” *Urban Science*, vol. 9, no. 7, pp. 251, 2025. doi: 10.3390/urbansci9070251.

[8] C. C. M. Kyba, F. Falchi, et al., “Rapid Brightening of Night Skies Globally: Recent Results from Citizen Science,” *Astronomy & Astrophysics Review*, vol. 31, pp. 1–25, 2023. doi: 10.1007/s00159-023-00139-0.