Dark Sky Protection for Space Sustainability and Space Exploration

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Increased levels of artificial light at night (ALAN) have resulted in ground-based light pollution. The disappearance of the natural dark sky impacts various domains, including astronomy, environment, biodiversity, human health, energy efficiency, and climate. Concurrently, the recent influx of satellites into Earth's orbit compounds the issue, by introducing orbital light pollution and further compromising night-time visibility. This article briefly introduces the issue of light pollution and discusses the relationship between dark sky protection, the space environment, and the realm of space exploration. Recognizing the growing significance of preserving dark skies for different fields, the paper elucidates the important role of dark sky protection in ensuring space sustainability.

Keywords: dark sky protection, dark and quiet skies, light pollution, space sustainability, space environment.

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Introduction

Over the past decades, research has evident the adverse impacts of ground-based light pollution, ranging from the creation of obstacles for astronomical observations to negative effects on ecosystems, habitats, biodiversity, and human health (Rodrigo-Comino et al., 2023; Falchi et al., 2023b). This issue has recently been escalated by orbital light pollution created by a growing number of satellites in Earth's orbit (Falchi et al., 2023b). The increased brightness of the night sky, resulting from the interplay of ground-based and orbital light pollution, poses additional challenges, necessitating prompt action to preserve dark skies in both natural and space environments.

While the problem of ground-based light pollution has started to gain due attention in legal and political agendas, with several international and national regulatory frameworks

adopting mitigation measures (Schroer et al., 2020; Yakushinaб 2022), orbital light pollution has only begun to receive recognition, and comprehensive regulatory measures are yet to be implemented. Therefore, drawing attention to the need to protect dark skies as an integral part of space sustainability is crucial for the prevention of further adverse consequences.

This article consists of six sections. The first section provides a brief introduction to the issue of light pollution by giving a light pollution definition and discussing its forms, sources, and impacts. The second section probes into the triggers which led to the adoption of light pollution regulations. The third section provides the results of my research on approaches to light pollution regulations worldwide. This section introduces the main areas where such regulations can be found. Section four discusses issues related to space sustainability and the protection of the space environment. The fifth section brings the value of the protection of the dark skies to the realm of space sustainability and future space exploration. Finally, the sixth section consolidates key insights, offering conclusive remarks and recommendations.

1. Light pollution: definition, forms, sources & impacts

Despite a lack of a uniform definition of light pollution, it can be defined as an environmental problem caused by increased, unwanted and misdirected artificial light at night (ALAN).

The commonly accepted forms of light pollution are:

1. *Light clutter*: bright and excessive groupings of light sources.
2. *Sky glow*: brightening of the night sky over inhabited areas.
3. *Light trespass*: light falling where it is not intended or needed.
4. *Glare*: excessive brightness which causes visual discomfort.

1.1. Sources of Light Pollution

Light pollution is caused by different sources of ALAN:

- *Outdoor lighting installations*, including streetlights, sports lighting, road lighting, advertisements, security lights, floodlights, etc.
- *Indoor lighting installations*, such as indoor illumination of glass offices or commercial buildings.
- *Satellites and mega-constellations of satellites*.

1.2. Light Pollution Impacts

Light pollution is a concern on many fronts, including:

1. *Dark skies*. Increased nighttime brightness creates obstacles for amateur and professional astronomical observations.
2. *Habitats*. Light pollution contributes to habitat fragmentation and can pose challenges for species' migration (Ditmer et al., 2021).
3. *Biodiversity*. While different species exhibit varied responses to increased nighttime illumination, light pollution has a significant impact on a diverse range of flora and fauna (European, 2023; Karan et al., 2023).
4. *Climate change and energy efficiency*. The use of ALAN contributes approximately to more than 38 TWh of energy use annually (Sánchez de Miguel, 2015; Sánchez de Miguel et al., 2021; Sánchez de Miguel et al., 2022).

5. *Human health*. Extended exposure to ALAN can result in both physical and mental health disorders in humans (Cupertino et al., 2023).
6. *Public and road safety*. Contrary to the common perception that ALAN enhances public and road safety, increased nighttime illumination has, in certain instances, been shown to either reduce safety levels or exhibit an inconclusive correlation (Fotios et al., 2021; Tompson et al., 2023). Nevertheless, the presence of ALAN does play a notable role in diminishing of "fear of crime" – the subjective sense of safety (Son et al., 2023).
7. *Culture and human rights*. The presence of dark skies always played a crucial role in shaping societies worldwide. Even now, numerous indigenous communities rely on dark skies for their cultural and traditional activities. Increased light pollution levels pose major hindrances to the performance of such activities (Hamacher, et al., 2020).

2. Triggers for Light Pollution Regulations

The analysis of regulatory approaches to light pollution mitigation worldwide has revealed that three main triggers have prompted the adoption of such measures:

(1) energy efficiency concerns;
(2) environmental concerns;
and (3) the need for the protection of astronomical observations and future space exploration.

From the beginning of the 2022 energy crisis, numerous national and local governments implemented measures aimed at the reduction of outdoor ALAN for energy-saving purposes. Research indicates that over 600 local governments in Europe have implemented ALAN-reduction measures, including complete nighttime lighting switch-offs and/or curfews (Nachtabschaltung, 2023).

Another reason to adopt regulatory measures to address light pollution is environmental concerns associated with increased ALAN levels. These impacts were identified within a substantial body of research conducted in recent decades. Light pollution mitigation measures have become an integral part of environmental protection efforts in many countries (Croatian, 2019; Slovenian, 2007; German, 2021).

Finally, the necessity of ensuring astronomical observations for scientific purposes and future space exploration has also prompted national governments to take measures to reduce light pollution. Several countries have enacted laws aimed at protecting dark skies above major observatories (Spanish, 1988).

3. Legal Approaches to the Protection of Dark Skies

Light pollution is a complex phenomenon, and its consequences, as mentioned earlier, have wide-ranging adverse impacts across various domains. This complexity, in turn, creates difficulties in identifying legal and regulatory frameworks applicable to mitigating light pollution. The table below outlines the primary regulatory areas, which encompass measures for addressing and mitigating ALAN-related impacts adopted in different jurisdictions.

Table 1. Legal Approaches to Dark Sky Protection: Areas.

Area of implementation	ALAN-related Measures
Energy efficiency	Reduction of ALAN to save energy
Urban planning	The amount of light is indicated per urban zone (residential, commercial, etc.)
Environmental protection	Light pollution is recognised as an environmental pollution
Protection of astronomical observations	Established dark zones to protect the needed conditions for astronomical observation
Public procurement	Minimizing light emissions for future projects
Protection of indigenous communities	Protection of dark skies to allow traditional activities
Cultural heritage	Dark sky is considered the common heritage of humankind
Space sustainability	Impacts from space objects and space debris on dark skies should be reduced and mitigated
Dark sky protection and/or light pollution mitigation regulations	Specifically address various impacts of light pollution and impose measures for ALAN reduction

4. Space Sustainability and Protection of the Space Environment

Similar to light pollution, there is no universally accepted definition of space sustainability. The Secure World Foundation (SWF) defines space sustainability as the ability of all humanity to continue to use outer space for peaceful purposes and socioeconomic benefit over the long term (Secure, 2018). This definition includes the following aspects of sustainability:

SPACE DEBRIS

SPACE WEATHER

RADIO FREQUENCY

INTERFERENCE

The provided definition, however, lacks specific consideration of environmental concerns associated with space activities. Expanding on this, the concept of space sustainability can also be examined through the framework of "sustainability," derived from the principles of "sustainable development" endorsed by the United Nations (UN) (Transforming, 2015). The latter encompasses three primary dimensions: social, economic, and environmental. In this context, a more comprehensive interpretation of space sustainability will include:

- Social development: scientific research and astronomical observations
- Economic development: future space exploration
- Environmental protection: protection of both outer space and Earth's natural environment.

Table 2. Interplay between Ground-Based and Orbital Light Pollution.

Ground-Based Light Pollution	Orbital Light Pollution
Disappearance of dark skies	Disappearance of dark skies: illumination and space debris
Inability to explore outer space and obstacles for astronomical observations	Disruption of astronomical observations
Environmental impacts	Additional environmental impacts on the Earth's natural environment
Reduction of proper guidance and management of space objects	Impacts on the outer space environment

Value of Dark Skies for Space Sustainability and Future Space Exploration

Incorporating additional considerations, such as the protection of dark skies, into the framework of space sustainability will result in:

- Overall improvement of space sustainability and advancement of the space sector
- Cultivation of a healthier outer space environment (protection of the space environment)
- Preservation of Earth's natural environment
- Unrestricted opportunities for conducting astronomical observations and space exploration (scientific research, as well as the management and guidance of space objects)

Conclusions

This article has provided a brief overview of the issue of light pollution and contributed to a discussion on incorporating the protection of dark skies into the context of space sustainability. The research indicates a pressing need for the ongoing development of regulations aimed at mitigating both ground-based and orbital light pollution. To facilitate the implementation of protective measures and enhance the sustainability of space activities, it is essential to consider space as an integral component of the natural environment. This approach enables the application of environmental regulations to current and potential challenges. Legal recognition of light pollution as an environmental concern is crucial for implementing more stringent measures to reduce its impact.

Particular attention should be directed towards addressing issues related to orbital light pollution, which currently lacks adequate regulatory attention. Addressing this problem involves the mandatory inclusion of impact assessments for satellites and mega-constellations, considering potential impacts from reflective surfaces, such as solar panels. Additionally, new technological requirements for satellites and space objects must be introduced to minimize their impact on the visibility of dark skies (Gaston et al., 2023).

Furthermore, addressing light pollution issues requires comprehensive awareness campaigns and the involvement of various stakeholders from research, industry, and policymaking. Collaborative efforts are essential to bring about the necessary changes in practices and policies related to light pollution and ensure future space sustainability.

🕮 References

Croatian Law on Protection against Light Pollution NN 14/19 (2019) Zakon o zaštiti od svjetlosnog onečišćenja. Available online: https://www.zakon.hr/z/496/Zakon-o-za%C5%A1titi-od-svjetlosnog-one%C4%8Di%C5%A1%C4%87enja

Cupertino, M.D.C., Guimarães B.T., Pimenta J.F.G., Almeida L.V.L.D., et al. (2023) Light Pollution: a systematic review about the impacts of artificial light on human health, *Biological Rhythm Research*, Volume 54. Issue 3, 263-275. https://doi.org/10.1080/09291016.2022.2151763

Ditmer, M. A., Stoner D. C., and Carter N. H. (2021) Estimating the loss and fragmentation of dark environments in mammal ranges from light pollution. *Biological Conservation*, Volume 257, 109135. https://doi.org/10.1016/j.biocon.2021.109135

European Commission, Directorate-General for Environment, Light pollution – Mitigation measures for environmental protection (2023) Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2779/906521

Falchi, F., Ramos F., Bará S., Sanhueza P., Arancibia M.J., Damke G., and Cinzano P. (2023a) Light pollution indicators for all the major astronomical observatories. *Monthly Notices of the Royal Astronomical Society*, Volume 519, Issue 1, 26–33. https://doi.org/10.1093/mnras/stac2929

Falchi, F., Bará, S., Cinzano, P. et al. (2023b) A call for scientists to halt the spoiling of the night sky with artificial light and satellites. *Nat Astron*. Volume 7, 237–239. https://doi.org/10.1038/s41550-022-01864-z

Fotios, S. A.; Robbins, C. J. and Farrall, S. (2021) The Effect of Lighting on Crime Counts. *Energies*. Volume 14, 4099. https://doi.org/10.3390/en14144099

Gaston, K. J., Anderson K., Shutler J. D., Brewin R. J. W., and Yan X. (2023) Environmental impacts of increasing numbers of artificial space objects. *Front Ecol Environ*. Volume 21(6), 289–296. https://doi.org/10.1002/fee.2624

German Federal Nature Conservation Act (amendments of 2021) *Gesetz über Naturschutz und Landschaftspflege*. Available online: https://www.gesetze-im-internet.de/bnatschg_2009/

Hamacher, D. W., Napoli, K. D., and Mott, B. (2020) Whitening the Sky: light pollution as a form of cultural genocide. arXiv: Popular Physics.

Karan, S, Shweta Saraswat and B. S. Anusha (2023) Light pollution and the impacts on biodiversity: the dark side of light. Biodiversity. Volume 24. Issue 4, 194-199, https://doi.org/10.1080/14888386.2023.2244920

Nachtabschaltung von Straßenbeleuchutung (2023) Hessisches Netzwerk gegen Lichtverschmutzung. Available online: https://www.lichtverschmutzung-hessen.de/Nachtabschaltung

Rodrigo-Comino, J., Seeling, S., Seeger, M. K., and Ries, J. B. (2023) Light pollution: A review of the scientific literature. *The Anthropocene Review*. Volume 10(2), 367-392. https://doi.org/10.1177/20530196211051209

Sánchez de Miguel, A. (2015) Spatial, Temporal and Spectral Variation of Light Pollution and its Sources: Methodology and Results. Available online: https://zenodo.org/records/1289933

Sánchez de Miguel, A., Bennie, J., Rosenfeld, E., Dzurjak, S., & Gaston, K. J. (2022) Environmental risks from artificial nighttime lighting widespread and increasing across Europe. *Science advances*. Volume 8(37). https://doi.org/10.1126/sciadv.abl6891

Sánchez de Miguel, A. Bennie J. Rosenfeld E., Dzurjak S., Gaston K. J. (2021) First Estimation of Global Trends in Nocturnal Power Emissions Reveals Acceleration of Light Pollution. *Remote Sens*. Volume 13, 3311. https://doi.org/10.3390/rs13163311

Schroer, S., Huggins B.J., Azam C., and Hölker F. (2020) Working with Inadequate Tools: Legislative Shortcomings in Protection against Ecological Effects of Artificial Light at Night. *Sustainability*. Volume 12, 2551. https://doi.org/10.3390/su12062551

Secure World Foundation. (2018) Space Sustainability. Practical Guide. Available online: https://swfound.org/media/206407/swf_space_sustainability_booklet_2018_web.pdf

Slovenian Regulation on limit values of light pollution of the environment (2007) *Uredba o mejnih vrednostih svetlobnega onesnaževanja okolja*. Available online: http://www.pisrs.si/Pis.web/pregledPredpisa?id=URED4520

Son, D., Hyeon T., Park Y., and Kim S.-N. (2023) Analysis of the relationship between nighttime illuminance and fear of crime using a quasi-controlled experiment with recorded virtual reality. *Cities*. Volume 134, 104184. https://doi.org/10.1016/j.cities.2022.104184

Spanish Law on Protection of the Astronomical Quality of the Observatories of the Institute of Astrophysics of the Canary Islands (1988) *Ley 31/1988, de 31 de octubre, sobre Protección de la Calidad Astronómica de los Observatorios del Instituto de Astrofísica de Canarias*. Available online: https://www.boe.es/eli/es/l/1988/10/31/31

Tompson, L., Steinbach, R., Johnson, S.D. et al. (2023) Absence of Street Lighting May Prevent Vehicle Crime, but Spatial and Temporal Displacement Remains a Concern. *Journal of Quantitative Criminology*. Volume 39, 603–623. https://doi.org/10.1007/s10940-022-09539-8

Transforming our world: the 2030 Agenda for Sustainable Development (2015) UN General Assembly, A/RES/70/1. Available online: https://sdgs.un.org/2030agenda

Yakushina, Y. (2022) The response of the Bonn Convention on Migratory Species to light pollution. IOP Conf. Ser.: Earth Environ. Sci. 1099 012048. https://doi.org/10.1088/1755-1315/1099/1/012048