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Research article

Light pollution regulations and where to find them

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ABSTRACT

The growing concerns about the adverse impacts of light pollution on astronomy, the environment, biodiversity, human health, and energy use have brought increased attention to the issue on legal and political agendas. Various international frameworks and governments at different levels have taken action to mitigate the impacts of nighttime lighting. This article provides an overview of regulatory instruments adopted to protect the nocturnal environment, explaining triggers for regulatory changes, using an interdisciplinary perspective. It proposes a classification of these instruments based on their nature: (1) law or policy, (2) binding or non-binding, and by their (3) levels and (4) areas of implementation, supported by specific examples. The article identifies current shortcomings and recommends future regulatory changes to address light pollution effectively. This interdisciplinary research aims to provide a better understanding of light pollution as an environmental concern and explains the development of light pollution regulations, helping to foster interdisciplinary communication and the adoption of more adequate regulatory measures to address light pollution. Additionally, this study intends to fill the gap in legal and policy research related to light pollution.

1. Introduction

Issues related to light pollution are widely discussed in the academic literature, particularly concerning its adverse impacts. The matter of legal regulation, however, has not received sufficient consideration. Studies on the regulatory framework for addressing increased levels of artificial light at night (ALAN) encompass the assessment of measures adopted in specific jurisdictions, discussions on more effective ways to tackle the issue, considerations of dark sky protection for astronomical activities, and analyses within national contexts (Ploetz, 2002; Zitelli et al., 2001; Morgan-Taylor, 2006; Schroer et al., 2019; Barentine, 2020; Morgan-Taylor, 2023).

Recently, the issue of light pollution has increasingly been brought onto the political agenda, with many countries contemplating the adoption of laws and policies or funding research to provide a sufficient scientific basis for appropriate actions. At present, the overall picture of the regulatory framework in this area remains unclear, although it is known that some individual countries or international conventions are undertaking separate, uncoordinated actions aimed at reducing certain impacts of ALAN.

The regulatory framework against light pollution started to evolve in the second half of the previous century (Nightscape, 2013). The first legislation to protect the nocturnal environment was adopted in Flagstaff, Arizona, USA, in 1958. Initially, measures against light pollution aimed at providing the minimum necessary conditions for astronomical activities and maximizing energy efficiency (City of Livingston, 2006; Portree, 2002). At the dawn of the new century, influenced by the rapid increase of ALAN levels, additional issues started to emerge, leading to a noticeable deterioration in the state of natural darkness. This has contributed, inter alia to a rapid decline in biodiversity. These new problems became a call for action to amend the existing regulatory instruments governing outdoor lighting. The emergence and recognition of a broad range of impacts induced by a new anthropogenic stressor – ALAN, particularly ecological concerns, determine the necessity to identify current shortcomings and gaps for future regulatory improvements, thereby highlighting the relevance of this research.

This article provides a comprehensive overview of the current state of regulation aimed at tackling light pollution and its impacts and proposes a classification of various regulatory instruments. This classification is intended to assist researchers, professionals, policy-, law- and decision-makers in identifying relevant provisions and measures applicable to the problem, potentially enabling them to assess their effectiveness. Due to an absence of a uniform definition, light pollution is defined as an environmental problem caused by increased, unwanted and misdirected ALAN (Yakushina, 2023). Based on sources, light pollution is classified into ground-based light pollution, which stems from outdoor ALAN sources, and orbital light pollution, caused by satellites, space objects, and debris. This research primarily focuses on provisions related to ground-based light pollution, with a brief

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Abbreviations

ALAN	Artificial light at night
LED	Light-emitting diode
ULOR	Upward light output ratio

discussion of instruments concerning space-related issues. Additionally, to provide a comprehensive overview of the regulatory landscape, this article analyses a wide array of instruments. For the purposes of this study, instruments are defined as rules, regulations, standards, recommendations, or procedures intended to regulate the conduct of individuals, businesses, or government agencies (Garner, 2019).

The structure of this paper is as follows. Firstly, triggers driving the development of the light pollution regulatory framework were identified and discussed. The subsequent section provides a detailed classification of existing regulatory instruments adopted to mitigate light pollution and its impacts, supported by examples from various jurisdictions. The concluding section discusses current regulatory shortcomings and proposes recommendations for amendments and future research.

2. Data & methods

This research was preceded by the collection and analysis of various regulatory instruments aimed at mitigating light pollution. The current study builds on previous work conducted under the International Astronomical Union Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (IAU CPS) Policy Hub national analysis project, which focused on the protection of dark skies for astronomical observations (Yakushina et al., in press).

The project included an analysis of regulatory frameworks from over 70 countries worldwide, encompassing laws and policies related to space, the environment, energy, and other relevant areas. To provide a more comprehensive understanding and identify additional regulatory instruments, the scope of the current study was expanded to include different regulatory levels and a broader spectrum of light pollution impacts, beyond those limited to astronomy. To achieve this, a classification of instruments has been developed based on fundamental theories of state and law, including the nature of regulatory instruments, policy and law decisions, the existence of regulatory areas, and the subject matter of regulation (Denisov, 1987; Kelsen, 1991; Baldwin et al., 2011; Kramer, 2015). Such classification is considered essential to effectively tackle both existing and emerging environmental problems (Keohane, 1998; Baldwin et al., 2011).

Key research questions of this study include (1) Why did light pollution regulatory instruments start to be adopted in various jurisdictions and levels? and (2) What instruments are relevant to address the problem, and where can these instruments be found?

The methodology includes an interdisciplinary approach, particularly to understand the impacts of ALAN as examined in other scientific fields, thereby demonstrating the need for regulatory improvements. Additionally, the research utilises doctrinal methods to identify and assess regulatory instruments and their legal foundations. It also includes a case study analysis for a detailed examination of specific instances of light pollution regulation and a literature review to support and contextualise the findings and conclusions. This methodology enables the study to provide a robust and nuanced understanding of light pollution regulation across different jurisdictions and levels, facilitating a comprehensive assessment of the adopted measures.

3. Triggers driving the development of the regulatory framework

The development of the regulatory framework for light pollution mitigation was induced by emerging political attention to the issue, triggered by four main drivers: scientific research, energy consumption, astronomical observations, and light pollution mitigation initiatives.

3.1. Research findings

One of the main triggers that prompted the development of a light pollution mitigation framework is scientific research, mainly studies on the environmental impacts of nighttime lighting.

Throughout history, people have seen ALAN as a symbol of development and prosperity, which rapidly became an invisible force for providing willing comfort and public safety. The widespread acceptance of ALAN caused it to fade from people's consciousness, fostering the perception that lighting is an integral part of the night (Holden, 1992). While the important role of ALAN cannot be diminished, the rapid proliferation of lighting sources has led to light pollution.

Light pollution experiences a dramatic annual increase of approximately 10% depending on the region (Kyba et al., 2023), thereby causing the disappearance of the nocturnal environment globally. It is estimated that due to a widespread transition from old light technologies, such as fluorescent lamps to light-emitting diode (LED) technology, light pollution has increased globally between 270% and 400% (Bennie et al., 2020). The new world atlas of artificial night sky brightness (Falchi et al., 2016) shows that 99% of the population of Europe and the United States live in light-polluted skies. It also demonstrates that light pollution is a transboundary international problem compounded by the spread of bright light radiation from the territory of one country to another.

A growing number of studies indicate that increased light pollution has numerous adverse impacts, inter alia, obstacles for astronomical observations, deterioration of health, increased energy consumption, contribution to climate change, impacts on cultural activities and Indigenous communities, and public and road safety. Yet, the most significant pressure is exerted on the environment, biodiversity, and human health, making it a major environmental concern.

Medical research shows that systematic disturbance of circadian rhythms due to prolonged exposure to excessive nighttime lighting, especially emitted from white or blue LEDs, can lead to physical and mental disorders, such as hormone-dependent cancer, obesity, allergies, diabetes, mood-changing and depression (Deprato et al., 2024; Zielinska-Dabkowska et al., 2023; Helbich et al., 2020). Light pollution can also cause alterations in daily life and social behaviours through changes in sleep states (Wang et al., 2023).

The negative ecological effects of light pollution are also well-evidenced. Nighttime illumination poses a severe threat to the environment as a whole, major habitats (terrestrial, aquatic, and aerial), including protected areas, and all levels of biodiversity from genes to ecosystems and their services (Hölker et al., 2010; Gaston et al., 2013; Davies et al., 2014; Sordello et al., 2022). The normal functioning of the environment and ecosystems strongly depends on the natural day and night cycle. Both diurnal and nocturnal environmental conditions, each representing approximately equal percentage within the 24-day cycle, are essential for the physiology and ecology of species. Therefore, any alterations in the cycle will be notable for every living organism (Falcón et al., 2020; Hirt et al., 2023). Research indicates that light pollution affects different species of flora and fauna (Barentine, 2023). Light pollution impacts biological activities, such as finding food (Tidau et al., 2022); reproduction (Li et al., 2022); flowering (Czaja and Kołton, 2022); migration (Burt and Kelly, 2023) and communication activities (Nakamura-Garcia and Ríos-Chelén, 2022); predator-prey relationships (Tougeron and Sanders, 2023); and species' movements (Owens and Lewis, 2022). For instance, the brightening of the natural dark environment in aquatic ecosystems adversely impacts the behaviours of marine organisms and causes avoidance behaviour (Li et al., 2022). More specifically, ALAN spectral composition affects activity patterns and feeding behaviour of beach amphipods and isopods

(Quintanilla-Ahumada et al., 2024a,b). Another study emphasizes that ALAN is a major driver of insect decline since the attracted insects die from exhaustion or predation (Owens et al., 2019). A recent global meta-analysis revealed that insect communities tend to be more active during nighttime rather than during the day, hence highlighting the urgent need to reduce light pollution due to its impacts on insects (Wong and Didham, 2024). Beyond that, light pollution can disrupt ecosystems and is also known as a cause of habitat fragmentation (Le Tallec et al., 2024). Particularly, in Madagascar, light pollution contributes to a growing localization of mouse lemurs to smaller and isolated forest patches. Another study suggests that light pollution created the fragmentation of many mammal ranges, causing isolated dark areas, specifically affecting species exhibiting light avoidance behaviour (Ditmer et al., 2021).

Despite that in some cases there is a lack of scientific certainty regarding the environmental impacts of light pollution, for instance, how light pollution might specifically impact different species or what are the precise adverse effects of prolonged ALAN exposure, the studies have not gone unnoticed. Some countries considered research results sufficient to take precautions and have adopted light pollution mitigation regulatory measures to protect the nocturnal environment, thereby enhancing nature conservation efforts (Australia, France, and Germany). The integration of research findings into the national framework mainly happened in two ways: (1) the enactment of light pollution laws that specifically target various ALAN impacts, including environmental effects; or (2) the amendment of existing environmental laws through inclusion measures addressing artificial light as a new environmental stressor. In some cases, even a total lack of provisions against light pollution does not become an obstacle to taking precautions to reduce potential pressure from nighttime lighting on the environment. In Belgium, for instance, the Flemish administrative court cancelled the permit for lighting installations on a bicycle path in connection with the failure to perform an adequate and appropriate impact assessment of ALAN prior to its installation (Flemish Administrative Court, 2022).

The international community also did not stand aside from highlighting the need to take joint action to reduce increased levels of ALAN for environmental protection. The Convention on the Conservation of Migratory Species of Wild Animals (CMS; Convention on Migratory Species) is one of the most important examples and a major actor in addressing the adverse impacts of ALAN among the United Nations Environmental Programme (UNEP) (Yakushina, 2022). The first State of the World's Migratory Species Report, adopted at the CMS 14th Conference of the Parties (COP) on February 12, 2024 (UNEP-WCMC, 2024), mentions light pollution among key drivers of migratory species decline: "Pollution, including pesticides, plastics, heavy metals and excess nutrients, as well as underwater noise and *light pollution*, represents a further source of pressure facing many species."

3.2. Energy consumption

The presence of nighttime illumination is intrinsically linked to energy consumption, particularly in the context of electrical light. A series of events at the end of the 19th century marked the advent and dissemination of electrical ALAN. The turning point was in 1882 when Thomas Edison presented his electric light bulb together with the system of power generation and its distribution (Hargadon and Douglas, 2001). Subsequently, electrical lighting commenced its universal spread, reaching its peak during the 1950s (Guarnieri, 2015; Guarnieri, 2018).

Initially, energy consumption and its efficient usage were never the issue. However, a significant paradigm shift, greatly influenced by concerns over climate change (Boyle, 1989), led to alterations in the use of technologies. The latter equally affected ALAN and resulted in a gradual replacement of old, lighting, such as incandescent and fluorescent lamps, with more energy-efficient, such as LED (Sánchez de Miguel et al., 2022). Studies estimate that ALAN accounts for 3–15% of global electricity consumption, varying depending on the country and the artificial light source, thereby constituting approximately 1–5% of worldwide greenhouse gas (GHG) emissions (DarkSky International, 2022; US Department of Energy; Economist Impact, 2023; Gaston and Sánchez de Miguel, 2022). For the USA, DarkSky International suggests (DarkSky International, 2023) that unnecessary and unwanted nighttime illumination leads to 60 billion kilowatt hours (kWh) of energy loss, equating to more than $6.3 billion and 21 million tons of carbon dioxide per year. For the European Union (EU), street lighting can account for between 30 and 50% of the total electricity consumption in municipalities (IEE Project Output, 2015). To reduce these negative impacts, LED was and remains to be considered the optimal technology, as according to some estimations, it allows for saving over 50% of energy usage (Balázs et al., 2023; US Department of Energy, 2019).

Concerns about the energy consumption of lighting and the need for a widespread propagation of more energy-efficient light formed the basis for the further adopted policies, regulations, and standards (Wu et al., 2018). At the international agenda, the transition to more energy-efficient lighting is viewed as one of the most effective strategies to reduce GHG emissions significantly and to facilitate achieving the ambitious climate change targets by 2030 (UNEP, 2017). The current goal is to double the global average annual rate of energy efficiency improvements from around 2% to over 4% every year until 2030 (UN, 2015, UNFCCC, 2023). The UNEP and United for Efficiency (U4E) report *"Accelerating the Global Adoption of Energy-Efficient Lighting"* offered policy recommendations, indicating the need for a market shift towards LED technology. The report states that LEDs have the potential to generate high-quality white light with unparalleled energy efficiency and financial savings.

The European Union followed international action and implemented measures to improve the energy efficiency of lighting, as reflected in various policy and legal documents. The EU has a comprehensive regulatory framework, encompassing, ecodesign, energy labelling, technical standards, and other relevant norms for different lighting sources. The Union put the principle of 'energy efficiency first' at the forefront of its energy policy. The recently revised *Energy Efficiency Directive (EU/2023/1791)* significantly heightened the ambition for energy efficiency and provided for an obligation to target the final energy consumption of all public services and installations, including public lighting (Directive (EU) 2023/1791). As for ecodesign and energy labelling, these regulations were also recently amended to provide clearer information to the consumers, regarding energy efficiency class and energy consumption of the light source (Commission Regulation (EU) 2019/2020). Additionally, the existing EU regulatory framework pushes for the transition to LED technology, aiming not just to decrease energy usage but also to introduce cleaner and more circular electronics into the market (Directive, 2011/65/EU; EU Commission, 2021). Similar provisions are implemented at the national and local levels.

Subsequent regulatory advancements aimed at reducing energy consumption from ALAN were adopted in response to the energy crisis that started in 2022 (Farghali et al., 2023). During this period, the measures primarily targeted public outdoor ALAN and were predominantly enacted by municipalities to save local budgets due to increased energy prices. Over 600 local governments in Europe have imposed reduction measures (LUCI Association, Hessian Network), among which the most adopted were complete shutdown, partial shutdown (curfews) or light dimming (City Council of Ghent, Belgium, 2023). Despite the positive effect on energy usage, the measures were not always well-received by the local population. In some places, the complete switch of lighting triggered the feeling of insecurity among residents, leading to an increased number of complaints requesting to switch ALAN back on (De Standaard, 2023; Politico, 2022). Conversely, in other municipalities, the situation was reversed, with citizens supporting the measures and expressing appreciation for the return of dark skies (VRT NWS, 2022; De Morgen, 2022; Hvass, 2024).

Undoubtedly, concerns about energy consumption have led to many positive outcomes. The focus on ALAN's energy efficiency could be a

double-edged sword, mainly due to conflicts that may arise between energy reduction and environmental protection measures. Particularly, the gradual transition to LEDs has brought additional pressure on the environment and further increased light pollution levels worldwide. Unfortunately, the technological choice mainly falls on highly bright LEDs of the blue and white colour spectrum, which is known for its detrimental effects (Gaston and Sánchez de Miguel, 2022). Furthermore, LEDs pose challenges for measuring light pollution using remote-sensing data, as they produce emissions at wavelengths that are undetectable to existing satellite sensors. This decreases the ability to accurately assess the real picture of global light pollution trends. Additionally, some studies suggest that the shift to LEDs, in reality, resulted in a rise in GHG emissions and energy consumption rather than their reduction. This phenomenon is explained by Jevon's paradox (Sánchez de Miguel et al., 2022), whereby more cost-effective and affordable ALAN has spurred greater demand for lighting. Consequently, any gains in efficiency have been negated by the increased consumption of artificial light. Therefore, the regulatory framework for light pollution reduction should not only consider impacts on energy consumption but also take into account other potential adverse effects it may entail. Strengthening the connectivity between different measures and integrating environmental considerations into diverse regulatory frameworks, is necessary to combat rapid environmental degradation and reduce biodiversity decline (TFEU, 2007).

3.3. Astronomy

The astronomical community was the first to raise the problem of light pollution. Back in the 1950s, astronomers began to experience obstacles in carrying out astronomical observations (Riegel, 1973). Due to the active actions of astronomers, the first legislation to protect astronomy from ALAN interference was adopted in Flagstaff, Arizona (USA) in 1958 (Dark-Sky International, 2013; Portree, 2002; Brown, 1998). Another significant example of the legal protection of dark skies for astronomical observations was the adoption of the Spanish Sky Law – formally known as the *Law for the Protection of the Astronomical Quality of the Observatories of the Institute of Astrophysics of the Canary Islands* - in 1988 (Spain, 1988). This law established a protection regime that restricts outdoor lighting emissions across the islands. Besides Spain, several other countries recognise the important cultural, historical, or scientific role of astronomy without adopting a separate law to protect dark skies. Countries such as the Russian Federation, the USA and Canada exemplify this approach. Russian and American urban planning legislation provides for the possibility of establishing dark and/or quiet protection zones around major observatories, within which light, radio, noise, and other emissions could be limited (Council of People's Commissioners of the USSR, 1945; Scientific Council of the Russian Academy of Sciences, 2015; FCC, 1958). In Canada, several municipalities, such as Saanich in British Columbia, have adopted bylaws that include various light pollution requirements to protect astronomical observations (Saanich, British Columbia, 2006). Unfortunately, the trend of developing regulatory measures to protect dark skies for astronomical activities did not receive global support, and problems with night sky visibility have not ceased its relevance.

Furthermore, the problem has only been exacerbated, leading to the resumption of discussions on the need to protect astronomy on the regulatory agenda. In recent years, ground-based light pollution stemming from ALAN sources has been accelerated by orbital light pollution, caused by the proliferation of satellites in Low Earth Orbit (LEO), adding further disruption to astronomical activities. The latter strengthened the movement of the astronomical community to lobby for regulatory changes (Rotola and Williams, 2021). A significant achievement was made in 2023 when the issue related to the protection of dark skies from satellite interference was raised as an agenda item for future discussions at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) (UNCOPUOS, 2023). This achievement highlights growing political attention to light pollution, making the astronomical community one of the key actors in developing light pollution regulations, benefiting other areas, such as nature conservation. Research estimates that enhancing environmental protection includes not only mitigation of ground-based light pollution but also addressing orbital light pollution. The rapid movement of satellites can potentially adversely affect the orientation and migration of different organisms, underscoring the need to tackle this form of light pollution as well (Gaston et al., 2023).

3.4. Activist groups and initiatives

The crucial role in the process of the formation of the regulatory framework for addressing light pollution is played by activist groups and initiatives.

Two major international organisations, which bring light pollution to the global political agenda and raise awareness about this issue globally, are the IAU CPS and DarkSky International. IAU CPS is working towards protecting dark and quiet skies for astronomical observations from adverse interference, such as orbital light pollution. In the first recommendation paper *"Call to Protect Dark and Quiet Sky from Harmful Interference by Satellite Constellations"*, IAU CPS raises the value of astronomy for society, explains growing concern about orbital light pollution, and encourages satellite industry, international bodies and national governments to implement mitigation measures, such as reduction of brightness, data sharing and suppression measures (IAU CPS, 2024). The recommendations outlined also include legal measures, notably, considering the possibility of implementing international environmental law and principles to protect astronomical observations and reduce the impacts of satellites on the Earth's environment. The efforts of the group significantly contributed to the inclusion of dark sky protection on the subsequent agendas of the COPOUS meetings.

DarkSky International (DarkSky) looks at light pollution from a broader point of view, covering the need to protect the nocturnal environment from all negative ALAN-induced impacts. Besides well-established outreach and advocacy activities, DarkSky actively supports legal and policy improvements. The organisation has developed a proclamation campaign to increase political attention to light pollution. A Dark Sky Proclamation is a ceremonial document, which can be signed by an authority as an official statement of support and endorsement (Dark Sky Proclamation Week, 2023). During the 2024 International Dark Sky Week, the event organised to celebrate the value of the night (International Dark Sky Week, 2023), DarkSky International collected more than 180 proclamations from different states and municipalities in the U.S. Another remarkable action was DarkSky's appeal with the US Court of Appeals for the District of Columbia of the order of the Federal Communications Commission (FCC) in the Matter of Space Exploration Holdings, LLC (SpaceX) (International Dark-Sky Association, Inc. v. FCC, 2023; FCC, 2023). The main claim regards the FCC's failure to conduct an environmental impact assessment of SpaceX's launch of a mega-constellation of satellites before giving the necessary permission, although the planned activity 'may have significant environmental effects' and such assessment was required under the National Environmental Policy Act (NEPA). This legal action has raised the issue of whether dark skies should be protected as a part of the natural environment before the court. Additionally, DarkSky together with the Illuminating Engineering Society (IES) jointly developed the Five Principles for Responsible Outdoor Lighting (International Dark-Sky Association, 2024) to prevent and reduce light pollution through the proper application of quality outdoor lighting. These principles determine that responsible ALAN encompasses: (1) light with a clear purpose; (2) light directed where it is needed; (3) lower light levels; (4) light should be used when it is needed; and (4) warmer colour of light. This approach to better lighting became a best practice and is reflected in many adopted regulatory instruments, as well as international and national standards (City of Pittsburgh, 2021a,b).

At the EU level, the achievements of the groups and initiatives aimed at legal recognition of light pollution as an environmental problem are specifically remarkable. Working closely with national governments, advocates for the protection of the nocturnal environment managed to make light pollution one of the political priorities. This is particularly evident in the agenda of the recent presidencies at the Council of the European Union (European Council) over the past few years. The first to choose light pollution as one of its priorities was the Presidency of the Czech Republic in 2022. Experts from across Europe and beyond met in Brno to discuss joint European action on light pollution, guided by a Czech Ministry of Environment working paper outlining key policy and legal acts adopted by member states (Ministry of the Environment of the Czech Republic, 2022). The major outcome of the meeting was the Brno Appeal which called the EU member states and the EU Commission to recognise the adverse impacts of ALAN and to raise a discussion on how to address light pollution at the European and national levels (Brno Appeal, 2022). Following the action of the Czech Republic, Spain also shed light on the new environmental pollutant during its Presidency in 2023 (Spanish Presidency, 2023). The international meeting on light pollution was held to again bring political attention and to further discuss the associated challenges, such as monitoring, measurements, and regulatory framework. Similar to the Brno, the major outcome of this meeting was an important document called *'Manifesto for Tackling Light Pollution and Proposing EU Light Pollution Monitoring'* (Yakushina et al., 2024). Apart from highlighting the need for recognising the issue, the Manifesto recalls the existing international and EU policy and legal documents. In particular, the Manifesto indicates that a lack of measures to reduce ALAN weakens environmental protection efforts since nature protection during the nighttime is neglected and, consequently, suggests EU include light pollution in the existing environmental regulatory framework, allowing for the achievement of the ambitious environmental goals and targets. The focus on addressing light pollution initiated by the Presidencies was followed by the Ministers of the Environment from the Visegrad Group (V4+) countries. During the minister's meeting in March 2024, it was highlighted that to reduce light pollution a change in the perception of nighttime lighting is needed, which should be subsequently supported by a technical standard at the European level (Ministry of the Environment of the Czech Republic, 2024). European groups continue to facilitate the action towards the adoption of a united approach to reduce light pollution in the EU.

The efforts of activists are especially evident at the national and local levels. Various groups and initiatives are actively involved in raising awareness of light pollution and its impacts within the country or municipality, thereby contributing to the necessary regulatory changes. There are several notable examples across jurisdictions worldwide, such as DarkSky Pittsburgh (city of Pittsburgh (PA, USA)), DarkSky Ireland (Ireland), and the Australian Dark Sky Alliance (Australia). The engagement in the dialogue with the local government allowed DarkSky Pittsburgh to facilitate the adoption of Pittsburgh's Dark Sky Lighting ordinance, aiming at minimizing light pollution for astronomical observations, human health and the environment (City of Pittsburgh, 2021b). DarkSky Ireland organises workshops and meetings with local and national government authorities to educate on the issue of light pollution and to bring the problem into the regulatory framework, for instance, to the Irish Biodiversity Strategy and Action Plan (Light Pollution Workshop, 2024). As for the Australian Dark Sky Alliance, one of the major outcomes of their work was the National Light Pollution Guidelines for Wildlife, which were developed together with the Australian Department of Climate Change, Energy, the Environment and Water (DCCEEW, 2023). These national guidelines explain the problem of increased nighttime illumination and its impacts on wildlife and propose assessment mechanisms and mitigation solutions to reduce ALAN-induced impacts. Remarkably, the guidelines were recognised by the CMS and formed the basis of the CMS's light pollution guidelines.

The individual action should be also highlighted. In 2024, in London, a resident, suffering from heightened sensitivity to ALAN, won a case against the Barnet London Borough Council (Allin, 2023). The decision imposed an obligation on the local government to replace intensive white light 4000K LED lights with warmer 2200K LED bulbs. The latter can potentially create a precedent for future court decisions and lighting regulations in the UK and beyond.

The work of the advocates and activist groups must not be underestimated. Thanks to their action, political attention is being directed towards research findings on light pollution and proposals for mitigation solutions, enabling the delivery of recommendations for the needed regulatory amendments.

4. Classification of regulatory approaches to light pollution mitigation

Over the past decade, there has been a significant increase in the adoption of measures aimed at addressing light pollution across various jurisdictions. This has led to complexity and a lack of a unified approach to tackling the issue. This section of the article provides a classification of adopted instruments to help identify existing provisions applicable to reducing the diverse ALAN impacts, and thereby help to highlight the most effective regulatory approaches and facilitate needed amendments.

4.1. Policy and law

Documents adopted to tackle light pollution primarily could be divided into laws and policies. Law and policy are interconnected and interdependent categories. This interplay is particularly evident in the role of policy in providing direction and objectives for law-making and implementation of laws. Law, in turn, serves as the enforceable framework for achieving policy goals and can also be an expression of adopted policy (Hart et al., 2012). Nevertheless, policy and law have some distinct differences as well.

A policy can be defined as a set of principles or broad guidelines, goals and priorities that inform decision-making and outline a plan of action to address specific issues, such as light pollution (Thierer et al., 2003). Policies can be adopted by an organisation, institution, or government to influence and determine all major decisions and actions. Policy documents are inherently more flexible than legal documents and can be adopted or amended without complicated legislative procedures (Ibid). Another distinction is that policy serves as a framework for law, without having the same enforceable power. This generally implies that, unlike legal norms, authorities are not able to ensure the realisation of the policy goals, particularly by imposing penalties or other sanctions since the penalty for violation is not specified (Stone, 2012). However, the limited court practice shows that the national governments can be ordered to follow and take active action towards achieving the defined policy goals and targets (Friends of the Earth v BEIS, 2022). On the other hand, law can be defined as a system of rules that governs the behaviour of individuals within a society (Hart et al., 2012). Laws are adopted by legislative bodies, such as parliaments or congresses. The main distinctive feature of the law is its legally binding nature and its consequent enforceability, which is ensured by appropriate government authorities and driven by the availability of specified penalties for non-compliance. Additionally, laws exhibit relative stability, as formal legislative processes are required to amend or repeal them (Sunstein, 1991). Thus, despite the differences, both policy and legal instruments are essential for effectively addressing emerging societal issues. Their interconnection ensures that societal objectives are well-articulated and effectively implemented through a structured and organised legal system.

The regulatory framework for light pollution mitigation includes both policy and law, with a predominance of policy documents due to the early stage of regulation in this field. On the policy side, attention to light pollution has taken three main directions: (1) promoting recognition of light pollution as a form of environmental pollution; (2) setting targets for its reduction; and (3) supporting the immediate action for reduction of ALAN levels and mitigation of its impacts. At the

international agenda, the Bonn Convention in its *Resolution 13.5* recognised ALAN as an emerging stressor for biodiversity and encouraged countries to implement solutions to reduce its impacts to meet human comfort and ensure environmental protection (UNEP/CMS/Resolution 13.5, 2020). Various countries have also included light pollution in their environmental policies. France's recent National Biodiversity Strategy indicated that light pollution will be reduced by half by 2030 (France, 2022). As one of the main reduction measures, France supports the widespread implementation of dark infrastructure and the strengthening of monitoring measures. Another notable example is Austria. In the Austrian Biodiversity Strategy 2030+ a whole section is dedicated to light pollution and its mitigation measures, including the creation of light management plans, certification system and promotion of dark sky tourism (Austria, 2022).

On the legislative front, in recent years, several countries have introduced significant legislative improvements to address light pollution directly. In 2021, Germany adopted the *Act on the Protection of Insect Diversity*, which made changes to the *Federal Nature Conservation Act*, by including measures to mitigate the adverse effects of ALAN (Germany, 2021). To enhance nature conservation efforts, the measures include, inter alia, the prohibition of the construction of new lighting on streets and paths and illuminated advertising structures in the outdoor areas in nature conservation areas. Unlike Germany, which amended its primary environmental protection law, Croatia has chosen a different path by enacting a law focused specifically on addressing light pollution. The *Law on Protection against Light Pollution* aims to safeguard the environment, human health, biodiversity, and ecosystems from the ALAN impacts (Croatia, 2019). It encompasses a wide array of mitigation measures, including the prevention of excessive light emissions and the reduction of existing lighting levels in the environment to the permissible values defined by the Croatian Ministry of Economy and Sustainable Development. A further example of the application of a special light pollution law is South Korea. The established legal regime provides for the development of the hierarchy of light pollution prevention plans at the national and local levels, which determine light pollution prevention measures with maximum permissible lighting parameters according to local particularities (South Korea, 2012). Additional examples of countries that have implemented legislative measures include Austria, France, Italy, Japan, Mexico and Spain.

When considering the legal aspects, it is important to highlight the role of existing legislation in addressing light pollution issues. Although the problem may not be explicitly mentioned in the legislation, the adverse impacts of ALAN may still be addressed by interpreting current provisions and principles, particularly those within environmental law (Macrory et al., 2013). This approach has been implemented in various court decisions. Thus, Article 6(2) of *Directive 92/43 on the Conservation of Natural Habitats and of Wild Fauna and Flora* (Habitats Directive, 1992) establishes a general obligation of the EU Member States to take appropriate steps to avoid the deterioration of natural habitats and the habitats of species as well as significant disturbance of the species (Council Directive 92/43/EEC). Referring to this, the European Court of Justice in Case C-504/14 found that Greece failed to fulfil the obligation under the mentioned article due to failing to take the appropriate measures to prevent existing street lighting from disturbing sea turtles (European Commission v Hellenic Republic, 2016).

4.2. Binding and non-binding instruments

Another way to categorise regulatory instruments for addressing light pollution is by dividing them into binding and non-binding.

Amidst the many approaches to defining the "legally binding" nature in both international and domestic contexts, this article will distinguish between binding and non-binding regulatory instruments based on their legality, formality, and enforceability (Shaffer and Pollack, 2010). In this regard, the legality of a regulatory instrument is manifested by the ability to create legal obligations. The latter is the main characteristic of binding instruments, which is consequently reinforced by their enforceability (Abbott and Snidal, 2000). Unlike non-binding instruments, such as recommendations, guidelines or resolutions, non-compliance with binding instruments can lead to the application of legal sanctions by authorised government bodies (Ebbesson, 2019). While non-compliance with non-binding instruments does not result in legal consequences, such actions may lead to political pressure or reputational damage. Recent jurisprudence, however, points to the increasing role of non-binding instruments, particularly those adopted at the international level (Peel and Paddock, 2017). On a case-by-case basis, a court could potentially refer to international documents, regardless of their nature, to stimulate the political commitments of a specific country. For instance, if a non-binding international document addresses significant risks and severe consequences for the entire international community, such as environmental concerns, it might be considered as imposing such obligations (Urgenda Foundation v State of the Netherlands, 2018). This approach can be explained by the challenging and lengthy process of adopting binding instruments at the international level, which consequently results in an inability to quickly respond to newly emerged problems. Another distinct feature of the binding instruments is their formality reflected by the formalization of legal obligation in specific sources of law, such as treaties, acts, regulations, etc (Hunter et al., 2020). Finally, binding and non-binding documents are distinguished by their decision-making body. While binding documents can be adopted by defined international or national government bodies, non-binding instruments can be adopted by a broader range of actors. These include non-governmental and professional organisations, as well as other entities and governmental bodies.

Binding and non-binding instruments both play crucial roles within the regulatory framework to address light pollution. Non-binding instruments, nevertheless, prevail, largely due to a simpler way of their adoption. Groups of experts from various fields facilitate the translation of knowledge and practices into recommendations, guidelines, and other non-binding documents. These efforts bring political attention, raise awareness, and inspire both authorised bodies to take necessary actions to address the problem, including imposing legally binding ALAN mitigation measures. They also motivate private stakeholders to change their lighting practices. The current regulatory framework for light pollution includes a significant number of non-binding instruments adopted by various actors and at various levels. Among notable examples of non-binding instruments are the *Declaration in Defence of the Night Sky and the Right to Starlight* (Starlight Declaration) (Starlight Declaration, 2007) and the *Australian National Light Pollution Guidelines for Wildlife* (DCCEEW, 2023). The Starlight Declaration was adopted in 2007 during the International Conference in Defence of the Quality of the Night Sky and the Right to Observe the Stars, which was attended by representatives of UNESCO, IAU, CMS and other major governmental and non-governmental organisations. The Declaration provides for solutions such as the promotion of dark sky tourism and recognising the right to unpolluted sky and remains one of the main efforts to express the concerns of light pollution at the international level. As for the Australian National Light Pollution Guidelines for Wildlife, this document was developed by the Western Australian Department of Biodiversity, Conservation and Attractions and aims at helping to protect Australia's threatened wildlife from ALAN-induced impacts. Subsequently, these guidelines were by the CMS (UNEP/CMS/Resolution 13.5, 2020).

Regarding binding instruments, in recent years, due to growing attention to light pollution and its impacts, an increasing number of countries have begun adopting legally binding measures. In the European region, more than 20 countries, including Austria, France, Germany, Italy, Portugal, Slovenia and Spain, have passed legislation or adopted other binding documents, such as standards, and this number continues to increase (Morgan-Taylor, 2023). To give an example, France amended the Environmental code and introduced a number of light pollution mitigation measures to reduce disturbance of people and environmental impacts (France, 2000). Failure to comply with the

requirements established by the code and related provisions may result in sanctions, ranging from a formal notice to the suspension of light sources, as imposed by the competent authority (Hart et al., 2012).

Therefore, although the importance of binding documents cannot be diminished, non-binding instruments also play a significant role, particularly given the urgency of actions required to address light pollution. Non-binding instruments can be considered as a needed form of communication with authorities and a means of transitioning towards legally binding measures within the regulatory framework. However, more binding instruments remain needed due to their enforceable power, allowing reliance on legal measures for non-compliance rather than on voluntary adherence to non-binding documents.

4.3. Levels of implementation

The next subcategory in the classification involves the division of the adopted instruments based on the territorial scope of application, namely, according to the regulatory level (Fig. 1).

According to the general theory of law, a regulatory instrument is effective within the territory over which the issuing authority has power or jurisdiction (Hart et al., 2012). The existence of authority is determined by the presence of a territory over which such authority is exercised, and vice versa (Agnew, 1994). Thus, documents adopted by government bodies at the international level apply to the territories of the countries that endorsed such documents. The development of the international regulatory framework aims at building global governance and cooperation, addressing transnational issues and facilitating the harmonization of national regulatory frameworks according to international standards (Gaeta et al., 2020). Within the vertical hierarchy of regulatory instruments, the international level is followed by the EU level, whose framework exclusively applies to the territories of EU member states. Similar to the international community, the EU adopts various regulatory instruments, such as directives, regulations and policy documents, to ensure the uniformity and compliance of the law- and policymaking of the member states with the overarching common goals and interests of the EU (Chalmers et al., 2024). As for the territories of the countries, the effectiveness of the adopted documents depends on the administrative-territorial units within which this country's authorities operate (Hart et al., 2012). Therefore, the highest regulatory level within a country is the national level, meaning the instrument will apply to the entire territory. Depending on the country's administrative structure, other levels may include federal subjects (in federations), regional, and local/municipal levels. With each level covering a different territorial scope, together all instruments adopted to address related issues form a hierarchical regulatory framework, encompassing multiple aligned documents, each targeting different aspects of the issue or area, thereby ensuring comprehensive and coordinated regulation. Even though it is hard to talk about a well-established hierarchy of light pollution norms, its foundations are slowly beginning to emerge.

At the highest regulatory level, the main argument for adopting measures derives from the understanding that light pollution is a transboundary concern which requires joint international action. For example, according to the Starlight Declaration, the protection of the nocturnal landscapes from increased ALAN levels represents *"a universal obligation for cooperation in safeguarding the quality of life"* (Starlight Declaration, 2007). Similar arguments are formulated in favour of adopting instruments at the EU level. In particular, the Czech Republic in its Brno Appeal urged EU bodies to take action against light pollution, alluding to the fact that *"light knows no borders"* and the coherence regulatory approach to its mitigation is required (Brno Appeal, 2022). At present, however, the efforts at the highest regulatory levels are very limited and characterised by fragmentation, and consequently, most of the instruments have been adopted within the individual countries.

The existence of the regulatory framework at the national level demonstrates the country's commitment to reducing light pollution in its whole territory. Given that for more effective governance, as mentioned earlier, countries are divided into administrative-territorial units, the authorities of such units typically have a broader lighting control competence rather than the national government bodies due to close proximity to the lighting sources installed in specific areas. A good example indicating the widespread of local light pollution mitigation frameworks is the existence of over 200 dark sky places designated by DarkSky International globally (Dark Sky Places, 2023). In most cases, the relevant local government body adopts a Lighting Standard, Dark Sky Ordinance or other document to ensure that the area meets the criteria for protecting the nocturnal environment from the day of establishment and over time. The world's first Dark Sky Community, the City of Flagstaff (AZ, USA), adopted the Flagstaff Zoning Code and Lighting Standards aimed at reducing a broad spectrum of light pollution impacts, such as light trespass, environmental impacts, impacts on safety and energy consumption (City of Flagstaff, 2023). This standard provides for, inter alia, lighting zones with different maximum permissible parameters, shielding and brightness limitations. The non-compliance with the standard is considered an administrative

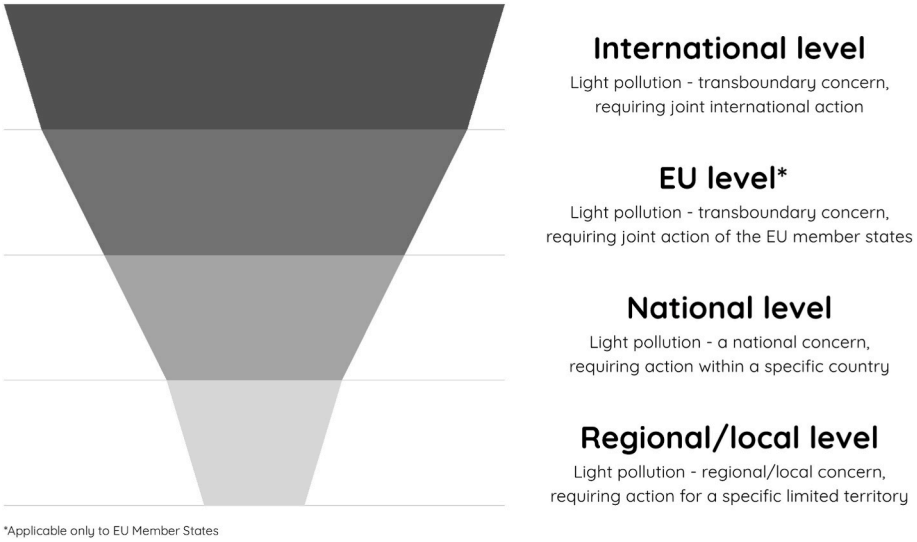

Fig. 1. Levels of implementation. Provides for the division of the adopted instruments based on the territorial scope of application, namely, according to the regulatory level.

offence. Another example is Ibara City in Japan, which adopted a special ordinance to protect the beautiful starry sky of the first Japanese international dark sky place (Ibara City, 1989).

In some other municipalities or regions, instruments aimed at reducing light pollution are not driven by the presence of designated dark sky places. Such as the City of Malibu (LA, USA) passed the Dark Sky Ordinance to protect Malibu's wildlife, habitat and quality of life from light pollution (City of Malibu, 2022). Another example is the various local laws and regulations in China that have introduced lighting control measures (Guanglei et al., 2018). A similar situation can be observed in Europe: in the absence of overarching national measures, local action would prevail. It is evident that, in most cases, the light pollution regulatory framework starts to develop at the local or regional level, subsequently, promoting the relevant action at the national level in most jurisdictions. This trend is largely due to the broad powers of authorities at the lower levels in the field of light control and active initiatives undertaken by local communities (Youyuenyong, 2015). Although there are some counter-examples when national regulatory amendments are followed by corresponding changes at lower levels. For instance, the German National Environmental Law introduced ALAN reduction measures, which were further reflected and sometimes strengthened at the regional level, such as in the State of Hesse (Hessian Law, 2023).

Despite a present lack of uniformity and homogeneity of regulatory approaches in different jurisdictions, the presence of regulatory framework at different levels will potentially help establish a unified regime throughout a specific country, and, subsequently internationally, thereby allowing the comprehensive reduction of light pollution and its impacts. Such an interdependent hierarchy of regulatory instruments plays a crucial role in the process: higher-level instruments indicate the necessary actions for lower levels, while the latter can serve as an incentive for changes at higher levels, making it necessary to support both top-down and bottom-up approaches to achieve common goals and create uniformity of the adopted measures.

4.4. Areas of implementation

The final subdivision in the classification of regulatory instruments adopted to address light pollution is based on the area of their implementation (Table 1).

Any regulatory framework governs various types of social relations, each with its own specific characteristics and distinctive features. The area of implementation is defined by the subject matter of regulation, namely a complex of homogeneous social relations that develop in any sphere of social activity and require a uniform legal regime (Baldwin et al., 2011). For instance, environmental instruments aim at the protection of the environment and biodiversity; urban planning targets the development and design of land use and the built environment; and energy instruments aim to govern energy use. In the context of light pollution, it is challenging to identify a single area of social relations, and consequently, a single regulatory area, that would adequately and fully address the problem. This complexity arises from the wide range of ALAN-induced adverse impacts and the corresponding diversity in regulatory approaches adopted in various jurisdictions intended to reduce and mitigate either all or individual impacts. The latter is further enhanced by the lack of a unified hierarchy and approach to regulation adopted at the higher levels, such as the international level, which would guide the lower levels. In other words, different impacts of light pollution are addressed by different regulatory areas, posing a challenge of selective and heterogeneous regulation. Light pollution mitigation measures are most commonly found in the following regulatory areas: (1) energy efficiency; (2) environmental protection; (3) urban planning; (4) technical documents; (5) protection of astronomical observations; (6) public procurement; (7) protection of cultural heritage and Indigenous communities; (8) space sustainability; and (9) dark sky protection and/or light pollution mitigation.

Table 1
Areas of implementation. Provides for the division of the adopted instruments based on regulatory areas.

Regulatory Area	Light Pollution Considerations
Energy efficiency	ALAN measures to reduce energy consumption
Environmental protection	Light pollution is recognised as an environmental pollution; measures to reduce ALAN environmental impacts
Urban planning	Lighting parameters relevant to urban development and construction
Technical regulations and other technical documents	Lighting specifications and product characteristics (e.g. energy efficiency labelling)
Protection of astronomical observations	Protection of dark skies for astronomical observations (e.g. buffer zones)
Public procurement	Minimizing public ALAN emissions for future projects
Protection of cultural heritage and Indigenous communities	Protection of significant cultural and spiritual value of dark skies for humanity or Indigenous communities
Space sustainability	Measures to protect the outer space environment and ensure the peaceful use and exploration of outer space
Dark sky protection and/or light pollution mitigation	Address a wide range of light pollution impacts

4.4.1. Energy efficiency

The regulatory framework aimed at ensuring energy efficiency considers light pollution solely from the perspective of its impacts on energy use and costs. To mitigate and reduce such adverse impacts, regulatory instruments provide for several measures, inter alia, switching to more energy-efficient lighting with enhancing luminous efficiency and setting ambitious reduction targets. Such measures can be found in the *Law on Climate Change and Energy Transition of the Foral Community of Navarra*, Spain. The government of Navarra promotes the energy efficiency of outdoor lighting through energy saving and the development of smart lighting control systems to minimize energy consumption from public lighting (Foral Community of Navarra, 2022). The stated target for reducing energy consumption is 25% by 2027 for buildings and infrastructures, including lighting installations (Ibid). Similar provisions for more energy-efficient lighting can be also found at the Spanish national level. The *Royal Decree on energy efficiency in outdoor lighting* sets requirements to establish the technical conditions for the design, implementation, and maintenance of outdoor lighting installations to reduce energy consumption and GHG emissions (Spain, 2008). As previously mentioned in Subsection 3.2 of this article, the regulatory instruments adopted to solely address the energy use of outdoor lighting may accelerate an increase of ALAN levels and cause other light pollution concerns due to the lack of considerations beyond energy efficiency.

4.4.2. Environmental protection

In contrast with energy efficiency regulations, the regulatory framework for environmental protection considers light pollution as an environmental pollutant imposing additional pressure on the environment and biodiversity, thereby bringing the adverse ecological impacts to the forefront. Integration of light pollution issues into the environmental regulatory framework allows the use of existing environmental measures, such as the environmental impact assessment (EIA) or monitoring, to address the newly recognised problem. Simultaneously, special measures to combat light pollution are also being introduced such as general lighting bans, light shielding and prohibition of light from being directed upwards or into water surfaces. In Germany, special environmental protection measures include a ban on illuminated advertising within nature reserves and in core and maintenance zones of biosphere reserves (Germany, 2021). Apart from that, general environmental provisions are applicable to ALAN providing for the avoidance of significant adverse effects on nature, landscape and species. In France,

the environmental regulatory framework encompasses a broad spectrum of provisions to address ALAN impacts on nature and biodiversity (France, 2018). These measures include, for instance, the limitation of the upward light output ratio (ULOR) of luminaires to zero and the colour temperature to 3000 K in nature reserves. Furthermore, municipalities can adopt stricter measures if necessary. The inclusion of light pollution into the stringent and robust environmental regulatory framework helps combat the issue and its impacts, which, in turn, will positively influence policies and regulatory instruments in other areas, thereby strengthening overall nature conservation efforts (Longcore and Rich, 2004).

4.4.3. Urban planning

Urban planning specifies ALAN requirements for the development of a particular area, using instruments such as master plans, zoning ordinances, land use plans, and other regulatory tools. Such requirements include: permissible lighting parameters, e.g. levels, brightness and direction, permits, and other categories, relevant to urban development and construction. For example, *Sweden's Planning and Building Ordinance* prohibits planning, location, placement or design of light sources in the event that this will result in a danger to people's health and safety or cause a significant impact (Swedish Parliament, 2010, 2011). Additionally, the Ordinance requires obtaining a permit for setting up, relocating, or altering light source facilities if the area where these activities are planned is covered by a detailed development plan. Another example is *Croatia's Ordinance on lighting zones, permitted lighting values and methods of managing lighting systems* (Croatia, 2020). The entire territory of Croatia is divided into 5 lighting zones depending on the content and activities in that area with each zone having its own lighting requirements, including maximum levels of the ULOR and brightness. For instance, zone E0 represents natural light areas where lighting should be generally turned off, whereas zone E4 compromises areas of high ambient lighting with high nighttime activity where outdoor ALAN is required for safety and comfort, therefore, light can be reduced as activity levels decrease.

The primary concern with urban planning regulatory framework is their human-centric focus, which often neglects environmental considerations in urban development. It is crucial to address light pollution by, for example, establishing maximum permissible parameters for lighting emissions to mitigate environmental impacts. At present, in most cases, urban planning instruments provide for only minimum lighting parameters which are generally considered excessive (Garde and Byrne, 2018).

4.4.4. Technical regulations and other technical documents

Technical regulations can be defined as documents which lay down product characteristics or their related processes and production methods, including applicable administrative provisions, with which compliance is mandatory (WTO, 1995). It is difficult to assert whether technical regulations provide direct measures to address light pollution; however, they remain relevant due to their indirect impact. A notable example is EU regulations on the ecodesign of light sources, which set minimum energy efficiency standards and labelling requirements for energy consumption information of lighting sources (Commission Regulation (EU) 2019/2020).

Other technical documents, such as technical standards, play a crucial role in setting lighting specifications, which may influence ALAN levels. Despite their voluntary nature, lighting standards can obtain mandatory character in the event of reference within a legal instrument. This approach is, for instance, applied by Austria. To strengthen efforts to reduce light pollution in Austria, the *Standard "Light pollution – Measurement and evaluation"* was incorporated as Annex 4 to the *Upper Environmental Law* amendments (Austria, 1996). The standard, for instance, sets detailed requirements for light colour temperature ranging from CCT 4000 K to CCT 2200 K, depending on the surrounding area of the lighting source.

Account needs to be taken of both technical regulations and other technical documents, especially lighting standards, as they inform the development of a regulatory framework applicable to lighting installations and provide guidance for lighting professionals.

4.4.5. Protection of astronomical observations

Another area which specifies light pollution mitigation measures is the regulatory framework adopted to protect astronomical observations. Measures, in this context, are directed to ensure the presence of dark skies to ensure proper implementation of astronomical activities in the long term. Although the regulatory framework in this area is limited, there are still notable examples. In the Canary Islands, Spain, to create adequate conditions for astronomy, the established regime requires avoidance of light emissions above the horizon and provides for a licensing procedure for outdoor lighting installations with some exceptions (Spain, 1988). In addition, in another example, acknowledging the role of astronomy, the Chilian government extended the regime of Special Protection Areas to the territories significant to astronomy within the entire country and implemented requirements for spectrum restrictions, maximum intensity and reflection levels (Chile, 2022).

4.4.6. Public procurement

Public procurement refers to the process by which public authorities and state-owned enterprises purchase work, goods or services from organisations. The regulatory framework governing public procurement may also comprise provisions relevant to light pollution. Such provisions concern the implementation of measures to prevent potential adverse impacts of public ALAN at the planning stage of activities. For instance, the *Virginia Public Procurement Act* requires the procurement of only shielded outdoor light fixtures, implying that no light should be emitted above the horizon and a maximum of 2% lumens allowed in a 90–180° zone for outputs over 3200 lumens. The purpose of this is to minimize glare, light trespass, and skyglow while ensuring a comfortable and safe outdoor environment (Commonwealth of Virginia, 1981). The efforts to include light pollution considerations into the public procurement were also undertaken in the EU. The recently proposed amendments to *EU Green Public Procurement (GPP) criteria for Road lighting and traffic signals* include recommendations to purchase low light pollution lighting equipment, e.g. with ULOR equal to zero (EU GPP, 2018). Furthermore, recommendations concern ecological light pollution and star visibility, proposing measures from lighting bans to dimming depending on the proximity to sensitive ecological areas.

4.4.7. Protection of cultural heritage and Indigenous communities

Measures to address light pollution concerns can be also found within the regulatory frameworks adopted for protecting cultural heritage and Indigenous People's rights. In this case, regulatory provisions refer to the significant cultural and spiritual value of dark skies for humanity or Indigenous communities. Starlight Declaration, for example, in its preamble, acknowledges the role of the dark sky as an essential element in the development of all cultures and civilizations throughout history, thereby supporting the need to protect starlight as a part of the cultural and natural heritage of humankind (Starlight Declaration, 2007).

For Indigenous Peoples, reducing light pollution levels is considered essential for protecting traditional knowledge and practices related to the stars (Hamacher et al., 2020). Although such measures are underdeveloped, some communities pay specific attention to the ALAN-induced impacts in this context. Such as in Hawaii, USA, the *Mauna Kea Comprehensive Management Plan* protects the presence of the dark skies, for their significance to Native Hawaiian culture (Mauna Kea Comprehensive Management Plan, 2009).

4.4.8. Space sustainability

One of the recent areas to begin addressing light pollution is the regulatory framework for space activities, namely provisions ensuring

space sustainability. Space sustainability can be defined as the ability of all humanity to continue to use outer space for peaceful purposes for social, economic and environmental benefit over the long term (Yakushina, 2023). In the context of space activities, measures to reduce ground-based and orbital light pollution levels are being developed to protect the outer space environment from contamination and to ensure the peaceful use and exploration of outer space, including through astronomical observations. Such measures are incorporated, in particular, by the European Space Agency (ESA). ESA's guiding principles for becoming a debris-neutral industry by 2030, as reflected in the *Zero Debris Charter*, indicate the need for anticipation and mitigation to the greatest possible extent of the adverse impacts of space debris on dark skies (European Space Agency, 2023).

4.4.9. Dark sky protection and/or light pollution mitigation

Finally, some countries at their national and various local levels started to enact dedicated instruments, such as special light pollution or dark sky protection laws, thereby establishing a new regulatory framework. A distinctive nature of this new regulatory area lies in broader considerations of a comprehensive range of light pollution concerns. The measures adopted within are diverse and generally incorporate elements from other regulatory fields, while striving to balance conflicting priorities, such as energy efficiency and environmental protection, reduction of lighting levels and public safety. These types of regulatory instruments have been adopted in more than 20 jurisdictions worldwide, with recent trends indicating an increase in such regulatory developments over the past few years. This is illustrated by the *Croatian Law on protection against light pollution.* The law aims at light pollution mitigation to ensure "the protection of human health, comprehensive preservation of environmental quality, preservation of biodiversity and landscape diversity, preservation of ecological stability, protection of flora and fauna, rational use of natural resources and energy in the most favourable way for the environment, as a basic condition of public healthcare, health and the basis of the concept of sustainable development … with the use of more energy-efficient lighting" (Croatia, 2019). In Peru, "the improvement of the quality of human life and wildlife, through the prevention of risks to health; promoting energy efficiency, road safety, and avoiding alteration of the landscape" is determined as a main objective of the *Light Pollution Prevention and Control Law* (Peru, 2021).

5. Discussion, conclusions and recommendations

The classification of regulatory instruments adopted to address light pollution presented in this article provides a comprehensive overview of light pollution regulation. Three main approaches to tackle the issue were identified: (1) incorporating light pollution concerns into existing regulatory frameworks, such as environmental protection, energy efficiency or urban planning (e.g., Germany, Austria); (2) adopting new instruments that address a broad range of light pollution impacts (e.g., Croatia); and (3) employing a mixed approach that combines both previously mentioned strategies (e.g., France). Understanding the global picture is important for identifying gaps, the most effective measures and for formulating recommendations for future improvements.

The conducted analysis has shown that the existing framework is distinguished by the high diversity, complexity and heterogeneity of regulatory approaches, and, accordingly, measures adopted to tackle light pollution. The problem is being addressed from different angles, depending on what adverse ALAN impacts were prioritised, and at different regulatory levels, encompassing international, EU, national, regional and local scales. The latter results in an absence of hierarchy among the adopted instruments, diminishing the possibility of a unified approach and efficiency of the measures. The heterogeneity of approaches is also facilitated by a variety of different triggers driving regulatory changes, e.g. research and actions of activist groups in a particular area. More specifically, currently adopted measures are mainly focused on energy efficiency concerns, rather than other ALAN-induced impacts. Moreover, most of the adopted instruments are policy instruments or non-binding recommendations, which lack or have reduced enforceability power. Furthermore, the existing framework often does not define light pollution control competence or include adequate sanction mechanisms for non-compliance, thereby reducing the effectiveness of the adopted measures (Table 2).

For an improved regulatory approach, one of the main solutions is the legal recognition of light pollution as an environmental problem. The reduction of extra ecological pressure, namely ALAN, will strengthen the overall conservation efforts, as well as bring lighting considerations to other fields, thus contributing to further regulatory improvements through the introduction of light pollution measures. A lack of protection for the nocturnal environment weakens overall environmental protection efforts by 50%, as it leaves only daytime activities safeguarded. The need to integrate environmental concerns into other regulatory areas is driven by the urgent necessity to take active measures to protect rapidly declining biodiversity. Another step will be the shift of the focus from only energy efficiency concerns towards a broader range of light pollution impacts, as should be reflected in the implemented measures. To increase uniformity, instruments should be adopted at all regulatory levels, contributing to the further development of a specialised regulatory area for light pollution mitigation. Such efforts can be also strengthened by the enaction of more binding regulatory instruments that would define light pollution control competence, e.g. authorities responsible for ALAN monitoring and measurements, as well as provide for liability for violation of established lighting requirements. Light pollution control, in turn, should be fundamentally grounded in the principle of openness and transparency regarding data on ALAN sources. This strategy will enable effective management to curb the rise in light pollution levels. Furthermore, the formation of the regulatory framework to address light pollution should be based upon cooperation and joint action of various stakeholders, including the lighting industry, researchers and government bodies. Awareness-raising campaigns can also play a crucial role in educating these stakeholders and the public about the impacts of light pollution and fostering support for regulatory changes. Additionally, since adopting and transitioning to a stricter regulatory framework for light pollution will take time, encouraging good practices is recommended. For instance, integrating light pollution credits into established building certifications, such as LEED (US) and BREEAM (UK), could be beneficial, as these frameworks have already proven effective as non-binding regulatory instruments for promoting sustainable practices.

Since this article provides an overview and classification, future research should focus on assessing the effectiveness of adopted regulatory measures in addressing light pollution and its impacts. This includes examining the collaboration between implementation efforts and changes in ALAN levels. Further studies can also explore the provisions that determine the competence to identify the most effective mechanisms for implementing such measures.

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Table 2
Application of classification: Examples of the regulatory instruments adopted to reduce light pollution and its impacts.

Instrument	Policy/Law	Binding/Non-Binding	Level of Implementation	Area of Implementation
UNEP/CMS/Resolution 13.5 Light Pollution Guidelines for Wildlife and Annex	Policy instrument	Non-Binding instrument	International level	Environmental protection
City of Flagstaff. Division 10–50.70: Outdoor lighting standards. In Flagstaff City Charter and City Code	Law instrument	Binding instrument	Local level	Technical document
Spain. Royal Decree 1890/2008, which approves the Regulation of energy efficiency in outdoor lighting installations	Law instrument	Binding instrument	National level	Energy efficiency
Lazio Regional Law 23/00 of 13/04/00 on the Reduction and Prevention of Light Pollution	Law instrument	Binding document	Regional level	Light pollution mitigation
Starlight Declaration in Defence of the Night Sky and the Right to Starlight (La Palma Declaration) 2007	Policy instrument	Non-Binding instrument	International level	Protection of dark skies

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No data was used for the research described in the article.

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