D2.2 - In-depth exploration report

VET–EcoLume

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Project Summary

The "Project VET EcoLume" is designed to confront the growing challenge of light pollution in the Europe and Latin America by pioneering a strategic blend of education, collaboration, and advocacy. This project sets out to cultivate a new wave of professionals equipped to counteract the harmful effects of light pollution on ecosystems, human health, and labour market. Project focuses on the development of a comprehensive VET curriculum aimed at producing Light Pollution Mitigation Specialists.

The project undertakes advocacy efforts to elevate the importance of sustainable lighting, pushing for policies and regulations that support environmentally friendly lighting practices. By focusing on the professional development of VET learners and provides, the project aims to empower educators with the knowledge and skills necessary for effective light management. Through its comprehensive approach, the project addresses the challenges of light pollution and contributes to the broader objectives of sustainable urban development and environmental well-being.

Research Objectives

Developing and empower a new generation of professionals to mitigate the harmful effects of light pollution so the focus of our project will be on three key areas:

- **Education**: We plan to develop a comprehensive curriculum for new occupation Light pollution mitigation specialists that will provide VETlearners with the knowledge, skills, and tools they need to identify, assess, and mitigate light pollution in urban environments.
- **Collaboration**: We will foster cross-cultural collaboration between EU and Latin American countries to share best practices and knowledge on sustainable lighting solutions.
- **Advocacy**: We will raise awareness about the importance of light pollution mitigation and advocate for policies and regulations that promote sustainable lighting practices

Methodology

For Steps 1-5 in the development of the **Research Report**, the methodology employed involves data and information collection through the following sources:

- **Primary Sources**: This includes the direct gathering of data from relevant stakeholders and interviews. (Survey Annex 2.)
- **Secondary Sources**: These encompass literature reviews from government reports, academic studies (Scopus, Web of Science, Google Scholar), patent reports (Lens.org, PatentScope), and case studies.
- **Analysis Methods**: Comparative analysis

For information retrieval from **secondary sources**, certain methods related to **scoping reviews** are applied. It is recommended to use:

- **Keyword strategies:** Refine search queries by selecting relevant terms and phrases.
- **Boolean operators Filter:** Refining searches by using logical connectors such as AND, OR, and NOT to include or exclude specific terms.
- **Backward searching:** Reviewing the references of a key article.
- **Forward searching:** Identifying studies that have cited a key article.

1. General Overview of Light Pollution

In this chapter, the aim is to provide a theoretical approach to the concept of light pollution in order to contextualize the process of reviewing literature focused on each country. Regardless of the theoretical frameworks defined herein, it is important to clarify that each member of the alliance is free to adopt a theoretical framework that is more relevant to their country's specific context if they deem it appropriate.

The following sections establish a foundational definition, outline the different types of light pollution identified in the literature, and provide a historical context along with a brief summary of how the issue has intensified over time. Additionally, a general perspective on the problem from a holistic standpoint is presented, followed by an analysis of its impacts on health, the environment, and the economy.

1.1 Definition and Types of Light Pollution

Light pollution is a form of environmental pollution characterized by the excessive or misdirected use of artificial light, which disrupts the natural darkness of the night-time environment. This phenomenon is primarily driven by human activities, such as urbanization and industrialization, leading to a significant alteration of natural light levels. In the context of light pollution, light does not only refer to the visible spectrum but also includes infrared and ultraviolet wavelengths. This is because certain organisms within flora and fauna are environmentally influenced by these wavelengths Goronczy (2021).

Longcore & Rich (2004) were among the first to comprehensively define the concept of light pollution. Their work provides a framework for understanding the phenomenon from multiple perspectives in a way that, despite evolving over time, has retained its core. Additionally, they introduced an initial typology of light pollution.

The initial typologies are related to the effects they produce. Sky glow refers to the brightening of the night sky caused by both natural and human-made factors. Light trespass occurs when light is cast in areas where it is neither wanted nor needed. Glare is characterized by excessive brightness that causes visual discomfort or impairment.

1.2 Historical Context and Growth of the Issue

Light pollution has developed alongside artificial lighting, transforming from an astronomical concern into a global environmental issue.

Early light sources, such as candles and oil lamps, had minimal impact, but the advent of gaslight and electric lighting in the 19th and 20th centuries dramatically increased artificial illumination (Ayres, 2021). The recent shift to LED technology has further amplified light emissions, with satellite data indicating a 49% rise from 1992 to 2017 (Sánchez de Miguel et al., 2021). However, LED wavelengths often evade satellite detection, complicating measurement and regulation.

Initially recognized as a threat to astronomy (Riegel, 1973), light pollution led to the creation of light-protected areas near observatories (Falchi & Bará, 2020). Yet, its impacts extend far beyond astronomy, affecting ecosystems, human health, and cultural heritage (Varela, 2023). Artificial light at night (ALAN) disrupts circadian rhythms, suppresses melatonin production, and is linked to increased risks of chronic diseases, while also threatening biodiversity by altering species behavior and ecological interactions (Hannachi & Slimani, 2022).

Awareness of light pollution has grown significantly, with research on the topic increasing by 466% between 2011 and 2020 (Jägerbrand et al., 2022). Remote sensing and monitoring technologies now help assess its global impact, revealing contrasting trends: while some developed nations have reduced per capita light pollution, developing regions experience rising ALAN intensity due to urban expansion (Huang & Ye, 2023).

Efforts to mitigate light pollution include improved public lighting practices, regulatory frameworks, and advocacy for dark sky preservation. However, challenges remain, such as the lack of standardized definitions and policies, as well as balancing the benefits of artificial lighting with the need to protect natural darkness (Shrimplin, 2023). Moving forward, a holistic approach integrating technology, policy, and environmental considerations will be essential to addressing this growing issue.

1.3 Global Perspective on Light Pollution

The global perspective on the issue of light pollution reflects the considerable complexity of the challenges to be addressed. Different regions around the world have approached this issue from various perspectives. Cities such as Shanghai or Seoul employ a metric-based regulatory approach, while more traditional cities like New York or London have incorporated lighting legislation into environmental law, resulting in a more flexible, yet less specific, framework (Law et al., 2024).

These legislative approaches, supported by extensive studies of the phenomenon, focus on the creation of regulations as a preventive measure. However, the literature reveals a notable gap in preventive strategies. In some cases, this has led to situations, as discussed by Bará and Falchi (2023), where there is a false belief that non-polluting lighting exists—when, by definition, all artificial lighting is polluting. Technological development in this field is primarily directed toward reducing wasted light, but there is no evidence of emphasis on technological innovations aimed at the elimination of artificial light.

1.4 Health, Environmental, and Economic Impacts

Light pollution, characterized by excessive ALAN, has profound health, environmental, and economic consequences. It disrupts natural light-dark cycles, affecting human circadian rhythms and biodiversity while contributing to energy waste and climate change. Addressing these impacts requires comprehensive policies and management strategies.

ALAN alters the human circadian system, suppressing melatonin production and increasing the risk of sleep disorders, obesity, mental health issues, and cancer (Cao et al., 2022). Night shift workers exposed to artificial light face a heightened cancer risk due to circadian disruption (Rajput et al., 2021). Additionally, ALAN contributes to stress and gut microbiota imbalances, further deteriorating overall health (Rajput et al., 2021; Zielinska-Dabkowska et al., 2023).

Light pollution disrupts ecosystems across terrestrial, marine, and freshwater environments, altering species behavior, reproductive cycles, and food webs (Kernbach et al., 2021; Zissis, 2020). Transition zones like mangroves and estuaries are particularly vulnerable, impacting biodiversity and ecosystem resilience (Mayer-Pinto et al., 2021).

Wasted artificial light contributes to unnecessary energy consumption, exacerbating climate change and increasing financial costs (Morgan-Taylor, 2023). Regulatory frameworks often focus on astronomical concerns, overlooking the direct impacts on human and ecological health. To mitigate light pollution, urban policies emphasize reducing nighttime light exposure, improving public lighting practices, and adopting a top-down regulatory approach to limit night sky deterioration (Falchi & Bará, 2020; Zielinska-Dabkowska et al., 2023).

Despite growing evidence of its harmful effects, public awareness remains limited. Strengthening regulations, promoting sustainable lighting practices, and implementing cross-realm management strategies are essential to mitigating light pollution and preserving ecological and human health.

2. Country-Specific Analysis

This section presents the results and analysis of the documents that illustrate the current state of the topic for each of the countries represented in the alliance. To carry out this task, suggested keywords and exclusion criteria—based on document type and publication year—are provided to guide the selection of relevant sources. Additionally, recommendations are made regarding databases that can be used as information sources.

It is important to note that these are merely suggestions, and each member of the alliance is free to consider alternative sources or keywords if deemed more appropriate.

Some keywords that can be used for search equations in this section include the following:

Light pollution; Nighttime lighting impact; Light pollution regulations; Lighting regulation; Environmental lighting legislation; Public policies and light pollution; Mitigation practices; Lighting management strategies; Best practices in lighting; Sustainable lighting; Energy efficiency in public lighting; Case studies; Light pollution case studies; Impact assessment; Challenges in managing light pollution; Gaps in regulations; Social awareness about light pollution; Citizen participation; Public perception; Social impact of light pollution.

Some examples of search equations include:
(“*Light pollution*” OR “*nighttime lighting impact*”) AND (“*regulations*” OR “*legislation*” OR “*regulation*”)

To ensure a structured and rigorous selection of relevant literature, a multi-step inclusion process will be applied to the documents gathered during the state-of-the-art review. The following criteria will guide this process:

1. Date Filter: Priority will be given to documents published within the last five years to ensure the inclusion of up-to-date information. However, this period may be extended if deemed necessary by the researcher, provided that a clear justification is included. For example, when analyzing laws and regulations, older documents may be necessary to understand legislative evolution and long-term trends.

2. Document Type Filter: Preference will be given to scientific articles, books, and book chapters, as they provide peer-reviewed and comprehensive insights into the topic. However, in the case of regulatory research, official government documents at the national, regional, or local levels must be prioritized to ensure the accuracy and relevance of legal frameworks.

3. Title Screening: After applying the initial filters, documents will be reviewed based on their titles to determine their relevance to the research objectives. Titles that clearly align with key topics, such as light pollution mitigation, regulatory frameworks, or sustainable lighting practices, will be retained for further review.

4. Abstract or Executive Summary Screening: A second level of screening will be conducted by reading the abstract (or equivalent sections) of each selected document. This step will help refine the selection by assessing whether the document's focus, scope, and methodology align with the objectives of this research.

5.:Full Document Review: Finally, a thorough reading of the selected documents will be conducted to confirm their relevance and validity. Only those that provide substantial contributions to the research topics will be included in the final analysis.

This structured approach ensures that the literature review is based on high-quality, relevant, and up-to-date sources while maintaining flexibility for justified exceptions when necessary.

2.1 Germany

Light pollution, an environmental concern that has grown alongside technological advancements and urbanization, is increasingly recognized as a significant issue in Germany. Unlike traditional forms of pollution, such as air or water contamination, light pollution is often overlooked because it does not have an immediate or easily observable impact on human health or ecosystems. However, its effects on biodiversity, human circadian rhythms, and energy consumption are profound. Excessive artificial light disrupts nocturnal wildlife, obscures the night sky for astronomers, and contributes to unnecessary energy waste, increasing the carbon footprint of modern societies (Leibniz Institute for Freshwater Ecology and Inland Fisheries, 2022).

Germany has long been a leader in environmental conservation efforts, yet light pollution remains a challenge that lacks a coherent national strategy. While various states and municipalities have begun to recognize the issue and introduce regulations, the absence of a unified federal policy results in inconsistent approaches across different regions. The increasing use of LED lighting, while more energy-efficient, has paradoxically led to greater light emissions because of its affordability and ease of use. According to a 2023 report by the International Dark-Sky Association, Germany's artificial brightness has been increasing by 6% annually, leading to rising concerns about its impact on natural ecosystems and human well-being.

This report provides an extensive analysis of light pollution in Germany, outlining its current state, key sources, historical trends, and comparative analysis with other nations. Additionally, the study examines the effectiveness of existing mitigation strategies, regulatory frameworks, and public awareness initiatives aimed at reducing unnecessary artificial lighting.

2.1.1 Current Situation of Light Pollution in Germany

Statistics and Affected Areas

Germany is one of the most heavily urbanized countries in Europe, and as a result, light pollution is a pervasive issue. Recent studies indicate that over 80% of the German population lives under artificially brightened night skies (European Environment Agency, 2023). In major metropolitan areas such as Berlin, Hamburg, and Munich, light pollution levels exceed internationally recommended limits, creating adverse effects on both the environment and human health.

Urban Centers and Skyglow

Skyglow, the brightening of the night sky due to artificial light scattered by atmospheric particles, is most pronounced in urban areas where excessive lighting from streets, buildings, and advertisements contribute to a significant increase in light pollution. According to research conducted by the German Aerospace Center (DLR) in 2022, artificial brightness in Germany's largest cities has risen by 40% over the last 20 years, significantly impacting visibility and disrupting nocturnal wildlife behaviors.

Rural areas, while less affected, are not completely free from the effects of artificial lighting. Light trespass from nearby cities, highways, and large-scale agricultural facilities has introduced artificial illumination into once naturally dark environments. For instance, the Federal Agency for Nature Conservation (BfN) reported that 60% of Germany's designated natural reserves are affected by light pollution, reducing the ability of nocturnal species to thrive in their natural habitats (BfN, 2021).

Key Sources of Light Pollution

The sources of light pollution in Germany are diverse, ranging from urban infrastructure to industrial operations. Some of the most significant contributors include:

- Street Lighting:

o Germany has over 9 million streetlights, and many of them are not designed to minimize upward light emissions (Federal Network Agency, 2022).
o Approximately only 30% of German municipalities have implemented energy-efficient and shielded street lighting systems (IGB, 2022).

- Commercial Advertising:

o LED billboards and illuminated signs contribute heavily to urban light pollution.
o Businesses, especially in commercial districts, operate 24-hour illuminated signage, leading to unnecessary energy consumption (Fraunhofer Institute, 2023).

- Industrial and Security Lighting:

o Airports, harbors, and manufacturing plants use high-intensity discharge lamps for security and operational purposes, often without adequate shielding.
o Studies indicate that industrial zones account for 25% of Germany's artificial light emissions (EEA, 2023).

- Residential and Private Property Lighting:

o Decorative garden lights and overuse of security lighting in private homes significantly contribute to light pollution.
o Surveys show that 50% of German households leave outdoor lights on overnight, even when not needed (Fraunhofer Institute, 2023).

Historical Trends and Comparative Analysis

Light pollution in Germany has undergone significant changes over the past century. Early urban development relied on gas lamps, which provided minimal illumination compared to modern electrical lighting. The widespread adoption of mercury-vapor and sodium-vapor lamps in the mid-20th century led to an increase in light emissions, but it was not until the LED revolution of the 2000s that artificial lighting saw an exponential rise (Leibniz Institute for Astrophysics Potsdam, 2018).

Comparative Trends

- Between 1995 and 2020, artificial brightness in German cities increased by 40% (AIP, 2018).
- In contrast, Scandinavian nations such as Norway and Sweden have implemented strict lighting regulations, leading to significantly lower levels of skyglow compared to Germany (Nordic Environmental Research Institute, 2022).
- France introduced a national law regulating artificial lighting in 2019, mandating dimming during nighttime hours, an approach that Germany has yet to adopt (French Environmental Agency, 2021).

2.1.2 Local Government Policies and Regulations

Germany has increasingly recognized the importance of controlling light pollution, and as a result, various policies and regulations have been developed at both the national and regional levels. However, these measures are not always uniformly applied, and enforcement remains a challenge due to the decentralized nature of governance in the country. While national policies provide overarching guidelines, regional governments and municipalities are primarily responsible for implementation and enforcement, leading to varying levels of effectiveness across different areas (Federal Ministry for the Environment, 2022).

National Laws and Policies

Germany does not have a single, comprehensive national law addressing light pollution, but several legal frameworks regulate artificial lighting and its environmental impacts. The Federal Nature Conservation Act (BNatSchG), Section 5mandates that environmental considerations be included in all aspects of land use and planning, including artificial lighting, to minimize ecological harm (Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, 2022).

The Federal Immission Control Act (BImSchG), Section 22(1) provides legal grounds for restricting excessive artificial illumination that could negatively affect human health or ecosystems (German Federal Environmental Agency, 2021). This regulation allows local communities to challenge high-intensity lighting installations that exceed accepted environmental limits.

The German Renewable Energy Act (EEG 2023), Article 42 indirectly impacts light pollution by promoting the use of energy-efficient lighting systems, including LED technology, which reduces power consumption but raises concerns about increased blue-light emissions (German Ministry for Economic Affairs and Climate Action, 2023). Additionally, the Ordinance on Outdoor Lighting Standards (2021) establishes technical requirements for outdoor lighting, including maximum luminance levels and shielding specifications to limit unnecessary skyglow (German Institute for Standardization, 2021). While these policies aim to mitigate light pollution, their enforcement remains inconsistent due to the lack of a central authority overseeing compliance across all regions.

Regional Regulations and Enforcement

At the regional level, some German states have adopted more stringent regulations to address light pollution. Bavaria's 2020 Conservation Act limits facade lighting between 11 PM and 6 AM and prohibits the use of skybeamers, which have been identified as significant contributors to skyglow (Bavarian Ministry of the Environment and Consumer Protection, 2020). Similarly, Berlin's Light Pollution Guidelines (2021) require commercial and public buildings to reduce excessive nighttime illumination by switching off non-essential lighting after midnight (Senate Department for the Environment, Transport, and Climate Protection Berlin, 2021). These measures aim to protect nocturnal wildlife and preserve the visibility of the night sky.

In Hessen, the Environmental Protection Act (2022), Paragraph 15 mandates motion-sensitive outdoor lighting systems in public spaces and ensures that protected natural areas remain minimally affected by artificial illumination (Ministry for the Environment, Climate Protection, Agriculture, and Consumer Protection Hessen, 2022). North Rhine-Westphalia (NRW) Urban Development Act (2023) encourages municipalities to implement fully shielded streetlights and offers financial incentives for adopting smart lighting solutions that reduce unnecessary upward emissions (NRW Ministry for Regional Development, 2023).

While these regional regulations represent significant progress, enforcement varies widely. Many municipalities lack the financial resources to update outdated streetlights and comply with new regulations. Furthermore, resistance from businesses reluctant to limit illuminated advertising complicates efforts to achieve widespread compliance (European Environment Agency, 2023).

Role of Environmental Agencies and NGOs

Environmental agencies and non-governmental organizations (NGOs) play a key role in advocating for stricter light pollution policies and supporting their implementation. The German Federal Environmental Agency (UBA) conducts research on the impact of artificial lighting on biodiversity and human health, publishing guidelines for

policymakers and local governments to implement environmentally responsible lighting solutions (UBA, 2022). The agency's reports highlight that over 60% of Germany's nature reserves are affected by light pollution, disrupting nocturnal ecosystems and altering wildlife behavior (UBA, 2021).

The Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB) has been at the forefront of scientific research on light pollution, demonstrating its effects on migratory species and aquatic environments (IGB, 2023). Their studies indicate that artificial brightness in Germany has increased by 40% since 1995, significantly affecting biodiversity and altering natural light cycles (IGB, 2022).

The International Dark-Sky Association (IDA) Germany is another key player in promoting awareness and advocating for dark-sky-friendly policies. Through partnerships with local governments, IDA Germany has successfully lobbied for the creation of protected dark-sky reserves where artificial lighting is minimized (IDA Germany, 2023). Similarly, the Nature and Biodiversity Conservation Union (NABU) works closely with urban planners to implement wildlife-friendly lighting solutions, particularly in areas critical to migratory bird species (NABU, 2023).

Despite these efforts, challenges remain in ensuring that environmental agencies and NGOs have sufficient influence over policymaking. Their recommendations often lack the legal backing necessary for enforcement, making it difficult to achieve lasting changes without stronger national regulations (UBA, 2022).

2.1.3 Effective Mitigation Practices and Case Studies

Germany has made significant progress in implementing mitigation strategies to combat light pollution. These efforts involve collaborations between government agencies, scientific institutions, and local municipalities to introduce innovative solutions that balance urban development with environmental conservation. Many German cities have taken proactive steps to limit unnecessary artificial lighting, while research institutions continue to provide data-driven recommendations to enhance policy effectiveness. Comparisons with other European countries further illustrate how Germany's strategies align with or differ from international best practices.

Success Stories from German Cities

Several German cities have successfully implemented mitigation measures to reduce light pollution while maintaining urban safety and functionality. In Augsburg, for instance, the municipality has introduced a comprehensive outdoor lighting plan that prioritizes warm-colored LED lights with reduced blue-light emissions. This initiative, combined with motion-sensitive streetlights, has resulted in a 35% reduction in skyglow (Leibniz Institute for Astrophysics Potsdam, 2023). The city's success demonstrates how targeted urban planning strategies can significantly improve nighttime environments while minimizing energy consumption.
In Freiburg, authorities have established "light reduction zones" where artificial lighting is restricted between 11 PM and 5 AM in residential areas and parks. A study conducted by the Fraunhofer Institute for Solar Energy Systems (ISE) in 2022 revealed that these policies have led to a 40% decrease in unnecessary artificial illumination and improved

nocturnal biodiversity, particularly for bats and nocturnal insects. The initiative aligns with the European Dark Sky Movement's recommendations, reinforcing the city's commitment to sustainable urban lighting practices.

Another exemplary case is Hamburg, which has adopted smart lighting technologies that dynamically adjust streetlight brightness based on pedestrian and vehicular activity. This adaptive system, developed in collaboration with the German Aerospace Center (DLR), has demonstrated a 25% reduction in energy consumption while simultaneously maintaining public safety standards (DLR, 2022). Furthermore, a 2023 report by the German Federal Environmental Agency (UBA) found that these measures have significantly mitigated light trespass into residential areas, reducing complaints from residents about intrusive night-time brightness.

Recommendations from Research Institutions

Research institutions in Germany have played a crucial role in shaping light pollution mitigation strategies. The Leibniz Institute for Freshwater Ecology and Inland Fisheries (IGB) has emphasized the importance of limiting short-wavelength blue light emissions, which have been shown to disrupt nocturnal ecosystems more severely than other forms of artificial illumination (IGB, 2022). In a nationwide study, IGB researchers recommended that cities transition to amber or warm white LEDs to minimize the impact on migratory birds and nocturnal species.

The Fraunhofer Institute for Solar Energy Systems (ISE) has advocated for widespread adoption of motion-sensitive streetlights and automated dimming technology. Their 2023 study on urban light efficiency indicated that implementing these technologies across Germany could lead to an estimated 50% reduction in unnecessary nighttime lighting(Fraunhofer ISE, 2023). The research also emphasized the economic benefits, projecting annual cost savings of approximately €100 million in municipal energy expenses.

The German Aerospace Center (DLR) has contributed by developing satellite-based monitoring systems to track changes in artificial night brightness. By analyzing historical satellite imagery, DLR researchers have been able to identify trends in urban light emissions and assess the effectiveness of different mitigation strategies. Their 2022 publication on satellite-based light pollution assessment highlighted the urgent need for stricter zoning regulations to prevent excessive light spillage from commercial and industrial areas into residential and natural zones (DLR, 2022).

Comparative Analysis with Other European Countries

Germany's approach to light pollution mitigation can be compared to strategies implemented in other European nations, such as France, Scandinavia, and the Netherlands. In France, the government introduced a national law in 2019 that strictly regulates artificial lighting in urban areas. The law mandates that all commercial buildings and advertising signs must turn off exterior lighting between 1 AM and 6 AM, significantly reducing unnecessary energy consumption and skyglow (French Environmental Agency, 2021). While some German municipalities have adopted similar policies, Germany has yet to introduce a federal regulation of this nature.

Scandinavian countries, including Norway and Sweden, have pioneered dark-sky-friendly policies by integrating strict lighting design guidelines into their national urban planning frameworks. Norway's national urban planning standards require that all new lighting installations use fully shielded fixtures to prevent upward light emissions, an approach that Germany has only partially adopted in select regions (Nordic Environmental Research Institute, 2022). Sweden has focused on preserving dark-sky reserves by designating areas where artificial lighting is heavily restricted, a practice that some German regions, such as Bavaria, have begun to implement.
The Netherlands has taken an innovative approach by developing bioluminescent road markings as a substitute for traditional street lighting in rural areas. This concept, pioneered in Eindhoven, has proven to be an effective method for reducing artificial illumination while maintaining nighttime visibility for drivers and pedestrians (Dutch Ministry for Infrastructure and Water Management, 2022). Germany has experimented with similar technologies, but large-scale implementation remains limited.

Conclusion

While Germany has made progress in addressing light pollution through a combination of municipal initiatives, research-based recommendations, and smart lighting technologies, the country still lacks a unified national strategy. The success of cities such as Augsburg, Freiburg, and Hamburg demonstrates that well-planned urban lighting policies can significantly reduce unnecessary artificial brightness while maintaining public safety. Research institutions continue to provide critical insights into best practices for nighttime illumination, but stronger national coordination is needed to ensure widespread adoption of effective mitigation strategies. Comparing Germany's efforts with those of France, Scandinavia, and the Netherlands highlights areas where the country could further refine its approach by implementing more uniform regulations, investing in dark-sky preservation, and exploring alternative lighting solutions such as bioluminescent pathways. Strengthening collaboration between government agencies, municipalities, and environmental organizations will be essential in securing Germany's long-term commitment to reducing light pollution.

2.1.4 Challenges and Gaps in Light Pollution Management

Despite Germany's progress in addressing light pollution, several challenges and gaps remain in effectively managing and mitigating its impact. These issues stem from policy enforcement inconsistencies, technological limitations, economic constraints, and the divided responsibilities between the public and private sectors. While various municipalities have introduced regulations and innovative lighting solutions, the lack of a unified national strategy hinders large-scale success. Addressing these barriers requires coordinated action between government institutions, scientific researchers, businesses, and civil society organizations.

Policy and Enforcement Issues

One of the major challenges in managing light pollution in Germany is the lack of a comprehensive national policy that uniformly regulates artificial lighting across all states.

While various laws, such as the Federal Nature Conservation Act (BNatSchG, Section 5) and the Federal Immission Control Act (BImSchG, Section 22(1)), provide general guidelines on limiting emissions, they do not establish strict, enforceable standards for artificial lighting at the federal level (Federal Ministry for the Environment, 2022). As a result, regulation falls to regional and municipal governments, leading to significant inconsistencies in enforcement.

For example, Bavaria and Berlin have implemented specific restrictions on facade lighting and skybeamers, while other regions, such as Saxony and Lower Saxony, lack similar mandates (Bavarian Ministry of the Environment, 2020; Senate Department for the Environment Berlin, 2021). This uneven approach results in highly localized compliance rather than a nationwide effort to reduce light pollution. Furthermore, while certain municipalities have introduced nighttime lighting curfews, enforcement remains difficult due to limited regulatory oversight and resistance from businesses dependent on illuminated advertising (European Environment Agency, 2023).

Another enforcement issue is the lack of monitoring and compliance mechanisms. Currently, no dedicated national agency is responsible for tracking light pollution trends and ensuring municipalities adhere to sustainable lighting regulations. Instead, local environmental agencies are often overburdened with other responsibilities, making it challenging to conduct regular audits of urban lighting practices (German Federal Environmental Agency, 2021). As a result, many businesses and homeowners continue using excessive outdoor lighting without facing consequences, contributing to rising skyglow levels.

Technological and Economic Barriers

In addition to regulatory challenges, technological limitations and economic constraints present significant hurdles in the effective management of light pollution. While LED lighting has been promoted as an energy-efficient alternative to traditional streetlights, studies have shown that high-intensity blue LED lights contribute more to skyglow than older sodium-vapor lamps (Leibniz Institute for Astrophysics Potsdam, 2023). The transition to LEDs has, paradoxically, resulted in an increase in total artificial brightness because of their affordability and widespread implementation without proper shielding requirements.

The Fraunhofer Institute for Solar Energy Systems (ISE) has recommended the use of warm-colored LEDs and adaptive lighting controls, such as motion sensors and dimmable streetlights, to mitigate excessive artificial brightness. However, the high initial investment costs associated with upgrading municipal lighting infrastructure have deterred many local governments from making the transition (Fraunhofer ISE, 2023). Despite the long-term energy savingsoffered by smart lighting technologies, many cities struggle to allocate funding for widespread implementation, particularly in economically disadvantaged areas.

Another challenge is the economic reliance of businesses on illuminated advertising. Many commercial sectors, particularly in large metropolitan areas such as Frankfurt and Düsseldorf, argue that nighttime lighting is essential for maintaining customer engagement and ensuring security (German Ministry for Economic Affairs and Climate Action, 2022). As a result, efforts to impose restrictions on excessive commercial lighting

have faced strong opposition from business associations, making it difficult to enforce regulations that could significantly reduce light pollution levels.

Public and Private Sector Roles

The division of responsibility between the public and private sectors also contributes to the challenges in managing light pollution. While municipalities are primarily responsible for public lighting infrastructure, much of Germany's excessive artificial illumination stems from privately owned properties, businesses, and industrial sites. This means that even the most stringent municipal policies cannot fully address the problem without cooperation from the private sector.

Efforts to encourage voluntary compliance among businesses and homeowners have had limited success. The International Dark-Sky Association Germany has launched educational campaigns urging property owners to use low-intensity, downward-facing lights, but adoption rates remain low due to a lack of incentives or enforceable mandates (IDA Germany, 2023). Similarly, while some businesses have participated in energy-efficiency programs, many continue using high-luminance displays without considering their impact on the surrounding environment.

Public-private partnerships have emerged as a potential solution to bridge this gap. In Hamburg, for example, a collaboration between the city government and local businesses resulted in a voluntary agreement to reduce advertising brightness by 20% after midnight (Hamburg Environmental Department, 2022). While this initiative has been praised as a step in the right direction, similar efforts have not been widely adopted across other German cities, limiting their overall impact.
Additionally, while some companies in the renewable energy sector have expressed interest in developing sustainable lighting solutions, the market for dark-sky-friendly products remains underdeveloped. There is currently insufficient financial support for research and innovation in this field, slowing down advancements in bioluminescent lighting alternatives and energy-efficient urban design (German Aerospace Center, 2022).

2.1.5 Community Awareness and Education on Light Pollution - Survey

Public awareness and education play a crucial role in addressing light pollution in Germany. While governmental regulations and technological advancements contribute to mitigation, long-term success depends on fostering a well-informed society that actively participates in sustainable lighting practices. Understanding how light pollution affects human health, biodiversity, and energy consumption is essential for influencing both individual behavior and policymaking. Surveys, educational programs, and media campaigns have emerged as key tools in spreading awareness and encouraging more responsible lighting practices.

Public Perception and Surveys

Despite the growing impact of light pollution, public perception remains relatively low compared to other environmental issues such as air and water pollution. According to a 2023 survey conducted by the Leibniz Institute for Freshwater Ecology and Inland

Fisheries (IGB), only 35% of German residents were aware of the environmental and health risks associated with excessive artificial lighting. This figure highlights a significant knowledge gap in understanding how urban lighting affects ecosystems and human well-being (IGB, 2023).

Additional studies conducted by the German Federal Environmental Agency (UBA) found that nearly 60% of respondents believed that street lighting was beneficial and necessary for urban safety, but only 20% recognized that excessive illumination contributes to energy waste and skyglow (UBA, 2022). This indicates that while people appreciate the benefits of artificial lighting, they often overlook its negative consequences.

Surveys also indicate a generational divide in awareness levels. Research conducted by the International Dark-Sky Association (IDA) Germany found that younger generations (ages 18-35) were more likely to support policies regulating artificial lighting, while older individuals expressed greater reluctance toward reducing night-time illumination (IDA Germany, 2023). Additionally, urban populations demonstrated higher tolerance for bright cityscapes, whereas residents of rural areas were more likely to support light pollution reduction measures.

These findings emphasize the need for targeted educational efforts to bridge the knowledge gap, particularly in urban communities where excessive lighting is most prevalent. Without proper awareness, the public remains largely uninvolved in efforts to reduce artificial light emissions, which further complicates policy implementation.

Educational Initiatives and Programs

Educational programs have become a key strategy in raising awareness about light pollution. Various initiatives have been introduced in schools, universities, and community centers to educate people on the importance of reducing unnecessary artificial illumination. The German Ministry of Education and Research (BMBF) has partnered with environmental organizations to integrate light pollution awareness into science curricula, allowing students to explore the ecological and health consequences of excessive lighting (BMBF, 2023).

One notable initiative is the “Dark Skies for Future” project, launched in 2022 by the Leibniz Institute for Astrophysics Potsdam (AIP). This program involves interactive workshops, public lectures, and astronomy-themed events that educate participants about the importance of preserving natural nightscapes (AIP, 2022). The project has successfully reached over 10,000 students and community members, demonstrating the effectiveness of hands-on educational approaches.

Additionally, non-governmental organizations such as NABU (Nature and Biodiversity Conservation Union) have implemented citizen science programs where participants measure and report light pollution levels in their local areas using smartphone apps. This initiative has not only increased public engagement but has also provided valuable data for researchers studying urban illumination trends (NABU, 2023). Several municipalities have also introduced sustainable lighting workshops for urban planners, business owners, and local government officials. For example, in Munich, the

city administration has organized training sessions on smart lighting technologies, helping decision-makers implement policies that balance safety with sustainability (Munich Environmental Office, 2022). These programs ensure that both individuals and institutions are equipped with the knowledge necessary to promote responsible lighting practices.

Role of Media and Campaigns

Media coverage and public campaigns play a vital role in shaping opinions and influencing behavior regarding light pollution. Various German environmental organizations and governmental agencies have launched awareness campaignsto educate the general public on the consequences of excessive artificial lighting. One of the most notable efforts is the “Save the Night” campaign, initiated by the German Federal Environmental Agency (UBA) in 2021. This nationwide campaign utilizes social media, television broadcasts, and public service announcements to highlight the environmental and economic costs of light pollution (UBA, 2021). The campaign includes before-and-after visualizations of cities with reduced lighting, demonstrating the significant impact of simple measures like dimming streetlights and using shielded fixtures.

The International Dark-Sky Association (IDA) Germany has also leveraged digital platforms to spread awareness through documentaries and online webinars. Their 2023 documentary, “Blinded by the Light: The Dark Side of Urban Illumination,” has reached an audience of over 1.5 million viewers, making it one of the most widely watched educational programs on the subject in Germany (IDA Germany, 2023). These initiatives demonstrate the power of media in shaping public attitudes toward light pollution.

Journalistic efforts have also contributed to awareness by exposing the economic and ecological costs of excessive urban lighting. Investigative reports from the Frankfurter Allgemeine Zeitung (FAZ) and Die Zeit have explored the financial burden of inefficient lighting on municipal budgets and the loss of biodiversity due to disrupted nocturnal habitats (FAZ, 2023). These media efforts have helped shift public discourse, leading to increased advocacy for light pollution regulations at local and national levels.

Detailed Narrative Interpretations and Conclusions of the EcoLume Survey

Introduction

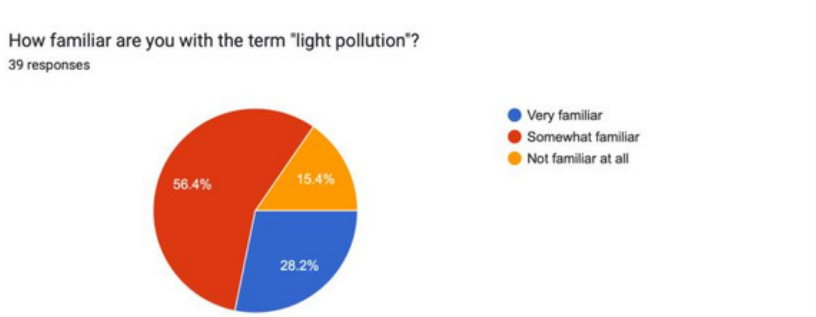
This report summarizes the findings from a Google Survey conducted to understand community perspectives on light pollution in Germany, as part of the EcoLume Project. An online survey method was utilized, reaching out to local community members through digital platforms. In total, 39 respondents from various backgrounds across Germany completed the survey. The survey explored participants' familiarity with the concept of light pollution, their perceptions of its significance, awareness of its environmental and health impacts, and willingness to participate in local actions to mitigate the issue. The collected data provide insightful information that will guide local authorities, community organizations, and educational institutions to effectively address the challenge of light pollution through increased public awareness, improved policy frameworks, and targeted educational initiatives.

Question 1: How familiar are you with the term "light pollution"?

Most respondents (56.4%) indicated they were "somewhat familiar" with the term "light pollution," suggesting that while many people have heard about it, they might not fully grasp its implications or detailed characteristics. This partial familiarity creates an opportunity to expand community knowledge and deepen understanding about the issue.

Conclusion:

Since there is only partial familiarity, educational efforts, awareness campaigns, and
public dialogues are essential to build stronger awareness and enable the community to
appreciate the broader impacts of light pollution.

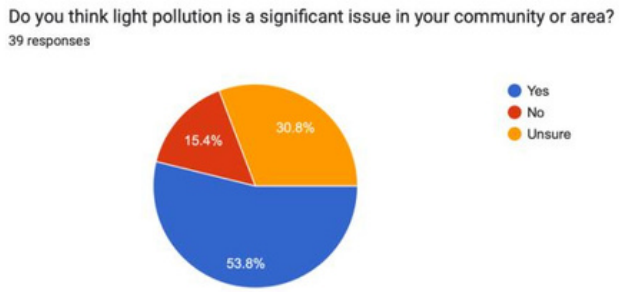


Question 2: Do you think light pollution is a significant issue in your community or area?

Over half the respondents (53.8%) perceive light pollution as a significant issue locally. This perception underscores a genuine concern within the community, indicating people notice the effects and are interested in addressing it proactively.

Conclusion:

This clear recognition provides a solid foundation for community-based actions, policy interventions, and environmental programs that target local concerns directly.



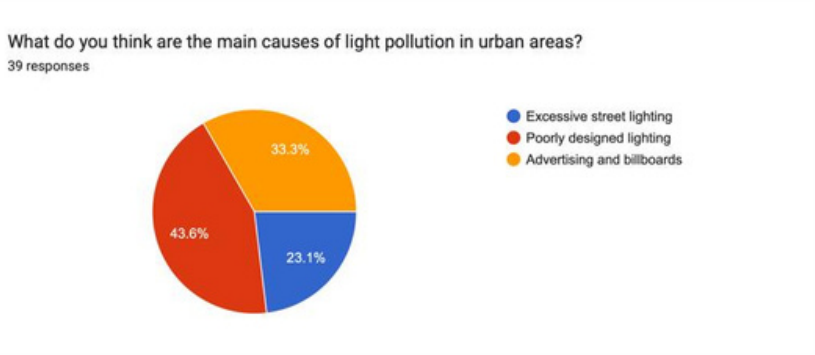
Question 3: What do you think are the main causes of light pollution in urban areas?

Respondents primarily identified "poorly designed lighting" (43.6%) as the leading cause of urban light pollution. This acknowledgment highlights the community's awareness of

specific, practical issues rather than vague concerns, emphasizing the importance of better urban planning and improved lighting infrastructure.

Conclusion:

Policymakers and urban planners should prioritize the adoption of better lighting practices and designs as key solutions to effectively reduce urban light pollution.

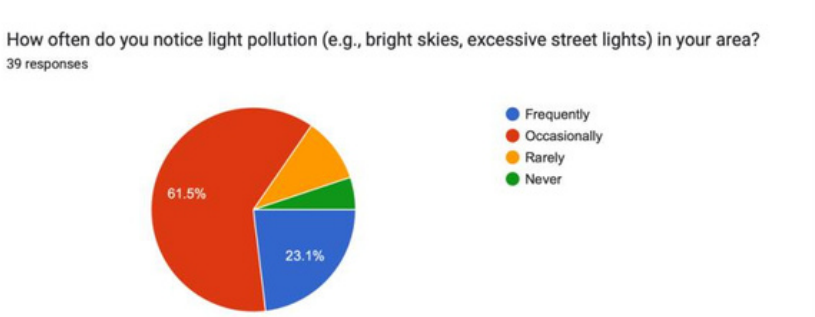


Question 4: How often do you notice light pollution (e.g., bright skies, excessive street lights) in your area?

The majority (61.5%) reported noticing light pollution occasionally, indicating it's a visible, though intermittent, concern. This suggests it's not constantly intrusive but present enough to create awareness and occasional discomfort among residents.

Conclusion:

Regular educational reminders and local awareness activities could maintain or increase sensitivity towards the issue, prompting greater community responsiveness.

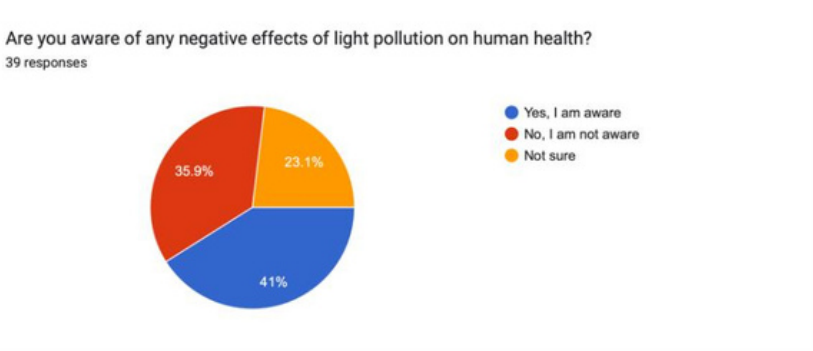


Question 5: Are you aware of any negative effects of light pollution on human health?

Many respondents (41%) explicitly acknowledged awareness of the negative health effects of light pollution, such as sleep disruption or psychological stress. However, this leaves a notable portion potentially unaware or uncertain, indicating a gap in detailed understanding.

Conclusion:

There is significant potential to improve health-focused education, clarifying the personal relevance and fostering broader community concern.

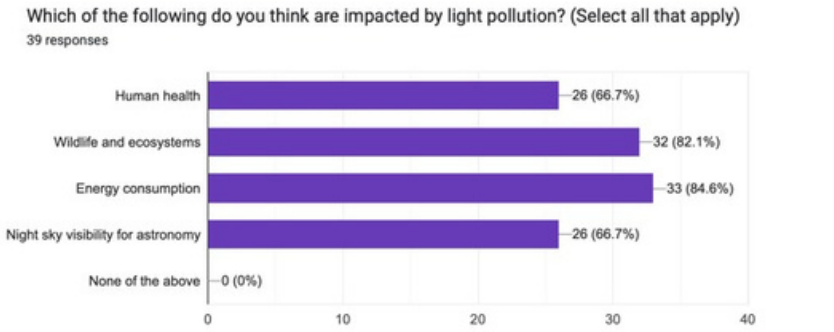


Question 6: Which of the following do you think are impacted by light pollution?

Respondents widely recognized impacts across multiple sectors, particularly human health (66,7%), wildlife (82,1%), and energy consumption (84,6%). This comprehensive understanding demonstrates that respondents see the issue as multifaceted, extending beyond a single domain.

Conclusion:

Community actions and policy measures should emphasize this broad perspective, advocating integrated strategies addressing environmental, ecological, and health-related
issues simultaneously.

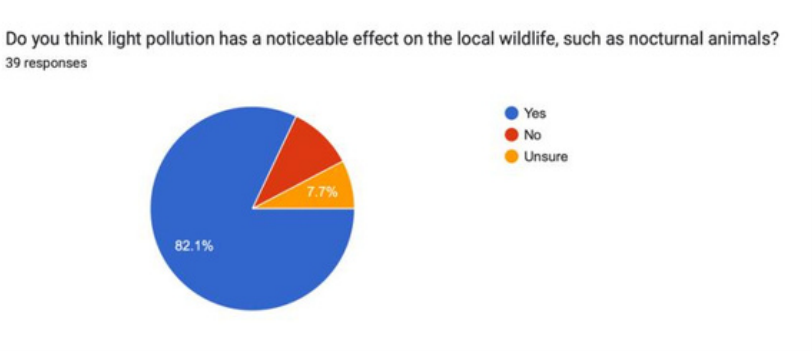


Question 7: Do you think light pollution has a noticeable effect on the local wildlife, such as nocturnal animals?

An overwhelming majority (82.1%) strongly perceive negative effects of light pollution on local wildlife, especially nocturnal animals. This widespread consensus underscores a deep environmental empathy and a clear community value of protecting biodiversity.

Conclusion:

Given this strong consensus, wildlife protection measures will likely receive robust community support and should be a priority for local environmental strategies.

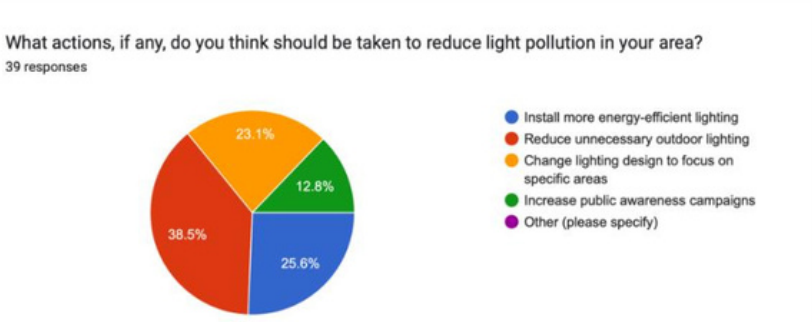


Question 8: What actions, if any, do you think should be taken to reduce light pollution in your area?

Respondents strongly favored practical, immediate steps like "reducing unnecessary outdoor lighting" (38.5%). This shows a pragmatic approach by the community, seeking straightforward, implementable measures rather than abstract solutions.

Conclusion:

Local governments and community groups should prioritize actionable, easily implementable lighting guidelines to immediately reduce environmental impacts and garner community support.

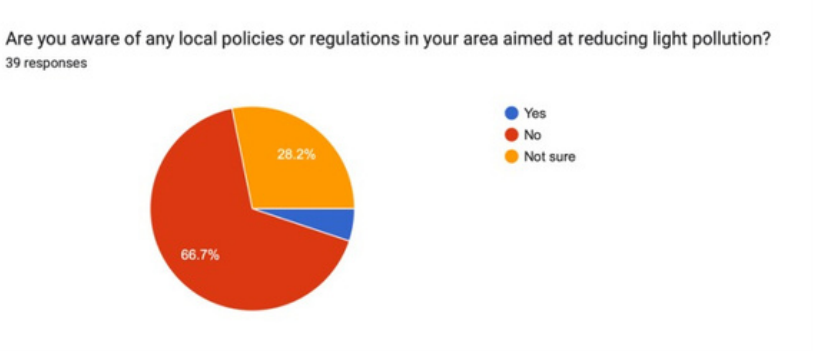


Question 9: Are you aware of any local policies or regulations in your area aimed at reducing light pollution?

A significant gap in awareness exists, as most respondents (66.7%) are unaware of local policies aimed at reducing light pollution. This gap could reflect either an absence of such policies or insufficient efforts to communicate existing regulations to the public.

Conclusion:

There is a crucial need for local authorities to either develop clear and accessible regulations or significantly improve how these policies are communicated to the community.

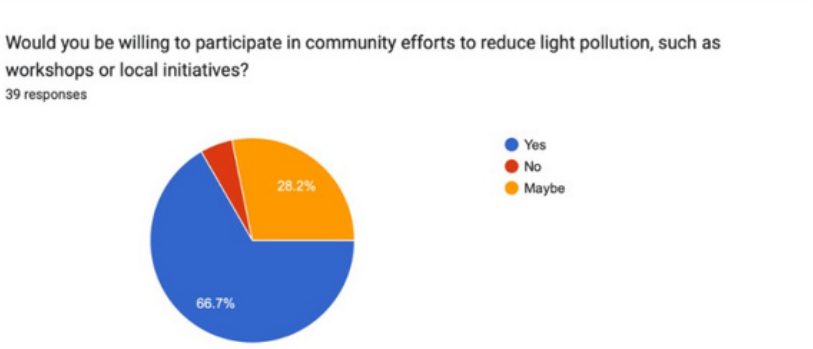


Question 10: Would you be willing to participate in community efforts to reduce light pollution, such as workshops or local initiatives?

A clear majority (66.7%) of respondents expressed willingness to actively engage in local initiatives, workshops, or other efforts to reduce light pollution. This strong expression of interest reveals a proactive community ready to contribute positively.

Conclusion:

Harnessing this readiness through well-organized, inclusive community initiatives could successfully mobilize local support and lead to tangible improvements.

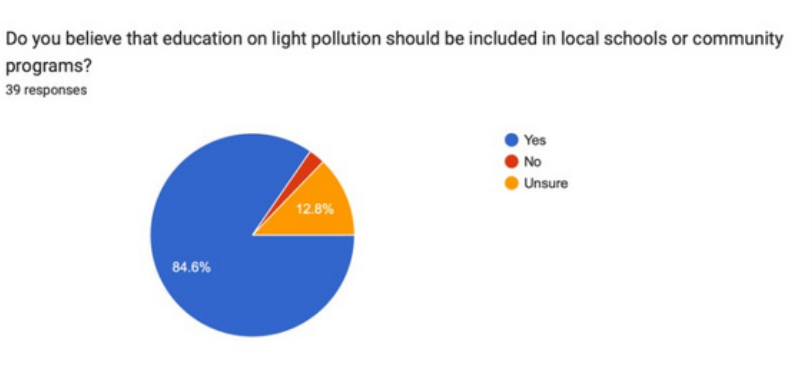


Question 11: Do you believe that education on light pollution should be included in local schools or community programs?

An impressive majority (84.6%) strongly supported incorporating education on light pollution into local schools or community programs. Respondents evidently view education as vital, not only to awareness but also to sustained community engagement.

Conclusion:

Educational institutions and local governments should promptly integrate structured educational activities on this topic to capitalize on this high public interest and foster sustained behavioral changes.

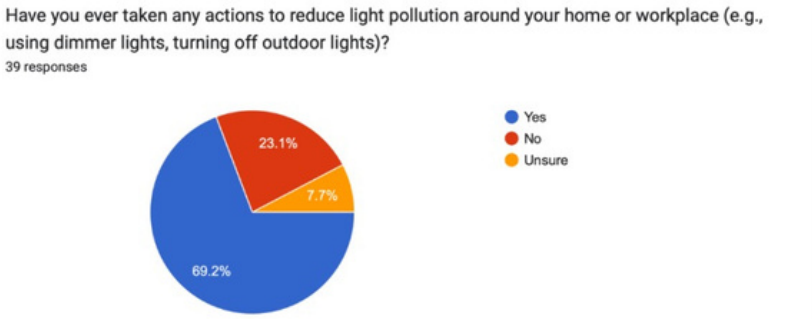


Question 12: Have you ever taken any actions to reduce light pollution around your home or workplace (e.g., using dimmer lights, turning off outdoor lights)?

Most respondents (69.2%) reported already taking personal steps, such as turning off unnecessary lights or using dimmers. This demonstrates existing proactive attitudes and environmental responsibility within the community.

Conclusion:

The community's existing behavior provides an excellent base for scaling up individual
actions into broader collective initiatives, enhancing the overall impact.

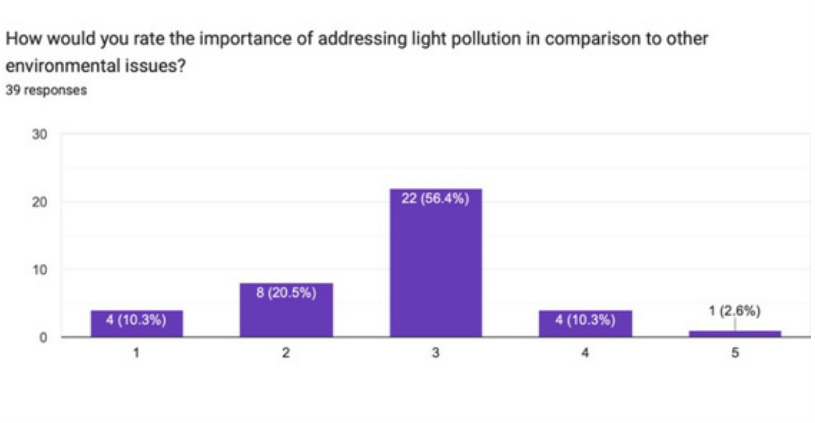


Question 13: How would you rate the importance of addressing light pollution in comparison to other environmental issues?

Respondents typically rated addressing light pollution moderately important (On the scale from 1 - Very important , 5 – Unsure; 56.4% rated "3" out of 5). This indicates that while community members acknowledge the issue's significance, it competes with other environmental priorities and might not be considered the most urgent.

Conclusion:

Community leaders should integrate the reduction of light pollution within broader environmental campaigns, highlighting its interconnectedness with other environmental issues to increase its perceived priority.

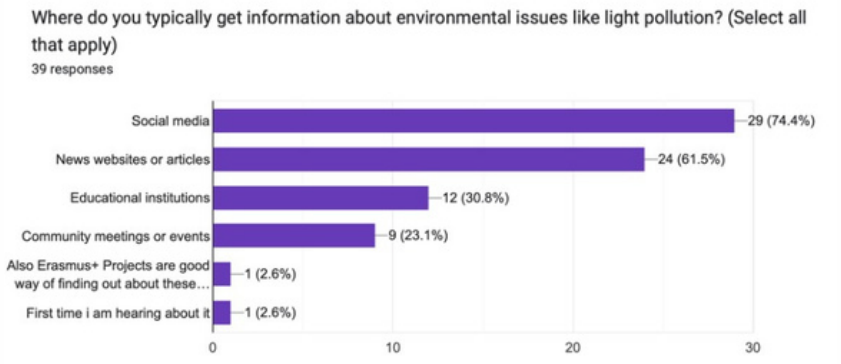


Question 14: Where do you typically get information about environmental issues like light pollution?

A significant proportion (74.4%) of respondents use diverse channels—social media, news websites (615%), and educational institutions (30,8%)—to get their environmental information. This indicates the necessity for multi-channel communication to effectively reach the entire community.

Conclusion:

Awareness campaigns should strategically leverage popular communication platforms identified by respondents, maximizing outreach and effectiveness.

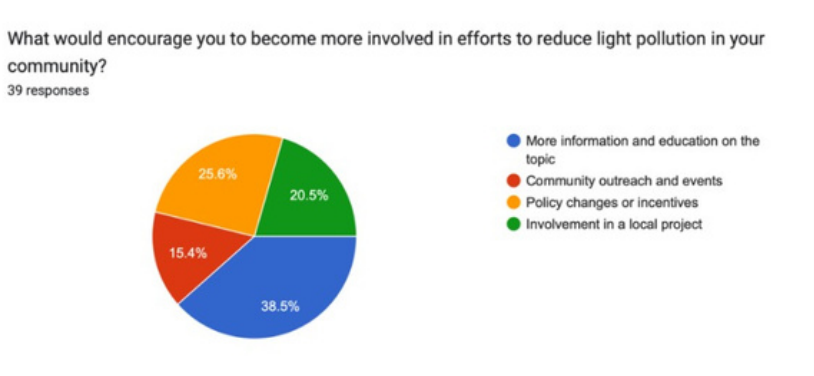


Question 15: What would encourage you to become more involved in efforts to reduce light pollution in your community?

Respondents emphasized that "more information and education" (38.5%) would notably motivate them to engage more deeply with community efforts. Clearly, education is seen as a vital catalyst for turning passive awareness into active involvement.

Conclusion:

Investing in accessible, engaging educational resources will likely yield high returns in
terms of increased public engagement and meaningful community action.



Conclusion

Overall, the community exhibits moderate-to-high awareness about light pollution and recognizes its environmental and health consequences. There is strong potential for effective engagement, especially through targeted education, improved communication about local policies, and practical community initiatives. Harnessing the existing willingness and proactive attitudes among residents through clear, informative outreach and tangible actions can significantly boost efforts to address and mitigate light pollution
in your community.

2.1.6 Conclusion

Germany has made significant strides in recognizing and addressing light pollution, yet many challenges remain. Despite regional efforts and localized policies, the absence of a comprehensive national strategy results in inconsistent implementation and enforcement across different municipalities. The adverse effects of excessive artificial lighting on biodiversity, human health, and energy consumption necessitate a more coordinated and systematic approach. The analysis presented in this report highlights the urgent need for stronger regulatory frameworks, investment in smart lighting technologies, and enhanced public awareness campaigns to mitigate the negative impact of artificial illumination on Germany's environment and society.

The Need for a Comprehensive National Policy

One of the major findings of this research is the fragmented approach to managing light pollution in Germany. While states such as Bavaria and Berlin have implemented policies to curb excessive lighting, other regions lack similar enforcement mechanisms, leading to a patchwork of regulations. Without a centralized legal framework, municipalities struggle to implement standardized measures, and businesses often find loopholes to continue excessive lighting practices (German Federal Environmental Agency, 2023).

A national light pollution law should be established to harmonize regional regulations, define clear lighting standards, and provide municipalities with the necessary resources to enforce these policies effectively.

This law should include restrictions on excessive commercial lighting, mandatory curfews for non-essential illumination, and guidelines for shielding outdoor lighting to minimize skyglow and light trespass. Countries such as France and Norway, which have introduced national policies, have successfully reduced their artificial night brightness levels while maintaining urban safety and economic activity (Nordic Environmental Research Institute, 2022).

Expanding Smart Lighting Technologies

Technological advancements in adaptive lighting, motion-sensor streetlights, and warm-colored LEDs present an opportunity to significantly reduce light pollution while maintaining energy efficiency. However, many German cities have been slow to adopt these innovations due to budgetary constraints and lack of public-private partnerships (Fraunhofer Institute for Solar Energy Systems, 2023). Research conducted by the Leibniz Institute for Astrophysics Potsdam found that replacing outdated streetlights with smart lighting solutions could result in a 50% reduction in unnecessary illumination, translating to €100 million in annual savings in energy costs (AIP, 2023).

A nationwide incentive program should be developed to encourage municipalities, businesses, and private homeowners to invest in smart lighting systems. The federal government can subsidize infrastructure upgrades, similar to energy efficiency programs in the Netherlands, where the adoption of bioluminescent and reflective road markings has significantly reduced the need for nighttime streetlights (Dutch Ministry for Infrastructure and Water Management, 2022). Encouraging investment in energy-efficient and wildlife-friendly lighting will help mitigate the long-term environmental and economic impact of excessive illumination.

Strengthening Public Awareness and Community Engagement

Public awareness remains one of the biggest obstacles in addressing light pollution. As surveys conducted by the German Federal Environmental Agency (UBA) have shown, only 35% of residents are aware of the negative effects of excessive artificial light (UBA, 2023). Without broad societal support, implementing and enforcing stricter policies will remain difficult.

Educational programs should be expanded to include school curricula, public lectures, and citizen science projects that encourage individuals to participate in light pollution mapping and monitoring. Initiatives such as the “Dark Skies for Future” project, which involves astronomy workshops and interactive exhibitions, have successfully increased public engagement in cities like Freiburg and Hamburg (Leibniz Institute for Freshwater Ecology and Inland Fisheries, 2023).

Additionally, municipalities should invest in media campaigns that highlight the benefits of reducing artificial lighting. The “Save the Night” campaign, launched by the German Federal Environmental Agency, has already demonstrated the effectiveness of television broadcasts, social media content, and interactive websites in informing citizens about responsible lighting practices (UBA, 2022). Expanding such initiatives at the local and national level will be critical to fostering long-term behavioral change.

Encouraging Corporate Responsibility and Private Sector Engagement

The private sector, particularly businesses that rely on illuminated advertising and extended operating hours, plays a significant role in light pollution levels. While some companies have voluntarily adopted dimming technologies and energy-efficient signage, a large portion of commercial lighting remains excessive due to a lack of incentives or legal restrictions (German Ministry for Economic Affairs and Climate Action, 2023).

To address this, the government should introduce corporate tax incentives for businesses that comply with low-impact lighting standards. In Hamburg, a collaboration between private corporations and city authorities has resulted in a 20% reduction in advertising brightness after midnight, demonstrating how public-private cooperation can lead to effective outcomes (Hamburg Environmental Department, 2022). Expanding such partnerships on a national scale would encourage more companies to voluntarily adopt light pollution mitigation strategies.

Final Thoughts

Germany stands at a crossroads in its approach to light pollution management. While local and regional efforts have yielded positive results, the lack of a cohesive national strategy remains a significant barrier to widespread implementation of effective solutions. By establishing a national light pollution law, expanding smart lighting technologies, increasing public awareness, and strengthening corporate accountability, Germany can take substantial steps toward reducing artificial brightness while preserving nighttime ecosystems.

Moving forward, collaborations between policymakers, scientific institutions, businesses, and community groups will be essential to ensuring that future generations can enjoy dark, star-filled skies while benefiting from sustainable urban development. With the right mix of policy reform, technological investment, and public engagement, Germany has the potential to become a global leader in responsible lighting practices and environmental conservation.

2.2 Estonia

2.2.1 Current Situation of Light Pollution in Estonia

Tallin's official, designated survey defines light pollution as referring to "the spread of light into areas or the environment where it should not reach" (Tallinn, 2023). Toomas Haidak, Deputy Head of Tallinn Urban Environment and Public Works Department, outlines a number of issues including disturbance of sleep for residents, a reduction in sky visibility, and environmental issues, harming ecosystems and disrupting circadian rhythms of people and wildlife.

Identifying and mitigating the impacts of major sources of light pollution is thus a key priority of the survey. Wider research from the University of Tartu points towards the problem of light pollution in Estonia noting the impact on melatonin production in humans and even the lifecycle and consumption of migratory bird species (Rats, 2023).

However, according to a report on the Available Information on Light Pollution in Europe, Estonia was found to be in the lowest 25% of European countries for increase in light pollution between 2014/15 and 2020/2021, with an areal increase of > 0.5 nW/cm2/sr measuring at only a 4 (Widmer et al., 2022). By comparison, the largest change was seen in Malta with a reading of 33.8, and several other countries including Belgium and the Netherlands receiving scores of over 10. By autumn of 2015, seven Estonian cities received new LED-based street lighting which may have contributed to these lower totals (Kik.ee, 2015). Haapsalu, Keila, Kuressaare, Jõhvi, Paide, Valga, and Võru received completely reconstructed lighting systems during this time. Furthermore, both Tallinn and Tartu have been members of the LUCI (Light Urban Community International) Association, the international network of cities on urban lighting, and have taken steps to ameliorate the impact of light pollution in line with this association's values and projects.

Despite this comparatively low growth compared to other European countries, TalTech Researchers have found a massive increase in light pollution following the coronavirus pandemic (ERR, 2023). For example, total light pollution in Tallinn increased by a quarter from 57866.8 nW/cm2/sr to 72759.6 nW/cm2/sr with the capital's light pollution growing three times faster than Turki in Finland and Gothenburg in Sweden. Geographically, there have been significant increases in areas with relatively high levels of light pollution including Kesklinn, Lasnamäe, and Mustamäe, and even districts with historically lower levels have begun to be affected, largely due to the construction of streetlights and real estate developments in places like Nõmme and Põhja-Tallinn.

Factors contributing to increased light pollution in Tallinn and wider Estonia include: an increase in traffic and population density; construction and renovation projects; institutions remaining open at night and in outdoor areas; the rising number of advertising screens; and even the impact of festive lighting at Christmas time and other holidays.

2.2.2 Local Government Policies and Regulations

The 2022 Light Pollution Reduction Measures in Europe report makes one thing abundantly clear: "In Estonia, there is no national policy on light pollution" (Ministry of the Environment of the Czech Republic, 2022). This is generally consistent with the lower-population EU member states, however, countries like Malta, Croatia, Sweden, Slovenia, and Slovakia have all adopted some form of legislation to combat the impacts of light pollution. Neither the NECP Estonia 2030 (National Energy and Climate Plan) nor the ENMAK (National Energy Sector Development Plan) mention the impact of (or mitigation strategies against) light pollution, preferring to focus on the economic consequences of switching to modern, energy-efficient lighting solutions.

The former plan does consider the renovation of public (central and municipal) buildings, commercial and residential buildings and street lighting as a priority but only for economic reasons, stating that by 2023, there were over 22000 renovated street lighting points across the country (Estonian Government, 2019).

That being said, the City of Tallinn outlines its own principles for city lighting which are managed through a GSM (Global System for Mobile Communication) network. This smart-city approach allows for real-time updates and maintenance and an adaptive adherence to "well-thought-out lighting [that] helps to create a safe and pleasant urban environment", as suggested by the Tallinn 2035 development strategy (Tallinn, 2020). Other lighting-related projects, including the Public Lighting Master Plan in Tartu and the installation of LED lights across the country (referred to above) focus on economic and energy-related impacts of lighting solutions which have clearly played a role in the comparatively lower increase in light pollution. Moreover, the EnlightenMe project carried out in Tartu researched the effects of indoor and outdoor lighting on population health and created links between health, well-being, lighting and socio-economic factors.

Looking at the numbers recorded by LUCI, Tallinn's switch to LEDs reduced energy consumption between 2021-2024 by 20% with the city now having over 70,000 lighting points (LUCI Association, 2024). Approximately 16,000 streetlights in Tartu are now LEDs and managed by the city's outdoor lighting management software "Valgis". This means that 96% of public lighting is now modern LEDs equipped with controllers for more accurate and efficient usage. Both Tartu and Tallinn have made thematic plans for lighting city walls, towers, and parks in line with these efficient and technological changes.

More broadly, the EU Green Deal recognises light pollution as "a pollutant of emerging concern and supports research and development through Horizon Europe" (Fetting, 2020). This is consistent with the collaboration of twenty-two international partners from ten countries (including Estonia) taking part in the Urban Lighting for Health and Wellbeing Project, funded through the European Union's Horizon 2020 Research and Innovation Programme (European Commission, 2020). Most recently, the European Light Pollution Manifesto calls for "coordinated action to reduce the negative impacts of artificial light at night (ALAN)", by recommending ways to monitor and reduce light pollution (Yakushina, et al., 2023). The manifesto makes it clear that the EU and member states should: recognise light as an environmental pollutant; create and include ambitious targets to reduce light pollution; implement a monitoring network for related issues; initiate the development and dissemination of toolkits for light pollution mitigation; promote openness, transparency, and accessibility of data concerning lighting; allocate funding and offer support for education in the field of lighting and light pollution monitoring; and initiate awareness-raising campaigns for issues surrounding light pollution. How this manifesto is enacted and how it may engender future discussion in Estonia is yet to be revealed.

2.2.3 Effective Mitigation Practices and Case Studies

The Science for Environment Policy Future Brief on Light Pollution: Mitigation Measures for Environmental Protection provides evidence of a number of successful case studies regarding light pollution mitigation (European Commission, 2023). This and a study by UCL highlight, above all else, a targeted approach to protecting specific species of wildlife or resolving specific environmental issues, with the latter study suggesting that "most of these examples involved management interventions that targeted a single species rather than an assessment at community or ecosystem levels" (Mayer-Pinto et al., 2022).

One such example involves the changing of timing and colour of streetlights during critical periods of the life cycle of nesting marine turtles. The study in Australia found that light pollution reduced the reproductive viability of turtle stocks by disrupting behaviour such as the ability of hatchling turtles to successfully reach the ocean. Attraction to artificial lights increases the time these hatchlings spent crossing areas with larger numbers of predators before reaching the safety of deeper water, thereby increasing their vulnerability. Mitigation measures and formal risk assessments on how ALAN affects marine turtles were created and a number of guidelines were put in place. These include the management of the physical aspects of the light such as intensity, colour and elevation, the maintenance of dark zones between turtle nesting beaches and light sources, and shielding light fixtures to avoid direct visibility. Such measures have shown promising results in reducing the terrestrial-aquatic impacts of light pollution.

Light pollution is also known to negatively impact seabirds in the Micronesian archipelagos of the Azores, Madeira, and the Canary Islands. Notably, when juvenile birds leave their natal colonies for the first time, they are attracted to artificial light and are disorientated. Actions decreasing light pollution during critical fledging periods and the initiative LuMinAves was designed to unite efforts across the region between 2016 and 2020. Rescue campaigns in the Azores partnered with private and public entities to turn off public lights in specific areas each year and enacted a plan to create sustainable smart lighting protocols on Madeira. Data gathered via monitoring schemes was able to inform the design of light pollution management strategies, improved energy efficiency, and reduced light pollution across the regions. As the project ended in 2020, they recorded improved impacts on ten petrel species, improved incentives for light pollution systems, and greater awareness of associated environmental problems.

Finally, Sweden implemented a road lighting decision-making process which assessed the need for a comprehensive environmental analysis and a light pollution mitigation strategy along roads under its jurisdiction. As such, road lighting or decorative lighting should be avoided outside urban areas, except for complex situations. Other requirements include: the need for luminaries to have flat glass; the maximum correlated colour temperature (referring to the colour appearance of a light source, measured in Kelvin with lower values (e.g., 2700K) indicating a warmer, more yellowish light, and higher values (e.g., 5500K) indicating a cooler, bluer light) of 3000K; requirements for luminary efficiency, limits on over-illuminated roads, allowing a maximum of 20% excess light above minimum requirements; standard night-time light reductions; and mandatory deactivation of all decorative lighting after 10pm, with no lighting permitted at wildlife passages. management.

The Swedish Transport Administration devised a lighting plan to decide on which measures to take based on contextual data which incorporates Geographic Information System (GIS) data, highlighting areas of ecological significance. Following a preliminary analysis, a decision can be reached to determine the impact on local fauna, at which point additional actions can be taken. The comprehensive attention to contextual ecological factors presents a data-rich and considered approach to light pollution which takes advantage of technological advancements in monitoring and management.

Such examples, alongside an academic report by the Proceedings of the National Academy of Sciences of the United States of America entitled 'Light Pollution is Fixable', suggest that light pollution mitigation is not only possible but relatively straightforward to implement (McDermott, 2023). The challenges of light pollution are explored in the following section.

2.2.4 Challenges and Gaps in Light Pollution Management

The primary issues associated with light pollution management is a lack of recognition of the dangers to urban populations, animal wildlife, and whole ecosystems that light pollution presents. Particularly in countries like Estonia, it has been noted that policy, urban planning, and economic development does not place enough priority on reducing the negative impacts of light pollution. The aforementioned report by UCL confirms this, stating more broadly that issues include "a lack of comprehensive understanding of the effects on wildlife and ecosystems, inconsistent and uncoordinated regulations, and a need for standardised measurement and monitoring techniques".

However, this lack of recognition is not the only barrier to effective light pollution management. UCL note the inconsistency of monitoring and understanding of how and when lighting should be defined as pollution causes discrepancies in the data. In a recent analysis, Schulte-Römer found that light pollution experts (including scientists and managers) had a stronger and more consistent view of what constitutes light pollution than lighting professionals (such as lighting designers, urban planners and engineers). Importantly, however, both groups had very skewed views when considering potential issues caused by light in areas where it is 'unwanted', depending on the habitat or realm. A lack of collaboration between different stakeholders also contributes to this inconsistency, and the compartmentalisation within governance structures generates a lack of consistency in management decisions.

Moreover, a dearth of standardised methods for modelling, measuring and monitoring light, including the use of lux meters, spectrometers, and cameras measuring light emitted directly from a source or light reflected from a surface produce inconsistent and often misleading or misrepresentative results. Such limitations, according to UCL, include "restrictions in the wavelengths they measure (i.e., they do not measure all wavelengths across the entire visible spectrum), detection limits that are not low enough to measure sky glow or intensities that elicit a biological response, highly technical instruments requiring specialised knowledge to operate and maintain, and a wide range of different measurement units."

The study also points out a need to match the scale of the intervention with the scale of impact, “light pollution impacts occur at the landscape scale, and include impacts caused by sky glow, light scattered in the atmosphere and those caused by direct illuminance from light sources (e.g., streetlights).”

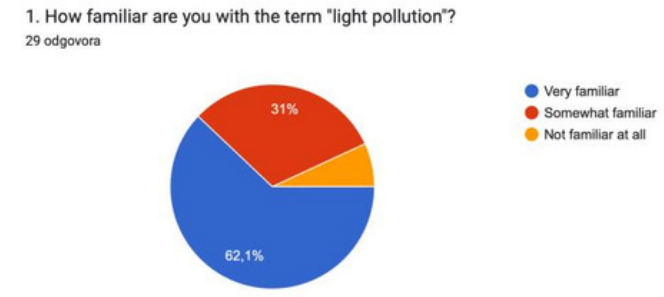
Yet another challenge relates to the understanding of specific biology and ecology of organisms and habitats of interest and their potential linkages. If light pollution mitigation is most effective when specific, it must be prefaced on a thorough understanding of its impacts. For example, aquatic insects are proposed as ideal bioindicators to assess the impact of cross-realm (aquatic and terrestrial) environmental change due to their sensitivity to anthropogenic stressors. However, we lack direct evidence to confirm how impacts from one realm may influence the other. Moreover, there is surprisingly little information regarding the specific impact of ALAN on the independent life history stages of secondarily aquatic insects: in the largest review of urban impacts on dragonflies, ALAN was not even included.

2.2.5 Community Awareness and Education on Light Pollution - Survey

In an effort to better understand how local communities in Estonia perceive and engage with the issue of light pollution, a survey was conducted among 29 participants. The primary aim was to assess their familiarity with the term, their perceptions of the issue’s relevance, and their understanding of its various manifestations and impacts. The insights gained from this survey will serve as a foundation for future educational and awareness-raising activities regarding light pollution.

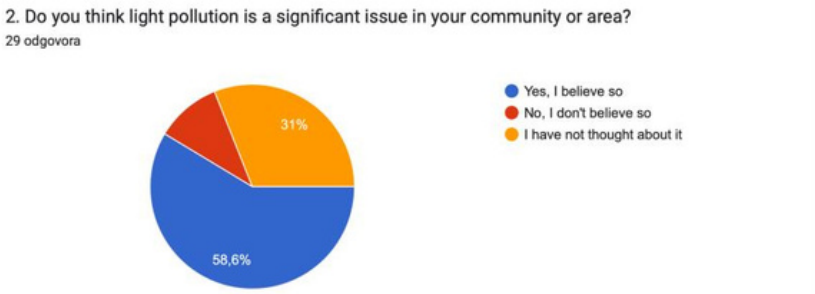
Familiarity with the term “Light Pollution”

The first question aimed to gauge how familiar participants were with the term “light pollution.” The results showed that a significant majority of respondents were already aware of the concept. 66% of participants stated they were “very familiar” with light pollution, while 28% indicated they were “somewhat familiar.” Only 6% of participants reported that they were “not familiar at all.” This suggests that light pollution is a concept that has already entered public consciousness in the community, providing a solid foundation for further discussion and action. The high familiarity rate indicates that people are generally aware of the term, making it easier to expand on the issue and its broader impacts.



Perception of light pollution as a local issue

The second question explored whether participants viewed light pollution as a significant issue within their local communities. Here, 66% of respondents agreed that light pollution is indeed a concern in their area. However, 28% stated that they had never really thought about light pollution as a problem before, and 6% did not consider it an issue at all. These responses reveal that while a majority recognizes light pollution as a problem, a substantial portion of the population has yet to fully acknowledge its presence or significance in their surroundings. This highlights an opportunity to raise awareness and stimulate further reflection on how light pollution affects both the environment and public health at the local level.

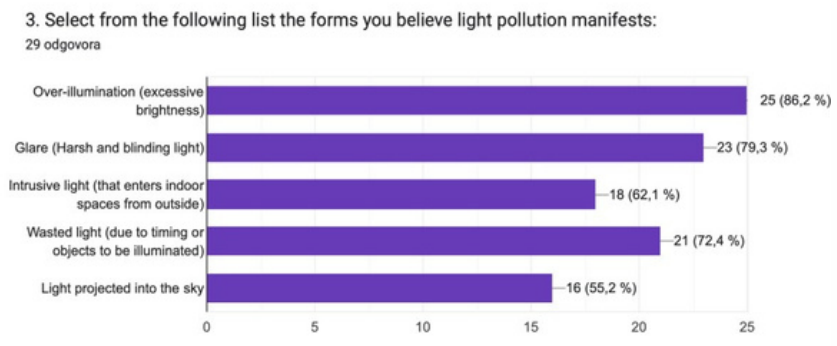


Identification of light pollution manifestations

The third question asked participants to identify the different forms in which light pollution manifests. Respondents were able to select from a range of options, and many chose multiple forms, indicating a sophisticated understanding of the issue. The most commonly cited forms of light pollution were:

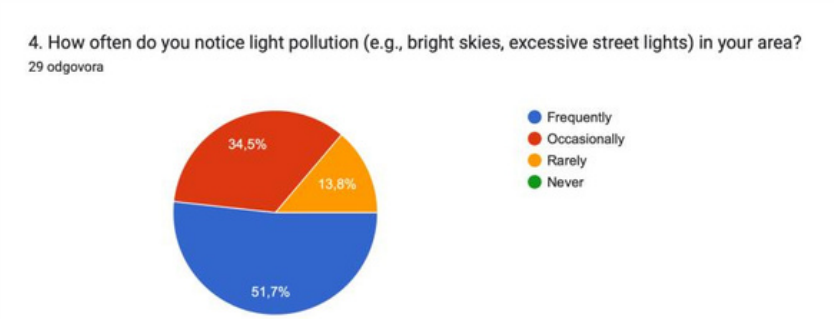
- Over-illumination (excessive brightness)
- Glare (harsh and blinding light)
- Intrusive light (unwanted light entering indoor spaces)
- Wasted light (due to poor timing or unnecessary illumination)
- Light projected into the sky (creating light domes)

These responses suggest that participants have a well-rounded understanding of the various ways light pollution can negatively impact both urban environments and natural ecosystems. The inclusion of different forms also indicates that respondents are aware of the multifaceted nature of the issue, which goes beyond a simple concern of excessive street lighting to include a range of environmental and societal effects.



Frequency of light pollution observation

The fourth question asked participants how often they notice light pollution in their local environments. Over half of the respondents (52%) stated that they observe light pollution frequently, while 31% reported noticing it occasionally. Only 17% of participants said they rarely notice light pollution in their area. These responses suggest that light pollution is a widespread and regularly encountered issue for many participants. The fact that even some respondents who didn't initially consider light pollution a significant issue still reported frequent observations indicates a potential disconnect between recognizing the symptoms of light pollution in everyday life and associating it with the term or understanding its broader impacts. This insight shows that while people may notice the effects of light pollution, they might not always make the connection between what they see and the environmental consequences.

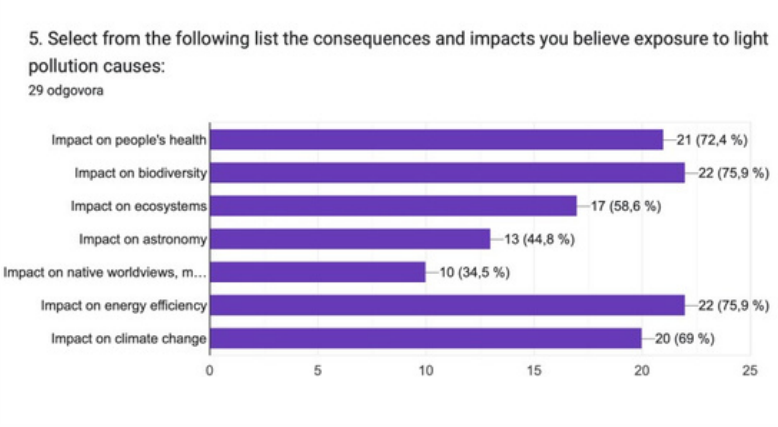


Impacts of light pollution

The fifth question in the survey explored the perceived consequences of light pollution. Participants were asked to identify what they believed were the major impacts of light pollution. The most commonly cited consequences included:

- Biodiversity and ecosystems: Many respondents acknowledged the harmful effects of artificial light on wildlife and natural habitats.
- People's health: Health issues such as sleep disruption, stress, and potential long-term effects were frequently mentioned.
- Energy efficiency: A number of participants recognized the role of light - pollution in wasting energy, contributing to inefficiency.
- Climate change: Some respondents linked light pollution to broader environmental concerns, such as its contribution to climate change.

Additionally, respondents noted impacts on astronomy, particularly the obstruction of night sky visibility, as well as cultural and societal disruptions, including the loss of connections to natural cycles and cultural heritage. This suggests that participants are not only aware of the environmental and health impacts but are also thinking systemically, understanding light pollution's far-reaching effects on ecosystems, human well-being, and even cultural traditions.

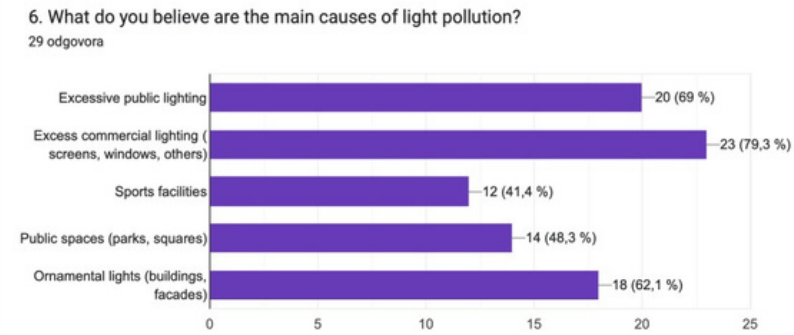


Perceived causes of light pollution

Participants were also asked to identify the primary causes of light pollution in their local environments. The responses highlighted several key contributors:

- Excessive public lighting, particularly street lamps that remain brightly lit at night.
- Commercial lighting, including lights from illuminated signs, windows, and screens.
- Ornamental and architectural lights used for aesthetic purposes, often without consideration for environmental consequences.
- Lighting in sports facilities and public spaces that remains active even when these areas are not in use.

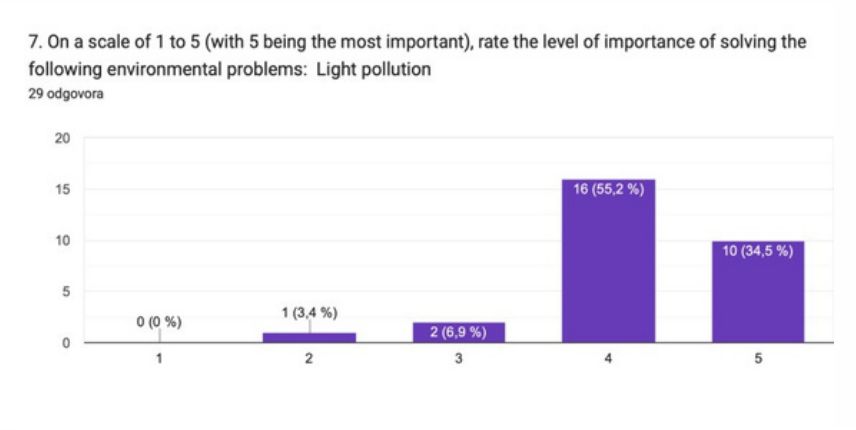
These answers point to a clear recognition that light pollution is often the result of over-illumination linked to urban infrastructure and commercial activity. It also suggests that light pollution is not merely a consequence of one sector but rather the result of a combination of factors, from public lighting to cultural habits related to aesthetics and safety.

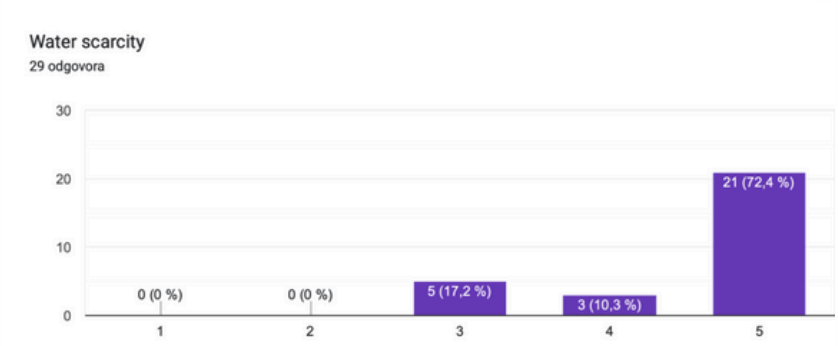


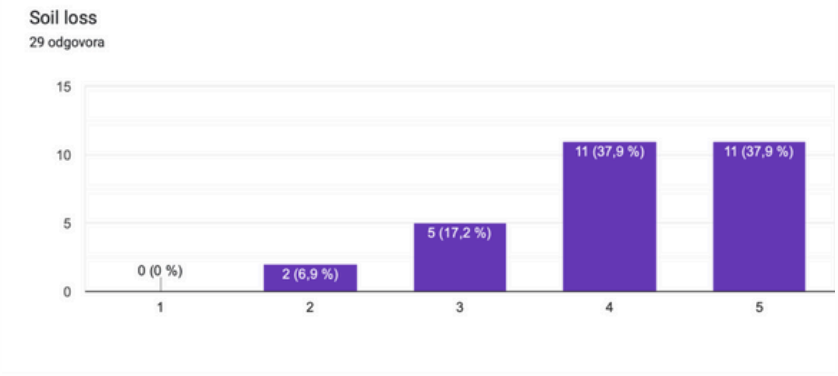
Importance of light pollution compared to other environmental issues

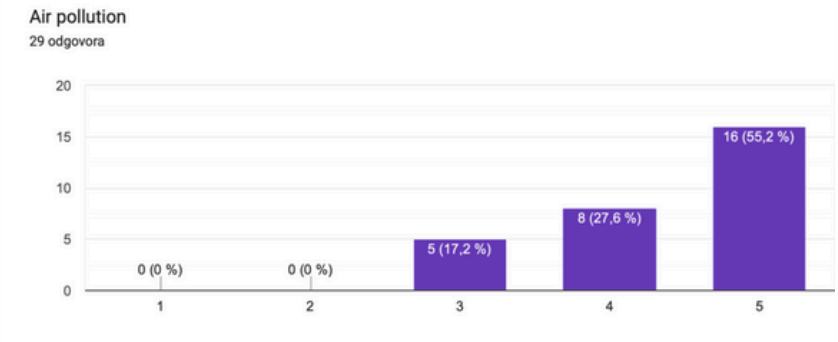
In the seventh section, participants were asked to rate the importance of various environmental issues, including light pollution. The responses indicated a high level of concern for light pollution, with most participants rating it as 4 or 5 on a scale of 1 to 5, with 5 being the most urgent. Several participants rated it as a 5, highlighting its significance.

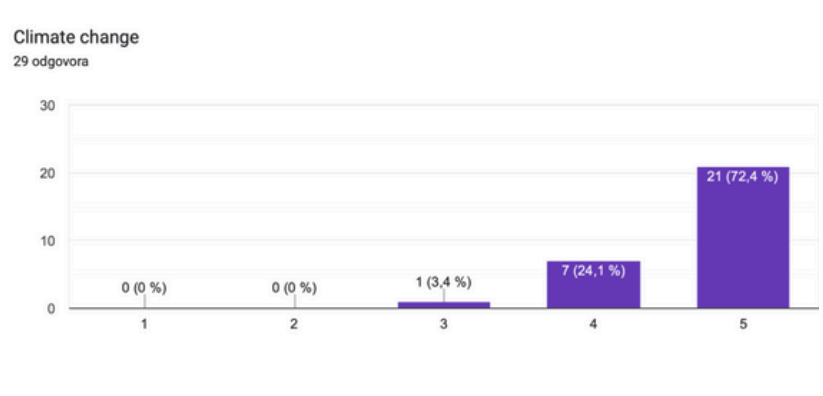
When compared to other environmental issues such as water scarcity, soil loss, climate change, and noise pollution, water scarcity received the highest average ratings, signaling its widespread recognition as a critical concern. Climate change and soil loss were also rated highly, while noise pollution garnered more varied responses, with some participants considering it less urgent.

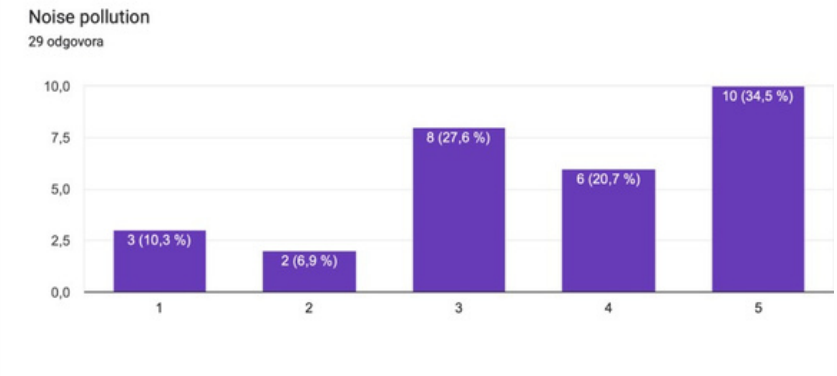










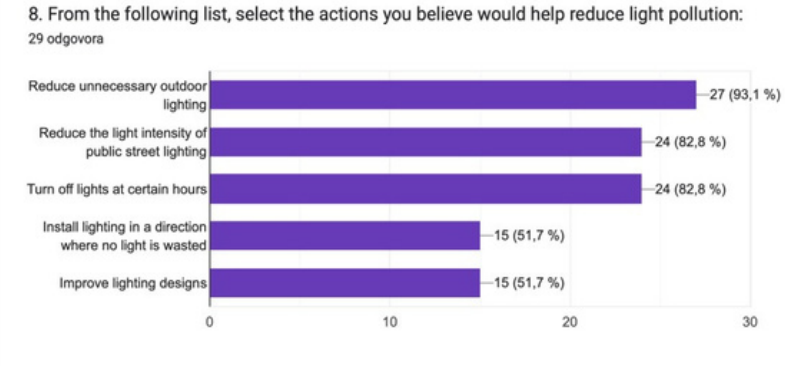


Actions to mitigate light pollution

The survey also asked participants to suggest actions that could reduce light pollution in their communities. The most frequently mentioned measures included:

- Reducing unnecessary outdoor lighting and lowering the intensity of street lights.
- Turning off lights during certain hours.
- Improving lighting designs to minimize waste and ensure that light is directed only where needed.

These responses reveal that participants prefer practical and actionable solutions that focus on reducing light usage while still maintaining safety and functionality. Additionally, the emphasis on improving lighting design and directing light efficiently indicates a desire for long-term, systemic changes in how lighting is approached in public spaces.

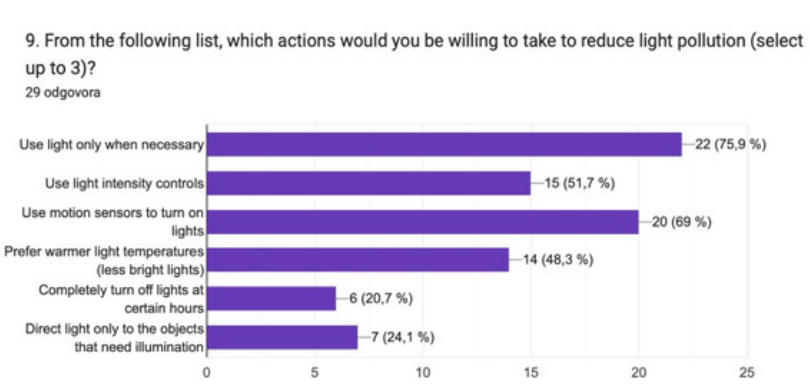


Willingness to take action

Finally, when asked about their own willingness to take action to reduce light pollution, the most common responses involved:

- Using light only when necessary.
- Using motion sensors to control when lights are activated.
- Preferring warmer light temperatures to reduce brightness.
- Completely turning off lights at certain hours.

These answers reflect a widespread desire among participants to adopt more mindful and energy-efficient lighting practices. The preference for solutions that minimize light usage without compromising functionality further underscores the respondents' interest in practical, low-effort ways to reduce light pollution.



Conclusion and key insights

The survey results suggest that Estonian communities are generally aware of light pollution, with many participants recognizing its environmental, health, and cultural impacts. There is a clear understanding of the causes, manifestations, and consequences of light pollution, although there remains room for deeper engagement, particularly around its broader implications. Respondents expressed a strong preference for practical actions, such as reducing unnecessary lighting and improving lighting design, while also showing willingness to adopt personal habits to reduce light pollution.

Key motivators for increased participation in light pollution reduction efforts include access to more information, opportunities for community involvement, and policy changes that incentivize action. The survey indicates that a combination of education, grassroots community engagement, and systemic policy support will be crucial to fostering widespread action. By focusing on these areas, local efforts to mitigate light pollution can gain greater traction, leading to more sustainable and meaningful changes in communities across Estonia.

2.2.6 Conclusion

Evidence from contemporary studies on Estonian and European light pollution suggest that efforts to increase the energy efficiency of urban lighting combined with technological approaches to manage the timely and effective use such lighting have resulted in Estonia having one of the lowest growths in overall light pollution in the EU since 2014.

It must be noted, however, that a significant rise in light pollution since the coronavirus pandemic, both in high-risk and previous unaffected areas, has created a need for thought-out, strategic intervention. Given this recent increase, the lack of relevant policy regarding light pollution places Estonia behind several fellow EU member states and makes incorporating ecologically-aware practices for urban and rural lighting a priority.

Successful case studies show promising signs for targeted light pollution mitigation strategies which take into account contextual ecological data and reporting. However, associated challenges, including the way in which light pollution is measured and recorded, make a case for further research defining the issues and measurement standards across the country or the EU as a whole.

2.3 Croatia

2.3.1 Current Situation of Light Pollution in Croatia

Light pollution in Croatia has increasingly moved from a niche concern of astronomers to a broad environmental issue over the past decade. Recent data indicate a clear upward trend in night sky brightness across the country, especially around urban areas. For example, long-term measurements around Zagreb show that night sky brightness has been rising by about 1.7% per year in rural sites and 1.8% per year in urban sites, with even faster increases (around 3.7% per year) at suburban locations (researchgate.net). This corresponds to sky brightness doubling in only two decades in some areas. Such findings confirm earlier observations that light pollution has been growing, particularly on the outskirts of major cities, consistent with the expansion of highways, industrial zones, and suburban development since the 1990s.

National studies (e.g. Čelebićanin 2021) also link these trends to infrastructure development modern motorways and associated commercial hubs tend to amplify local illumination, and new suburban settlements contribute to increased skyglow. In essence, while Croatia still has some dark areas, the overall trajectory is one of intensifying brightness, especially in and around cities. There are significant regional differences within Croatia in terms of light pollution intensity. Surveys across 20 locations found that most sites had moderate light pollution, but mountain and highland regions such as Gorski Kotar and Lika report minimal levels. These sparsely populated areas remain relative refuges of darkness. In contrast, coastal tourist centers and big cities like Zagreb, Split, and Dubrovnik are among the brightest, with extensive nighttime lighting for tourism and safety (e.g. waterfront promenades, historic monuments) contributing to higher skyglow .

Urban areas are unquestionably the primary sources of light pollution out of more than 6,500 settlements in Croatia, the 143 officially urban settlements generate a disproportionate share of upward light . On average, Croatian cities have been measured to be five times brighter than a comparable city in Central Europe (Augsburg, Germany) . Even some smaller towns can produce significant light spill into the night sky if lighting is poorly managed. By contrast, many rural villages and Adriatic islands have much lower levels of artificial light at night. The urban–rural gap is evident: satellites and ground measurements show that while major city centers regularly experience sky brightness on the order of 15–30× natural dark-sky levels, remote rural locales often remain near natural darkness at zenith (with only localized glows from distant cities on the horizon) . This dichotomy underscores the need for tailored approaches – preserving darkness in low-impact areas while curbing excess in hotspots. In an international context, Croatia's situation reflects broader global challenges. Europe is among the most light-polluted continents, and it is estimated that over 60% of Europeans live in areas where the Milky Way is no longer visible (darksky.org). Croatia is no exception – in its densely populated regions, the Milky Way has largely vanished from the night sky. According to the New World Atlas of Artificial Night Sky Brightness, 99% of Europe's population (including Croatia's) lives under some level of light-polluted sky . Recent assessments even suggest that light pollution may be increasing faster than previously thought: a 2023 global study found the night sky brightness has been growing by ~9–10% per year (in terms of star visibility loss) over the last decade , far outpacing earlier satellite-based estimates of ~2% per year. This divergence is partly due to the rapid adoption of LED lighting, whose blue-rich emissions are not fully captured by satellites but greatly affect human perception of skyglow . In Croatia, the shift to LED street lighting (often in the 4000K range historically) has saved energy but, when misapplied, can contribute to harsher skyglow because blue light scatters more in the atmosphere . The net effect is that without intervention, light pollution could double in less than a decade, eroding Croatia's starry nights even in areas that once had pristine skies . It is especially telling that the night sky above Zagreb is now brighter than the skies of many larger world cities, surpassing even Vienna, Budapest, Hong Kong – and reportedly outshining Las Vegas (vijesti.hrt.hr). This startling comparison, confirmed by measurements in 2023, highlights how intense and unregulated urban lighting has become in the Croatian capital. The renowned astronomer Korado Korlević notes that such measurements "always took us aback," emphasizing that excessive illumination has made Zagreb's sky an outlier in its brightness . The implications for ecology and human health are serious, as overly bright nights disrupt wildlife behavior, confound migratory patterns, and interfere with human circadian rhythms (total-croatia-news.com).

The level and changes in light pollution in the center of Zagreb and its suburban areas between 2014 and 2017 were investigated by Pavlić and Andreić (2020). The main conclusion of this study is that the increase in light pollution was more significant in the suburban areas of Zagreb compared to the city center. In his master's thesis, Čelebićanin (2021) conducted a study aimed at analyzing changes in light pollution in the period from 1992 to 2018. The study confirmed several hypotheses proposed by the author, namely: the development of transport infrastructure, particularly modern motorways, especially through regions such as Gorski Kotar, Lika, Dalmatia, and Slavonia, contributes to a local increase in light pollution in settlements located near motorway junctions; industrial and business zones constructed near these junctions and settlements, as well as economic activities along the motorways (e.g., rest stops with petrol stations and hospitality

facilities), partially contribute to the rise in light pollution; and processes of suburbanization and the emergence of satellite settlements lead to an increase in local light pollution. The analysis results indicate a growing trend of light pollution in the outskirts of cities, especially larger urban centers such as Zagreb and Split. This is also evident in the expansion of zones with high light pollution since the beginning of measurements in the vicinity of smaller, regional centers. Bakarić (2024), in his final thesis, highlights the impact of light pollution on tourism in Croatia, particularly in coastal areas that are popular tourist destinations. He emphasizes that coastal cities such as Dubrovnik, Split, and Rovinj are often characterized by intense nighttime lighting, which contributes to light pollution. This artificial light can diminish the appeal of the night sky for visitors seeking dark-sky experiences, such as stargazing or enjoying moonlit landscapes. Furthermore, Zagreb was awarded the title of the best Christmas market in Europe for three consecutive years (2016, 2017, and 2018), confirming its status as a top-tier winter holiday destination. This recognition reflects the city's outstanding organization and festive atmosphere, which includes beautifully decorated squares, traditional Christmas markets, a rich cultural program, and a wide variety of culinary delights. The Advent in Zagreb attracts visitors from around the world who come to enjoy the magical ambiance and holiday spirit that fills the city. In 2023 alone, more than 6 million lights illuminated Zrinjevac Park. While it is reassuring that all the lights were energy-efficient LED bulbs, this still represents an immense amount of lighting. Although this is a positive step in terms of energy efficiency, the increasing level of light pollution in urban areas raises concerns about the long-term sustainability of tourism. Excessive illumination during the Advent season and other holidays can contribute significantly to light pollution, negatively affecting the quality of the night sky, human health, and ecosystems. Over-illumination can disrupt natural sleep patterns in humans, interfere with nocturnal wildlife, and lead to ecological imbalances.

To mitigate the adverse effects of light pollution on tourism in Croatia, it is essential to implement measures to control and reduce lighting intensity in tourist areas. These measures could include the use of low-emission lighting sources, directing light downward to reduce skyglow, and promoting awareness about the importance of preserving natural nighttime darkness as a valuable tourism asset. The preservation of the natural environment and the night sky is crucial for the long-term sustainability of tourism in Croatia. Croatia faces a growing challenge: balancing the benefits of illumination (safety, tourism, lifestyle) with the urgent need to protect its night environment. The current situation calls for informed action to prevent further loss of the country’s natural night darkness.

2.3.1 Current Situation of Light Pollution in Croatia

The Law on Protection from Light Pollution (Official Gazette, No. 14/19).

This law regulates the principles of light pollution protection in Croatia, defining the responsible entities and the standards for managing artificial lighting. It aims to reduce the consumption of electricity and other energy sources through regulated lighting practices. The law establishes specific protective measures against excessive illumination, introduces restrictions and prohibitions related to light pollution, and outlines guidelines for the planning, maintenance, and reconstruction of lighting infrastructure. Additionally, it defines the responsibilities of manufacturers of lighting products.

Regulation on Lighting Zones, Permissible Illumination Values, and Lighting System Management Methods (Official Gazette, No. 128/20)

This regulation prescribes mandatory methods and conditions for managing lighting systems. It defines lighting zones, protective measures, and the maximum permissible values of illumination. Furthermore, it sets conditions for selecting and installing luminaires, includes energy efficiency criteria, specifies the highest allowable correlated color temperatures for light sources, and promotes the use of environmentally friendly lighting.

Regulation on the Measurement and Monitoring of Environmental Illumination (Official Gazette, No. 22/23)

This regulation defines the methodology for measuring environmental illumination levels, the content and format of reports on conducted measurements, and the procedures for determining illumination intensity in outdoor spaces. It establishes clear standards for assessing the extent of artificial lighting in the environment, which is essential for monitoring and mitigating light pollution.

Regulation on the Content, Format, and Preparation of Lighting Plans and Action Plans for the Construction and/or Reconstruction of Outdoor Lighting (Official Gazette, No. 22/23)

This regulation sets out the required content, format, and submission process for lighting plans and action plans related to the construction or reconstruction of outdoor lighting systems. It also defines procedures for informing the public about such plans, outlines how data must be submitted to the Environmental and Nature Protection Information System, and addresses other relevant issues concerning planning and transparency in outdoor lighting development.
Enforcement, however, remains a critical challenge. The national law officially took full effect in February 2023, when the last of the implementing ordinances came into force . At that point a one-year countdown began for all cities and municipalities to adopt their local Lighting Plans. By early 2024, every local government must draft a Lighting Plan, and thereafter they have up to 11 years to retrofit or replace non-compliant outdoor lighting infrastructure to meet the new standards . While this extended timeline (a transition period until 2034) gives communities time to budget and implement changes, it also reflects the scale of adjustments required. The law's success will depend on diligent follow-through: enforcing the shielding of lights, lumen caps, and curfews where mandated. Some concerns have been raised about the capacity for enforcement local utility inspectors and environmental wardens have to be trained to recognize violations, and the Environmental Protection Inspectorate needs resources to handle the workload . Initial indications show uneven progress; larger cities like Zagreb are actively working on compliance plans , whereas smaller municipalities may lag due to limited technical expertise.

Nevertheless, Croatia's legislative framework is now largely in place, aligning with European best practices, and if implemented effectively it could substantially reduce excessive lighting. Neighboring countries offer cautionary tales and motivation: Slovenia, for instance, passed a national light pollution law back in 2007 but found that continuous updates and strict enforcement (including fines) were necessary to make it effective (eionet.europa.eu). Croatia's focus in the coming years will be on turning its robust policies on paper into darker skies in practice, through persistent enforcement and public cooperation.

2.3.3 Effective Mitigation Practices and Case Studies

Croatia has begun to showcase successful examples of light pollution mitigation, both through city-led initiatives and the creation of dark-sky protected areas. These case studies demonstrate how policy and practice can converge to produce positive outcomes, and they provide models that can be replicated elsewhere in the country. Below we highlight several notable efforts in urban settings, rural parks, and even internationally that serve as inspiration for reducing light pollution while balancing social and economic needs.

City of Rijeka

One pioneering effort is Rijeka's large-scale modernization of its public lighting system, aimed at improving energy efficiency and cutting light pollution. By the end of 2023 (Phase I of the project), Rijeka had replaced over 13,500 street lamps with new high-efficiency LED fixtures, about 85% of all public lights in the city . These LED luminaires are fully compliant with Croatia's light pollution law, featuring proper shielding and optics that direct light downward. The city invested around €663,620 from its municipal budget for this first phase . Early results are promising: the modern LEDs provide the same illumination on the ground with far less upward waste light, thereby reducing skyglow. Rijeka's project, executed by the city-owned utility Energo, is phased over several years and is expected to significantly curb excessive lighting. In fact, preliminary measurements show reduced night sky brightness in neighborhoods where old fixtures were replaced, indicating a tangible drop in light pollution (while also achieving energy savings) . It's noteworthy that Rijeka took care to comply with heritage considerations, about 15% of fixtures (mostly decorative historic lamps in areas like Korzo and Trsat) were left out of this phase due to monument conservation restrictions . Those will be tackled with special solutions later. Overall, Rijeka stands as a leading domestic example of how a city can proactively align with national legislation and demonstrate environmental leadership. Its success provides a template (and confidence) for other Croatian cities to upgrade lighting infrastructure in a way that both saves energy and restores the night sky.

Jelsa – First International Dark Sky Community in Croatia

Another success story comes from the small municipality of Jelsa on the island of Hvar, which has garnered international recognition for its commitment to dark skies. In 2022, Jelsa was designated as the first International Dark Sky Community (IDSC) in Croatia – in fact, in all of Southern Europe . This designation, awarded by the International Dark-Sky Association, reflects Jelsa's exceptional dedication to preserving the night environment. The community, including Jelsa town and surrounding villages, implemented a quality outdoor lighting ordinance that strictly controls glare and spill light. Over the past few years, the local government (in collaboration with the Croatian Astronomical Union) retrofitted street lights with fully shielded, low-color-temperature lamps, and removed or adjusted floodlights that were lighting the sky instead of the ground. They also ran public education campaigns about the importance of darkness for wildlife and stargazing tourism. These efforts paid off: Jelsa achieved IDSC status as the 37th such community worldwide, setting "a high standard for other communities in the country and region to follow," according to IDA's Director of Conservation . The town now serves as a model that even larger cities can learn from demonstrating that enforcing smart

lighting (like turning off or dimming lights in the late night, using warm-tone LEDs, and shielding fixtures) can coexist with tourism and safety needs. Jelsa's dark-sky certification has also become a selling point for eco-conscious tourists, showing the economic benefit of protecting the night sky. Its leadership underscores how local initiative and community support are key ingredients in the fight against light pollution.

Lastovo Island – Preserving a Night Sky

In the Lastovo Archipelago, a remote Adriatic Island group known for its stunningly clear night skies, a concerted effort has been made to safeguard this natural asset. Lastovo has long been celebrated by astronomers as having one of the darkest skies in Europe (measured at a Bortle class 2 on the darkness scale). To combat creeping light pollution, the island undertook a project to replace all old public lighting with eco-friendly designs. A total of 235 new street lamps were installed across Lastovo, each carefully selected to significantly reduce light spillage upward (lastovo.org). The new lamps have full cut-off fixtures directing light only toward the ground and use bulbs with a lower brightness and color temperature. This island-wide retrofit, essentially completed in the 2010s, was driven by the local Nature Park authority with support from the Ministry of Environment. It came after surveys noted an increasing glow in the sky due to a few poorly directed floodlights (even a single mis-aimed lamp on a church had noticeably brightened the sky by 2009) . By acting early to "rescue the starry sky" of Lastovo , the community managed to reverse the trend and restore truly dark nights. The payoff is immense: not only is biodiversity (like nocturnal birds, bats, and sea turtles) better protected on this island, but Lastovo has capitalized on Astro tourism. Stargazing events and "Lastovo Island of Stars" programs attract visitors, leveraging the pristine night as a natural resource. This case exemplifies how even small communities can implement lighting overhauls with big environmental returns, and it complements Croatia's Dark Sky Parks by adding an island locale to the map of protected night environments.

Dark Sky Parks – Papuk and Petrova Gora

Croatia has also joined the international movement of establishing Dark Sky Parks/Reserves to protect natural nocturnal habitats. Notably, the country now boasts two certified dark-sky sites recognized by DarkSky International. The first is Vrani Kamen Dark Sky Park, located on the slopes of Papuk Mountain in Western Slavonia. Designated in 2019 with a Gold Tier status, Vrani Kamen covers about 80 km² of forest land near Daruvar . In this area, strict measures ensure that local municipalities limit light pollution streetlights are retrofitted, and outdoor lighting in villages is minimized or curfewed. The park offers an exceptional star-viewing experience; on a clear night the Milky Way arches brightly, and thousands of stars can be seen due to the very low skyglow. The second site is Petrova Gora-Biljeg, a hilly, forested landscape near Karlovac and Zagreb, also designated in 2019. Petrova Gora faced threats from nearby Zagreb's light dome, but coordinated efforts by several municipalities and astronomy enthusiasts led to changes such as installing motion-sensor lights at facilities and shielding lamps at a military base on the mountain. Now, both Vrani Kamen and Petrova Gora have become hubs for education and Astro tourism, they host public stargazing events, astrophotography workshops, and school field trips to learn about astronomy and the importance of darkness .

These parks are part of a network of just over a hundred Dark Sky Parks worldwide . They highlight how environmental protection can go hand-in-hand with sustainable tourism and community engagement. By preserving large areas of natural darkness, Croatia not only safeguards wildlife (many nocturnal species thrive in these parks) but also creates unique destinations that diversify tourist offerings beyond the usual sun-and-sea. The success of Papuk and Petrova Gora is encouraging other nature parks in Croatia to consider dark-sky certifications, potentially expanding the dark sky network.

2.3.4 Challenges and Gaps in Light Pollution Management

Key challenges in managing light pollution in Croatia include issues such as excessive and poorly planned lighting, weak enforcement capacity, and negative environmental and health impacts (Glavaš, 2021).

- Excessive and inadequate lighting: There is a growing trend of intense illumination along highways, rural roads, promenades, and bike paths. Strong lighting is often used unnecessarily, significantly contributing to light pollution.
- Lack of training and inspection resources: Although the Law on Protection from Light Pollution was adopted in 2019 and fully enforced as of 2023, its implementation faces obstacles. Municipal officers are often not adequately trained, and the Environmental Protection Inspectorate operates with limited capacity, slowing down responses to violations.
- Traffic safety concerns: Bright lighting on roads can cause glare and temporary blindness when drivers transition from lit to darker zones, increasing the risk of accidents.
- Health and environmental impact: Artificial lighting at night disrupts natural rhythms, potentially leading to sleep disorders, elevated stress levels, and other health problems. Additionally, light pollution can disturb ecosystems, affecting animal behavior and migration patterns.

Croatia has recognized the growing environmental and societal threat posed by light pollution, yet significant challenges persist in effectively managing this issue. Although substantial legislative progress was made with the adoption of the Law on Protection against Light Pollution (NN 14/19), which requires local governments to develop Lighting Plans to reduce excessive illumination, practical implementation has faced considerable obstacles (darksky.org). One of the primary challenges involves compliance and enforcement. Many municipalities have encountered difficulties due to insufficient technical knowledge and a lack of trained personnel. This shortage has resulted in delays or ineffective implementation of required Lighting Plans, creating a gap between policy and practice (darksky.org). Furthermore, despite awareness campaigns, there remains limited public understanding regarding the negative impacts of light pollution, leading to reduced community engagement and cooperation. Another notable gap lies in the widespread adoption of energy-efficient LED lighting solutions. Although LEDs significantly reduce energy consumption, their inappropriate use has inadvertently increased the level of light pollution. Specifically, the blue-rich spectrum emitted by LEDs contributes to higher levels of skyglow and disruption of ecosystems, emphasizing the need for more rigorous technical guidelines and training on responsible LED application (darksky.org). Geographically, Croatia experiences uneven levels of light pollution management.

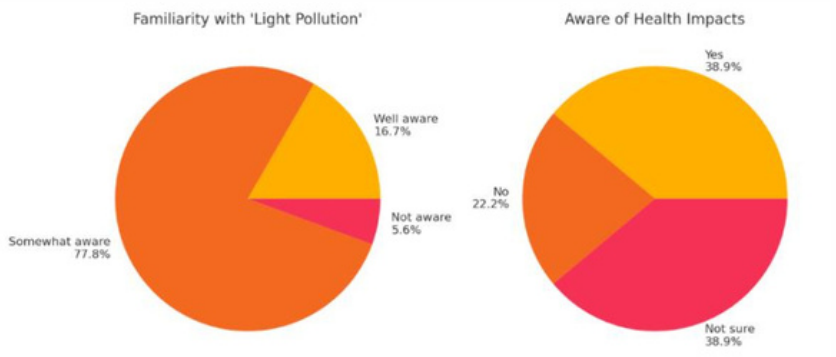
While some regions, such as remote islands or protected mountainous areas in Lika and Gorski Kotar, exhibit lower pollution levels, urbanized coastal and continental areas continue to struggle with excessive and poorly managed illumination (researchgate.net). This spatial imbalance reflects resource disparities among local authorities, with smaller municipalities often lacking the financial means or expertise to adequately address the problem. Despite these issues, Croatia has made noteworthy progress through initiatives such as the establishment of the Vrani Kamen Dark Sky Park, internationally recognized with a Gold Tier status. Such projects provide positive examples of how sustainable management of nightscapes can offer economic and ecological benefits, enhancing local tourism through Astro tourism initiatives (darksky.org).

Although Croatia has taken meaningful steps toward managing light pollution through policy development and the establishment of exemplary projects, persistent gaps remain regarding compliance, public education, technical expertise, and equitable resource distribution. Continued investment in capacity-building, community engagement, and clearer technical guidelines will be crucial to bridging these gaps in the future.

2.3.5 Community Awareness and Education on Light Pollution - Survey

The VET EcoLume survey in Croatia (conducted in 2025) aimed to gauge public awareness, concerns, and behaviors regarding light pollution at the local community level. This analysis interprets the survey's percentage results, revealing what they say about public understanding and engagement with light pollution in Croatia. Key findings and trends are highlighted, supported by graphs for clarity, and discussed in the context of Croatian communities.

Awareness and Knowledge of Light Pollution



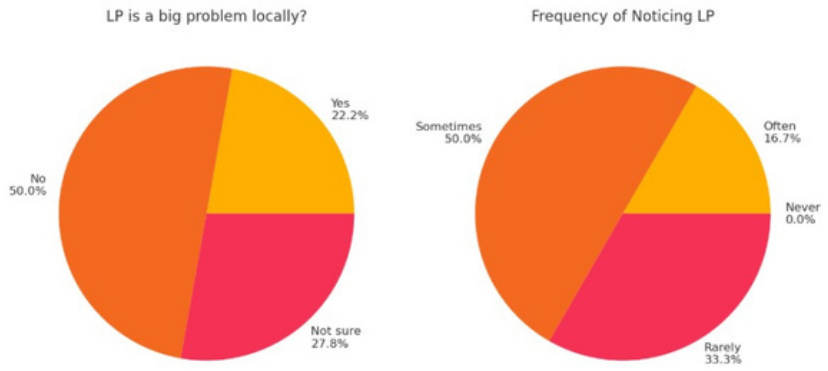
The survey indicates that awareness of the concept of light pollution is relatively high among respondents, though depth of knowledge varies. About 94% have at least heard of "light pollution," with 77.8% "somewhat aware" and 16.7% "well aware." Only one respondent (5.6%) had never heard the term. This suggests that basic familiarity is widespread, aligning with prior research finding that general awareness among Croatian youth is relatively high (Sensitivity of Croatian High School Students to Light Pollution). However, deep understanding is limited – fewer than one in five feel well-informed about the issue.

Knowledge of specific impacts is more uneven. Only 38.9% responded that they are aware of light pollution's harmful effects on human health, while an equal share (38.9%) said they are "not sure." About 22.2% admitted they are not aware of any health impacts. This implies moderate public understanding that light pollution can affect human well-being (for example, through disrupted sleep cycles or other health issues), but a large portion of people lack clear information or certainty. The substantial "not sure" group highlights a knowledge gap regarding health consequences.

Awareness of official policies on light pollution is very low. Only 22.2% said they are aware of any local policies or regulations to reduce light pollution, whereas half (50%) responded "No" and 27.8% "Not sure." In other words, over 77% of respondents were unaware of any local rules addressing light pollution. This is notable given that Croatia has been cited as having advanced national light pollution laws (). The public's lack of awareness suggests that these policies or their local implementations are not well-publicized or that community members have not been effectively informed. It points to a disconnect between policy and public knowledge.

Encouragingly, respondents recognize the need for education. Two-thirds (66.7%) believe that education about light pollution should be included in school curricula and community programs, with only 11.1% opposed and 22.2% unsure. This strong support for formal education on the topic reflects an understanding that public awareness needs improvement. In summary, most people in the surveyed Croatian community have heard of light pollution and consider it important to learn about, but detailed knowledge (especially regarding health effects and policy measures) remains limited. This highlights an opportunity for public education initiatives, as also evidenced by the respondents' support for integrating light pollution topics into schools.

Perceptions of the Problem and Concern



2.3.5 Community Awareness and Education on Light Pollution - Survey

Despite broad awareness of the term, only a minority of respondents view light pollution as a "big problem" in their own community. Just 22.2% answered "Yes" when asked if light pollution is a significant problem in their area. In contrast, half of the respondents (50.0%) answered "No," indicating they do not consider it a major local issue, and another 27.8% were uncertain.

This suggests that while the concept of light pollution is known, many people in this Croatian sample do not perceive urgent light-pollution problems in their immediate surroundings. It may be that in their communities, other environmental issues are seen as more pressing, or the effects of light pollution are not acutely felt day-to-day.

Nonetheless, nearly everyone reports some experience with the effects of light at night. All respondents notice light pollution at least on occasion – 16.7% said they notice it "often," 50.0% "sometimes," and 33.3% "rarely." Tellingly, 0% answered "never" to noticing phenomena like overly bright streetlights or a washed-out night sky. This indicates that even if many do not label it a "big problem," light pollution is a visible part of everyday life for the community. Half of the respondents sometimes see signs of light pollution, suggesting moderately frequent encounters (for example, seeing the night sky obscured by city glow or experiencing glare from poorly directed lamps). Only one-third notice it rarely. In essence, the issue is present in the environment, but not always recognized as severe.

There is a slight paradox in the perceptions: respondents experience the symptoms of light pollution frequently, yet a majority do not consider it a serious local problem. This could mean that some impacts (like a bright sky) have been normalized or are not viewed as harmful. It might also reflect that respondents differentiate between observing light pollution and ranking it among top community problems. Indeed, when asked to rate the importance of light pollution relative to other environmental issues, the concern is evident – over 94% of respondents rated it as a moderate to very important issue. On a scale of 1 (not important) to 5 (very important), nobody rated light pollution as unimportant; 61.1% chose 4 and 33.3% chose the maximum 5, indicating that virtually all respondents acknowledge light pollution as an important environmental concern in general. Only one person (5.6%) gave a middling rating of 3, and none rated it 1 or 2. This trend shows that while they may not see it as a pressing local problem, they do understand that light pollution matters as an environmental topic (perhaps more on a national or global scale).

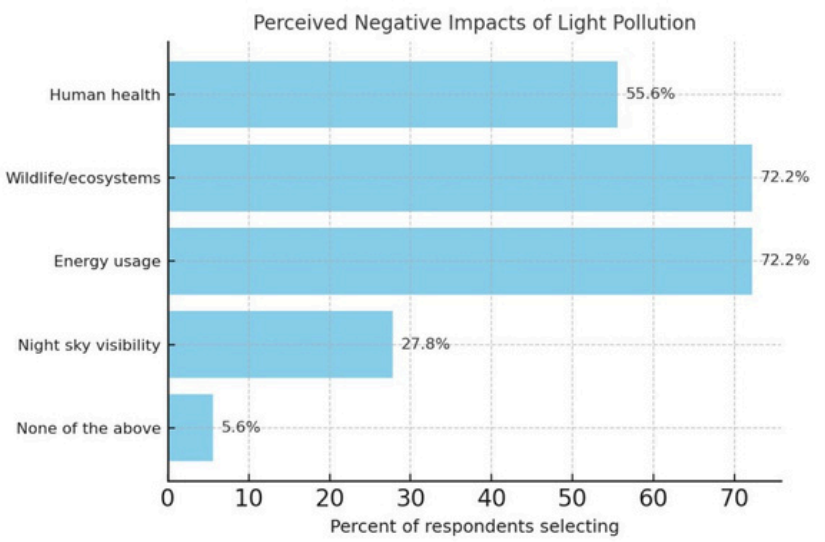
Furthermore, a large majority recognize ecological concerns related to light at night. About 78% of those surveyed believe light pollution affects local wildlife (such as nocturnal animals). Only 16.7% thought it does not impact local fauna, and 5.6% were unsure. This high level of agreement (consistent with many selecting wildlife as impacted, discussed below) demonstrates considerable awareness of light pollution's potential harm to ecosystems. It suggests that people are concerned about issues like birds, insects, or other animals being disoriented by artificial lighting. In summary, the community acknowledges light pollution as an important environmental issue and notices its effects regularly, but many do not yet frame it as a major problem in their own community. This may indicate a need to translate general concern into local action, by helping people connect broad environmental importance with their local context.

Perceived Causes and Impacts of Light Pollution

Understanding what people believe causes light pollution and what it affects can shed light on their awareness level. When asked "What do you consider the main cause of light pollution in urban areas?", respondents most commonly blamed poorly designed lighting systems. 50.0% chose "loše dizajnirano osvjetljenje" (poorly designed lighting) as the primary cause.

This reflects a recognition that how we install and direct lights matters – for example, unshielded fixtures that send light upward or too much lighting in general. The second most-cited cause was advertising signs and billboards, chosen by 27.8%. About 22.2% pointed to excessive street lighting. These results suggest that the public in this survey tends to attribute light pollution more to quality and design issues (design of fixtures, unnecessary illuminated ads) rather than just the quantity of streetlights. In other words, the prevailing view is that better lighting design and controls, more than simply fewer lamps, would mitigate urban light pollution. This perspective aligns with modern light pollution management, which emphasizes shielding and directing light where needed.

The survey also asked which aspects of the environment and life are negatively affected by light pollution, allowing multiple selections. Respondents demonstrated a broad understanding of light pollution's impacts, especially on wildlife and energy waste. As shown below, the majority selected wildlife, ecosystems, and energy usage as areas of concern:



We see that 72.2% of respondents believe light pollution negatively impacts wildlife and ecosystems, and an equal 72.2% believe it leads to excessive energy use. This indicates strong awareness that artificial lighting can disrupt animal behavior (for example, confusing nocturnal insects and birds, or altering predator-prey interactions) and that it represents a wasteful use of energy when lights are overused or misused. Additionally, 55.6% recognize human health as being negatively affected – more than half link light pollution to health issues, likely thinking of how artificial light at night can disrupt human circadian rhythms or sleep quality. Meanwhile, 27.8% pointed to astronomical visibility (the night sky view) being harmed, which is a smaller but significant segment appreciating the loss of stars and sky for stargazers and scientists.

Notably, only one person (5.6%) said "none of the above," meaning almost everyone agrees light pollution has at least one detrimental effect. The fact that most respondents checked multiple categories (the average respondent chose around 2–3 impacts) shows an understanding that light pollution has diverse consequences – ecological, energy-related, and human. The top concerns were wildlife and energy, reflecting perhaps that these impacts are more intuitive or visible in daily discourse (e.g. seeing insects around lights, or knowing that lights left on waste electricity).

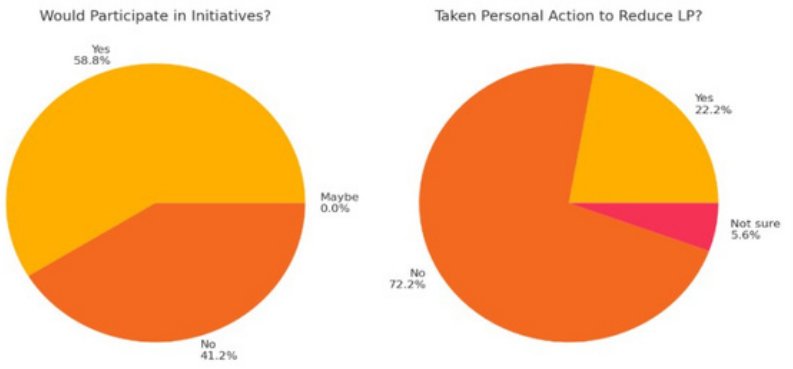
The relatively lower percentage for night sky visibility might suggest that fewer people are engaged in astronomy or have experienced truly dark skies, so this impact is less personally felt in urban areas of Croatia.

Consistent with these views, the vast majority (77.8%) believe that light pollution affects their local animal life (as noted earlier). There is a slight discrepancy regarding human health: while 55.6% selected human health as impacted in the multiple-choice question, only 38.9% earlier said they were aware of health impacts. This could imply that once prompted, more people recognize potential health effects, but initially many were uncertain. It underscores that knowledge about health implications exists but isn't firm – people might suspect harm (hence selecting it as an impact) even if they aren't confidently informed (hence many were "not sure" in the direct awareness question). This nuance suggests awareness campaigns could use more emphasis on clarifying the human health risks of excessive nighttime lighting.

Respondents identify poor lighting practices and overly bright advertisements as key causes of light pollution, and they clearly acknowledge a range of negative impacts, especially on wildlife, ecosystems, and energy efficiency. Human health is also on the radar for over half, though with some uncertainty, and loss of the night sky is recognized by a smaller group. Only a negligible fraction think light pollution causes no harm. These perceptions indicate a fairly well-rounded understanding of why light pollution matters, with particular concern for environmental and energy consequences.

Actions and Community Engagement

The survey results also shed light on how people behave regarding light pollution and what actions they support to address it. A striking finding is the gap between personal action and willingness to engage in community efforts. Most respondents have not personally taken steps to reduce light pollution, even as many express willingness to be involved in collective initiatives.



According to the survey, only 22.2% have ever taken direct action to curb light pollution in their own household or workplace (such as dimming outdoor lights or turning lights off). In contrast, a large majority – 72.2% – have not made any such personal efforts, and 5.6% were unsure if they had. This means roughly 3 out of 4 people have done nothing specific to reduce their own lighting footprint. This may reflect a lack of awareness of what actions to take, or a sense that individual actions are inconvenient or insignificant. It could also correlate with earlier findings that many do not see it as a "big problem" locally, hence not feeling compelled to act at home.

However, when it comes to collective action, the attitudes are more positive. About 58.8% said they would participate in community efforts (like workshops or local initiatives) to reduce light pollution. The remaining 41.2% indicated they would not, and interestingly, none chose "maybe" – respondents apparently felt either definitively willing or not willing. So, nearly six in ten are prepared to get involved in community-based solutions, which is a solid base of public support for local initiatives or volunteer programs. The fact that this proportion is much higher than the 22% who have acted individually suggests that people might be looking for organized opportunities or guidance to contribute, rather than acting alone. It also implies that with the right outreach, more than half the community could be mobilized to help reduce light pollution (through neighborhood projects, citizen campaigns, etc.).

The survey also inquired what specific actions people think should be taken in their area to reduce light pollution. The answers highlight a preference for awareness and efficiency measures. The most popular proposed action (chosen by 38.9%) was "increase people's awareness through campaigns." This aligns with the recognition that many are not fully informed – respondents feel that education campaigns and raising public awareness are key to tackling light pollution. The next most supported actions were technical fixes: 22.2% selected installing more energy-efficient lighting (upgrading to better technology, likely LED with proper shielding), and another 22.2% chose changing lighting design to focus illumination only where needed. These reflect support for improving lighting infrastructure – for example, using fixtures that direct light downward and using bulbs that give sufficient light with less waste. A smaller group, 16.7%, advocated reducing unnecessary outdoor lighting outright (e.g. turning off or removing some lights).

The relatively lower support for simply "use less light" (16.7%) compared to "use better lights/design" (22.2% each) and "run awareness campaigns" (38.9%) might indicate that people prefer solutions that optimize lighting rather than drastically cut it. In other words, the community favors smarter lighting over just fewer lights, coupled with efforts to inform people. This is in line with modern approaches (efficient, well-directed lighting and public awareness) and possibly reflects a desire to balance safety or comfort with dark-sky principles.

Respondents were also asked what would motivate them to be more involved in efforts to reduce light pollution. The responses here underline the importance of institutional support and information. A majority (55.6%) said that stronger initiatives and policy changes (e.g. new regulations, official initiatives by authorities) would spur them to participate more. This suggests that if people see leadership and concrete action from local government or organizations, they would be more inclined to get on board. The next largest group (33.3%) said they would be motivated by community meetings and events focused on the issue – indicating that opportunities for dialogue and local engagement can draw in volunteers. Meanwhile, 11.1% said more information and education on the topic would motivate them personally, implying some feel they need to learn more before getting involved (though this was a smaller fraction, perhaps because many are already somewhat aware).

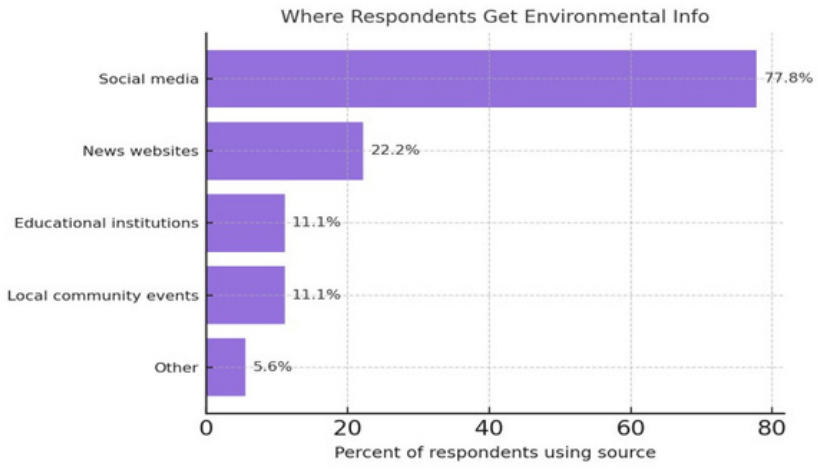
Notably, 0% responded that involvement in a local project would motivate them – possibly because this option was abstract (it may require being already involved), or respondents did not view it as a motivator in itself. The takeaway is that top-down action (policies) and community-driven events are seen as catalysts for public involvement, whereas simply providing information alone is less motivating for most (even if it's still important).

The survey shows strong support for education and outreach as long-term solutions. As mentioned, two-thirds of participants believe that light pollution topics should be taught in schools and addressed in community programs. This consensus (only 11% disagreed) reinforces the idea that the public feels education is key to prevention – perhaps recognizing that future generations need to learn about responsible lighting. Combined with the 38.9% who explicitly called for awareness campaigns in their community, the results point to a clear mandate for educational initiatives at both grassroots and formal levels.

In summary, there is a willingness among the Croatian public to engage in solving light pollution, especially through community and policy-driven actions, even though few have acted on their own so far. People are looking for guidance, information, and leadership (campaigns, policies, community events) to channel their concern into action. They favor improving lighting efficiency/design and boosting awareness as the primary strategies for reducing light pollution locally. This suggests that with well-organized efforts – such as municipal programs to retrofit lighting and public awareness campaigns – a significant portion of the community would participate or support the changes. The challenge is bridging the gap between passive awareness and active personal involvement, possibly by making it easier and more compelling for individuals to take action at home and in their neighborhoods.

Information Sources and Communication

Any successful awareness campaign must consider where people currently get their information. The survey asked respondents "Where do you most often find information about environmental issues like light pollution?" (multiple answers allowed), and the results reveal a clear trend: social media is the dominant source of environmental information for this community.



Over 77% of respondents cited social media as a regular source of information on issues such as light pollution. This was by far the highest of any source. In contrast, traditional or formal channels lag behind – only 22.2% said they commonly get environmental information from news websites or online news articles. Even fewer rely on educational institutions (11.1%) or local community events/meetings (11.1%) for such information. A small fraction (5.6%) indicated "other" sources (which could include television, radio, or word of mouth, though it was not specified). These proportions highlight that the vast majority of people are informally informed, primarily via social networking platforms, rather than through schools, community workshops, or even news media.

This has important implications. It suggests that any outreach or educational content about light pollution should leverage social media channels to be effective in Croatia's context. The prevalence of Facebook, Instagram, Twitter or local social networks means environmental organizations and local authorities should disseminate information and tips about light pollution through these platforms to reach a broad audience. The low percentage for community meetings indicates that simply holding local lectures or events may not reach many people unless those events are promoted online or made more appealing. Similarly, while schools and universities are crucial for education, only a small portion of respondents currently get information that way – perhaps because the respondents are not all students or because environmental topics like light pollution might not yet be prominently featured in curricula. It reinforces the earlier point that incorporating such topics into educational programs could fill a gap.

Another interpretation of the heavy reliance on social media is that information quality might be variable – people could be encountering both accurate information and misconceptions online. This underscores the need for credible sources (experts, NGOs, agencies) to actively provide content on these platforms. The fact that relatively few people use news sites (which often have science or environment sections) suggests that specialized articles might not be reaching the general public unless they are shared via social networks.

In summary, the community's information ecosystem is centered on social media, with traditional media and institutional sources playing a much smaller role. Any efforts to increase public understanding of light pollution in Croatia should therefore include a strong online presence. By tapping into the channels people already follow, such as social media groups or local influencers, information about light pollution's effects and ways to mitigate it can achieve far greater penetration. This finding is crucial for designing communication strategies – meeting the public where they are (online) will likely determine the success of raising awareness and promoting behavior change.

Key Findings and Implications

In conclusion, the VET EcoLume survey results provide a comprehensive picture of public awareness and attitudes toward light pollution in a Croatian community. The data reveals a community that is aware of the issue in principle and concerned about its impacts, but which has not yet fully translated that concern into personal action. Below are the key findings and trends from the survey, along with their implications:

- High Awareness of the Term, Moderate Depth of Knowledge: Nearly all respondents have at least heard of “light pollution,” and virtually everyone recognizes it as an important environmental issue. However, only a small fraction feels well-informed, and many are unsure about specific impacts like health effects. Implication: There is a strong base of awareness to build on, but educational efforts should focus on deepening understanding (especially regarding health and solutions).
- Light Pollution is Not Seen as a “Local” Problem by Many: Only 22% perceive it as a major problem in their community, even though everyone notices some light pollution at least occasionally. Implication: People may underestimate local light pollution or view it as a distant issue. Local monitoring and publicizing of light pollution levels, or citizen science projects (e.g. measuring sky brightness), could help people recognize the extent of the problem in their area.
- Broad Recognition of Environmental Impacts: Most respondents believe light pollution harms wildlife and wastes energy, indicating good awareness of ecological and economic consequences. A majority also link it to human health (though some uncertainty exists), and a significant minority note the loss of the night sky. Implication: Messaging can leverage these concerns – for example, emphasizing how reducing light pollution can protect wildlife, save energy costs, and improve human well-being – since these resonate with the public.
- Attribution to Poor Lighting Practices: Half of the respondents identified badly designed lighting as the main cause of urban light pollution, rather than simply too many lights. Implication: There is public support for technical fixes such as installing shielded, efficient fixtures and regulating neon signs/billboards. Policies or guidelines for better lighting design (which Croatia’s national law already encourages ()) would likely be well-received.
- Support for Solutions via Education and Policy: The most favored approaches to reducing light pollution were awareness campaigns (39% picked this) and improvements in lighting efficiency/design (around 22% each). Additionally, 67% want light pollution education in schools. Implication: Communities are open to initiatives that increase knowledge (campaigns, education) and to infrastructure upgrades. Authorities and organizations should prioritize public awareness programs and demonstrate lighting improvements (e.g. LED retrofit projects) to show solutions in action.
- Limited Personal Action, but Willingness to Engage: While only ~22% have personally tried to reduce lighting, about 59% are willing to participate in workshops or local initiatives. Implication: There is unrealized potential for community engagement. By organizing local events (night sky watching events, neighborhood “lights out” challenges, etc.) and providing clear steps for individual action (like shielding home lights or using timers), those willing participants can be activated. Making personal action more accessible and visibly part of a community effort might convert willingness into real impact.
- Low Awareness of Existing Policies: 78% of respondents were unaware of any local light pollution regulations. Implication: Municipalities and the national government should publicize any lighting ordinances or dark-sky protection measures they have, as public awareness of these could encourage compliance and community pride. Since Croatia has advanced light pollution laws on the books (), better communication of these rules to the public is needed to ensure they are effective.

- Reliance on social media for Information: Over three-quarters get environmental information from social media, far more than from news outlets or community events. Implication: Outreach campaigns must have a strong social media component. Educational content, infographics, and calls to action related to light pollution should be shared on popular platforms. Collaborating with local social media influencers or community Facebook groups could help disseminate information quickly. Traditional methods (workshops, flyers, news articles) might have limited reach unless they are shared online or tailored to the audience.

Overall, the survey paints an encouraging picture of a community that acknowledges light pollution and is receptive to learning and doing more about it, even if many have not yet acted on their own. Public awareness in Croatia is at a point where people recognize the stakes – impacts on wildlife, energy, health, and the night sky – and they support solutions in principle. The task ahead is to convert this awareness into concrete changes in behavior and policy implementation. By focusing on education (especially via social media and schools), improving lighting practices, and actively involving the community in initiatives, local stakeholders can bridge the gap between awareness and action. In doing so, Croatian communities can further reduce light pollution, preserving their night environment for the benefit of human health, biodiversity, and the shared heritage of starry skies.

2.3.5 Community Awareness and Education on Light Pollution - Survey

Light pollution is becoming a serious issue in Croatia, with growing impacts on human health, the environment, and tourist destinations. According to research, intense public lighting, especially in larger cities such as Zagreb, Split, and Dubrovnik, significantly contributes to increased levels of light pollution. Additionally, urbanization, the expansion of transportation infrastructure, and suburbanization processes, particularly near highways and settlements, further exacerbate the problem. This increase in light pollution reduces the appeal of dark night skies, negatively affecting tourism, especially in coastal areas where dark skies hold considerable tourist value.
Fortunately, significant steps have been taken in the past decade to research and mitigate light pollution. Initiatives such as replacing traditional lamps with energy-efficient LED lighting as implemented in the city of Rijeka are good examples of how negative environmental impacts and energy consumption can be reduced. Furthermore, Croatia has designated two locations as Dark Sky Parks, actively working to preserve dark night skies and raise public awareness regarding their importance.

Although regulations like the Law on Protection Against Light Pollution and the Ordinance on Lighting Zones, along with other legal measures, are in place, challenges persist in their implementation. Issues such as inadequate training for inspectors, poor enforcement of existing laws, and inappropriate lighting, particularly along roads, continue to complicate efforts in managing light pollution effectively. Additionally, the negative impacts on human health and ecosystems must be considered in future infrastructure planning and improvements.

2.3.6 Conclusion

Light pollution is becoming a serious issue in Croatia, with growing impacts on human health, the environment, and tourist destinations. According to research, intense public lighting, especially in larger cities such as Zagreb, Split, and Dubrovnik, significantly contributes to increased levels of light pollution. Additionally, urbanization, the expansion of transportation infrastructure, and suburbanization processes, particularly near highways and settlements, further exacerbate the problem. This increase in light pollution reduces the appeal of dark night skies, negatively affecting tourism, especially in coastal areas where dark skies hold considerable tourist value.

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For the future, it is crucial to ensure better enforcement of existing laws, increase awareness among citizens and tourists, continue projects aimed at reducing light pollution, and introduce innovative solutions for sustainable urban development.

2.4 Colombia

2.4.1 Current Situation of Light Pollution in Colombia

The current light pollution situation in Colombia is characterised by a significant increase in artificial night-time lighting, particularly in urban areas. This environmental issue is gaining attention due to its adverse effects on ecosystems, human health, and quality of life. Although some cities show a decrease in light pollution levels, the general trend indicates an expansion in the coverage of illuminated areas, highlighting the increasing spatial extent of the problem. This situation is aggravated by factors such as urbanisation, population growth and economic development, which drive the demand for artificial lighting. The following sections provide a detailed analysis of the current state of light pollution in Colombia, its impacts and the measures being taken to address it.

Urban light pollution trends

A decade-long analysis of satellite imagery reveals that light pollution levels have increased in major Colombian cities such as Bogotá, Barranquilla and Cartagena, while cities such as Medellín, Cali and Bucaramanga have seen a decrease in light pollution levels. However, all these cities have experienced an expansion in the spatial coverage of illuminated areas, indicating a wider spread of light pollution (Vargas-Dominguez, 2023).

The increase in light pollution is linked to the installation of new luminaires, the transition to LED technologies, and the increase in population density and GDP, particularly in Bogotá.(Vargas-Dominguez, 2023).

Mitigation efforts and challenges
The efforts to mitigate light pollution in Colombia include promoting the rational and efficient use of energy and implementing environmentally friendly lighting systems. However, the distribution of light energy in urban areas remains a challenge due to inadequate lighting solutions. (García & María, 2016).

Effective mitigation requires the adoption of energy-saving light sources, the use of reflected light lamps and the reduction of lighting costs during certain intervals. (Bayneva, 2022).

Despite these efforts, the effectiveness of existing regulations to prevent and reduce light pollution in Colombia remains limited, requiring further research and policy development. (García & María, 2016).

While the current light pollution situation in Colombia presents significant challenges, it also offers opportunities for improvement through better urban planning and the implementation of sustainable lighting practices. The transition to LED technologies, while contributing to the increase in light pollution, also presents an opportunity to adopt more energy efficient and environmentally friendly lighting solutions. Addressing light pollution requires a holistic approach that considers both technological advances and the socio-economic factors that drive the demand for artificial lighting.

2.4.2 Local Government Policies and Regulations

Colombia has developed a technical regulatory framework aimed at energy efficiency in lighting systems, which includes provisions that, although not directly focused on mitigating light pollution, do contain relevant elements for its control. Most of these regulations have been issued by the Ministry of Mines and Energy and are embodied in resolutions, laws and decrees of national scope.

The Technical Regulation on Public Lighting and Illumination (RETILAP), updated by Resolution 40150 of 2024, is the main technical regulation in force on lighting. This resolution introduces mandatory standards for the design, installation and maintenance of public lighting systems, including restrictions on colour temperature (maximum 4500 K), control of luminaire tilt and guidelines on interaction with urban trees.

Although the focus of RETILAP is primarily economic and technical, environmental benefits such as reduced stray light to the sky are indirectly recognised.

Other resolutions, such as 40156 of 2022 and 180540 of 2010, update the Programme for the Rational and Efficient Use of Energy (PROURE), promoting practices such as the use of targeted, low-intensity luminaires with adjusted operating hours. These measures, although conceived under energy efficiency criteria, can contribute significantly to the reduction of light pollution if properly implemented. However, the absence of an explicitly environmental approach limits their direct effectiveness in this area.

From a legislative point of view, laws such as Law 697 of 2001, Law 143 of 1994, and Decree 3450 of 2008 give the Ministry of Mines and Energy the authority to issue technical regulations on lighting, and promote the use of efficient technologies. In addition, Decree 2424 of 2006 establishes the competence of municipalities to provide public lighting services, and they must respect the efficiency guidelines issued at the national level.

It is relevant to note that, although some regulations mention environmental preservation and landscape protection, as established in Article 63 of the 1991 Political Constitution, these references have not yet been translated into specific policies for the control or monitoring of light pollution. The lack of legislation dedicated to this phenomenon makes it difficult to address it comprehensively. The main implementation challenges include the limited technical and financial capacity of municipalities to upgrade lighting infrastructure, lack of effective enforcement, low public awareness of the effects of artificial light at night, and the need for specialised technical training on RETILAP provisions and their application. In conclusion, Colombia has a solid set of regulations in terms of energy efficiency that could be leveraged to develop a national strategy to control light pollution. However, greater coordination between environmental and energy policies, the institutional strengthening of local authorities and the explicit inclusion of the light pollution component in the country's regulatory and educational agendas are required.

2.4.3 Effective Mitigation Practices and Case Studies

In Colombia, efforts aimed at mitigating light pollution are still incipient and are mainly framed in initiatives linked to the improvement of public lighting under energy efficiency criteria. However, several diagnostic studies, technological interventions in cities such as Bogotá and satellite analysis on a national scale have generated useful evidence on the state of night-time lighting and opportunities for intervention.

One of the first notable efforts was carried out in Bogotá by the Universidad de La Salle in 2002, where a detailed diagnosis of light pollution was developed based on direct observations of the night sky. This study made it possible to draw up an isophotal map of the city, identifying critical areas such as El Campín Stadium and Tunal Park, where the use of reflective lighting generated high levels of glare.

The extensive use of globe-type luminaires and mercury vapour bulbs, whose configuration favours the dispersion of light towards the sky, was also documented. From the analysis, it was estimated that Bogotá could save more than 21 billion pesos annually by adopting more responsible lighting practices. The study highlighted the need to promote public awareness campaigns and lead mitigation strategies from local mayor's offices.

In subsequent years, concrete actions to replace luminaires were implemented by CODENSA (now Enel Colombia). Between 2010 and 2015, more than 140,000 mercury vapour luminaires were replaced with more efficient technologies such as high-pressure sodium and, subsequently, LED lighting. More than 80% of canister-type luminaires, which had high levels of light dispersion, were also removed. Although these measures were in compliance with national technical standards, their direct impact on light pollution reduction was limited, as the new technologies installed, especially LEDs, did not always have a targeted optical design or regulated colour temperature. In addition, citizen evaluations indicated that the new lighting, while improving visibility, failed to reduce perceptions of insecurity and crime rates, highlighting the need to address the relationship between urban lighting, security and light pollution in a more holistic manner.

Another noteworthy initiative is the use of VIIRS (Visible Infrared Imaging Radiometer Suite) satellite images to analyse night-time radiance in six of the country's main cities (Bogotá, Medellín, Cali, Barranquilla, Cartagena and Bucaramanga) during the period 2012-2022. This study, led by the National University, allowed correlating GDP growth with the increase in artificial light emission, especially in Bogotá. However, cities such as Medellín, Bucaramanga and Cali managed to stabilise or even reduce average radiance levels, suggesting that economic development does not necessarily imply a proportional increase in light pollution if good urban planning and technological practices are applied. The study also highlighted technical limitations in the satellite's ability to detect horizontally emitted light, typical of LED luminaires, which may underestimate the real impact on the night sky. In response, it recommends limiting artificial light in natural protected areas and promoting low-intensity, downward-facing technologies.

In summary, experiences in Colombia reflect a progressive evolution in the understanding and management of urban lighting, with important advances in energy efficiency, but still with significant challenges in terms of specific environmental regulation and citizen culture. Key opportunities are identified to integrate responsible design practices, technical training, systematic monitoring and educational campaigns that position light pollution as an environmental, public health and urban sustainability problem.

2.4.4 Challenges and Gaps in Light Pollution Management

The management of light pollution in Colombia faces several challenges and gaps, mainly due to rapid urbanisation and economic development that have led to increased artificial lighting. Despite growing awareness of the environmental impacts of light pollution, there is a lack of comprehensive studies and effective regulatory frameworks to address the problem. The challenges are multifaceted, involving technological, ecological and policy-related aspects, which need to be addressed to mitigate the adverse effects of light pollution on biodiversity and human health.

Technological and Urban Development Challenges

The expansion of artificial night lighting in Colombian cities such as Bogotá, Barranquilla and Cartagena has been significant, driven by urban growth and economic factors such as increasing GDP and population density. This expansion has not been matched by adequate management strategies to control light pollution (Vargas-Domínguez, 2023).

The transition to LED technologies, although energy efficient, has contributed to increased light pollution due to the higher intensity and wider spectrum of light emitted, which is not always properly regulated (Vargas-Domínguez, 2023).

Policy and regulatory gaps

Colombia's environmental policies have not fully integrated light pollution management, focusing more on air, water and soil pollution. This neglect is partly due to the lack of specific regulations and enforcement mechanisms for light pollution, which limits the effectiveness of existing environmental management strategies (García & María, 2016).

Greater coordination between environmental organisations and compliance with international standards, such as those set by the OECD and the Sustainable Development Goals (SDGs), is needed to enhance the regulatory framework and ensure compliance (Pérez Vásquez, 2020).

Public awareness and co-responsibility

Public awareness of light pollution and its impacts remains low, which hinders community engagement and co-responsibility in managing this environmental problem. Effective management requires the involvement of various stakeholders, including the public, to promote sustainable lighting practices.

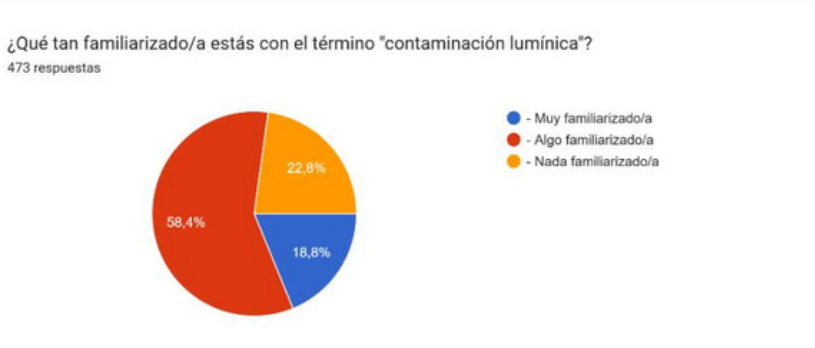
While the challenges in managing light pollution in Colombia are significant, there are opportunities for improvement. Increased research efforts to understand the ecological impacts of light pollution, the development of transboundary management frameworks and improved public awareness can contribute to more effective strategies. In addition, integrating light pollution considerations into broader environmental policies and fostering international collaboration can help address regulatory gaps and promote sustainable urban development.

2.4.5 Community Awareness and Education on Light Pollution - Survey

In order to assess the level of community awareness and knowledge about light pollution, a virtual survey was designed and applied using the Google Forms platform. The data collection was carried out during the month of April 2025, obtaining a total of 473 valid responses.
The sample consisted of participants of various ages, educational levels and affiliations. Respondents were predominantly in the 25-44 age range, with a high percentage of respondents with university or postgraduate education. In terms of gender representation,

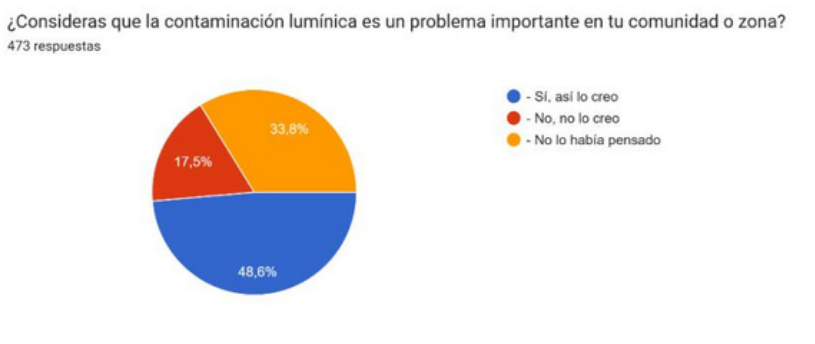
there was an even distribution between men and women. In addition, participants included both members of public and private entities as well as individuals responding in their personal capacity.
This diversity in the socio-demographic characteristics of the sample allows for a representative approach to the knowledge and perception of light pollution in different sectors of the community, offering relevant inputs for the analysis of results and the formulation of awareness and action strategies.

Level of knowledge and familiarity with light pollution



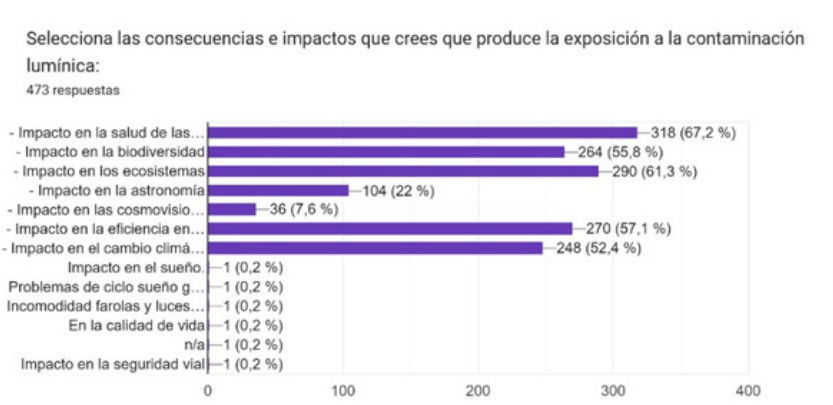
The analysis of the results shows that there is a general level of familiaritywith the term "light pollution" among the respondents. However, this knowledge is mostlysuperficial, as a significant proportion of participants acknowledge having heard oftheconcept, but do not necessarily understand its technical scope or its environmental implications. These findings suggest that, although basic awareness is in place, there remainsaneed to deepen conceptual understanding of the phenomenon.

Perception of the problem in the community



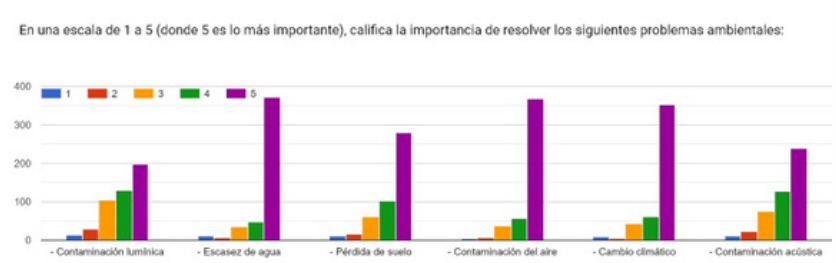
Despite the high frequency with which respondents report observing manifestations of light pollution in their surroundings, a considerable proportion do not perceive it as a priority environmental problem at the local level. This dissonance between daily experience and perception of severity indicates a possible normalisation of the effects of light pollution or a lack of awareness of its cumulative impacts, which represents a challenge for community awareness strategies.

Perceived causes of light pollution



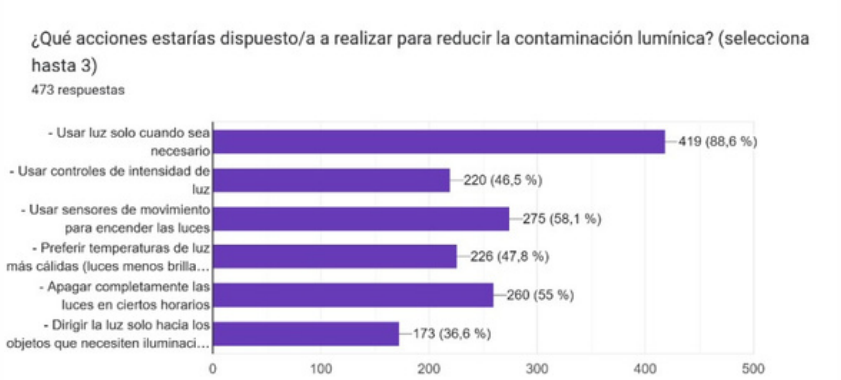
The identification of inadequate lighting practices, such as poor luminairedesign and excessive use of illuminated advertising, as the main causes of light pollution reflects a public perception aligned with the main technical diagnoses of the problem. This awareness of the specific sources of pollution provides an opportunity to target targeted interventions to promote better design practices and use of artificial lighting.

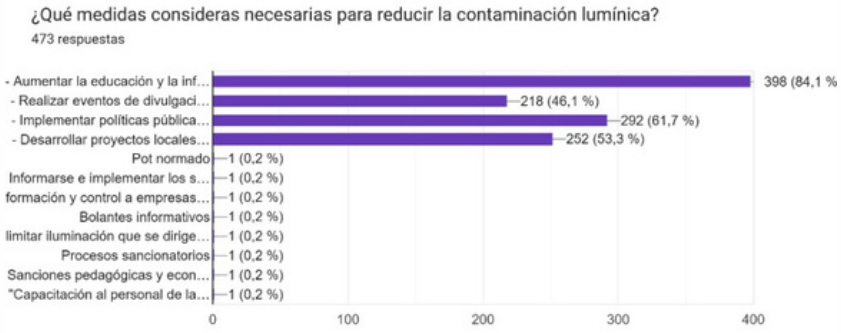
Importance attributed to light pollution compared to other environmental problems



The results show that, although light pollution is perceived as a relevant environmental problem, its priority ranks below more recognised threats such as climate change, water scarcity and air pollution. This ranking suggests that awareness campaigns should emphasise the links between light pollution and other major environmental problems to raise its perceived urgency and relevance on the public agenda.

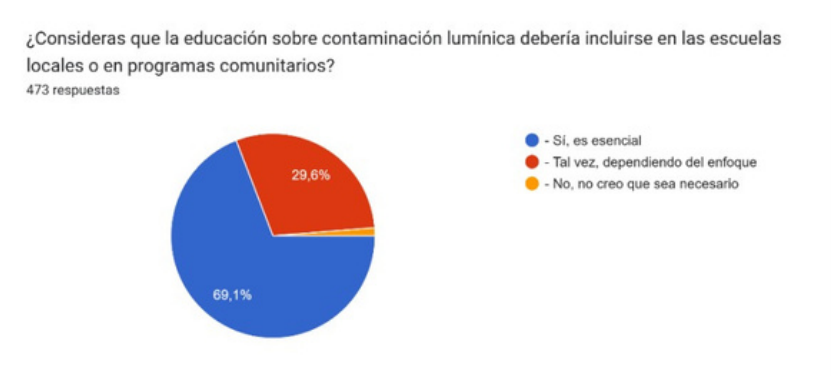
Proposed actions to mitigate light pollution

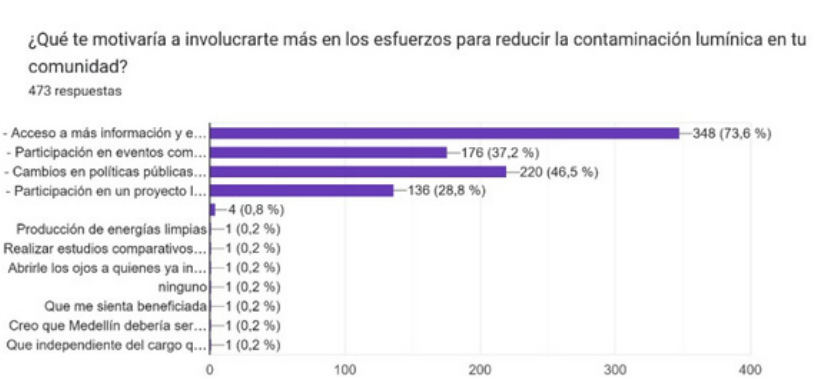




Respondents' willingness to take individual actions, such as the responsibleuse of light and the implementation of more efficient technologies, is complementedby strong support for collective strategies of education and infrastructure redesign. Thispattern of responses reveals an emerging awareness of the need to combine individual and community efforts to achieve effective light pollution reduction.

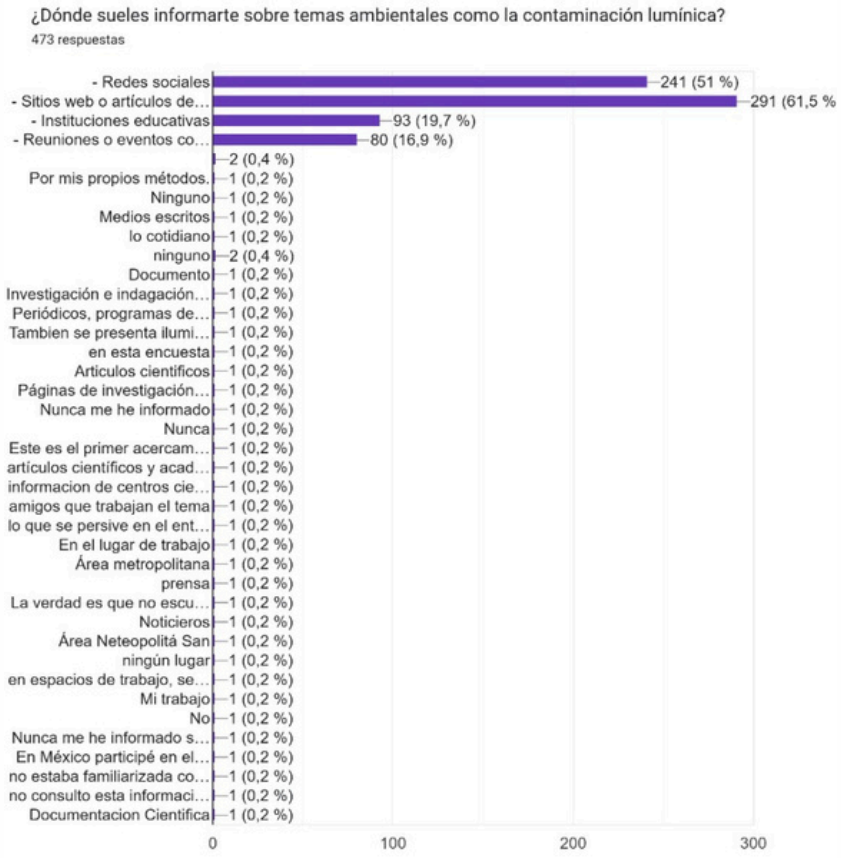
Willingness and motivation for community involvement





The survey reveals considerable potential for community mobilisation, evidenced by a high willingness to participate in local initiatives to mitigate light pollution.However, this willingness is conditioned by the existence of adequate incentives, such asawareness- raising campaigns and the implementation of visible public policies. The resultsunderline the importance of designing participation strategies that combine information, institutional leadership and opportunities for concrete action.

Sources of information on environmental issues



The predominance of social networks as the main source of environmental information among respondents reflects a change in information consumption patterns, with direct implications for communication strategies in environmental education. The low use of traditional sources such as formal media and educational events suggests that outreach efforts need to adapt to more accessible and dynamic formats to reach a broad and diverse audience.

Implications and opportunities for awareness-raising and action strategies

The survey was conducted as part of the research activities of the VET EcoLume project, an initiative that aims to train a new generation of light pollution mitigation specialists through education, international collaboration and the promotion of sustainable lighting practices.

The results obtained reveal both a generalised level of familiarity with the concept of light pollution and important gaps in the in-depth knowledge of its impacts, especially on human health and ecosystems. These findings reinforce the relevance of developing specific educational strategies aimed at consolidating technical skills in artificial light management and raising community awareness of the need for responsible lighting practices.

In this context, key opportunities are identified to strengthen awareness-raising efforts through communication campaigns adapted to the main information channels used by the community, such as social media, and educational initiatives integrated into vocational training programmes. The results also support the need to promote collaborative and advocacy actions to promote regulations that favour the sustainable use of lighting, in line with VET EcoLume's strategic objectives,

2.4.6 Conclusion

The Colombian case study shows a complex and evolving situation with respect to light pollution. Despite having a technical regulatory framework focused on energy efficiency -particularly through RETILAP and PROURE-, there is still no explicit regulation that comprehensively addresses this problem from an environmental perspective. Mitigation initiatives, although valuable, are fragmented and do not respond to an articulated national strategy. Satellite data and local studies show a sustained increase in night-time radiance in major cities, associated with urban growth, the technological transition to wide-spectrum LED luminaires, and the lack of adequate optical design. In parallel, the applied survey reveals that, although there is widespread awareness of the term "light pollution", there remains a superficial understanding of its real impacts and a low level of individual or collective action.

These findings suggest that Colombia is at a critical point to consolidate a public agenda that integrates light pollution into environmental and territorial planning policies. Coordinated efforts are required that include the institutional strengthening of territorial entities, the formulation of specific environmental standards, the promotion of responsible lighting technologies and the implementation of educational strategies adapted to the prevailing information channels. The articulation between scientific research, public policies and technical-professional training will be key to advance towards a model of sustainable management of artificial night-time lighting in the country.

2.5 Chile

2.5.1 Current Situation of Light Pollution in Chile

Chile has skies that are internationally recognized for their quality to study and understand the universe, which constitute true natural laboratories for astronomy and related sciences. This has attracted the installation of international megaprojects for astronomical observation in the north of the country, which allow the Chilean and global scientific community to study the universe and answer fundamental questions about our origins and our destiny. Chile is on the way to concentrating about 70% of all astronomical observation capacity installed on Earth. The national astronomical community includes more than 1,000 people among students and professors, spread across 23 universities throughout the national territory.

In turn, thanks to the quality of its skies, Chile has been able to develop a tourism offering related to astronomy, generating an important source of income for operators, tour guides, lodging services, transportation, tourist observatories, etc.

In this sense, Chile seeks to position itself as a world leader in Astro tourism, focusing on offering a high-quality service, in order to encourage the arrival of tourists that contribute to the economic development of these territories based on the care of a natural and scientific heritage, increasing from 262,000 to 750,000 tourists by 2030.

Recent studies have evidenced a significant increase in light pollution in various regions of Chile. Research led by Angeloni et al. (2023) presented the results of a monitoring campaign aimed at quantifying the effects of artificial light at night (ALAN) on the brightness and colors of the Chilean sky. Through the analysis of photometrically calibrated images captured at four representative sites in the Coquimbo Region, it was observed that significant levels of light pollution have already altered the appearance of the natural sky even in remote areas. The results suggest that much remains to be done in Chile to keep the phenomenon of light pollution under control and thus preserve the darkness of its night sky, a natural and cultural heritage that it is our responsibility to protect.

Additionally, a study carried out by NOIRLab (2024) presented the first results of a monitoring campaign aimed at quantifying the effects of artificial light at night on the brightness of the Chilean sky. Measurements confirmed that Fray Jorge National Park is an exceptional dark sky site, with only 4% of the night sky brightness coming from artificial lights. However, at Las Campanas Observatory, artificial lights contributed around 11% of the observed sky brightness, with the greatest contributions coming from the cities of La Serena and Vallenar.

It is important to highlight the development of new methodologies for measuring light pollution in Chile. In 2024, a team from the Astronomy Center of the University of Antofagasta presented the city's first light map. The study shows how the city is illuminated and presents a methodology that can be replicated in other municipalities of the country. The map was made based on 416 individual shots taken along the coastal edge of Antofagasta, using a drone. The objective of the project is to generate a tool to optimize the inspections of polluting light sources.

The study presents three key findings regarding light pollution and the use of outdoor lighting in the municipality. One of them is that a significant number of paddle courts and sports fields of educational establishments use luminaires with a greater presence of blue light that remain lit during the night, functioning as large polluting reflectors of the city.

On the other hand, the significant presence of cold lights in the coastal area raises alarms regarding the negative effects that this type of lighting has on marine ecosystems, especially on coastal birds. Finally, it was observed that the color of the lights in the city is not homogeneous, and colder lights are more concentrated in the northern part of the municipality. Given this finding, the research mentions the existence of "light segregation," a concept originating from American academia, where lower-class neighborhoods present luminaires with a higher index of light pollution compared to higher-class neighborhoods in a city.
In the Coquimbo region, the University of La Serena presented the IluminAconciencia project, which seeks to measure the brightness of the night sky in the region and train local tour guides about the problem of light pollution. The purpose of IluminAconciencia

is divided into two main functions. One is the monitoring network, composed of fifteen technological nodes that measure the brightness of the night sky in various places in the region.
These measurement points are located in various tourist observatories in the region, and some have been placed in local schools to raise awareness among new generations about the impact of light pollution. The oldest nodes have been installed for about a year, and within the next few months, they expect to complete the twenty nodes contemplated by the project.

Two years ago, a team of researchers from the Light Pollution Group of the PUCV School of Electrical Engineering observed that the local academy did not have protocols, methodologies, or the necessary instruments to measure the impact of light pollution on the night sky in Chile. Despite the existence of technology to measure sky brightness, the team opted to create their own tool, since the New Light Pollution Standard in Chile has a very specific blue light range, so the blue filter must be specific for the Chilean standard.

The tool was coined as Blubo, a word composed of “bubo,” which means owl in Latin, and “blue” in English. The name alludes to the owl's ability to see in the dark and to the tool’s function of detecting blue light in the brightness of the night sky, contributing to the advancement of a monitoring network of night sky brightness throughout Chile that can use this easily accessible measuring tool. For this reason, the project also includes the publication of a measurement methodology, so that those who wish to use it know how.

Additionally, this team of researchers is working on a second project to create a technological tool and a methodology that allows identifying sources of light pollution from the air. The objective of this tool will be to facilitate the inspection tasks of the Environmental Superintendency on polluting sources in view of the beginning of the New Light Pollution Standard.

2.5.2 Local Government Policies and Regulations

Chile has had regulations regarding light pollution since 1998, when Decree No. 686 of the Ministry of Economy, Development, and Reconstruction was promulgated. This regulation has a limited territorial scope, applying only to three regions of the country where astronomical activity is concentrated (Antofagasta, Atacama, and Coquimbo), with the objective of protecting the astronomical quality of those skies by regulating light emission. This regulation sets the basis for being an emission standard, therefore regulating mainly the luminous flux and the maximum emission of this flux towards the upper hemisphere.

Mainly, lamps with a nominal luminous flux greater than 15,000 lumens could not emit, once installed in the luminaire, an upward flux exceeding 1.8% of their nominal luminous flux. For lamps intended for public road lighting, they must also be limited to the visible light spectrum for the human eye (between 350 and 760 nanometers), for which the luminous efficacy of the light sources used could not be less than 80 lumens per watt.
In terms of deadlines, the regulation established that from the moment of its approval, all new luminaires had to comply with the regulation, and a maximum replacement period of five years was set.

In 2012, the regulation was updated, coming into effect in 2014, since Chilean legislation establishes that environmental standards must be systematically reviewed and updated in light of the latest findings. From this review, the need was estimated to increase the restrictions on radiant flux at zenith angles near 90°, as well as to incorporate maximum limits for ground and surface reflections, taking as reference the minimum values recommended by the International Commission on Illumination (CIE). The update also included increasing restrictions on the emitted spectrum, considering the impact of artificial light exposure on human health and various species, affecting biodiversity and the environment.

With this background, Supreme Decree No. 43 of 2012 of the Ministry of the Environment was promulgated. The Ministry of the Environment was created in Chile in 2010, and with its creation, added to the evidence of the impacts of light pollution on people's health and the environment, the new standard migrated from the Ministry of Economy to the Ministry of the Environment, emphasizing that not only a productive and scientific activity—the astronomical activity—is protected, but that the impacts of light pollution are broader. However, in territorial terms, the standard maintained its scope to the regions of Antofagasta, Atacama, and Coquimbo.

This regulation is also an emission standard, therefore mainly regulating aspects of luminaires, including in this version ornamental, sports, advertising, and industrial lighting. The limits for maximum luminous intensity distribution, for a gamma angle equal to 90°, must be between 0.00 and 0.49 candelas per 1,000 lumens of the lamp's flux, and for gamma angles greater than 90°, in candelas per 1,000 lumens of the lamp's flux.

Regarding spectral radiances in the blue light range (between 300 nm and 379 nm), they could not exceed 15% of the spectral radiance between 380 nm and 780 nm. Emission limits due to reflection could not exceed 20% over the minimum values established in standard NSEG 9.n71—Lighting: Public Road Lighting Design in Urban Areas, of the Superintendency of Electricity and Gas Services. The regulation maintained the provision that new luminaires must immediately adapt to the regulation, while existing ones must be replaced within a maximum period of five years.

During 2019, a major advance was made for the reduction and mitigation of light pollution. In that year, Law No. 19,300 of Environmental Bases was modified with three major advances. The first was recognizing artificial light as a pollutant within Chilean environmental legislation, equating it with compounds, substances, chemical or biological derivatives, energy, radiation, vibration, or noise, whose presence in the environment, at certain levels, concentrations, or periods of time, may constitute a risk to human health, the quality of life of the population, the preservation of nature, or the conservation of environmental heritage.

The second modification corresponds to the need for an Environmental Impact Study if areas of scientific interest for astronomy are affected: "Projects or activities will require the preparation of an Environmental Impact Study if they generate or present at least one of the following effects, characteristics, or circumstances...: location in or near areas with value for astronomical observation for scientific research purposes, likely to be affected, as well as the environmental value of the territory where it is intended to be located."

The third modification was to task the Ministry of Science, Technology, Knowledge, and Innovation with proposing to the President of the Republic the areas with scientific and research value for astronomical observation. This act translated into the approval of Decree No. 2 of 2023 of the Ministry of Science, where 29 municipalities of the regions of Antofagasta, Atacama, and Coquimbo were identified as areas with scientific and research value for astronomical observation.
From the review of Supreme Decree No. 43/2012, recommendations are collected from the Declaration of La Palma on the right to dark skies convened by UNESCO. Likewise, it is recognized that despite the regulation, there is evidence of deterioration in the quality of the skies for astronomical activity, growing evidence of the impact on the health of the population, and the direct impact of light pollution on species that are endangered.

Thus, the main advance brought by Supreme Decree No. 1 of 2022 of the Ministry of the Environment—or the new light pollution regulation—is to extend its scope to the entire national territory, making Chile the first country in the world to have a light pollution standard for its entire population. Furthermore, it increases restrictions regarding the spectrum of luminaires in the portions of near-infrared, visible blue, and near-ultraviolet, and differences are established between luminaires installed in Special Protection Areas, which require greater demands than the rest of the country, given their relevance from the point of view of astronomy and biodiversity. The update of the regulation also reincorporates the time restriction for sports, advertising, ornamental, and decorative lighting, and improves the preventive control of the emission standard to ensure the commercialization of properly certified products and the development of public and private outdoor lighting projects, according to its requirements.

The regulation came into force on October 18, 2024, and establishes differentiated deadlines depending on the territories. In the Protection Areas (astronomical areas, biodiversity protection areas, and areas protecting species endangered by light pollution), all new luminaires must comply with the updated requirements and renew their lighting stock within five years, while for the rest of the national territory, the regulation comes into force within two years (October 2026) for new luminaires and does not contemplate a replacement period for existing luminaires.

2.5.3 Effective Mitigation Practices and Case Studies

Since Chile has had protection measures for dark skies against light pollution since 1998, a large part of the mitigation efforts come from the application of the light pollution regulation. Nevertheless, multiple and diverse efforts have also been made to raise awareness of the need to reduce light pollution.

OPCC

One of the longest-standing initiatives for light pollution control is the creation, in the year 2000, of the Office for the Protection of the Quality of the Skies of Northern Chile (OPCC), at the time when Supreme Decree No. 686/1998 of the Ministry of Economy, Development, and Reconstruction came into force. Over more than two decades of work, the OPCC has developed a wide range of tasks in favor of the protection of the night sky,

not only in the north of the country but also extending its activities to the entire country and even the whole American continent.
To this end, it worked with CONAMA (National Environmental Commission), the Ministry of Economy, the Regional Directorates of the Superintendency of Electricity and Fuels (SEC), the Regional Governments of the north, the Intendancies, and the 34 municipalities of the regions of Antofagasta, Atacama, and Coquimbo. In addition, it elaborated terms of reference for various luminaire replacement bidding processes. Implementation trials of Supreme Decree No. 686/1998 MINECON were conducted in Vicuña, La Serena, Vallenar, and Antofagasta. In the industrial and mining sectors, various implementation trials and compliance diagnostics of the Light Pollution Regulation were carried out with different mining companies.

Among its outreach activities, and acting as the Latin American Focal Point of the Starlight Initiative, the OPCC has supported the Regional Governments of Coquimbo and Antofagasta in obtaining Starlight certifications for the Fray Jorge Forest National Park and the Starlight Tourist Destinations of Mano del Desierto, Chug-Chug, and Alto El Loa. It has also supported sky quality parameter measurements for Pumalín Park, Chacabuco Ranch, Torres del Paine National Park, and, together with AURA and the International Dark Sky Association (IDA), supported the certification of the AURA Compound in the Elqui Valley as a Dark Sky Sanctuary—the world's first certification of its kind.

Brigada de la Protección de los Cielos de Andacollo

The Andacollo Sky Protection Brigade is a community-driven initiative aimed at preserving the night sky as a natural, cultural, and scientific heritage. This experience represents an exemplary case of active citizen participation in light pollution mitigation, aligned with sustainable development goals and the local environmental agenda.

The municipality of Andacollo, located in the Coquimbo Region, is recognized for its privileged conditions for astronomical observation. However, in recent years it has faced a sustained increase in light pollution levels, mainly due to population growth and improper outdoor lighting practices, primarily from nearby mining activities. Faced with this problem, and within the context of local environmental awareness programs, the Andacollo Sky Protection Brigade was formed in 2012, led by astronomy educator Andrea Castillo, who conducted astronomy workshops at the Patricio Lynch School in Andacollo.

The brigade's main objectives were to promote environmental education on light pollution, encourage sky observation as a cultural and scientific practice of local value, monitor the night sky brightness conditions in the municipality, and contribute to the design and implementation of public policies that support sustainable outdoor lighting.

Among its main lines of action are: community-based monitoring of dark skies using sky brightness measurement instruments, the execution of educational and awareness campaigns in educational institutions and public spaces, and the provision of technical advice to the community regarding the replacement and proper orientation of household luminaires. The brigade also promoted the participatory development of a registry of critical light pollution points in the municipality and their incorporation into municipal

planning instruments such as the Communal Development Plan (PLADECO) and the Communal Public Safety Plan.
The Brigade has trained more than 200 students and teachers on topics related to dark skies and light pollution, and its experience has been presented at various national congresses and seminars. As a result of its impact, the community organization model developed in Andacollo has been replicated in other municipalities in the Coquimbo Region and northern Chile, consolidating its role as a reference in night sky conservation initiatives from a territorial perspective.

2.5.4 Challenges and Gaps in Light Pollution Management

The main challenge that arises in Chile regarding the management of light pollution corresponds to the general awareness about the different impacts of light pollution and the implementation of the light pollution regulation at the national scale. Regarding awareness about light pollution, this is still an incipient issue among the general public, given that the groups for whom this topic has gained relevance and importance are still few. Given Chile's potential for astronomical observation due to the quality of its dark skies, the problem of light pollution was raised in the country by the astronomical community, hence the first regulations had a territorial focus on the municipalities where astronomical activity develops, but limiting its reach toward other stakeholders.

Currently, the recognition of the impacts on biodiversity and human health from exposure to artificial light has not been sufficient for the general public to become aware of these impacts. Added to this is that issues related to public safety have raised the demand for measures to combat crime. Although there is no clear and conclusive evidence about the relationship between lighting and public safety, over-illumination emerges as an easy and simple solution to reduce the perception of insecurity. However, these measures can be counterproductive to the goal sought. It is necessary to advance environmental education regarding light pollution and its effects, as well as in local, municipal, or regional strategies to reverse the current state of light pollution. Efforts are also needed for the private sector to increase measures of control and prevention of light pollution.

Regarding the challenges in implementing the new light pollution regulation, it is necessary to advance mechanisms for effective financing of massive luminaire replacements, given the contribution that public lighting makes to light pollution. Specific resources must be allocated for these purposes, particularly in municipalities that are more economically disadvantaged.

It is also necessary to have technicians and specialists in sustainable lighting design. Currently, those responsible for lighting are mainly engineers and electrical technicians, who, although they have important competencies, need to be complemented with lighting designers. It is possible to see in multiple municipalities in the country that public lighting systems are oversized relative to the types of roads they serve. Likewise, there is an observed oversizing in industrial lighting, which could be reduced without jeopardizing worker safety.

In the same vein, it is important that new professionals in sustainable lighting also possess concepts of integral design, so that they know how to select types of luminaires that are not only efficient in energy terms but also beneficial to human health and the protection of the environment.

2.5.5 Community Awareness and Education on Light Pollution- - Survey

According to the survey conducted among various communities in Chile, which aimed to assess public awareness, perceptions, and educational needs related to this phenomenon, we present below a detailed analysis of the results obtained.

Sociodemographic Profile of Participants:

According to the data collected regarding age, the highest percentage of respondents belonged to the 35–44 (23.3%) and 25–34 (22.1%) age groups, suggesting an active base of young and middle-aged adults interested in environmental issues. Furthermore, regarding educational attainment, most had completed Secondary Education (20.3%), followed by Technical/Technological studies (30.2%) and Postgraduate studies, reflecting a diverse educational background among participants, with a tendency towards continued education.

Likewise, the majority of respondents participated in a personal capacity, indicating individual civic interest in the subject, although representatives from organized groups such as entrepreneurs were also included.

With respect to gender, there was a marked female representation of 75%, reinforcing the trend of greater female participation in community environmental initiatives.

Awareness and Perception of Light Pollution:

Regarding familiarity with the term, 74% declared themselves to be somewhat familiar with the concept, indicating a basic to moderate level of knowledge among the population. This is supported by their perception of light pollution as a relevant problem for the community, although a segment reported not having previously reflected on the issue, highlighting an educational opportunity that needs to be addressed.

As for the most recognized types of light pollution within the community, the main issues identified were over-illumination, intrusive light, light wastage, and upward-directed lighting, which were reported as occasional or frequent problems, particularly in inhabited areas.

Additionally, 20.3% of respondents associated the impacts and consequences of light pollution mainly with effects on human health, as well as sleep disturbances, disruption of biodiversity affecting nocturnal species, and the hindrance of astronomical observation, a key aspect for Chile.

Regarding the main causes of light pollution, 91% of respondents indicated that the most significant factors identified were the lack of effective regulations for commercial lighting, inadequate design of public lighting, and the excessive use of decorative lighting.

Proposed Actions and Willingness to Act:

Among the most suggested collective actions, the majority (69.7%) highlighted reducing unnecessary lighting, switching off lights at designated times, improving lighting designs, and installing efficient and properly directed luminaires. The most mentioned individual commitments included the rational use of lighting, installation of efficient luminaires, and switching off non-essential lights.
Regarding community participation, 97% expressed their willingness to participate in community actions, particularly if clear information and access to well-structured programs are provided.

Although respondents recognized the importance of light pollution, they indicated that issues such as air pollution and climate change were considered higher priorities. Nonetheless, there was a strong consensus (97%) on the need to include light pollution in school educational programs and community environmental awareness initiatives.

The most commonly used sources of information on this topic were social media, news websites, and educational institutions. Factors that would motivate and encourage greater involvement in this issue include: access to reliable information, the existence of accessible and engaging participation programs, and awareness of environmental and health benefits.

In summary, the results obtained from the survey reflect an encouraging outlook, where there is an emerging but growing awareness within the community regarding light pollution. The population is willing to act if provided with appropriate tools and education, with environmental education and effective communication being essential to consolidate community efforts. It is noteworthy that social networks and digital media are among the main channels that should be leveraged for awareness campaigns.

2.5.6 Conclusion

Chile is globally recognized for the exceptional quality of its night skies, positioning itself as a leader in astronomical research and Astro tourism. However, recent studies show that light pollution is advancing even into remote areas, threatening not only scientific activities but also biodiversity, human health, and the cultural value associated with the natural darkness of the night.

Although Chile has made important progress by developing pioneering regulations at the national level—becoming the first country to have a comprehensive light pollution standard—challenges remain significant. Public awareness about the different impacts of artificial light remains low, and the widespread perception of lighting as a security measure encourages practices that exacerbate pollution. At the same time, implementation of the new regulatory framework faces obstacles, including funding for the massive replacement of luminaires and the urgent need to train professionals specialized in sustainable lighting design.

Successful experiences such as the work carried out by the OPCC, community initiatives like the Sky Protection Brigade of Andacollo, and technological innovations such as Blubo, demonstrate that coordinated efforts between public agencies,

academia, the private sector, and civil society can effectively mitigate light pollution and protect the night sky.
Going forward, it is essential to strengthen environmental education programs, facilitate access to financing for municipalities, support innovation in lighting technologies, and promote citizen participation at all levels. Protecting Chile's skies is not only a matter of preserving a strategic scientific and tourism resource; it is also a commitment to environmental sustainability, the conservation of biodiversity, and the health and well-being of current and future generations.

3. Conclusion

This chapter presents the key findings from the literature review conducted earlier sections, where each country outlines the current state of light pollution from both the European and Latin American contexts. Important recommendations related to light pollution are established, highlighting key elements that vocational education should cover regarding mitigation strategies.

This chapter serves to identify the essential aspects for designing a curriculum focused on training personnel dedicated to mitigating light pollution.

3.1 Summary of Findings for LATAM and Europe

The comparative analysis of the case studies from Latin America (Colombia and Chile) and Europe (Germany, Croatia, and Estonia) reveals significant disparities in regulatory maturity, technical implementation, and societal engagement regarding light pollution. European countries generally exhibit more advanced regulatory frameworks, often embedded within broader environmental and urban planning policies, which include clear guidelines on luminaire design, spectral control, and monitoring. These are supported by institutional capacities, systematic data collection, and public awareness strategies.

In contrast, Latin American countries face regulatory fragmentation, with existing norms primarily focused on energy efficiency rather than the environmental or ecological dimensions of artificial lighting. Both Colombia and Chile demonstrate promising localized initiatives—such as urban lighting retrofits and protected dark sky areas—but these are often limited in scope, underfunded, and lack nationwide coordination. Satellite data confirms ongoing radiance increases in urban areas of both regions, yet the growth rate is notably higher in Latin America, reflecting the absence of enforceable standards and oversight.

A shared challenge across all countries is the need to enhance public understanding of light pollution as an environmental issue. Survey responses indicate varying levels of awareness, with European respondents generally demonstrating a deeper comprehension and higher likelihood of individual and collective action. However, even in countries with advanced legislation, knowledge gaps persist, particularly regarding health and biodiversity impacts.

Overall, the findings underscore the importance of integrating light pollution mitigation into technical and vocational education and training (TVET) systems. Strengthening institutional capacities, harmonizing policies with international best practices, and promoting interdisciplinary collaboration are essential to ensuring sustainable lighting practices that balance functionality, energy efficiency, and ecological preservation across both regions.

3.2 Key Recommendations for Addressing Light Pollution

Based on the cross-regional analysis of regulatory frameworks, mitigation practices, and community awareness, several strategic recommendations emerge to advance the effective management of light pollution:

Develop and Enforce Comprehensive Regulatory Frameworks

It is essential to establish or update national regulations that explicitly address light pollution beyond energy efficiency goals. These frameworks should incorporate limits on spectral emissions, enforce curfews or dimming protocols in sensitive areas, and mandate the use of fully shielded luminaires, particularly in urban, peri-urban, and ecologically fragile zones.

Promote Evidence-Based Urban Lighting Planning

Urban development policies should integrate scientific data on skyglow, biodiversity impacts, and human health to guide lighting designs. The use of satellite imagery, light pollution modeling tools, and geospatial data analysis must inform lighting master plans at municipal and regional levels.

Strengthen Institutional and Technical Capacities

Local governments and environmental agencies need capacity-building programs to effectively monitor, regulate, and enforce lighting standards. This includes technical training, access to measurement tools, and the creation of interdisciplinary units specialized in sustainable lighting and nocturnal environmental quality.

Foster Public Engagement and Education

Awareness campaigns should be tailored to diverse audiences using accessible language and channels. Educational materials integrated into school curricula, community workshops, and media outreach can significantly enhance citizen participation and behavioral change regarding responsible lighting use.

Embed Light Pollution Mitigation in VET Systems

Technical and Vocational Education and Training (TVET) institutions should incorporate modules focused on sustainable lighting design, environmental regulations, and monitoring technologies. This will equip a new generation of professionals with the skills required to design, implement, and advocate for low-impact lighting systems across sectors.

Facilitate International Collaboration and Knowledge Exchange

Establishing platforms for interregional cooperation can help share best practices, harmonize standards, and stimulate joint research. International guidelines such as those from the International Dark-Sky Association (IDA) and EU Green Deal initiatives should inform national strategies, particularly in Latin American contexts where regulatory development is still nascent.

These recommendations reflect a multidimensional approach that aligns technical, educational, institutional, and societal efforts toward the reduction of artificial light at night. Their implementation will be pivotal for achieving both environmental sustainability and public well-being in an increasingly illuminated world.

3.3 The Role of Education and Vocational Training in Light Pollution Mitigation

Education and vocational training play a pivotal role in the long-term mitigation of light pollution, serving as a bridge between scientific knowledge, policy implementation, and on-the-ground technical practices. The findings from this study underscore that regulatory frameworks and technological solutions alone are insufficient without a qualified workforce and an informed society capable of understanding, executing, and maintaining sustainable lighting systems.

Technical and Vocational Education and Training (TVET) institutions are uniquely positioned to address this gap. By integrating light pollution mitigation into their curricula, TVET programs can produce professionals with interdisciplinary competencies in lighting design, energy efficiency, environmental impact assessment, and regulatory compliance. These specialists can operate across various sectors — including urban planning, electrical engineering, environmental consultancy, and public administration — becoming agents of change in the transition toward responsible nighttime lighting.

Moreover, vocational education enhances local capacities, especially in municipalities and regions lacking specialized expertise. Training programs focused on shielded lighting installation, spectral selection, lighting audits, and monitoring techniques (e.g., use of lux meters or satellite data interpretation) empower technicians to implement best practices that align with national and international standards.

In addition, education fosters a cultural shift. Embedding concepts related to light pollution, biodiversity protection, and circadian health into broader educational efforts — from secondary schools to lifelong learning programs — raises public awareness and encourages behavioral changes that support policy goals.
Finally, education and training initiatives should be dynamic, incorporating the latest scientific advancements, regulatory updates, and technological tools. Partnerships between academic institutions, local governments, and private sector stakeholders are essential for the co-creation of relevant, context-sensitive training content that addresses both regional challenges and global sustainability agendas.

In this context, the VET EcoLume project contributes to the development of a new professional profile — the Light Pollution Mitigation Specialist — as a cornerstone for building institutional and community capacities to effectively reduce the environmental, health, and economic impacts of artificial light at night.

4. References

Angeloni, R., et al. (2023). Towards a spectro-photometric characterization of the Chilean night sky: A first quantitative assessment of ALAN across the Coquimbo Region. arXiv preprint arXiv:2312.10542. https://arxiv.org/abs/2312.10542
Ayres, R. U. (2021). The history of artificial light. In Springer eBooks (pp. 339–364). https://doi.org/10.1007/978-3-030-71393-5_15

Bakarić, M. (2024). Svjetlosno onečišćenje [Završni rad, Sveučilište u Zagrebu, Metalurški fakultet].

Bará, S., & Falchi, F. (2023). Artificial light at night: A global disruptor of the night-time environment. Philosophical Transactions of the Royal Society B: Biological Sciences, 378(1892). https://doi.org/10.1098/rstb.2022.0352

Bavarian Ministry of the Environment and Consumer Protection. (2020). Bavaria's 2020 Conservation Act. Munich, Germany. https://www.umweltpakt.bayern.de
Bayneva, I. I. (2022). Current problems of light pollution of the urban environment. Spravochnik. Inzhenernyi Zhurnal. https://doi.org/10.14489/hb.2022.05.pp.051-055

Cao, M., Xu, T., & Yin, D. (2022). Understanding light pollution: Recent advances on its health threats and regulations. Journal of Environmental Sciences, 127, 589–602. https://doi.org/10.1016/j.jes.2022.06.020

Čelebićanin, B. (2021). Analiza svjetlosnog onečišćenja u Hrvatskoj [Diplomski rad, Sveučilište u Zagrebu, Prirodoslovno-matematički fakultet].

Dark and Quiet Skies for Science and Society. (2020). Report and recommendations. La Palma, Spain. https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf

De Miguel, A. S., 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 Sensing, 13(16), 3311. https://doi.org/10.3390/rs13163311

Dutch Ministry for Infrastructure and Water Management. (2022). Sustainable lighting solutions in the Netherlands: Bioluminescent roadways. https://www.government.nl

ERR. (2023, September 28). Tallinn's light pollution rapidly increased after coronavirus pandemic. ERR; Eesti Rahvusringhääling | ERR. https://news.err.ee/1609115477/tallinn-s-light-pollution-rapidly-increased-after-coronavirus-pandemic

Estonian Government. (2019). Estonia's 2030 National Energy and Climate Plan (NECP 2030). https://energy.ec.europa.eu/system/files/2022-08/ee_final_necp_main_en.pdf

European Commission. (2020). Horizon 2020. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en

European Commission. (2023). Science for Environment Policy FUTURE BRIEF: Light Pollution: Mitigation measures for environmental protection (28th ed.). https://op.europa.eu/en/publication-detail/-/publication/5727bc7c-843c-11ee-99ba-01aa75ed71a1/language-en#

European Environment Agency. (2023). Europe's air quality status 2023. https://www.eea.europa.eu/publications/europes-air-quality-status-2023
Falchi, F., & Bará, S. (2020). A linear systems approach to protect the night sky: Implications for current and future regulations. Royal Society Open Science, 7(12), 201501. https://doi.org/10.1098/rsos.201501

Fetting, C. (2020). THE EUROPEAN GREEN DEAL. ESDN Office. https://www.esdn.eu/fileadmin/ESDN_Reports/ESDN_Report_2_2020.pdf

García, B., & María, L. (2016). Eficacia de la reglamentación para la prevención y disminución de la contaminación lumínica en Colombia, en el periodo 2010 - 2016.

Glavaš, R. (2021). Svjetlosno onečišćenje u Republici Hrvatskoj [Završni rad, Sveučilište Josipa Jurja Strossmayera u Osijeku].

Goronczy, E. E. (2020). Light pollution in metropolises. In Springer eBooks. https://doi.org/10.1007/978-3-658-29723-7

Hannachi, E., & Slimani, Y. (2022). Source, impact, and perspective of light pollution. In CRC Press eBooks (pp. 57–75). https://doi.org/10.1201/9781003185109-4

Huang, C., Ye, Y., Jin, Y., & Liang, B. (2023). Research progress, hotspots, and evolution of nighttime light pollution: Analysis based on WOS database and remote sensing data. Remote Sensing, 15(9), 2305. https://doi.org/10.3390/rs15092305

Jägerbrand, A., Gasparovsky, D., Bouroussis, C., Schlangen, L., Lau, S., & Donners, M. (2022). Correspondence: Obtrusive light, light pollution and sky glow: Areas for research, development and standardisation. Lighting Research & Technology, 54(2), 191–194. https://doi.org/10.1177/14771535211040973

Kernbach, M. E., Miller, C., Alaasam, V., Ferguson, S., & Francis, C. D. (2021). Introduction to the symposium: Effects of light pollution across diverse natural systems. Integrative and Comparative Biology, 61(3), 1089–1097. https://doi.org/10.1093/icb/icab157

Kik.ee. (2015). Street lighting in seven cities. https://kik.ee/en/eic-projects/street-lighting-seven-cities

Law, C. K., Lai, S. Y. T., & Lai, J. H. K. (2024). Light pollution control: Comparative analysis of regulations across civil and common law jurisdictions. Laws, 13(6), 74. https://doi.org/10.3390/laws13060074

Leibniz Institute for Astrophysics Potsdam. (2023). Smart lighting solutions for reducing skyglow: Findings from German cities. https://www.aip.de

Leibniz Institute for Freshwater Ecology and Inland Fisheries. (2023). Dark skies for future: Citizen science and light pollution awareness initiatives in Germany. https://www.igb-berlin.de

LUCI Association. (2024, August 28). LUCI Association. https://www.luciassociation.org/city-members/tartu/

LUCI Association. (2024, July 18). LUCI Association. https://www.luciassociation.org/city-members/tallinn/

Mayer-Pinto, M., Jones, T. M., Swearer, S. E., Robert, K. A., Bolton, D., Aulsebrook, A. E., et al. (2022). Light pollution: a landscape-scale issue requiring cross-realm consideration. UCL Open Environment, 4. https://doi.org/10.14324/111.444/ucloe.000036

McDermott, A. (2023). Light pollution is fixable. Can researchers and policymakers work together to dim the lights? PNAS, 120(27). https://doi.org/10.1073/pnas.2309539120

Ministry of the Environment of the Czech Republic. (2022). Light Pollution Reduction Measures in Europe (pp. 19–20). https://mzp.gov.cz/sites/mzp.cz/files/tiskove-zpravy/Light_pollution_reduction_measures.pdf

Morgan-Taylor, M. (2023). Regulating light pollution: More than just the night sky. Science, 380(6650), 1118–1120. https://doi.org/10.1126/science.adh7723

Munich Environmental Office. (2022). Sustainable urban planning: Smart lighting for a greener future. https://stadt.muenchen.de/infos/muenchen-setzt-auf-led-technik.html

NOIRLab. (2024). Light pollution measurements of Chilean night sky. https://noirlab.edu/science/news/announcements/sci24029

OECD. (2024). Reaching climate neutrality for the Hamburg economy by 2040. OECD Regional Development Studies. https://doi.org/10.1787/e1e44672-en

Perez, A. M. V. (2023). The increasing effects of light pollution on professional and amateur astronomy. Science, 380(6650), 1136–1140. https://doi.org/10.1126/science.adg0269

Pérez Vásquez, M. A. (2020). Retos de la política ambiental colombiana frente a los desafíos de la OCDE y los ODS. Análisis Político, 33(99), 101–120. https://doi.org/10.15446/anpol.v33n99.90970

Pravilnik o sadržaju, formatu i načinu izrade plana rasvjete i akcijskog plana gradnje i/ili rekonstrukcije vanjske rasvjete. Narodne novine, 22/2023.

Pravilnik o zonama rasvijetljenosti, dopuštenim vrijednostima rasvjetljavanja i načinima upravljanja rasvjetnim sustavima. Narodne novine, 128/200.

Rajput, S., Naithani, M., Meena, K., & Rana, S. (2021). Light pollution: Hidden perils in light and links to cancer. Sleep and Vigilance, 5(1), 5–16. https://doi.org/10.1007/s41782-020-00123-3

Rats, L. (2023, December 24). Festive light pollution can impact sleep patterns of humans and birds. ERR; Eesti Rahvusringhääling | ERR. https://news.err.ee/1609204090/festive-light-pollution-can-impact-sleep-patterns-of-humans-and-birds

Riegel, K. W. (1973). Light pollution. Science, 179(4080), 1285–1291. https://doi.org/10.1126/science.179.4080.1285

Senate Department for the Environment, Transport, and Climate Protection Berlin. (2021). Berlin's light pollution guidelines and urban illumination policies. https://www.berlin.de/sen/uvk/en/

Shrimplin, V. (2023). Dark skies and light pollution: An art-historical approach. Culture and Cosmos, 27(1–2), 117–134. https://doi.org/10.46472/cc.01227.0213

Subsecretaría de Turismo de Chile. (2020). Hoja de ruta para el astroturismo en Chile 2016–2025. https://www.subturismo.gob.cl/wp-content/uploads/2020/07/Hoja-de-Ruta-Resumen.pdf

Tallinn. (2020). Tallinn 2035 Development Strategy. https://www.tallinn.ee/en/media/313030

Tallinn. (2023). Participate in City's Light Pollution Survey. https://www.tallinn.ee/en/news/participate-citys-light-pollution-survey

UBA. (2022). Save the night: A national campaign for light pollution awareness in Germany. https://www.umweltbundesamt.de

UBA. (2023). Public perception of light pollution in Germany: Results from the 2023 national survey. https://www.umweltbundesamt.de

Vargas-Domínguez, S. (2023). Illuminating the threat: A decade-long analysis of light pollution in Colombian main urban centers through satellite imagery. Revista de La Academia Colombiana de Ciencias Exactas, Físicas y Naturales. https://doi.org/10.18257/raccefyn.1867

Wibowo, A. R. R. (2022). International effort to combat light pollution. Jurnal Global & Strategis, 16(2), 239–256. https://doi.org/10.20473/jgs.16.2.2022.239-256

Yakushina, Y., Smith, D., & Sanchez De Miguel, A. (n.d.). Light Pollution: Challenges and Responses for Monitoring. https://darksky.org/app/uploads/2025/02/EU-Manifesto-1.pdf

Pravilnik o zonama rasvijetljenosti, dopuštenim vrijednostima rasvjetljavanja i načinima upravljanja rasvjetnim sustavima. Narodne novine, 128/200.

Rajput, S., Naithani, M., Meena, K., & Rana, S. (2021). Light pollution: Hidden perils in light and links to cancer. Sleep and Vigilance, 5(1), 5–16. https://doi.org/10.1007/s41782-020-00123-3

Rats, L. (2023, December 24). Festive light pollution can impact sleep patterns of humans and birds. ERR; Eesti Rahvusringhääling | ERR. https://news.err.ee/1609204090/festive-light-pollution-can-impact-sleep-patterns-of-humans-and-birds

Riegel, K. W. (1973). Light pollution. Science, 179(4080), 1285–1291. https://doi.org/10.1126/science.179.4080.1285

Senate Department for the Environment, Transport, and Climate Protection Berlin. (2021). Berlin's light pollution guidelines and urban illumination policies. https://www.berlin.de/sen/uvk/en/

Shrimplin, V. (2023). Dark skies and light pollution: An art-historical approach. Culture and Cosmos, 27(1–2), 117–134. https://doi.org/10.46472/cc.01227.0213

Subsecretaría de Turismo de Chile. (2020). Hoja de ruta para el astroturismo en Chile 2016–2025. https://www.subturismo.gob.cl/wp-content/uploads/2020/07/Hoja-de-Ruta-Resumen.pdf

Tallinn. (2020). Tallinn 2035 Development Strategy. https://www.tallinn.ee/en/media/313030

Tallinn. (2023). Participate in City's Light Pollution Survey. https://www.tallinn.ee/en/news/participate-citys-light-pollution-survey

UBA. (2022). Save the night: A national campaign for light pollution awareness in Germany. https://www.umweltbundesamt.de

UBA. (2023). Public perception of light pollution in Germany: Results from the 2023 national survey. https://www.umweltbundesamt.de

Vargas-Domínguez, S. (2023). Illuminating the threat: A decade-long analysis of light pollution in Colombian main urban centers through satellite imagery. Revista de La Academia Colombiana de Ciencias Exactas, Físicas y Naturales. https://doi.org/10.18257/raccefyn.1867

Wibowo, A. R. R. (2022). International effort to combat light pollution. Jurnal Global & Strategis, 16(2), 239–256. https://doi.org/10.20473/jgs.16.2.2022.239-256

Yakushina, Y., Smith, D., & Sanchez De Miguel, A. (n.d.). Light Pollution: Challenges and Responses for Monitoring. https://darksky.org/app/uploads/2025/02/EU-Manifesto-1.pdf

Zakon o svjetlosnom onečišćenju. Narodne novine, 14/2019.

Zielinska-Dabkowska, K. M., Schernhammer, E. S., Hanifin, J. P., & Brainard, G. C. (2023). Reducing nighttime light exposure in the urban environment to benefit human health and society. Science, 380(6650), 1130–1135. https://doi.org/10.1126/science.adg5277

Zissis, G. (2020). Sustainable lighting and light pollution: A critical issue for the present generation, a challenge to the future. Sustainability, 12(11), 4552. https://doi.org/10.3390/su12114552

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