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Transnational Strategy

The Future of Dark Skies in Central Europe

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Purpose and Scope of the Transnational Strategy — the future of dark skies in Central Europe

Artificial light at night is currently one of the fastest-growing sources of environmental pressure in Europe. Ongoing urbanisation, the expansion of technical and transport infrastructure, and the increasingly widespread use of outdoor lighting are driving a systematic rise in light pollution. This phenomenon affects not only the functioning of ecosystems but also human quality of life and the perception of the nocturnal landscape. In Central Europe, the issue assumes particular significance, as it encompasses both densely populated and highly urbanised regions, as well as extensive natural areas, including valuable and protected sites that have retained a high quality of the night sky.

The *Transnational Strategy - the future of dark skies in Central Europe* has been developed within the framework of the DARKERSKY4CE project as an instrument to support coordinated actions aimed at reducing light pollution across the nine countries participating in the Interreg Central Europe Programme. The document responds to the need to establish a common approach to the protection of the nocturnal natural environment in the context of the diverse legal, spatial and social conditions characterising individual European countries.

The primary objective of the strategy is to identify directions for action that enable the effective reduction of artificial light pressure while maintaining the functionality of outdoor lighting. Particular emphasis is placed on the protection of nocturnal ecosystems and the natural night sky, commonly referred to as “dark skies”. The document highlights the importance of preserving the natural nocturnal landscape as an element of the region’s natural and cultural heritage.

An important component of the strategy is the identification of development potential arising from dark sky protection, particularly in the context of astro-tourism and other forms of educational and experiential tourism. Areas characterised by high-quality night skies, especially rural and protected areas, may constitute a significant economic asset for local communities, supporting economic diversification and strengthening local territorial identity.

The *Transnational Strategy - the future of dark skies in central Europe* also takes into account the growing number of local conflicts associated with the installation of new artificial lighting sources and the transformation of the nocturnal landscape. In this regard, it proposes forms of cooperation between public administration, managers of protected areas, the tourism sector, spatial planners, researchers, and local communities in order to develop solutions that balance the needs of technical infrastructure development with the protection of the nocturnal environment.

The scope of the strategy includes the identification of key challenges related to light pollution in Central Europe, a review of existing legal frameworks, and a set of strategic

recommendations and directions for action that can be implemented at the local, regional and national levels. The document is based on an analysis of regional reports, the outcomes of working groups established under the DARKERSKY4CE project and implemented in six partner countries, the international body of literature on the subject, and the interdisciplinary experience of the authors representing various institutions and sectors.

The transnational nature of the strategy facilitates the exchange of knowledge and best practices, and the development of joint actions aimed at reducing light pollution. In the longer term, the document is intended to support the strengthening of the region's environmental, social and economic potential through the protection of the night sky as a shared asset of Central Europe.

The protection of dark night skies does not imply the abandonment of outdoor lighting, but rather its rational, purposeful, and responsible use, with due regard for human needs, safety, public health, and nature conservation.

Acknowledgments

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Disclaimer

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Summary

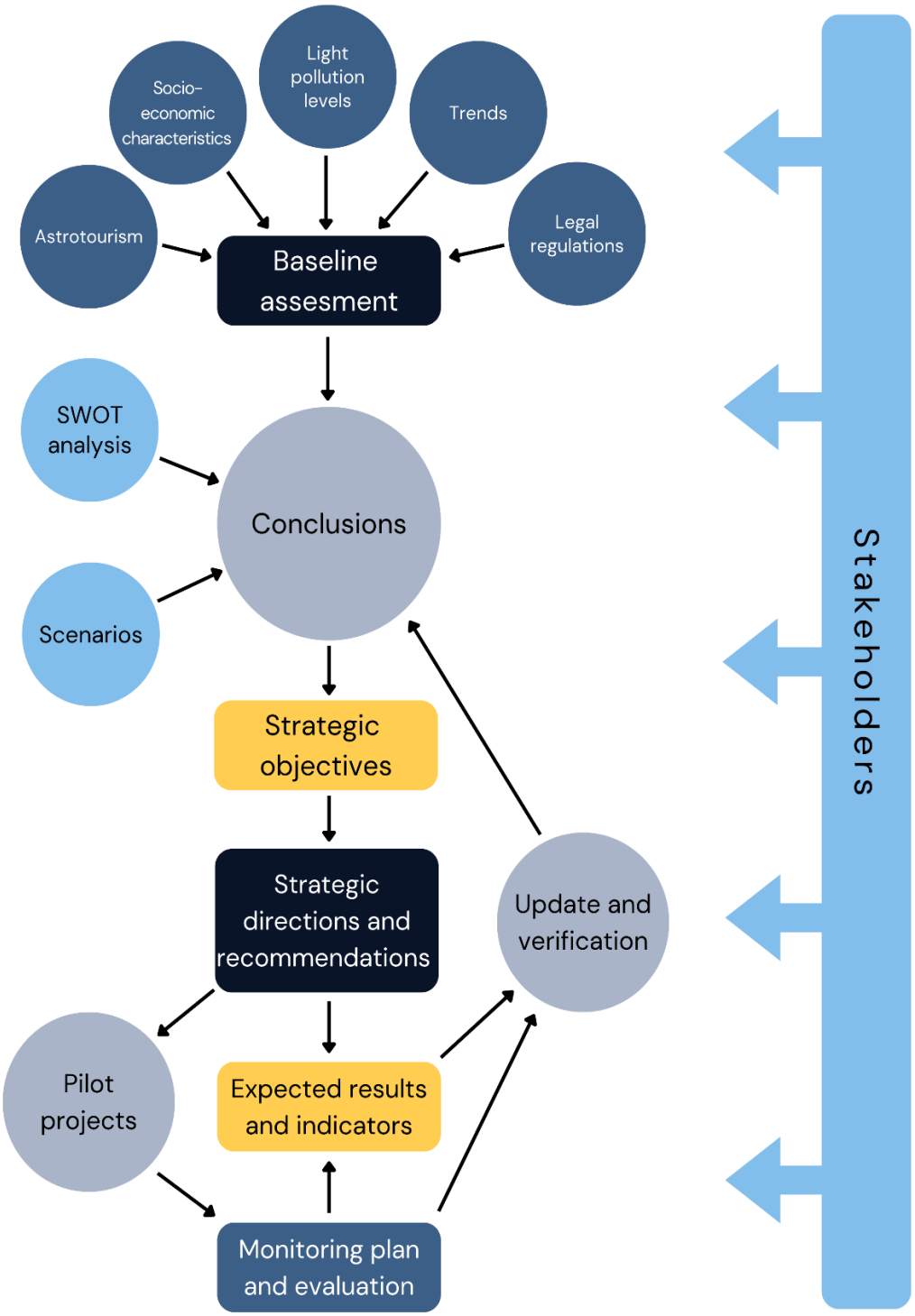
Introduction

The *Transnational Strategy - the future of dark skies in Central Europe*, developed under the DARKERSKY4CE project, constitutes a comprehensive strategic document supporting coordinated actions aimed at reducing light pollution across the nine countries covered by the Interreg Central Europe Programme.

Light pollution is a form of environmental pollution caused by artificial lighting, negatively affecting human health, ecosystems, landscapes, and astronomical observations. Outdoor lighting infrastructure plays a key role in determining the impact of light pollution, as artificial light spreads through the atmosphere and affects areas far from its sources. As a result, naturally dark night skies are becoming increasingly rare, especially in densely populated regions. Light pollution is growing globally due to both intensification of existing lighting and expansion into previously unlit areas. This widespread and transboundary problem is further driven by the use of poor-quality lighting and insufficient public awareness of its environmental impacts. Because its impacts extend across borders, effective mitigation requires international cooperation. Dark sky protection delivers tangible benefits for human health, ecosystem stability and economic development. Reducing light pollution supports biodiversity, improves quality of life, and enables the development of sustainable tourism. It also represents an important element of efficient energy and resource management.

The primary objective of the strategy is to identify directions for action that enable the effective reduction of artificial light pressure while maintaining the functionality of outdoor lighting.

During the preparation of the strategy, an in-depth analysis of the current situation (Baseline assessment), a SWOT analysis, and a future scenarios analysis were conducted; various types of stakeholders collaborating within the Interreg DS4CE project were involved in each of these analyses. Following these analyses, conclusions were drawn, which served as the basis for developing the strategic objectives. Next, strategic directions and recommendations were established. Expected outcomes and indicators were identified, and a monitoring plan was proposed. All of these elements are presented in the diagram below. Additionally, the diagram indicates that, following the completion of pilot projects and further consultations with stakeholders, an update and verification should be conducted. It is possible that modifications resulting from updates will occur during the implementation of the strategy. The strategy should be “living/dynamic” and may be partially modified during implementation.



Components of the Study Constituting the *Transnational Strategy - the future of dark skies in Central Europe*

Diagnosis

Monitoring and satellite data confirm a **continued increase in light pollution across Central Europe between 2015 and 2023**, consistent with global trends. The transition from older outdoor lighting (mainly sodium and metal halide lamps) to LED-based

lighting may partly contribute to this trend. The main sources of artificial light, and therefore light pollution, include urban areas, airports, industry, and logistics infrastructure. At the same time, relatively dark regions suitable for astro-tourism still remain.**Dark sky protection** in Europe and worldwide remains **fragmented** and **inconsistent**, relying mainly on indirect and often non-binding regulations, despite growing awareness of its importance for the environment, public health and cultural heritage. Astro-tourism is developing steadily in Central Europe, supported by growing efforts in dark sky protection. More than **20 certified dark sky places** operate across the region, including the pioneering cross-border dark sky parks in the Izera Mountains and the Beskids, as well as the unique tri-border dark sky area in the Bieszczady Mountains. The region offers a diverse range of astro-tourism products, including dark sky parks and reserves, observatories, educational centres, astronomy outreach events, and communities implementing policies aimed at reducing light pollution. However, the sector's development is hindered by the fragmentation of initiatives, the absence of common standards, and limited cooperation in promotion and marketing activities. At the same time, the growing demand for niche tourism and increasing awareness of environmental protection create favourable conditions for the further expansion of astro-tourism. In particular, cross-border products and the establishment of a "Dark Sky Region" cluster offer significant potential by enabling joint promotion, service standardisation, infrastructure development, and the creation of a strong and recognisable regional brand.

SWOT analysis

In order to ensure the effective, responsible and sustainable protection of dark skies in Central Europe, a SWOT analysis was conducted. Strategic factors were identified in terms of threats (T) and weaknesses (W), as well as strengths (S) and opportunities (O), relating to the potential for strengthening dark sky and nocturnal biodiversity protection, the development of astro-tourism, and social cooperation aimed at reducing light pollution. Methods for leveraging current trends and opportunities, as well as using strengths to mitigate risks and minimize weaknesses, have been presented. Although the current timing is favourable for dark sky conservation efforts, there is a **lack of stable, long-term financial and legal mechanisms**. It is essential to **strengthen cooperation between sectors and regions** and to conduct intensive **educational activities** to expand the number of qualified personnel.

Target groups and stakeholders engagement

The future of dark skies in Central Europe depends to a significant extent on the identification of key target groups and the mechanisms through which they are engaged in the protection and sustainable use of dark sky resources. The effective implementation of the strategy requires a **multi-sectoral approach**, based on **cooperation among public administration, the tourism sector, scientific institutions, non-governmental organisations, local communities, and private entities**. The

Transnational Strategy provides a detailed identification of stakeholders and target groups of the strategy (drawing also on thematic reports developed by working groups, as well as on practical experience and expert reflection), defines the relationships between them, and outlines the forms of their engagement in the implementation process.

Strategic objectives

The main objective—**the long-term protection of dark skies**—was presented, which depends on actions in three thematic areas:

- the protection of nocturnal ecosystems,
- local and transnational cooperation,
- the sustainable development of tourism.

The relationships between the objective and the thematic areas were illustrated, and strategic objectives were defined for each thematic area: **(1)** to preserve high levels of biodiversity and natural night-time conditions by halting the increase in light pollution in Central Europe, **(2)** to develop an effective strategy for promoting existing astro-tourism sites and establishing new dark sky places in areas with the highest potential for astro-tourism development, **(3)** to support and activate community self-organization for the reduction of light pollution. It was noted that achieving the strategic objective requires the implementation of specific objectives across various time horizons.

Scenarios for dark sky protection

As part of the preparation of the strategy for dark sky protection in Central Europe, a strategic foresight analysis was conducted. Its objective was to identify possible development pathways for the protection of nocturnal ecosystems and to determine the factors that may influence the scale of light pollution in the future. The developed scenarios—**status quo and pessimistic—do not enable the achievement of the strategic objectives** defined for each thematic area. In such cases, the focus shifts primarily to preventive rather than corrective measures, aimed at avoiding further deterioration of the current quality of dark skies in Central Europe. **Only the optimistic scenario enables the achievement of the defined strategic objectives** and therefore should be actively supported through the implementation of the proposed measures. The optimistic scenario demonstrates that it is possible to stop the increase in light pollution, if the EU policies are harmonised, smart lighting technologies are developed, urbanisation processes are moderated, and long-term public education is implemented. The most effective outcomes result from **combining legal, technological and social actions**.

Strategic directions and recommendations

The document presents a comprehensive set of strategic directions and recommendations aimed at the effective protection of the dark sky in Central Europe. Building on the conclusions of the SWOT analysis and a scenario-based approach, the

document structures actions across **six** mutually reinforcing areas: **strengthening institutional and financial mechanisms; legal regulations and spatial planning; the development of monitoring systems; education and public awareness; sustainable night-time tourism; and climate policy.**

The key message of this document is the need to move from reactive and fragmented measures toward a **proactive, coordinated, transnational, and systemic approach engaging local governments, public institutions, the private sector, the scientific community, and local stakeholders**. The protection of the night sky is framed not as a constraint, but as a **resource**—environmental, health-related, cultural, and economic—whose **rational management** requires common standards, durable partnerships, and modern tools for the governance of lighting infrastructure.

Outcomes

In the final part, the expected outcomes of measures aimed at the protection of the dark sky in Central Europe are defined and specific indicators are assigned to them for their assessment. A two-level classification of outcomes was introduced—**soft outcomes**—relating to knowledge, competencies, and institutional readiness—and **hard outcomes**, verifiable through documents, systems, and implemented solutions. This distinction is of key importance for realistic planning. Rather than formulating distant, long-term civilizational objectives, focuses on outcomes that are directly attainable by identified stakeholders within a defined time horizon.

The strategy also includes detailed directions for action and recommendations, covering, inter alia, the development of legal regulations, the implementation of modern and energy-efficient lighting technologies, public education, and the strengthening of cooperation among countries in the region. It further specifies the expected results, indicators for their achievement, and a system for monitoring the progress of implementation.

Monitoring plan

The monitoring plan is designed to assess the effectiveness and progress of implementing the strategy using an indicator-based approach and continuous data collection. It focuses on tracking changes in light pollution levels, policy implementation, and stakeholder engagement, including public awareness and astro-tourism development. The results are to be reported **annually** and reviewed **periodically** to support adaptive decision-making and updates to the strategy.

The document highlights the importance of protecting the natural **nocturnal landscape** as a significant component of Central Europe's **natural and cultural heritage**. It is complemented by descriptions of pilot projects implemented under the DARKERSKY4CE project, which provide practical examples of the implementation of the proposed solutions and form a basis for the further development of measures aimed at protecting dark skies in the region.

List of Acronyms Used

AHA – American Heart Association
AI - Artificial Intelligence
AR - Augmented Reality
CCT - Correlated Color Temperature
CE – Central Europe
CINEA - The European Climate, Infrastructure and Environment Executive Agency
CICES - Common International Classification of Ecosystem Services
COB-LED - Chip-On-Board LED
CRI – Color Rendering Index
DMO - Destination Management Organisations
DSAG - Dark Sky Advisory Group, branch of the International Union for Conservation of Nature
DS4CE – Darkersky for Central Europe (Darkersky4CE)
ELEA – European Lighting Expert Association
ESV – Ecosystem Services Value
FCO – Functional Controlled Office
GDP – Gross Domestic Product
GeoAI – Geospatial Artificial Intelligence
HPS - High-Pressure Sodium Lamp
IAU - International Astronomical Union
IoT - Internet of Things
LED - Light Emitting Diode
LGU - Local Government Unit
LTO - Local Tourist Organisation
LP – Light Pollution
MH - Metal Halide Lamp
ML - Machine Learning
NWL - Non-White Light
PWM - Pulse Width Modulation
RASC - Royal Astronomical Society of Canada
RTO - Regional Tourist Organisation
SDGs – Sustainable Development Goals
UAV - Unmanned Aerial Vehicle
ULOR - Upward Light Output Ratio
UNDP – United Nations Development Programme
UNWTO – United Nations World Tourism Organisation
VIIRS - Visible Infrared Imaging Radiometer Suite

1. Introduction

The chapter presents light pollution as a growing environmental challenge of both global and regional significance. It discusses its causes, scale, and impacts on human health, ecosystem functioning, and the economy. The text also highlights the need for coordinated action in Central Europe by outlining the objectives of the strategy and the role of international cooperation, including the DARKERSKY4CE project.

Light pollution is one of the fastest-growing environmental challenges in Europe. Urbanisation, infrastructure development, and the widespread availability of inexpensive lighting have led to permanent changes in the nocturnal landscape. Effective mitigation of this phenomenon requires long-term strategies based on reliable assessments and taking into account the specific characteristics of individual regions.

1.1 The Objective of the Strategy and Its Significance for Central Europe

Light pollution in Central Europe requires a coordinated approach due to the region's diversity and the inconsistency of existing regulations. The strategy establishes common objectives and actions by combining environmental, social and economic dimensions. Its purpose is to reduce light emissions while maintaining public safety and supporting regional development.

The primary objective of the *Transnational Strategy - the future of dark skies in Central Europe* is to develop a coherent, long-term framework for reducing light pollution across this part of Europe. This objective is pursued through a set of complementary measures addressing informational, technical, social, educational and institutional aspects, including:

- promoting the principles of sustainable outdoor lighting, the implementation of modern technologies, and improvements in the energy efficiency of lighting systems, thereby contributing to the limitation and, ultimately, reduction of excessive light emissions,
- strengthening public awareness of the benefits associated with dark sky protection and the reduction of unnecessary outdoor lighting. These measures contribute both to improving quality of life and ensuring more efficient use of electricity, while also reducing disturbances to animal behaviour, migration, reproduction and communication among species dependent on natural darkness. The expected outcomes also include improved functioning of the vegetation of plants and entire complex natural ecosystems,
- establishing frameworks for international cooperation to ensure that actions undertaken by individual countries are consistent and mutually reinforcing, particularly in environmentally valuable and cross-border areas.

A comprehensive diagnosis of the problem made it possible to define the strategic objective and the measures required to achieve it. The strategy also takes into account the need to adapt lighting policies to contemporary standards of environmental protection and to the healthy functioning of people and other living organisms.

Central Europe is characterised by considerable spatial diversity, encompassing both highly urbanised metropolitan areas and extensive peripheral regions with significant natural value. Although the dynamic economic development of recent decades has delivered numerous socio-economic benefits, it has also contributed to substantial environmental degradation, including the deterioration of nocturnal ecosystems. At the same time, the region possesses a unique natural heritage which, without coordinated protection measures, will remain exposed to further negative impacts.

A major barrier to effective dark sky protection is the variation in regulatory approaches among individual countries. These differences concern both the scope of legal provisions and the administrative levels at which they are implemented. Combined with inconsistent technical standards, this creates regulatory gaps. The problem is particularly evident in border regions, where inconsistent measures reduce the effectiveness of nocturnal environment protection. The strategy addresses these challenges by proposing a unified regional approach.

The strategy is of particular importance for Central Europe, as it may provide a foundation for future actions aimed at protecting dark skies and nocturnal ecosystems across this part of the continent.

In addition, the strategy:

- provides justification for the introduction of harmonised lighting standards, which is particularly important in the context of increasing levels of artificial light generated by large settlement units and transport hubs,
- organises fragmented and diverse national regulations, creating a basis for joint action in the field of dark sky protection and establishing guidelines for more effective cooperation between countries,
- takes into account public opinion and the need for social consultation, indicating ways to reconcile restrictions on artificial night-time lighting with residents' expectations regarding safety and the quality of public spaces,
- highlights the potential to strengthen regional economic competitiveness through the development of astro-tourism, which is becoming one of the most promising forms of sustainable tourism in Europe,
- emphasises the opportunity to protect biodiversity, particularly in countries containing protected areas such as Natura 2000 sites, national parks and landscape parks, and valuable habitats of nocturnal species.

1.2 The Context of the DARKERSKY4CE Project and the Interreg Central Europe Programme

The DARKERSKY4CE project, implemented under the Interreg Central Europe Programme, represents an example of international cooperation in response to shared environmental challenges. It combines research, educational and implementation activities, supporting the development of effective strategies for reducing light pollution and raising public awareness.

The Interreg Central Europe Programme has supported transnational cooperation since 1997, covering nine countries and approximately 150 million inhabitants. It enables the implementation of environmental, social and economic projects, as well as the testing of innovative solutions.

Within this framework, the DARKERSKY4CE project aims to reduce light pollution through the development of strategies, tools and educational activities. The project seeks to change the perception of the issue among decision-makers, businesses and society, while promoting sustainable lighting practices.

In the long term, the project is intended to reduce the pollution of the night sky, increase public awareness, and support the development of astro-tourism. It also contributes to the creation of tools for assessing the economic potential of regions and to strengthening international cooperation.

1.3 Light Pollution as a Global and Regional Challenge

Light pollution is a growing environmental problem caused by artificial lighting—primarily outdoor lighting infrastructure—that harms human health, ecosystems, landscapes, and astronomical observations, while also spreading far beyond its sources. Its rapid global increase—driven largely by excessive and poorly designed lighting—means that naturally dark night skies are becoming rare, making coordinated international action essential.

Light pollution is a form of environmental pollution arising from human activity. The term refers to a state of the environment in which light emitted from artificial lighting sources (artificial light) gives rise to a range of adverse phenomena and processes that negatively affect both the environment and society, including:

- adverse impacts on human health and functioning,
- disruption of ecosystem functioning, including effects on individual organisms — both flora and fauna — as well as interspecies relationships,
- degradation of the natural and cultural landscape,
- impairment of astronomical observations,
- excessive consumption of electrical energy.

Outdoor lighting infrastructure plays a key role in determining the impact of light pollution on ecosystems, landscapes, and astronomical observations. Artificial light propagates readily through the atmosphere and may directly reach areas far from outdoor lighting sources. In addition, atmospheric scattering and cloud reflection of artificial light brighten the night sky. This phenomenon, known as skyglow, affects areas far beyond the regions containing the light sources. Skyglow can be visible from distances of many tens of kilometers from large cities. As a result, light pollution degrades the night sky and landscape not only in illuminated urban areas but also in surrounding non-urbanised regions. In densely populated countries with extensive lighting infrastructure, areas free from light pollution are rare or nearly non-existent. This implies that the environmental, landscape and astronomical impacts of light pollution extend over large areas. As a result, locations where the night sky can be experienced in a near-natural state are relatively scarce. This is particularly true in EU countries, including Central Europe, as demonstrated by the study conducted by the team of Fabio Falchi in 2016.

Light pollution is increasing globally. According to available research results from the team led by Christopher Kyba (2017), between 2012 and 2016 the spatial extent and brightness of artificially lit areas grew by approximately 2.2% per year, with an upward trend observed in most countries worldwide. This increase is driven by two main processes:

- areas already equipped with artificial lighting are becoming increasingly illuminated, which may result both from an increase in the number of light sources and from their brightness,
- artificial lighting is being installed in areas that were previously unlit.

Analysis of satellite data conducted by the research group led by Jonathan Bennie in 2014, comparing average radiance for the period 2005–2010 with that for 1995–2000, demonstrated an increase in night-time light emissions across most of Europe. During the analysed period, in countries covered by the Interreg CE Programme, increases in radiance or its emergence in previously unlit areas were recorded over areas ranging from several to more than 30% of the territory of individual countries. The increase in artificial light observed in satellite data, as reported by various research groups, has a significant impact on the condition of the night sky. A study conducted by the team of Christopher Kyba in 2023 showed that between 2011 and 2022 the brightness of the night sky increased at a rate of as much as 9.6% per year.

The upward trend in artificial lighting, combined with the aforementioned spread of light pollution beyond illuminated areas, implies increasing exposure of ecosystems to artificial light. Analyses presented in numerous scientific studies demonstrate that this adverse phenomenon affects all types of global ecosystems, further intensifying anthropogenic pressure resulting from other forms of environmental pollution.

A significant contributor to the increase in light pollution is poor-quality artificial lighting, understood as lighting that results in excessive light emissions, often also at

inappropriate times of night, in inappropriate directions and with unsuitable spectral characteristics. This increase is not justified by the actual needs associated with the functions of night-time lighting. Poor-quality lighting is widespread and usually results from low awareness among the general public and local or regional authorities of the negative environmental impacts of artificial light.

The uncontrolled spread of artificial light means that its impacts constitute a transboundary problem. Addressing the growing challenge of light pollution therefore requires cross-border international cooperation.

1.4 The Benefits of Dark Sky Protection for Society, the Environment and the Economy

Dark sky protection is of significant importance for health, the environment and economic development. In terms of human health, it supports the proper functioning of circadian rhythms and melatonin production, thereby reducing the risk of disease and improving sleep quality and overall well-being.

From an environmental perspective, its role is crucial. Artificial light disrupts plant development, reduces crop yields, and negatively affects pollinators and wildlife, leading to biodiversity loss and the destabilisation of ecosystems. Animals and plants provide numerous ecosystem services to humans, which are disrupted by artificial light at night (Figure 1).

Protection of natural darkness supports:

- the preservation of ecosystem services,
- improved crop productivity,
- the protection of nocturnal species.

From an economic perspective, dark sky protection creates opportunities for the development of astro-tourism and nature-based tourism, particularly in rural areas. It contributes to job creation, economic diversification, and increased regional attractiveness.

In addition, rational lighting management reduces energy consumption, infrastructure maintenance costs, and greenhouse gas emissions.

Dark sky protection also has cultural and scientific significance. It enables astronomical observations and strengthens cultural heritage and local identity. Education in this field supports more informed social and environmental decision-making.

The strategic framework for action aimed at *Transnational Strategy – the future of dark skies in Central Europe* is presented in detail in Figure 2.

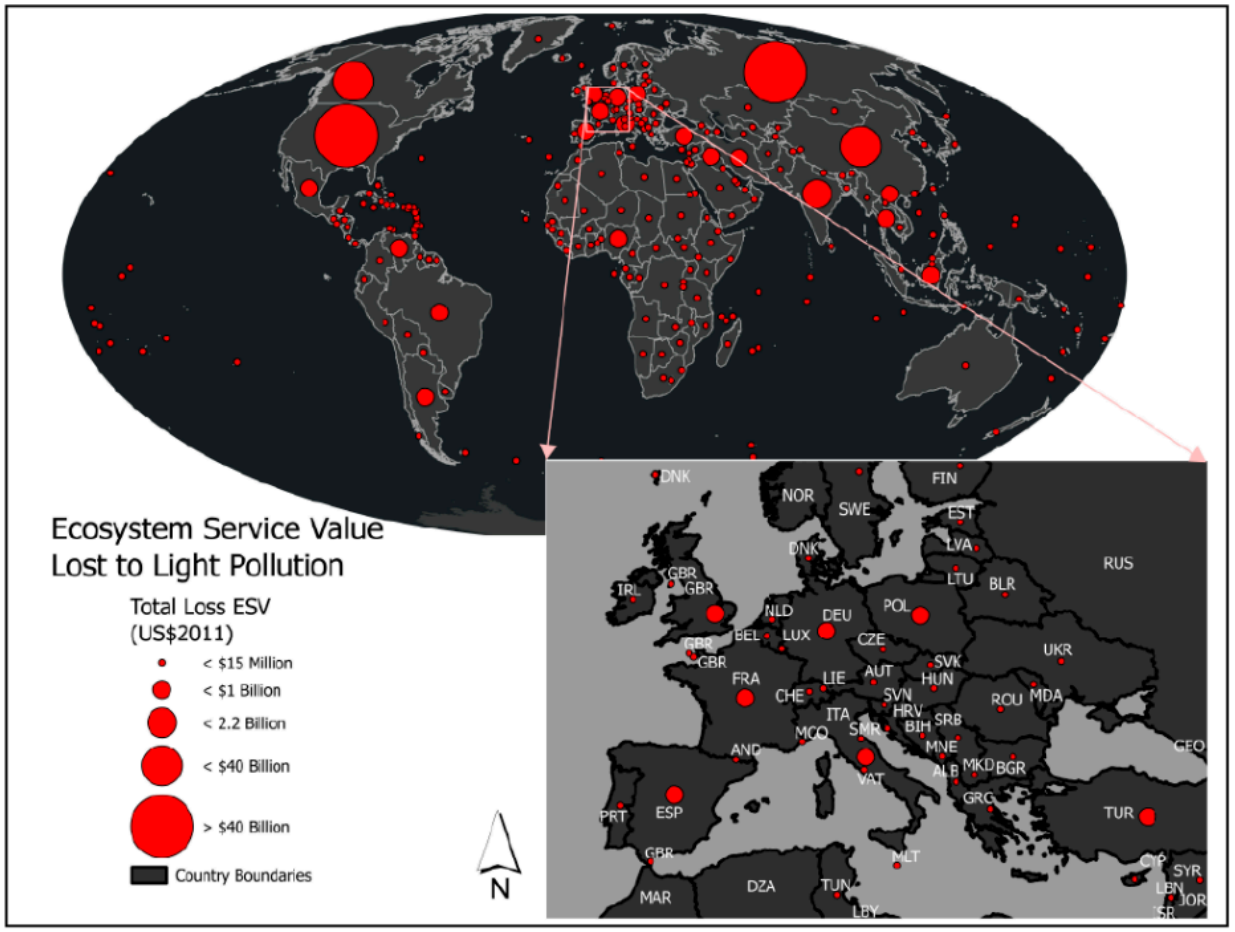


Figure 1. Estimated total loss of ecosystem service value (ESV) resulting from light pollution (source: Anderson S., Kubiszewski I., Sutton P., 2024, The Ecological Economics of Light Pollution: Impacts on Ecosystem Service Value. *Remote Sensing* 16).

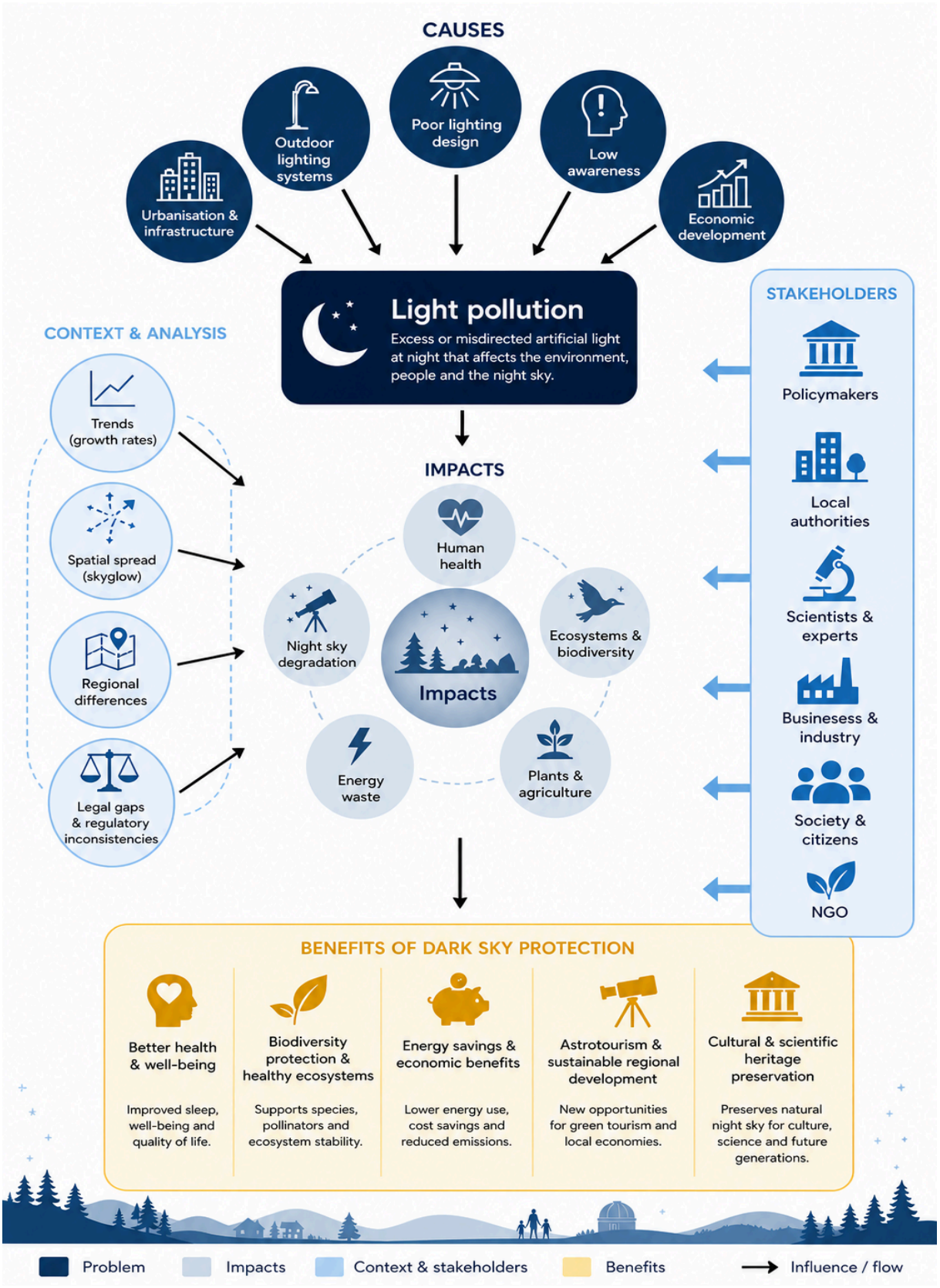


Figure 2. Strategic framework for action to reduce light pollution and protect dark skies in Central Europe.

2. Diagnosis of the Current Situation

This chapter provides an introduction to the understanding of the analyses and strategic recommendations presented, offering a comprehensive overview of the situation in the countries covered by the *Transnational Strategy - The Future of Dark Skies in Central Europe*. It presents the socio-economic characteristics, the current level of light pollution, and the key technological, ecological, social, and regulatory trends that determine the directions of change in the field of dark sky protection. The chapter is complemented by an assessment of the current state and development prospects of astro-tourism products and dark sky protection areas, highlighting their potential for further growth in the partner countries.

2.1. Socio-economic Characteristics of the Interreg Central Europe Programme Countries

The Interreg CE program covers a large part of Central Europe, which is diverse in terms of population, settlement patterns, urbanization processes, and levels of development. This region plays an important economic role in the European Union, despite the noticeable differences between individual countries and areas.

The Interreg Central Europe Programme covers 81 NUTS-2 regions inhabited by approximately one third of the European Union's population (around 150 million inhabitants in 2025). This represents approximately 30% of the total territory of the Union.

From an economic perspective, this area constitutes the industrial core of the European Union. Its economy generates around 30% of the EU's GDP, and industrial development is a key factor underpinning the Union's global competitiveness. However, it is characterised by structural disparities between urban—industrialised—and rural—peripheral—areas.

The countries of Central Europe covered by the Interreg Programme exhibit considerable variation both in terms of demographic potential and levels of economic development. In terms of the degree of urbanisation, the region is characterised by a moderate level of population concentration in cities. The highest shares of urban population are observed in Germany, Czechia, Hungary and Italy, where they exceed 70%, while the lowest are found in Slovakia and Slovenia. The settlement structure of Central European countries is polycentric, with a significant role played by medium-sized regional cities (Figure 3).

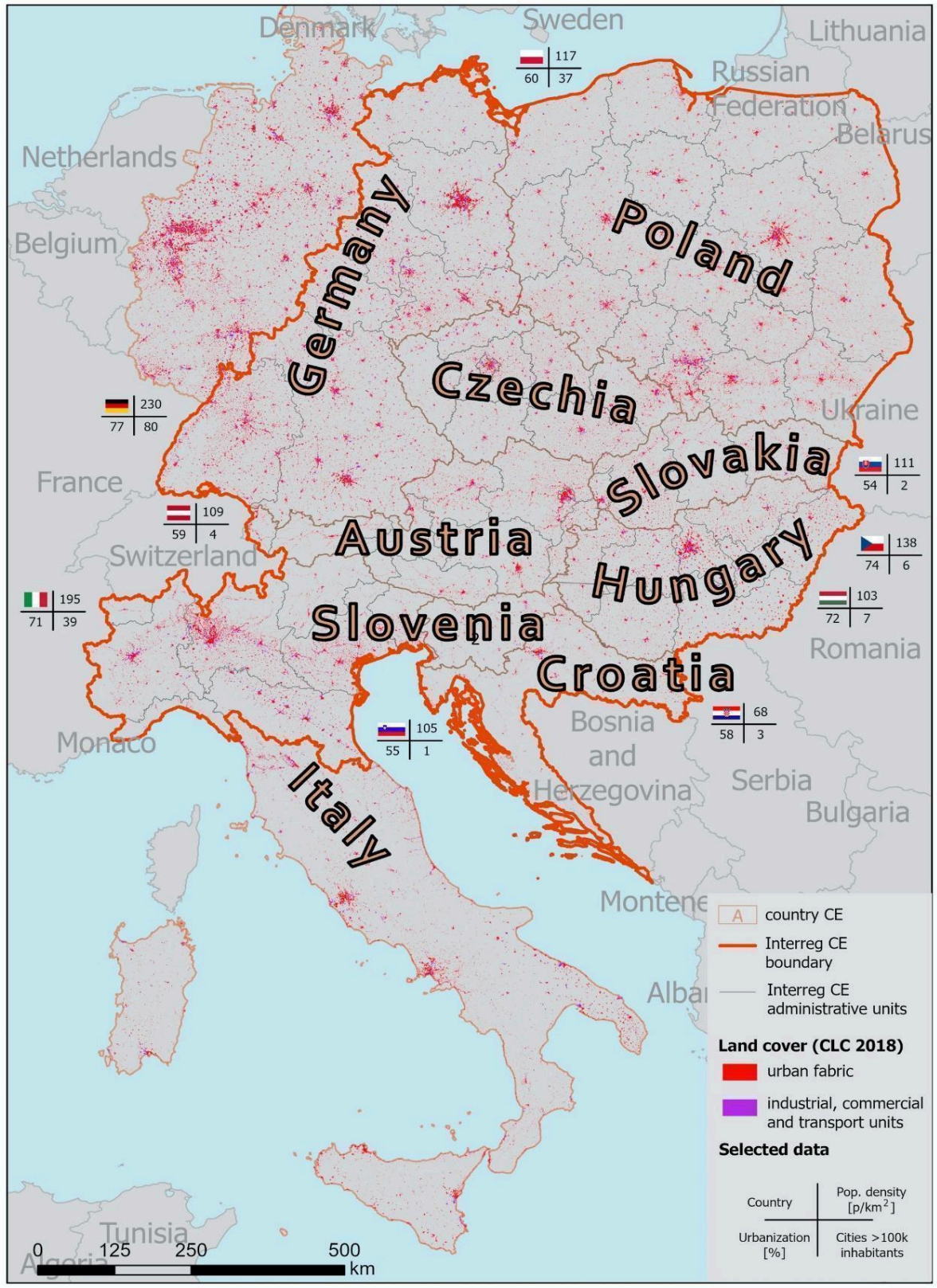


Figure 3. Countries participating in the Interreg Central Europe Programme, together with selected socio-demographic data.

An important feature of the region is also the growing share of renewable energy sources in the energy mix. Nevertheless, this indicator is steadily increasing as a result of the energy transition and the implementation of the European Union's climate policy.

Environmental indicators point to a relatively high share of protected areas in most countries of the region, which is highly favourable from the perspective of the proposed measures aimed at reducing the extent and intensity of light pollution.

2.2. Analysis of Light Pollution Levels in Partner Countries

Monitoring and satellite data confirm a continued increase in light pollution across Central Europe between 2015 and 2023, consistent with global trends. The transition from HPS and MH lamps to LEDs may partly contribute to this trend through the rebound effect, while also increasing uncertainty in VIIRS-based radiance estimates due to spectral limitations. The main sources of artificial light include urban areas, airports, industry, and logistics infrastructure. At the same time, relatively dark regions suitable for astro-tourism still remain.

Monitoring of light pollution in Central European countries, together with published findings from existing scientific studies and the content of regional reports prepared by partner countries, indicates an increase in the intensity, scale and spatial extent of the phenomenon. This is consistent with a global trend observed over several decades.

This is further confirmed by an analysis of satellite data from the period 2015–2023 (Figure 4 and 5). Figure 4 presents the annual average radiance[1] observed in 2023 by the Suomi NPP (National Polar-orbiting Partnership) satellite equipped with the VIIRS instrument for Central European countries. Figure 5 illustrates the change in radiance in 2023 compared with 2015. For earlier years, an upward trend in radiance was identified based on DMSP/OLS (Defense Meteorological Satellite Program / Operational Linescan System) data, as presented in the analysis by the research group led by Jonathan Bennie in 2014.

Selected statistical data on radiance are summarised in Table 1. The calculated sum of lights[2] indicates that in each country participating in the DARKERSKY4CE project, it increased between 2015 and 2023. This increase is at least partly attributable to the ongoing transition in outdoor lighting from high-pressure sodium (HPS) lamps and metal halide (MH) lamps to LED-based luminaires, as the lower operating costs and higher energy efficiency of LED technology may lead to a rebound effect, encouraging the installation of additional lighting points, higher illumination levels, or longer operating times.

[1] **Radiance** – in the context of the data discussed here, this parameter may be interpreted, in simplified terms, as a measure of the amount of artificial light emitted upwards from a given point on the Earth's surface. It thus provides information on the quantity of light emitted at a specific location by artificial lighting. Radiance is measured using appropriate instruments mounted on satellites.
[2] **Sum of lights** – the area sum of radiance values for all measurements in the specified area.

Table 1. Comparison of statistics on the radiance emitted into the sky in 2015 and 2023 from the area of Central European countries, calculated according to VIIRS-DNB measurements [nW $cm^{-2}sr^{-1}$].

Country	2015			2023			Increase/ Decrease of sum [%]
	Max	Mean	Sum	Max	Mean	Sum	
Austria	**238**	**0.8**	**461591**	**760**	**0.9**	**501562**	**8.7**
Croatia	165	1.3	498930	154	1.3	471172	**-5.5**
Czechia	163	1.4	811501	187	1.4	792533	**-2.3**
Germany	**550**	**1.3**	**3388251**	**344**	**1.4**	**3659599**	**8.0**
Hungary	**156**	**0.9**	**596049**	**308**	**1.1**	**696273**	**16.8**
Italy	**352**	**3.5**	**6588947**	**268**	**3.5**	**6642494**	**0.8**
Poland	**2178**	**1.2**	**2931878**	**923**	**1.3**	**3165565**	**8.0**
Slovakia	345	0.9	312029	139	1.0	342261	**9.7**
Slovenia	200	**1.0**	**135933**	**167**	**1.0**	**136986**	**0.8**

The increasing prevalence of LED sources introduces greater uncertainty into data derived from remote sensing instruments such as the VIIRS, as these devices do not capture the full spectral range emitted by such sources. Some types of LED sources emit a substantial proportion of their radiation outside the spectral sensitivity window of VIIRS. As a result, the replacement of sodium lamps with LED sources in a given area may be recorded by VIIRS measurements as an apparent decrease in radiance. Our estimates show that if sodium lighting were completely replaced with LEDs of 3000K correlated colour temperature, while maintaining the same luminous flux[3], the radiance measured by VIIRS would decrease by around 20%. Therefore, it should be noted that the changes in radiance presented in Table 1 may represent a lower-bound estimate of actual changes. Particular attention should be paid to decreases in radiance recorded for city centres (see Figure 5). This phenomenon may be at least partly artefactual, reflecting the replacement of sodium lighting with LEDs in urban centres rather than the effect of light pollution reduction policies.

According to information contained in partner reports, research on various aspects of light pollution is conducted in all Central European countries, primarily by scientific institutions, research groups and, in some cases, private individuals.

[3] **Luminous flux** – the measure of the power of light perceived by the human eye.

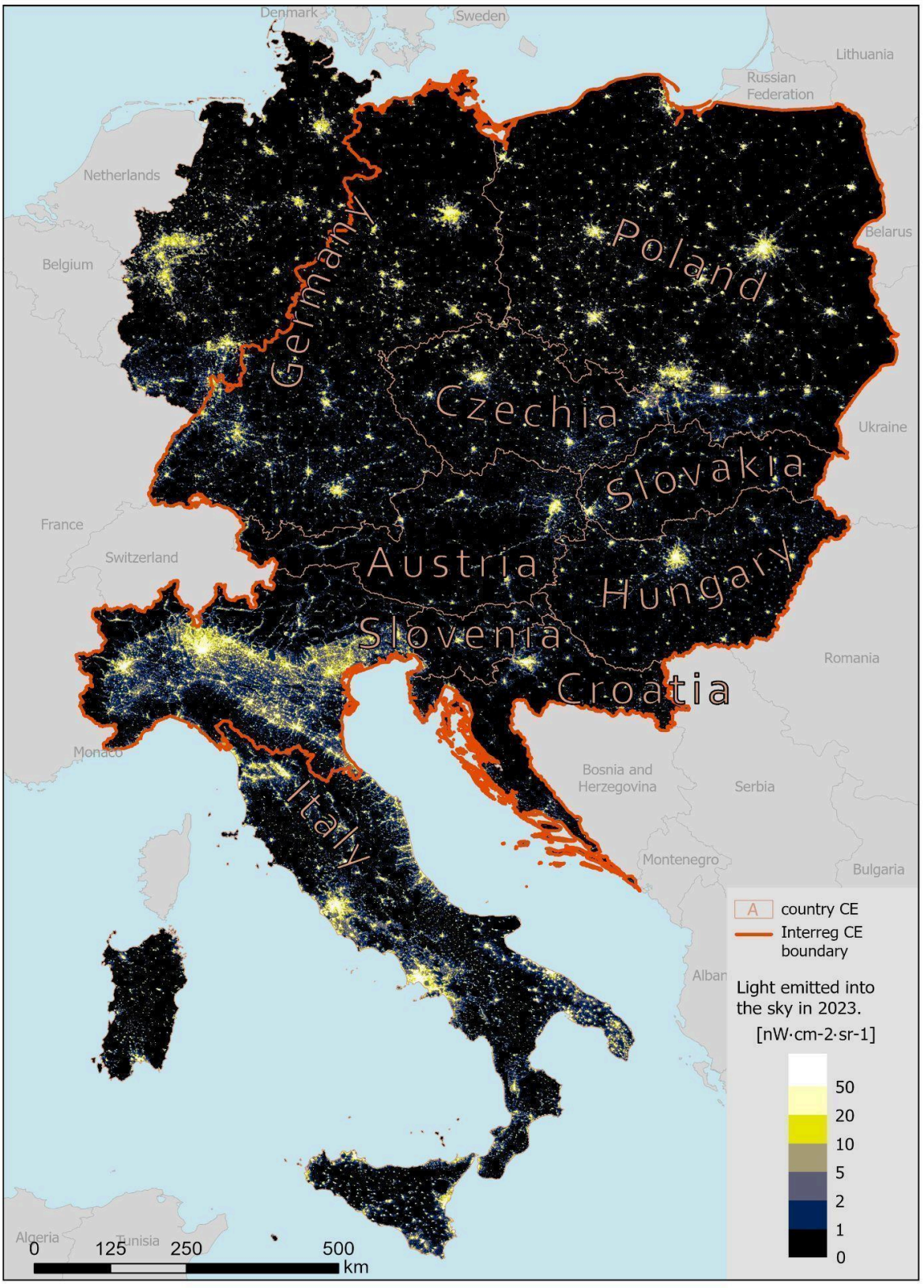


Figure 4. Total radiance across the countries of the Interreg Central Europe Programme area in 2023.



Figure 5. Difference between 2023 and 2015 in night-time light emissions across the countries of the Interreg Central Europe Programme area.

Permanent light pollution monitoring sites are located in all partner countries; however, open access to collected data and analyses varies depending on the region. Data are obtained both in the form of individual measurements and through larger monitoring networks capable of recording values over extended periods. Differences in measurement methods, instruments, and time series coverage make comparative analyses of light pollution trends across countries challenging. The only consistent data source, albeit spatially aggregated, used also in regional reports, is VIIRS satellite data.

Researchers consistently agree that the principal sources of artificial light include: urban agglomerations, large-scale greenhouses, international airports, logistics centres, extensive parking facilities, large sports complexes, and industrial, warehousing, and service developments.

It should also be emphasized that, in Central Europe, relatively dark areas can still be identified that may serve as potential reference sites compared to light-polluted regions. These areas offer potential for the development or intensification of astro-tourism and for the promotion of night sky observation.

2.3. Identification of Trends in the Context of Light Pollution

The identification of trends related to light pollution constitutes an important component in assessing both the scale and the dynamics of this phenomenon. An analysis of current development directions enables the identification of technological and systemic solutions that may contribute to reducing the emission of artificial light during night-time hours.

Transition to Semiconductor LED Light Sources

The most significant technological trend in recent years has been the replacement of traditional discharge light sources, such as high-pressure sodium (HPS) and metal halide (MH) lamps, with luminaires based on LED technology.

In the context of light pollution, the manner in which this technology is implemented is of critical importance. Modern LED luminaires enable precise control of luminous intensity distribution and regulation of luminous flux, thereby allowing for the limitation of light emission beyond areas requiring illumination. This development is associated with the application of advanced optical systems and LED arrays, which make it possible to tailor lighting characteristics to road geometry while simultaneously minimizing emissions above the horizontal plane.

At the same time, a significant issue remains the high proportion of blue light in the spectrum of white LEDs, which contributes to the intensification of sky glow and exerts adverse effects on living organisms. In response, luminaires with reduced correlated colour temperature, as well as solutions with controlled emission spectra, are being developed. In environmentally sensitive areas, amber and red lighting is also employed to limit short-wavelength emissions.

Luminaires with adjustable luminous flux and correlated colour temperature are also increasingly deployed. These systems, based on hybrid warm-white / cool-white LED arrays and controlled by PWM algorithms, enable the creation of adaptive lighting profiles depending on the time of night and traffic intensity. Integrated COB LED sources with tuneable correlated colour temperature are also under development, providing high colour rendering quality and chromatic stability.

From the perspective of mitigating light pollution, particular importance is attached to:

- the directionality of light emission (full cut-off luminaires),
- the capability for dynamic control of luminous flux,
- the reduction of the blue component in the emission spectrum.

It should be emphasized, however, that the mere replacement of light sources with LED technology does not in itself guarantee a reduction in light pollution without appropriate luminaire design and control strategies.

Smart and Adaptive Lighting Systems

Another significant direction of development is the implementation of smart, adaptive outdoor lighting systems, forming part of the Smart City concept. These systems utilize sensors (including motion, ambient daylight intensity, and weather conditions), IoT-based communication, and control algorithms to dynamically adjust lighting parameters.

The application of adaptive control enables energy consumption reductions in the range of 50–80%, which directly translates into a decrease in unnecessary light emissions during nighttime hours. Of particular importance is the concept of “lighting on demand,” whereby luminaires operate at a reduced level and emit full luminous flux only in the presence of users.

Modern solutions also enable lighting control at the level of individual luminaires, allowing for the reduction of excessive illumination in unoccupied areas.

Lighting Systems Supporting Environmental Protection

In the context of environmental protection, lighting systems incorporating motion control and solutions minimizing impacts on nocturnal organisms are increasingly deployed. For example, luminaires emitting light with a low correlated colour temperature are used; under conditions of no user presence, they operate at reduced intensity levels, while in the presence of people, they increase luminous flux.

In addition, zones with restricted lighting or entirely devoid of artificial illumination (so-called dark corridors) are being introduced to ensure the continuity of nocturnal ecosystem functioning.

Application of Artificial Intelligence and Machine Learning

A key trend is the implementation of artificial intelligence (AI) and machine learning (ML) algorithms in lighting control systems. These technologies enable not only real-time

responses to sensor data but also the forecasting of lighting demand based on traffic patterns, weather conditions, and seasonal variability.

In particular, predictive algorithms and reinforcement learning methods are employed to optimize the balance between user safety and the minimization of night-time light emissions.

Monitoring and Analysis of Light Pollution

In parallel, methods for monitoring light pollution are being developed, utilizing satellite data, remote sensing, and computer vision techniques. These approaches enable the analysis of the spatial distribution of brightness and the identification of excessively illuminated areas.

The integration of satellite data with information obtained from ground-based IoT systems, supported by GeoAI capabilities, enables the development of tools supporting the planning of urban lighting policies, including the designation of dark sky protection zones and the optimisation of luminaire placement.

2.4. Existing Regulations and Policies on Dark Sky Protection in the Context of Key Documents and Policies at the Local, Regional, National and International Levels in EU

Dark sky protection in Europe and worldwide remains fragmented and inconsistent, relying mainly on indirect and often non-binding regulations, despite growing awareness of its importance for the environment, public health and cultural heritage.

Dark sky protection is becoming an increasingly important element of contemporary environmental policy, although it remains an insufficiently regulated area. Light pollution is a transboundary and cross-sectoral issue affecting spatial planning, energy policy, nature conservation and public health. Effective protection of the nocturnal environment therefore requires coordinated action at local, regional, national and international levels. At present, however, there is no single coherent legal framework governing this issue, and the existing measures remain fragmented and often indirect in nature.

At the international level, light pollution has not yet been addressed through a binding convention or treaty. Nevertheless, the issue is increasingly recognised in various forms of “soft law”, including declarations, resolutions and guidelines developed by international organisations and the scientific community. Although these documents are not legally binding, they play an important role in shaping public policies through their scientific and institutional authority.

Particularly significant roles are played by organisations within the United Nations system, especially UNESCO and UNEP, which emphasise the importance of dark skies as

part of natural, cultural and scientific heritage. In the context of astronomy, attention is drawn to the need to preserve natural observing conditions, while in the field of nature conservation increasing evidence is highlighted regarding the negative impacts of artificial lighting on ecosystems. Although dark sky protection cannot be directly implemented under the UNESCO World Heritage Convention due to the requirement for clearly defined boundaries, the organisation actively promotes initiatives related to the protection of the nocturnal landscape.

An important contribution to the development of normative frameworks is also made by the International Astronomical Union (IAU), which recognises the night sky as a common heritage of humankind. A landmark document in this regard was the 2007 La Palma Declaration, which identified access to dark skies as a fundamental human right and an essential element of landscape protection. At the same time, non-governmental organisations such as DarkSky International have developed guidelines and certification systems that influence lighting practices worldwide.

In recent years, the ecological dimension of the issue has also gained increasing attention. Light pollution is now more frequently recognised as a threat to biodiversity, affecting, among other things, animal migration, the behaviour of nocturnal species, and the functioning of ecosystems. Although global environmental conventions do not regulate this issue directly, references to the negative impacts of artificial lighting are appearing with increasing frequency. A further emerging challenge is light pollution originating from outer space, linked to the development of satellite constellations, which additionally highlights the global nature of the problem.

At the level of the European Union, dark sky protection has likewise not yet been addressed through comprehensive regulation. Light pollution appears only marginally in strategic documents and legal acts, most often in an indirect manner. Key environmental strategies, such as the European Green Deal and the EU Biodiversity Strategy for 2030, do not directly address this issue. Some references can, however, be found in pollution reduction plans, which underline the need for further research and monitoring activities.

Within EU law, lighting issues are regulated primarily from the perspective of energy efficiency. Regulations concerning Ecodesign and energy labelling are intended to reduce energy consumption, but they do not sufficiently address the impacts of light on the environment and human health. There are also certain indirect legal bases, for example within environmental impact assessment procedures or nature protection directives, which may require the limitation of light emissions in sensitive areas. However, the absence of clear and mandatory standards means that such measures remain limited in scope.

Overall, the European Union’s approach to light pollution remains cautious and fragmented. Despite the growing body of scientific evidence demonstrating the negative impacts of artificial lighting, there are still no coherent and binding regulations addressing the protection of the nocturnal environment in a systematic manner.

At the national level, the situation is even more diverse. Individual member states have adopted different approaches, ranging from comprehensive regulations to a complete absence of dedicated legal provisions. In some countries, such as Croatia and Slovenia, extensive legal frameworks have been introduced, including technical standards, planning obligations and enforcement mechanisms. In other countries, regulations are sectoral in nature and dispersed across different areas of law, including nature conservation, construction and spatial planning.

A common approach is the decentralisation of responsibilities, with regional or local authorities playing a key role. Examples include the Italian model, in which regions independently develop lighting regulations, and the Austrian system, which is based on the legislation of the federal states. In many cases, measures are limited to the protection of selected areas, such as protected sites, or to the regulation of specific aspects, for example upward light emissions.

In some countries, light pollution is treated mainly as a nuisance affecting people, leading to a focus on health and quality-of-life aspects while overlooking the broader ecological context. In countries where dedicated regulations are absent – such as Poland – the issue appears only indirectly in legislation related to spatial planning or environmental protection, resulting in insufficient safeguards.

In summary, the current regulatory framework for dark sky protection is characterised by a high degree of fragmentation and inconsistency. Although awareness of the issue and the number of initiatives at different governance levels are increasing, there is still a lack of comprehensive and effective legal instruments capable of addressing the problem in a systematic way. In the future, stronger international cooperation and the development of more harmonised standards will be necessary to ensure effective protection of the nocturnal environment as a shared public good.

Further details concerning individual countries are provided in *Appendix 1*.

2.5. The State and Development Prospects of Astro-tourism Products and Dark Sky Protection Areas in Partner Countries

Current situation: Central Europe is an important region for the development of astro-tourism, with more than 20 certified attractions, including pioneering and globally unique cross-border dark sky parks. Key barriers: insufficient cooperation between astro-tourism attractions, weak promotion and marketing activities, fragmented initiatives, and a lack of standardised terminology and branding. Development prospects: more effective use of cross-border dark sky areas, stronger promotional activities, and the establishment of a "Dark Sky Region" cluster.

Current situation of astro-tourism products

Dark sky tourism has been developing since the 1990s, following the establishment of the first protected areas dedicated to preserving the natural qualities of the night

landscape. By 2025, more than 400 certified dark sky sites had been recorded worldwide in the database maintained by the Dark Skies Advisory Group (DSAG). According to the DSAG classification, six main categories of dark sky areas are distinguished: Dark Sky Astronomy Sites, Dark Sky Parks, Dark Sky Heritage Sites, Dark Sky Outreach Sites, Dark Sky Reserves, and Dark Sky Communities.

In Central Europe, the development of dark sky protection has played an important role both in safeguarding the nocturnal environment and in creating new tourism products. Cross-border initiatives implemented in environmentally valuable areas are of particular significance. In 2009, the world's first cross-border dark sky park was established in the Izera Mountains, alongside Europe's first international dark sky park – the Zselic Starry Sky Park in Hungary. In subsequent years, additional parks and reserves were created, together with communities and educational centres using the quality of the night sky as a driver of local development and tourism promotion. Altogether, 24 certified sites currently operate in the region and can be divided into four main categories of astro-tourism products: dark sky reserves, dark sky parks, dark sky outreach sites, and dark sky communities.

Dark sky parks constitute the largest group and are present in countries including Poland, the Czech Republic, Germany, Croatia, Slovakia, and Hungary. Their offer typically includes night sky observations, astronomy workshops, educational events, and dedicated observation infrastructure. Some parks also provide additional attractions such as astronomical observatories, educational centres, and thematic trails. Dark sky reserves also play an important role, although they currently exist only in Germany and Austria. These reserves host guided night walks, astronomy festivals, and educational activities related to the protection of the nocturnal landscape (a more detailed description, as well as additional information on the current state and future prospects of astro-tourism development, is provided in *Appendix 2*).

Dark Sky Outreach Sites primarily serve educational and astronomy outreach functions. The region currently includes two such sites: the Ostrowik Dark Sky Protected Area in Poland and the Val d'Aosta Starlight Stellar Park in Italy. Dark Sky Communities, in turn, focus mainly on improving residents' quality of life through lighting modernisation and the reduction of light pollution. In several of these communities, tourism and educational activities have also been developed, including astronomy events, workshops, and observation infrastructure (e.g. Izdebno and Chalin, Jelsa, and Sopotnia Wielka).

Despite the existence of more than twenty certified astro-tourism products and a broad tourism offer, particularly during the summer season, the development of astro-tourism in Central Europe remains uneven. Some destinations operate as well-managed, almost year-round educational and astro-tourism centres (e.g. Zselic Park, Sopotnia Wielka, and the Val d'Aosta Starlight Stellar Park), while others remain niche destinations due to limited promotion and insufficient infrastructure (e.g. the Izera Park, the Beskid Park, and Vrani Kamen). In addition, the COVID-19 pandemic significantly slowed the certification process for new dark sky areas, with most recent growth occurring among

Dark Sky Communities. Nevertheless, four new parks and reserves were established between 2025 and 2026, which may indicate a return to pre-pandemic development trends (Figure 6).

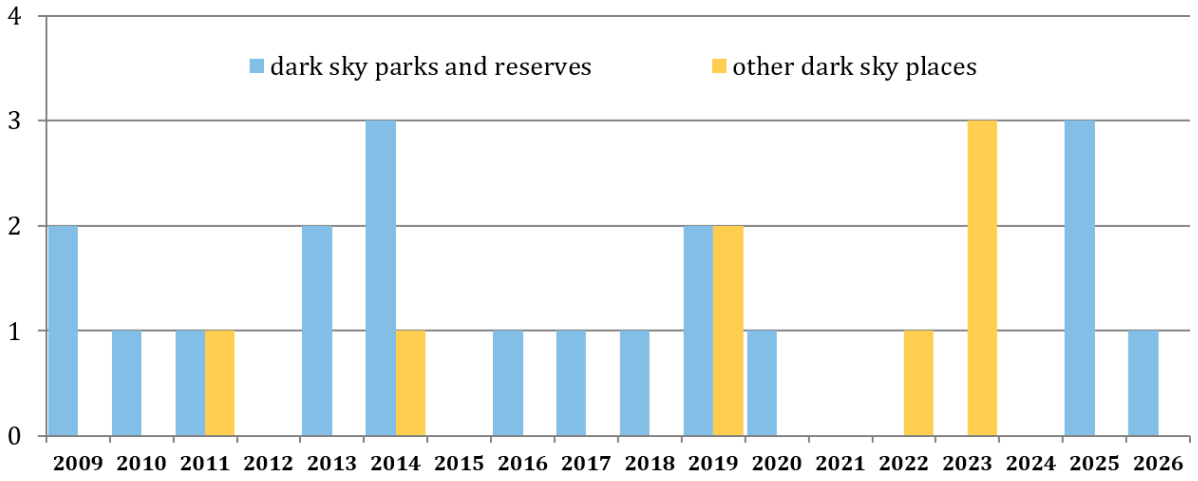


Figure 6. Establishment of certified dark sky protection areas in Central Europe in the period 2009–2026. *Source: authors' own elaboration based on data from DSAG and certifying institutions.*

Development Prospects of Astro-tourism Products

Industry forecasts indicate that in the coming years niche tourism based on authentic experiences, high environmental quality, and environmental education will continue to gain importance. Astro-tourism aligns closely with this trend by combining astronomical observation with nature conservation, education, and the promotion of cultural heritage.

The greatest development potential in Central Europe lies in cross-border astro-tourism products. Particularly important in this context are:

- the cross-border dark sky park in the Izera Mountains,
- the tri-border dark sky protection area in the Bieszczady Mountains,
- certified dark sky areas located along the German–Czech and German–Austrian borders,
- the dark sky park in the Beskids.

At present, however, the potential for cross-border cooperation remains only partially utilised. Existing partnerships operate mainly at a formal level and have not yet translated into broadly developed joint tourism products, coordinated marketing strategies, or integrated promotional activities.

In the coming years, further growth in the number of certified dark sky areas can be expected. New initiatives are currently being developed, among others, in Poland and Austria. At the same time, some existing astro-tourism facilities could be incorporated into a joint "Dark Sky Region" cluster. The establishment of such a cluster could provide several important benefits, including:

- joint promotion of the region,
- the creation of a strong and recognisable tourism brand,
- standardisation of service quality,
- development of astro-guide competencies,
- joint training activities,
- integration of accommodation, gastronomy, and educational services,
- the creation of a shared events calendar,
- more effective access to national and EU funding opportunities.

One of the key challenges remains the absence of a coherent regional strategy for the promotion of astro-tourism. Cooperation between institutions involved in dark sky protection, local governments, tourism organisations, and the private sector is still insufficient. There is also a lack of effective audience segmentation, visibility in modern promotional channels, and systemic approaches to certification and quality control. Without stronger integration of public and private sector activities, the development of astro-tourism may remain fragmented and seasonal in nature. Conversely, the implementation of a common regional strategy and the strengthening of cross-border cooperation could position Central Europe as one of the leading dark sky tourism regions in Europe.

3. SWOT Analysis

The SWOT analysis indicates that dark sky protection and the reduction of light pollution in Central Europe are grounded in scientific research. Social and institutional initiatives are being undertaken; however, lack of systemic solutions and stable financing mechanisms limits the full utilisation of favourable conditions.

Leveraging strengths to realise opportunities (S-O)

Effective promotion and further development of existing areas with high-quality night skies, combined with support for the growing engagement of local communities and institutions, can help build interest in tourism based on nature interpretation and environmental education. Existing cooperation networks, long-standing interdisciplinary and transnational collaboration, access to scientific tools, and a growing scientific consensus on the negative impacts of artificial light at night create a real opportunity to utilise the current “policy window” for addressing light pollution within EU policy frameworks (climate, biodiversity, territorial cohesion), as well as to benefit from available EU funding and cross-border cooperation instruments. Technological advances in adaptive and smart lighting systems may also be harnessed to reduce light pollution. Accordingly, the development strategy should focus on the **active use of existing cooperation structures to establish durable implementation and regulatory mechanisms at both regional and European levels**.

Using opportunities to overcome weaknesses (O-W)

Growing interest in education-based tourism, increasing environmental awareness, technological progress, and the availability of EU funding constitute favourable external trends that may be used to implement wide-ranging educational campaigns, increase the visibility of the issue, raise public awareness, train qualified personnel (e.g. specialists in nocturnal ecosystems), modernise tourism and technical (lighting) infrastructure in peripheral areas, and develop systems for collecting light pollution data. It will be essential **to translate the outcomes of pilot initiatives into systemic solutions ensuring continuity of funding and the long-term sustainability of results**.

Using strengths to minimise threats (S-T)

Progressive urbanisation, the lack of coherent legal frameworks and uniform lighting standards, inappropriate application of LED technologies, and conflicts between environmental objectives and urban development and safety priorities represent major threats to the future of dark skies in Central Europe. Existing strengths—such as dialogue with local authorities, growing scientific consensus, established cooperation networks and expert capacity—can be utilised **to develop uniform lighting standards**, integrate light pollution considerations into spatial planning and safety policies, apply evidence-based arguments in the development and revision of legal frameworks, and promote good practices to enhance cooperation and reduce institutional fragmentation. The strategy should focus on **the development of systemic solutions that are not dependent solely on time-limited projects or temporary stakeholder engagement**.

Minimising weaknesses and threats (W-T)

The combination of low public awareness, limited recognition of the issue, and underdeveloped infrastructure with the absence of coherent legal regulations, fragmented actions and insufficient institutional cooperation may lead to the loss of existing dark sky assets due to ongoing urbanisation pressures. To prevent these processes, it is necessary to **foster pro-environmental attitudes, establish durable cooperation mechanisms**—including in the field of supra-local promotion of astro-tourism—**secure long-term funding sources, and ensure coordination of activities aimed at dark sky protection**.

Strategic conclusion

The SWOT analysis (*Appendix 3*) demonstrates that dark sky protection and the reduction of light pollution in Central Europe are currently at a favourable stage of development. These efforts are based on solid scientific foundations, expanding institutional and social cooperation, and growing public and political interest; however, they still require reinforcement through **stable systemic and financial mechanisms**. A key condition for effectively leveraging existing strengths and opportunities is the transition from project-based and pilot actions to systemic solutions, including **coherent legal regulations, durable structures for cross-sectoral and transnational cooperation, professionalisation of personnel, and the implementation of stable financing and**

monitoring frameworks. From a strategic perspective, it is essential to capitalise on current trends—rising environmental awareness, the development of sustainable tourism, technological progress, and the availability of EU financial instruments—before ongoing urbanisation, fragmentation of institutional actions, and the absence of uniform lighting standards lead to the irreversible degradation of the nocturnal landscape and the loss of the environmental value of dark skies.

4. Target Groups and Stakeholder Engagement

Effective dark sky protection and astro-tourism development in Central Europe require coordinated cooperation among public administration, scientific institutions, tourism stakeholders, NGOs, and local communities. Sustainable astro-tourism growth depends on cross-sector partnerships, integrated tourism products, visitor management, and stronger engagement of local communities and tourism entrepreneurs.

Protection of nocturnal ecosystems in Central Europe

The key target group in the area of nocturnal ecosystem protection is public administration at the local, regional and national levels. These authorities hold competencies in spatial planning, the adoption of lighting standards, and the implementation of local regulations limiting light emissions. The integration of provisions concerning the protection of the nocturnal landscape into strategic documents and spatial development plans should become standard practice, in close cooperation with another key group—research institutions, including experts specialising in light pollution.

An important stakeholder group also includes managers of protected areas—national parks, landscape parks and other forms of nature conservation. In many cases, these areas encompass territories of high night sky quality that may serve as core zones for future dark sky parks and reserves. Their role should include monitoring sky brightness, implementing pilot projects for lighting modernisation, and conducting educational activities on the importance of natural darkness for ecosystems. Cooperation with scientific institutions can ensure an appropriate research base and methodological support for these activities.

Another significant stakeholder group is the energy sector and manufacturers of lighting equipment. The modernisation of street and public lighting—based on energy-efficient technologies and luminaires designed to minimise light emission beyond target areas (full cut-off type)—can deliver dual benefits: reduced energy consumption and improved quality of the nocturnal environment. Moreover, reduced energy use may contribute to enhanced energy security. Achieving these benefits, however, requires the introduction of appropriate public procurement criteria and the promotion of best technological practices.

Local communities (together with local government units) play a crucial role in this context, as their acceptance is essential for the effective implementation of regulations. Public concerns often relate to safety or perceived reductions in comfort. Therefore, information campaigns should emphasise that well-designed lighting improves visibility, reduces glare, and increases energy efficiency, while simultaneously protecting human health and the environment. Public awareness campaigns, consultations, and pilot

projects can significantly enhance acceptance and should be carried out in a coordinated manner, involving multiple stakeholder groups.

Transforming dark skies into an asset for the sustainable development of tourism

The key target groups in the development of astro-tourism potential primarily include institutions responsible for tourism development—regional and local tourism organisations, as well as promotion departments within administrative units at various levels. Their role is to coordinate comprehensive tourism products, encompassing accommodation, thematic events, workshops and astronomical festivals, by building platforms for stakeholder cooperation and promoting the overall offer. The integration of astro-tourism components into regional promotion strategies by Destination Management Organisations (DMOs) can contribute to extending the tourist season and increasing visitor numbers outside peak summer or winter periods. However, actions extending beyond fragmented local initiatives and promotional campaigns are essential. In this context, effective cooperation between administrative promotion departments and both Local Tourism Organisations (LTOs) and Regional Tourism Organisations (RTOs) is of critical importance.

Entrepreneurs in the tourism sector also play a significant role in the development of dark sky tourism, including accommodation providers, guides, tour operators, and—crucially—managers of astro-tourism facilities. The latter exert a decisive influence on infrastructure development, including observation platforms, educational trails, and the necessary buildings and equipment. A supporting role is played by non-governmental organisations and local or regional astronomical clubs, which constitute natural stakeholders in the development and quality enhancement of astro-tourism products. Their expert knowledge and experience in organising astronomy outreach events can be utilised in creating authentic and credible offers, even in areas where naturally dark skies are not present (e.g. Urban Night Sky Places).

Cooperation among these groups, including collaboration with the scientific sector, should be based on mutual benefit: the dissemination of scientific knowledge should go hand in hand with the economic development of regions possessing favourable conditions for astro-tourism. From a sustainable development perspective, it is also essential that the growth of dark sky tourism does not lead to excessive environmental pressure. This requires the implementation of visitor management measures, including limiting the number of participants in events held in the most sensitive areas and promoting responsible tourist behaviour. The integration of nature conservation with tourism offerings constitutes the foundation for long-term success and may expand the traditional astro-tourism offer to include elements of “noctourism”, thereby enhancing visitor experiences and reinforcing the outcomes.

Local participation and transnational cooperation in reducing light pollution

The key stakeholder groups include, above all, public administration at the local, regional, national and European levels, responsible for establishing regulatory

frameworks, spatial planning, and the implementation of investment solutions. At the transnational level, the principal stakeholders are European Union institutions, in particular the Directorates-General of the European Commission: DG ENV, DG ENER, DG CLIMA, DG AGRI and DG SANTE, as well as the executive agency CINEA. Their role is to shape EU policy frameworks and to support synergies between projects financed through different EU instruments.

Another important group comprises the residents of regions covered by the strategy, including local communities and property owners, whose acceptance and participation in pilot actions are essential for the effective implementation of proposed solutions. Non-governmental organisations and civic initiatives (such as Cielo Buio, Paten der Nacht, the Hungarian Astronomical Association, and Dark Sky International) also play a significant role, acting as substantive, educational and outreach partners in the dissemination of knowledge and best practices. This group is complemented by scientific and educational institutions, which provide research, methodological and expert support, enabling the conduct of analyses, monitoring activities and the testing of pilot solutions.

A further important stakeholder group includes entities from the lighting and energy sectors, including large enterprises with technological and implementation capacities, as well as industry and expert organisations (LightingEurope, the European Lighting Expert Association – ELEA) and the scientific and standardisation body CIE – International Commission on Illumination, which shape quality standards and the development directions of sustainable lighting systems. Managers of protected areas and institutions responsible for nature conservation also play an important role, enabling the testing of solutions in environmentally valuable areas and facilitating the integration of such measures with the development of sustainable tourism. Complementary roles are played by transnational initiatives and projects, which serve as sources of knowledge, experience and platforms for international cooperation.

The relationships among stakeholders are multi-level, network-based and complementary in nature. Public administration performs coordinating and regulatory functions, while drawing on the expert knowledge of the scientific community and the experience of civil society organisations. Scientific institutions cooperate both with public authorities and local communities, supporting the transfer of knowledge into practice. The private sector engages in partnership relations with local authorities and research institutions, participating in the testing and implementation of technological solutions. Managers of protected areas cooperate with local governments, civil society organisations and the tourism sector, facilitating the integration of environmental and socio-economic objectives.

In order to ensure meaningful and continuous stakeholder participation, feedback mechanisms have been envisaged. These will include, inter alia, regular working consultations, tools for collecting stakeholder input, and procedures for incorporating submitted comments into subsequent versions of strategic documents developed at

different governance levels. This approach will enable the ongoing adjustment of policy directions and enhance the transparency of the decision-making process (including the self-assessment of dissemination and participatory activities). It is also recommended to establish a permanent stakeholder cooperation platform, serving as a forum for the exchange of experience, coordination of actions, and monitoring of the progress of strategy implementation.

Detailed information on stakeholders and target groups is provided in Figure 7 and *Appendix 4*.

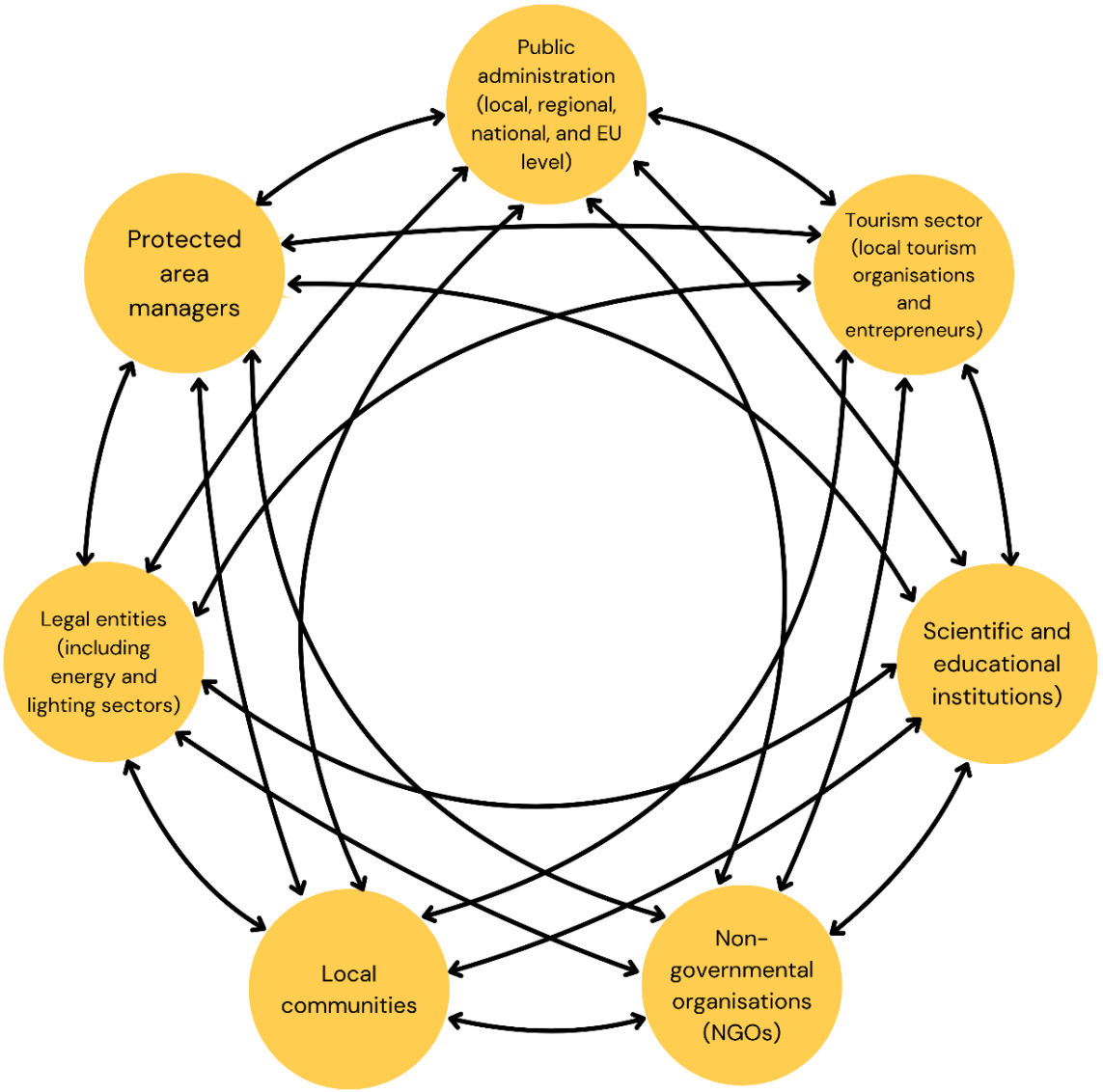


Figure 7. Network of relationships among stakeholders.

5. Strategic Objectives

The main objective—the long-term protection of dark skies—was presented, which depends on actions in three thematic areas: the protection of nocturnal ecosystems, local and transnational cooperation, and the sustainable development of tourism.

The overarching objective of the *Transnational Strategy - the future of dark skies in Central Europe* is the long-term protection of dark skies. Achieving this requires the coordination of three thematic areas: the protection of nocturnal ecosystems, local and transnational cooperation, and the sustainable development of tourism. Conceptually, this objective is illustrated in Figure 8. The protection of nocturnal ecosystems requires both local and transnational cooperation, as well as the sustainable development of tourism. Conversely, efforts to protect nocturnal ecosystems should reinforce cooperation and support the development of sustainable tourism. Cooperation is essential for the proper development of tourism, while tourism-related activities can further strengthen cooperation. Intensive cooperation and sustainable tourism development will contribute to achieving the overarching objective of dark sky protection, which in turn will support the conservation of ecosystems.

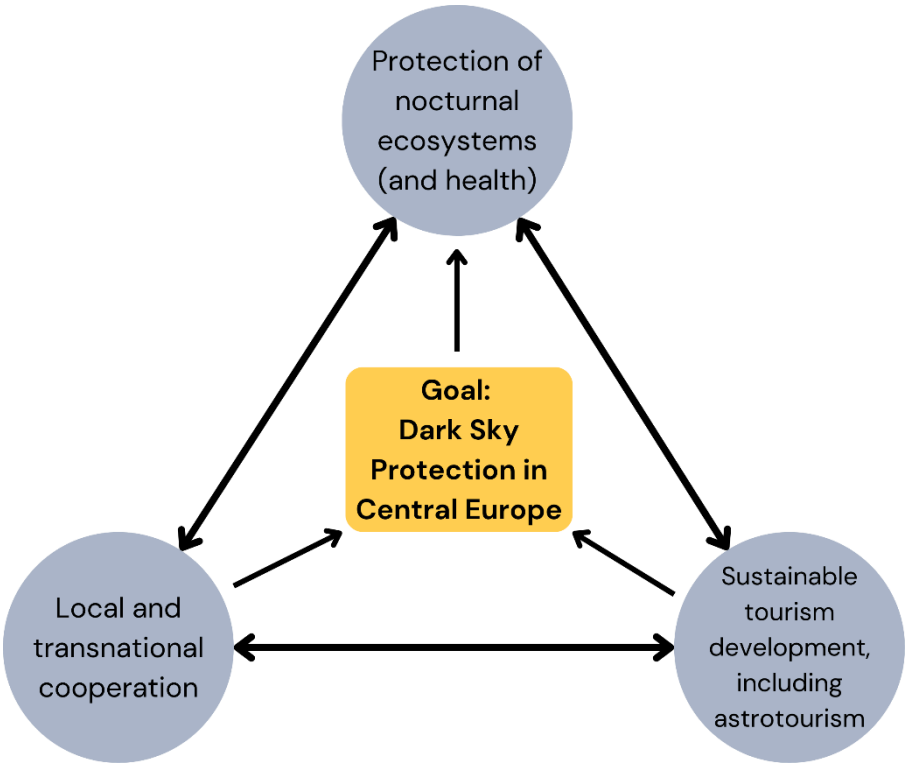


Figure 8. The interaction of the three thematic areas with one another and their combined contribution to achieving the objective of protecting dark skies over Central Europe.

Specific objectives have been defined using the SMART methodology, meaning they must be: Specific (S), Measurable (M), Achievable (A), Relevant (R), and Time-bound (T). It

is essential that each objective is clearly formulated, measurable in terms of progress, realistic, meaningful, and associated with a defined timeframe.

Protection of nocturnal ecosystems in Central Europe

Strategic objective: to preserve high levels of biodiversity and natural night-time conditions by halting the increase in light pollution in Central Europe.

Specific objective 1

To integrate bottom-up processes aimed at reducing light pollution (e.g. projects, scientific research, social initiatives) with biodiversity protection policies.

The strategy highlights the need to develop coherent, multi-level governance mechanisms that recognise artificial lighting as a significant pressure factor affecting nocturnal ecosystems, light-sensitive species, and the continuity of ecological corridors. The protection of naturally dark nights contributes positively to biodiversity and enhances opportunities for astronomical observation.

SMART framework:

- S – integration of light pollution-related actions with biodiversity policies,
- M – increase in the number of countries, regions, and strategic documents addressing light pollution,
- A – utilisation of existing bottom-up processes and documents at various administrative levels,
- R – fragmentation of actions and partial regulation contributes to uncontrolled growth of light pollution, posing a threat to biodiversity,
- T – target horizon set for 2040.

Specific objective 2

To enhance the capacity of regional and local administrations in protecting biodiversity from light pollution.

The strategy emphasises the need to implement measures aimed at improving the competencies of staff across administrative levels responsible for biodiversity management and implementation.

SMART framework:

- S – establishment of an educational platform for training on light pollution, its impacts on biodiversity, and mitigation methods,
- M – increase in the number of trained individuals and institutions,
- A – achievable based on existing scientific knowledge,
- R – insufficient administrative capacity leads to inadequate ecosystem protection,
- T – target horizon set for 2035.

Transforming dark skies into an asset for sustainable tourism development

Strategic objective: to develop an effective strategy for promoting existing astro-tourism sites and establishing new dark sky places in areas with the highest potential for astro-tourism development.

Specific objective 1

To strengthen the activity of existing astro-tourism sites in Central Europe by developing targeted actions and promotional models, and by building a shared "dark sky region" brand, with particular emphasis on cross-border areas. The objective also includes the transfer of best practices in solutions, ideas, and initiatives.

SMART framework:

- S – development of coherent promotional campaigns aimed at establishing a common brand,
- M – monitoring tourist flows before and after campaigns to assess effectiveness,
- A – involvement of research institutions and experts ensures effective implementation,
- R – essential for maximising the use of existing astro-tourism infrastructure,
- T – target horizon set for 2032.

Specific objective 2

To develop astro-tourism products within national parks, landscape parks, and other forms of area-based nature protection, as well as in other areas with above-average potential for astro-tourism.

The strategy focuses on leveraging dark sky potential to create tourism offers combining astronomy, ecosystems, education, and local attractions.

SMART framework:

- S – establishment of at least one astro-tourism product in each designated area,
- M – determination of the percentage share of areas with newly created astro-tourism products (e.g. 25%),
- A – consistent with current trends in the establishment of new dark sky areas,
- R – facilitates future efforts to protect dark skies, particularly in areas already engaged in active conservation or astro-tourism,
- T – target horizon set for 2040.

Local participation and transnational cooperation in reducing light pollution

Strategic objective: to support and activate community self-organisation for the reduction of light pollution.

Specific objective 1

To strengthen multi-level, partnership-based governance in the reduction of light pollution.

The strategy envisages the development of durable cooperation mechanisms among stakeholders operating at local, regional, national and transnational levels, including local authorities, public institutions, the scientific community, non-governmental organisations, economic partners, and civic initiatives.

SMART framework:

S – defining the scope and opportunities for cooperation among diverse stakeholders,

M – increase in the number of partnerships, models and agreements,

A – based on existing stakeholder cooperation structures,

R – multi-level cooperation enhances effective protection of dark skies and supports the development of future common regulatory frameworks,

T – target horizon set for 2040.

Specific objective 2

To increase the engagement of local communities and stakeholders in concrete actions for dark sky protection, while enhancing public acceptance and preventing related social conflicts.

The strategy focuses on transitioning from awareness-raising to active participation of residents, businesses, civil society organisations and educational institutions in planning and implementing measures to reduce light pollution.

SMART framework:

- S – building social consensus and identifying local leaders,
- M – number of communities, projects, participants, agreements and memoranda,
- A – based on NGOs and local social capital,
- R – local engagement increases acceptance and supports bottom-up initiatives,
- T – target horizon set for 2035.

Specific objective 3

To ensure the sustainability of project outcomes and their integration into public policies, financial frameworks, and transnational instruments.

The strategy aims to ensure that pilot actions and best practices continue beyond project funding cycles and are incorporated into policy documents and budgets at various administrative levels, including the transnational level.

SMART framework:

- S – integration of project results and light pollution-related actions into public documents,
- M – increase in the number of policy documents and financing mechanisms,
- A – achievable within existing public policy frameworks,
- R – integration ensures the durability and wider impact of project outcomes and facilitates the transfer of best practices,
- T – target horizon set for 2040.

6. Scenarios for Dark Sky Protection in Central Europe

This chapter presents the results of a foresight analysis, the aim of which was to identify possible development paths in three strategic areas related to the protection of nocturnal ecosystems and to determine the factors that may influence the scale of light pollution in the future. Key risks were identified, and three development scenarios were described: continuation of current trends - status quo scenario, a pessimistic scenario, and an optimistic scenario.

As part of the preparation of the strategy for dark sky protection in Central Europe, a strategic foresight analysis was conducted (Figure 9). Its objective was to identify possible development pathways for the protection of nocturnal ecosystems and to determine the factors that may influence the scale of light pollution in the future. The analysis was carried out across three thematic areas:

- protection of nocturnal ecosystems in Central Europe,
- transforming dark skies into an asset for sustainable tourism development,
- local participation and transnational cooperation in reducing light pollution.

For each group, key risks and uncertainties related to future developments were identified (*Appendix 5)*.

Thus, with regard to the protection of nocturnal ecosystems in Central Europe two key uncertainties were identified as having the greatest potential to determine the future of nocturnal environmental protection: **the lack of systemic legal regulations at the international level** and **ongoing urbanisation and suburbanisation processes**. These factors were identified as the most significant threats to the protection of nocturnal ecosystems. Three of the most probable and representative scenarios were selected for further analysis: **status quo scenario** - absence of systemic legal regulations with the continuation of current rates of urbanisation and suburbanisation, **pessimistic scenario** – absence of systemic legal regulations combined with accelerated urbanisation and suburbanisation and **optimistic scenario** – introduction of systemic legal regulations alongside a slowdown in urbanisation and suburbanisation.

In the area transforming dark skies into an asset for sustainable tourism development the following were identified as the most significant threats: **light pollution level** and the **interest in thematic tourism** (astro-tourism). The three possible future trajectories are outlined: the continuation of current trends in approaches to light pollution and astro-tourism development (status quo scenario), a deterioration of night sky observation conditions resulting from increased light pollution and declining interest in astro-tourism (pessimistic scenario), and the effective reduction of light pollution combined with the dynamic development of astro-tourism as a component of sustainable nature-based tourism (optimistic scenario).

The analysis in the area of local participation and transnational cooperation in reducing light pollution indicates that the future of efforts to reduce light pollution depends primarily on two factors. The first is the **level of social engagement and environmental awareness** among residents, local authorities and non-governmental organisations. The second is the **degree of development of transnational cooperation and the capacity to establish durable coordination mechanisms at the European level**. On the basis of these two factors, three development scenarios have been formulated: continuation of current trends, a negative scenario, and a positive scenario.

The adopted scenario-based approach allows for the design of actions tailored to different potential pathways (full scenarios are presented in *Appendix 5*). As a result, institutions responsible for implementing the strategy can respond more effectively to changing conditions and increase the likelihood of achieving strategic objectives related to the protection of the nocturnal environment.

The developed scenarios—status quo and pessimistic—**do not enable the achievement of the strategic objectives** defined for each thematic area. In such cases, the focus shifts primarily to preventive rather than corrective measures, aimed at avoiding further deterioration of the current quality of dark skies in Central Europe.

Only the optimistic scenario enables the achievement of the defined strategic objectives and therefore should be actively supported through the implementation of the proposed measures.

Concluding remarks

- The future of nocturnal ecosystem protection and dark skies depends on the level of legal regulation, the implementation of technological solutions, the dynamics of urbanisation and suburbanisation, and the growth of public awareness regarding the consequences of inappropriate outdoor lighting. **Without common, systemic legal solutions, Central Europe will remain vulnerable to increasing light pollution and ecosystem degradation**.
- **The status quo scenario will not prevent the increase of light pollution; it may only slow it locally, primarily through bottom-up initiatives**.
- The pessimistic scenario demonstrates that the absence of regulation, combined with accelerated urbanisation and suburbanisation, will lead to a profound ecological, health and scientific crisis, including a dramatic decline in biodiversity, the collapse or reduction of ecosystem services, and the decline of observational astronomy in Central Europe.
- **The optimistic scenario demonstrates that it is possible to stop the increase in light pollution, if the EU policies are harmonised, smart lighting technologies are developed, urbanisation processes are moderated, and long-term public education is implemented**.

- **The most effective outcomes result from combining legal, technological and social actions**. The development of advanced lighting technologies alone is insufficient without supporting legal frameworks, regulations and standards; conversely, regulations alone will not be effective without increased public awareness and well-informed administrative structures at all levels.
- **A key priority is the implementation of well-coordinated action at the European level, synchronised with national-level efforts by project partners, in order to avoid the pessimistic scenario and to translate growing public awareness into durable, system-wide environmental progress**.

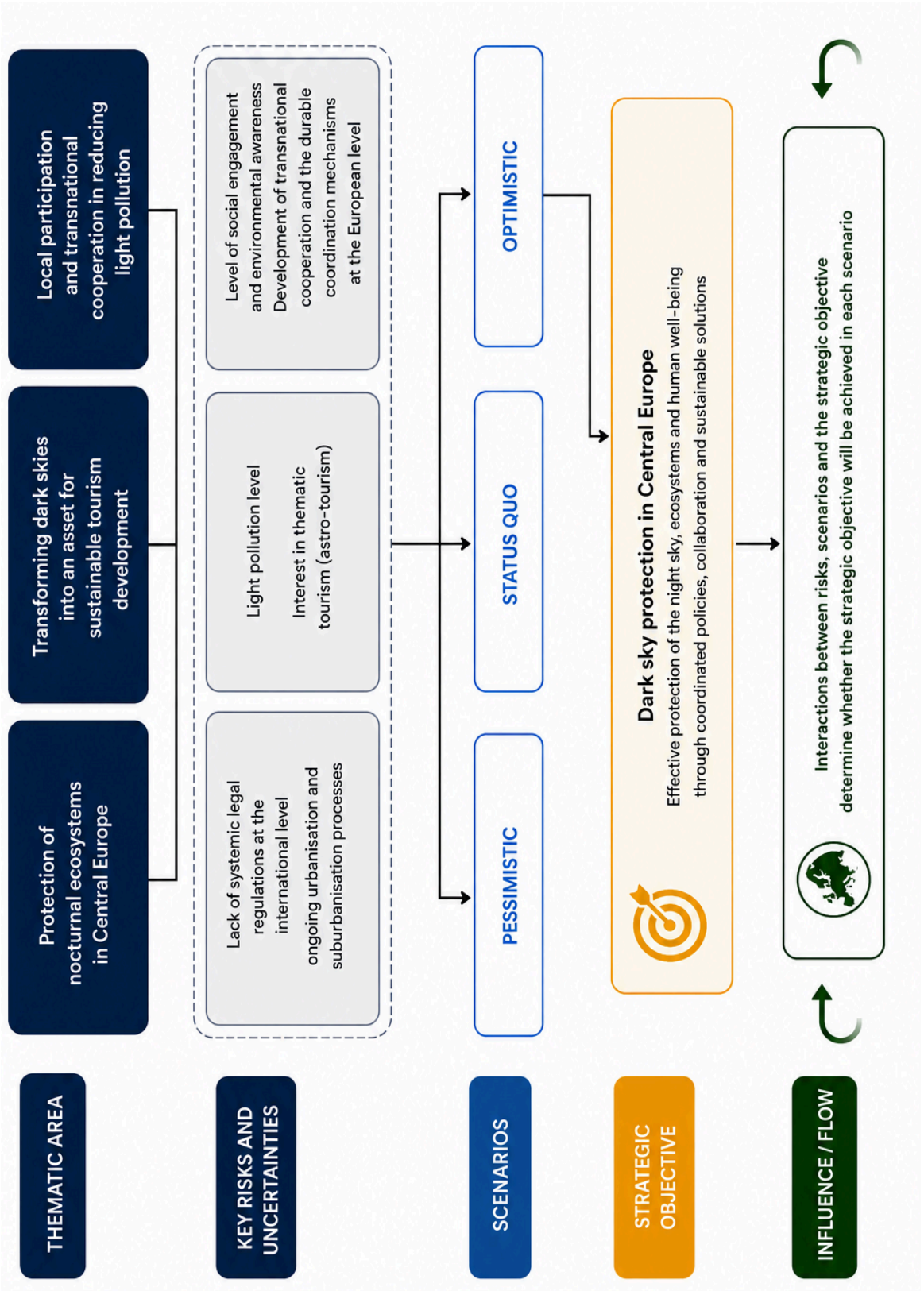


Figure 9. Flowchart for the Analysis of Strategic Forecasts.

7. Strategic directions for action and recommendations

This chapter constitutes an operational elaboration of the strategic objectives formulated in the preceding sections of the document. Its point of departure is defined by two earlier analytical stages: the SWOT diagnosis, which identifies, inter alia, the absence of coherent regulations, the weakness of monitoring mechanisms, and insufficient public awareness; and the scenario analysis, which demonstrates that, in the absence of coordinated action, a further deterioration in the quality of the nocturnal environment is likely. The adopted recommendations are addressed to a diverse group of stakeholders, including local governments, public institutions, civil society organizations, the scientific community, and the private sector—and are designed for implementation at multiple levels: local, regional, and national.

Building on the conclusions of the SWOT analysis and a scenario-based approach, the document structures actions across six mutually reinforcing areas: strengthening institutional and financial mechanisms; legal regulations and spatial planning; the development of monitoring systems; education and public awareness; sustainable night-time tourism; and climate policy.

The key message of this chapter is the need to move from reactive and fragmented measures toward a coordinated, transnational, and systemic approach engaging local governments, public institutions, the private sector, the scientific community, and local stakeholders. The protection of the night sky is framed not as a constraint, but as a resource—environmental, health-related, cultural, and economic—whose rational management requires common standards, durable partnerships, and modern tools for the governance of lighting infrastructure.

Reinforcing Measures

Effective reduction of light pollution requires the establishment of durable institutional and financial mechanisms. A key priority is the creation of consortia of municipalities and regions capable of jointly acquiring funding and implementing lighting projects in a coordinated manner. It is recommended to develop regional and metropolitan strategic documents that incorporate the planning of lighting infrastructure and the creation of so-called dark infrastructure—spaces designed to be compatible with dark-sky protection and nocturnal ecosystems.

A crucial component is the development of long-term cross-border partnerships extending beyond individual projects, as well as the establishment of permanent cooperation networks, such as the Sentinel Alliance initiative developed within the DARKERSKY4CE framework. Complementary measures include financial instruments such as participatory budgets, tax incentives, grants, and awards for investments

implementing solutions that reduce excessive light emissions by local government units and enterprises.

Regulations and Spatial Planning

The integration of light pollution issues into legal frameworks and planning documents is a prerequisite for long-term effectiveness. It is recommended to develop common European guidelines for lighting infrastructure, covering: permissible emission levels; correlated colour temperature of light sources; the use of luminaires with zero or minimal upward light emission (ULOR≈0); and intelligent control systems enabling the reduction of luminous flux during periods of low traffic intensity.

It is also proposed to introduce regulations allowing for the designation of protection zones for areas of high environmental value or significance for astro-tourism, with defined emission thresholds, spectral requirements, and restrictions on illuminated advertising and architectural lighting. At the same time, the introduction of economic instruments supporting the reduction of light emissions is recommended, including environmental charges for excessive light emission and financial mechanisms incentivizing the modernization of lighting infrastructure.

From a systemic perspective, it is necessary to incorporate light pollution into European environmental policies, particularly within biodiversity protection strategies, recognizing the dark sky as a scientific, environmental, and cultural resource.

Light Pollution Monitoring Systems

Effective management requires reliable, comparable, and up-to-date data. It is recommended to develop integrated monitoring systems combining ground-based automatic measurement points with satellite, aerial, and UAV data. A systematic inventory of lighting infrastructure is essential, covering the number and location of light points, luminaire types, correlated colour temperature, and luminous flux control capabilities, and should be conducted already at the investment planning stage.

Monitoring should encompass not only levels of light emissions but also their impact on nocturnal ecosystems, including populations of nocturnal insects (notably moths), bats, and migratory birds, as well as plant pollination processes and other ecosystem services. The deployment of intelligent lighting management systems (IoT, dimming, and tuneable correlated colour temperature) simultaneously provides tools for both emission reduction and monitoring, with the potential to incorporate citizen science initiatives.

Public Awareness and Education

Effective protection of the nocturnal environment is not possible without a sustained shift in societal attitudes. Long-term educational programmes are recommended, encompassing formal education at schools and universities, as well as initiatives undertaken by cultural institutions, national parks, and civil society organizations, aimed at communicating the impacts of artificial light on human health, ecosystem functioning, and the economy. An important role is played by tools enabling residents to

report issues related to excessive lighting, as well as campaigns promoting the introduction of "dark hours". Cooperation among civil society organizations, astronomical groups, and local governments can foster networks of cities and municipalities actively engaged in the protection of the nocturnal landscape.

Sustainable Night-time Tourism

The protection of the dark sky generates tangible economic value. The development of astro-tourism contributes to the diversification of local economies and enhances the attractiveness of regions with low levels of light pollution. It is recommended to establish certification systems for locations and tourist facilities conducive to astronomical observation, as well as to expand offerings to include nocturnal nature-based tourism, such as wildlife observation, night-time educational and cultural events, and interpretive activities in protected areas. In this perspective, the dark sky – traditionally regarded primarily as an environmental issue—assumes the role of a strategic regional resource.

Climate Action Measures

The reduction of light pollution is directly aligned with the objectives of climate policy. Rational management of public and commercial lighting reduces electricity consumption and greenhouse gas emissions. The integration of sustainable lighting policy principles into climate strategies and adaptation plans simultaneously supports improvements in energy efficiency, the protection of nocturnal ecosystems, and the well-being of humans and other living organisms. The synergy between dark-sky protection and decarbonisation objectives provides a strong rationale for the urgent integration of this issue into the mainstream of European environmental and energy policy.

8. Expected Outcomes and Indicators of Their Achievement

This chapter defines the expected outcomes of efforts to protect the dark sky in Central Europe and assigns specific indicators for their assessment. The outcomes are divided into soft outcomes—related to knowledge, competencies, and institutional readiness—and hard outcomes, which are verifiable through documents, systems, and implementations.

Principles for Formulating Outcomes

The definition of expected outcomes for the measures proposed in the *Transnational Strategy - the future of the dark sky in Central Europe* requires a clear distinction between effects directly achievable by beneficiaries and systemic changes dependent on the broader legal, financial, and social environment. For this reason, a two-level framework for assessing effectiveness has been adopted. The first level comprises soft outcomes, relating to knowledge, competencies, cooperation, institutional readiness,

and changes in practices. The second level includes hard outcomes, leaving a formal, material, or measurable trace in the form of documents, systems, implementations, networks, tools, procedures, or datasets.

Indicators should be formulated in a realistic manner, ensuring that they refer to effects attainable within the implementation period by the identified beneficiaries. They should not assume the immediate achievement of distant, large-scale societal outcomes, such as a comprehensive improvement in quality of life, the full restoration of biodiversity, or a systemic transformation of the regulatory framework across Central Europe. A significant proportion of outcomes will be of a mixed nature, with a predominance of organizational and implementation-related effects over final environmental impacts.

Soft Outcomes

Soft outcomes primarily include an increase in the institutional capacity of beneficiaries to plan and implement measures aimed at reducing light pollution. This encompasses the establishment of cooperation mechanisms, the professionalization of staff, and the development of supra-local and cross-border partnerships. This outcome may be measured by the number of trained individuals, the number of entities participating in cooperation networks, the number of working meetings held, and the number of jointly developed assumptions or action plans. While it does not yet resolve the issue of light pollution, it creates the conditions necessary for subsequent regulatory, monitoring, technical, and financial measures.

A second soft outcome is the increase in public awareness and the shift in social attitudes toward excessive night-time lighting. In this regard, the strategy highlights the importance of educational programmes, public awareness campaigns, initiatives undertaken by schools, universities, and cultural institutions, as well as tools enabling citizen engagement. Achieving this outcome does not require demonstrating a complete behavioural change across the entire population; rather, it may be confirmed through increased knowledge and engagement within target groups. Relevant indicators include the number of participants in educational activities who demonstrate an increase in knowledge based on ex-ante and ex-post assessments, as well as the number of institutions participating in the programme that report a defined level of increased awareness.

Another soft outcome is the enhanced readiness of local governments, institutions, and local partners to implement dark-sky-friendly solutions within sectorial policies. This includes the integration of light pollution considerations into strategic documents, spatial planning, and environmental, climate, and tourism policies. The attainment of this outcome should be understood as securing declarations, working-level agreements, prepared concepts, draft provisions, or joint recommendations. Indicators may include the number of entities declaring the implementation of standards, the number of draft provisions developed for policy documents, the number of expert consultations conducted, and the number of sectors in which the issue has been formally addressed.

Hard Outcomes

Hard outcomes include the establishment of formal cooperation structures and implementation documents. This reflects the need to create cross-border partnerships, cooperation networks, strategic documents, and financing mechanisms. This outcome can be measured by the number of signed agreements, established partnerships, developed or adopted strategies, plans, programmes, and *dark infrastructure* concepts, as well as the number of support instruments launched. These are effects directly related to the organizational dimension of strategy implementation and are among the most attainable, as they remain within the scope of beneficiaries' actions.

A significant hard outcome is the development and deployment of elements of a light pollution monitoring system. This may include a network of measurement points, the integration of ground-based, satellite, and aerial data, the inventory of lighting infrastructure, and the observation of light pollution impacts on selected nocturnal species or ecosystems dependent on darkness. This outcome should be assessed through indicators such as the number of operational measurement points, completed inventories, applied standardized measurement procedures, collected datasets, and the degree of comparability across partners. The establishment of a measurement system shifts the focus from declarations to data, and therefore constitutes a hard outcome subject to direct verification.

Another hard outcome is the implementation of standards or technical solutions aimed at reducing artificial light emissions. This includes lighting infrastructure design guidelines, the use of luminaires limiting upward emission, intelligent control systems, dimming, and the regulation of correlated colour temperature. Given the varying scale of potential interventions, this outcome should be formulated cautiously—for example, as the number of facilities subject to pilot modernization, the number of deployed street lighting control systems, the number of light points adapted to dark-sky protection standards, or the number of investments designed in accordance with new guidelines. It is therefore more appropriate to refer to pilot, model, or phased implementations rather than assume full-scale modernization of entire lighting systems.

A further key hard outcome is the creation or expansion of sustainable night-time tourism offerings. This includes certification systems, new forms of tourism activity, night-time events, interpretive materials, and routes related to nocturnal landscapes and astronomical observation. Indicators may include the number of new tourism products, facilities prepared for certification, number of events, tourism partners engaged, and interpretive materials or routes developed. This outcome does not directly imply a sustained increase in local economic performance or tourism flows, as such effects depend on multiple external factors. What is achievable in the short term is the creation of a ready-to-deploy offer capable of generating further development impacts in the future.

Hard outcomes also encompass the formal integration of sustainable lighting policy principles into sectorial documents, particularly those related to environmental, climate, and spatial planning policies. This includes the incorporation of relevant provisions into official documents, the adoption of resolutions, strategies, plans, or programmes addressing light pollution reduction, and the number of administrative units that have formally adopted such measures. These effects are directly linked to the organizational and regulatory dimensions of strategy implementation, remain within the control of beneficiaries, and are subject to clear verification.

The expected outcomes of the strategy should therefore be understood as a set of directly attainable organizational, educational, planning, technical, and implementation-related effects. Their measurement should be based on verifiable indicators, such as the number of participants, institutions, partnerships, documents, consultations, measurement points, datasets, pilot modernizations, and night-time tourism products. Such an approach ensures the realism of strategy implementation while establishing a foundation for the long-term reduction of light pollution, the protection of nocturnal ecosystems, and the utilization of the dark sky as an environmental, social, and economic resource in Central Europe.

9. Monitoring Plan

The indicators and the monitoring plan for the actions proposed in the strategy have been described, along with the principles of data collection and analysis for evaluating the effectiveness of their implementation in protecting the quality of the night sky and landscape.

The purpose of the monitoring plan is to assess the effectiveness of the measures undertaken and to track the progress of implementing the *Transnational Strategy - the future of dark skies in Central Europe*. The proposed plan (Table 2) is intended to support stakeholders in effectively monitoring progress, identifying deviations from the adopted assumptions, and diagnosing areas requiring improvement. The basis for monitoring the implementation of the Central Europe night sky protection strategy is primarily an indicator-based approach, as well as the use of the Dynamic Monitoring Tool, which, unlike traditional methods, relies on continuous data collection and analysis of stakeholder interactions. The adopted monitoring framework supports flexible decision-making regarding further implementation of the strategy and the evaluation of individual stages, thereby ensuring the effective delivery of implementation measures and pilot actions.

It is recommended that the monitoring process be based on the continuous and systematic acquisition, collection and analysis of data related to the implementation of strategic actions, environmental changes, and the level of engagement of public institutions and local communities in activities aimed at raising public awareness of light

pollution and the protection of the night sky. Thematic data should be collected and made publicly available not only by project partners but primarily by scientific institutions, regional bodies and organisations involved in the implementation of the strategy. These data should subsequently be analysed within annual progress reports prepared according to a consistent methodology. It is recommended that the Lead Partner coordinates these activities, in line with the principles of ensuring the sustainability of soft outcomes in Interreg CE projects.

Particular attention should be paid to monitoring changes in light pollution levels, which constitute a key and comparable indicator for assessing changes in the condition and quality of the nocturnal environment. It is further recommended that monitoring include systematic analysis of changes and progress in the implementation of policies and actions aimed at reducing excessive artificial light emissions.

An important component of monitoring is also the assessment of changes in public awareness and stakeholder engagement in activities supporting dark sky protection. In this regard, the analysis should include the number of educational and awareness-raising activities undertaken, the number of participants in such events, and the number of partnerships and formal cooperation initiatives between public institutions, non-governmental organisations, businesses and the scientific community.

It is recommended that monitoring encompass astro-tourism. This should include not only the number of accommodation facilities suitable for dark-sky observation, but also the number of thematic events related to them.

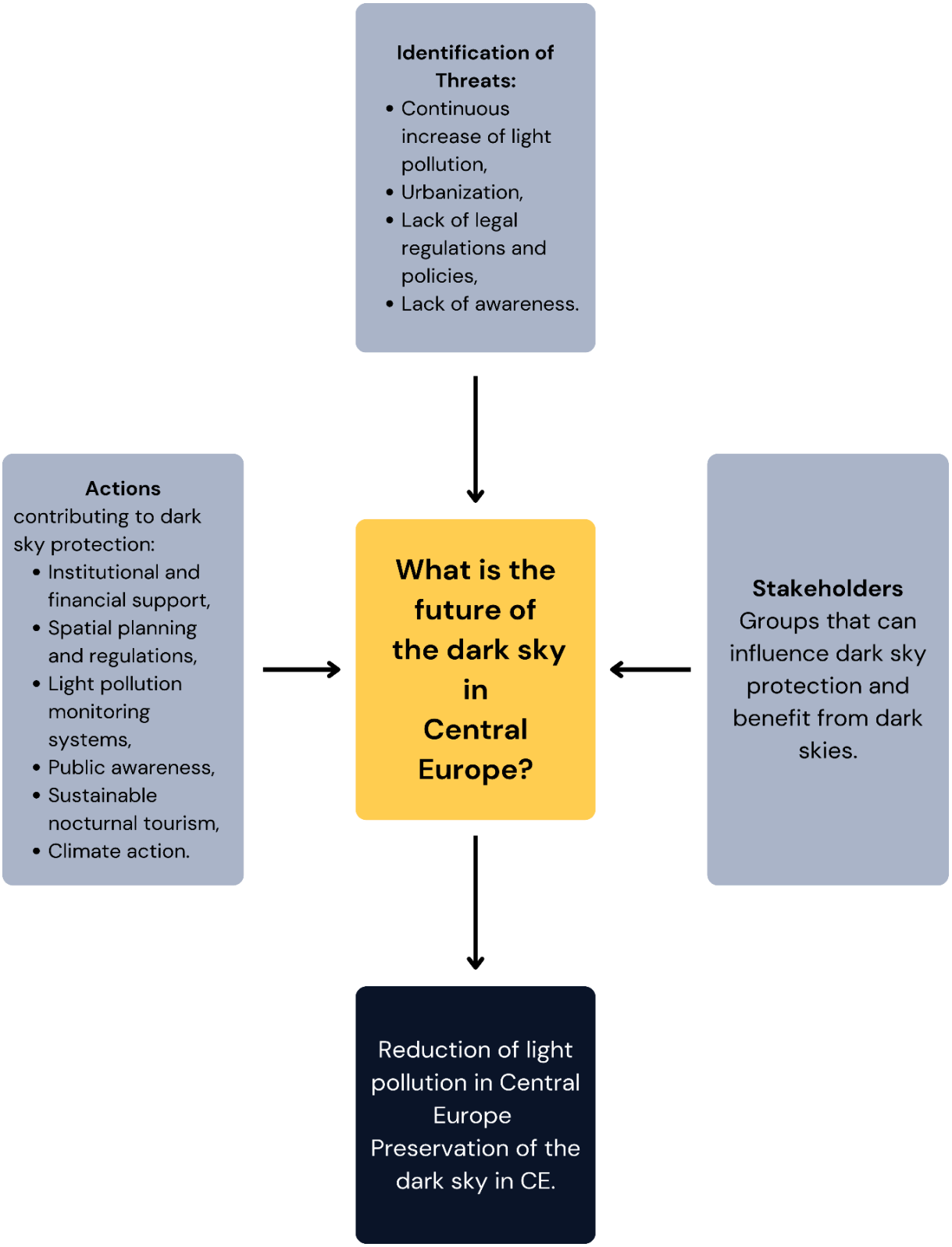
The monitoring results coordinated by the project partners should be presented in annual strategy implementation reports. These reports should include an analysis of progress in implementing agreed actions, an evaluation of changes in indicator values, and an identification of factors facilitating or hindering the implementation of the strategy. It is recommended that the conclusions drawn from these reports serve as a basis for updating strategic actions and adapting public policy directions to evolving environmental, social and technological conditions.

Additionally, a comprehensive review of the strategy implementation should be conducted every three years. This review should include an analysis of long-term trends in light pollution, the development of astro-tourism, and the socio-economic effects of protecting the nocturnal environment. It should also present the economic, social, health, and environmental benefits achieved during this period, including an in-depth assessment of ecosystem services performed every five years. The findings of this periodic review will serve as the basis for updating the strategy's provisions and formulating new recommendations for national and regional policies.

Table 2. Monitoring the implementation of the *Transnational Strategy* in Central European countries.

Monitoring area	Indicator	Proposed data	Frequency
nocturnal environment condition	average level of night sky brightness in reference areas	field measurements, observatories	annually
light emissions	level of artificial light emissions at night in regions covered by the strategy	satellite imagery, field studies	annually
public policies	number of regions and municipalities with regulations limiting light pollution	administrative documents	annually
lighting modernisation	number of public lighting systems modernised in accordance with "dark-sky-friendly" principles	reports of local institutions	annually
nature conservation	number of areas covered by dark sky protection initiatives	project data, regional institutions	annually
education and awareness	number of educational events related to night sky protection, together with an assessment of public awareness levels	reports of organisers	annually
regional cooperation	number of partnerships and cooperation initiatives in the field of dark sky protection	reports of Partners	annually
astro-tourism	number of visitors to areas associated with dark sky tourism	regional statistics	every 2 years
economy, society and environment	balance (assessment) of ecosystem services	global datasets	every 5 years
overall	extended periodic review of strategy implementation	in-depth data from all Partners	every 3 years

Factors influencing the future of dark skies in Central Europe



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Appendix 1. Current Regulations and Policies for the Protection of Dark Skies at International, National and Regional Levels

1. International Context

At the international level, no legally binding convention or treaty specifically addresses light pollution or dark sky protection. Nevertheless, the issue is increasingly recognized through non-binding instruments such as declarations, resolutions, manifestos, guidelines, and expert reports. These instruments constitute soft law: while they do not impose formal obligations on states, they shape policy development through scientific authority, institutional credibility, and normative influence.

The United Nations system, particularly UNESCO and UNEP, plays a central role. Their activities focus on two main dimensions: (1) the protection of dark skies as a natural, cultural, and scientific heritage, especially in relation to astronomy, and (2) the protection of dark skies for nature conservation and biodiversity, given the growing evidence of ecological impacts of artificial night lighting.

Dark skies cannot be independently protected under the UNESCO World Heritage Convention due to the requirement of clearly defined boundaries[4]. Nevertheless, UNESCO actively promotes dark sky protection through thematic initiatives related to astronomy and night landscapes. The International Astronomical Union (IAU) has further contributed through resolutions recognizing the night sky as a common heritage of humanity and calling for the limitation of intrusive artificial lighting and increased public awareness. A key milestone is the La Palma Declaration (2007), which frames the right to dark skies as a fundamental human right and a core element of landscape protection[5]. Although non-binding, it has become a widely cited normative reference for dark sky policies.

In parallel, non-governmental organizations play a significant role. DarkSky International, in particular, develops guidelines, policy recommendations, and voluntary certification schemes for “International Dark Sky Places”, thereby influencing lighting practices at local and regional levels worldwide[6].

The ecological dimension of dark sky protection has gained increasing attention. While no global biodiversity convention directly regulates light pollution, related instruments acknowledge its harmful effects. Resolutions adopted under the Convention on the

[4] For further details, see: UNESCO (1972) Convention Concerning the Protection of the World Cultural and Natural Heritage. Paris: UNESCO. Available at: https://whc.unesco.org/en/convention/ (Accessed: 12 January 2026); UNESCO (2003) Convention for the Safeguarding of the Intangible Cultural Heritage. Paris: UNESCO. Available at: https://ich.unesco.org/en/convention (Accessed: 12 January 2026).

[5] Starlight Initiative (2007) *Starlight Declaration in Defence of the Night Sky and the Right to Starlight (La Palma Declaration)*. Adopted at the International Conference in Defence of the Quality of the Night Sky and the Right to Observe the Stars, La Palma, Canary Islands, Spain. Available at: http://www.starlight2007.net (Accessed: 12 January 2026).

[6] For further information on the public activities of Dark Sky International, see the official website: https://darksky.org/ (Accessed: 12 January 2026).

Conservation of Migratory Species of Wild Animals address the impacts of artificial lighting on bats and other wildlife and provide guidance on mitigation measures[7]. Although non-binding, these documents confirm that light pollution is increasingly recognized as a global environmental threat affecting ecosystems, species migration, and human well-being.

A new and growing challenge is space-based light pollution, caused by the rapid expansion of satellite constellations in low Earth orbit. This issue has been raised by the scientific community and international bodies, including the IAU and the UN Committee on the Peaceful Uses of Outer Space[8]. While no binding rules exist, these discussions highlight the global and multi-actor nature of contemporary light pollution.

2. European Union Legal Context

Within the European Union, there is no comprehensive legal framework specifically dedicated to light pollution or dark sky protection. The issue remains marginal in EU environmental law and policy and is addressed only indirectly through other regulatory objectives.

Major strategic documents, including the European Green Deal[9] and the EU Biodiversity Strategy for 2030[10], do not explicitly refer to light pollution. Limited recognition appears in the EU Action Plan for the Reduction of Pollution of Water, Air and Soil[11], which highlights the need for research and monitoring of light pollution impacts, without introducing binding standards or obligations.

In EU hard law, light pollution is primarily considered in the context of energy efficiency. Relevant instruments include legislation on energy efficiency, eco-design requirements for light sources, and energy labelling[12]. These measures aim to reduce energy consumption rather than address the environmental, ecological, or health effects of

[7] UNEP (1979) *Convention on the Conservation of Migratory Species of Wild Animals*. Bonn: United Nations Environment Programme. Available at: https://www.cms.int/en/convention-text (Accessed: 12 January 2026).

[8] For further information on the activities of the UN Committee on the Peaceful Uses of Outer Space (COPUOS), see the official website: https://www.unoosa.org/oosa/en/ourwork/copuos/index.html (Accessed: 12 January 2026).

[9] European Commission (2019) *The European Green Deal*. Brussels: European Commission. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (Accessed: 12 January 2026).

[10] European Commission (2020) *EU Biodiversity Strategy for 2030: Bringing nature back into our lives*. Brussels: European Commission. Available at: https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en (Accessed: 12 January 2026).

[11] European Commission (2021) *EU Action Plan: Towards Zero Pollution for Air, Water and Soil*. Brussels: European Commission. Available at: https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en (Accessed: 12 January 2026).

[12] European Union (2012) *Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency*. Official Journal of the European Union, L 315, 14 November 2012, pp. 1–56; European Union (2019a) *Commission Regulation (EU) 2019/2020 laying down ecodesign requirements for light sources and separate control gears*. Official Journal of the European Union, L 315, 5 December 2019, pp. 209–240; European Union (2019b) *Commission Delegated Regulation (EU) 2019/2015 with regard to energy labelling of light sources*. Official Journal of the European Union, L 315, 5 December 2019, pp. 68–101.

artificial lighting. As a result, improved energy performance does not necessarily lead to higher biological or environmental lighting quality.

Some indirect legal bases exist. Environmental impact assessment legislation refers to emissions, including light, but does not require mandatory or detailed assessment of light pollution[13]. The Birds and Habitats Directives[14] also offer potential for stronger protection, as obligations to safeguard species and habitats may, in practice, require mitigating light pollution in sensitive areas such as Natura 2000 sites.

Although recital 49 of the Nature Restoration Law explicitly acknowledges robust scientific evidence demonstrating that artificial light adversely affects biodiversity and may also pose risks to human health, the EU legislator conspicuously avoids translating this knowledge into any concrete normative commitments. Instead of establishing binding standards or enforceable obligations, it relegates the issue of light pollution to a purely optional consideration, permitting Member States merely to "consider" preventive, reductive or remedial measures when drafting their national nature restoration plans. This approach significantly weakens the regulatory response to a well-documented environmental pressure and underscores the broader reluctance to address light pollution through substantive and legally operative provisions[15].

Overall, EU law demonstrates slow and incremental progress in acknowledging the negative effects of light pollution, but it still lacks a coherent and binding framework for dark sky protection.

3. National and Regional Legal Context

The lack of specific regulations on light pollution and dark sky protection places responsibility on individual Member States. Regulatory approaches vary: some countries have dedicated legal provisions, others address light pollution within broader nature or investment laws, while some treat it in a fragmented way, without recognizing it as a separate environmental category. Some countries have no legal measures at all. This analysis focuses on the territorial scope of the INTERREG CENTRAL EUROPE 2021–2027 program, covering Austria, part of Germany, Czechia, Croatia, Slovenia, Slovakia, Hungary, Poland, part of Italy.

The analyses of three countries: Hungary, Slovenia and Austria, have been expanded to include regional and local contexts. The move to a lower administrative level is intended

[13] European Union (2011) *Directive 2011/92/EU of the European Parliament and of the Council on the assessment of the effects of certain public and private projects on the environment*. Official Journal of the European Union, L 26, 28 January, pp. 1–21, as amended by Directive 2014/52/EU, Official Journal of the European Union, L 124, 25 April, pp. 1–18.
[14] European Union (2009) *Directive 2009/147/EC of the European Parliament and of the Council on the conservation of wild birds (Birds Directive)*. Official Journal of the European Union, L 20, 26 January, pp. 7–25; European Union (1992) *Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitats Directive)*. Official Journal of the European Union, L 206, 22 July, pp. 7–50.
[15] European Union (2024) *Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on the restoration of nature and amending Regulation (EU) 2022/869*. Official Journal of the European Union, L 2024/1991.

to show that dark sky protection and light pollution reduction require a comprehensive approach involving all administrative levels.

3.1. Austria

In Austria, there is no national law comprehensively limiting light pollution.
A technical standard, ÖNORM O 1052:2022-10, provides guidelines for measuring and assessing light emissions, but its application is not mandatory. Regulation of artificial light from outdoor infrastructure falls to the federal states (so-called 'lands'), particularly in the areas of nature conservation, building law and spatial planning.

Upper Austria stands out as its parliament amended the Environmental Protection Act in 2024 to introduce Chapter 'Vb: Prevention of Light Pollution'. The law covers outdoor lighting installations (§41b) and the responsibilities of municipalities (§41c), aiming to control light emissions in public spaces such as roads, squares, and publicly accessible areas. The law requires lighting to be efficient and environmentally friendly, minimizing impacts on people, nature, and the landscape. Light intensity and operating times must be limited to safety or functional needs. Compliance with points 4 and 7 of ÖNORM O 1052:2022-10 is mandated, unless overriding public interests, such as public order, or safety, prevent it. Municipalities have significant powers, including developing 'lighting concepts' and setting operating times for outdoor lighting under their management, strengthening local autonomy in managing light pollution.

In addition several Austrian states have established binding legal frameworks to mitigate light pollution, primarily through Nature Conservation Acts and Building Codes. Carinthia, Vorarlberg, Salzburg and Lower Austria have the most explicit and direct regulations.

Carinthia

The basic legal act is the Kärntner Naturschutzgesetz 2002 (Carinthian Nature Conservation Act 2002). The Act contains a direct provision concerning lighting installations (§ 32c), according to which outdoor installations must be designed and operated in such a way as to minimise glare and upward and lateral light emissions to the necessary minimum. This regulation introduces the principle of minimising emissions without specifying specific numerical values. Control takes place at the stage of issuing building permits.

Vorarlberg

The key piece of legislation is Bauordnung 2019 (Building Code). Section 47a introduces an obligation to avoid avoidable light emissions (a legal norm interpreted during permitting). The provision does not set technical limits, but constitutes a standard interpreted in the course of administrative proceedings. Supervision is carried out as part of standard building procedures.

Salzburg

The legal basis is the Naturschutzgesetz 1999 (Nature Conservation Act 1999). The Act requires a permit for lighting installations in open areas if they could significantly disturb the night landscape or harm protected animals. Control is exercised through a system of environmental permits.

Lower Austria

The issue of light pollution is addressed in the 2014 Spatial Planning Act (NÖ ROG 2014). The term 'immissions' is used, which also covers light emissions. These impacts should be limited to the minimum necessary at the stage of drawing up planning documents.

3.2. Croatia

Croatia has very advanced legislative solutions when it comes to combating light pollution and protecting the dark sky. Most importantly, there is a separate national Law on protection against light pollution No. 14 (2019), which comprehensively regulates: protection against light pollution, including obligations related to light pollution prevention, legal measures, the method of determining maximum permissible lighting values, restrictions and prohibitions concerning lighting, conditions for planning, construction, maintenance, and reconstruction of outdoor lighting, measurements and methods of monitoring environmental lighting, as well as other issues aimed at reducing light pollution and its effects on the environment.

The law's protective measures against light pollution include limiting unnecessary and harmful light emissions, protecting the night sky, natural water bodies, and areas shielded from artificial lighting, while considering health, ecological, economic, cultural, legal, safety, and astronomical factors. Implementation relies on an "action plan" for the construction or reconstruction of outdoor lighting, prepared by local authorities, the City of Zagreb, and lighting operators. Notably, Croatian regulation features monitoring and enforcement: the environmental inspectorate oversees compliance by authorities, the city, operators, and polluters, while municipal inspectors supervise measures beyond the national inspectorate's scope.

The national law is complemented by executive ordinances: 1) on lighting zones, permissible lighting values, and methods of managing lighting systems (No. 128/2020); 2) on the content, form, and rules for preparing the lighting plan and the action plan for the construction/reconstruction of outdoor lighting (No. 377/2023); and 3) on the measurement and monitoring of environmental lighting (No. 376/2023).

3.3. Czechia

Czechia was a pioneer in regulating light pollution. The national Law No. 86/2002 on Air Protection defined it as visible radiation from artificial sources harmful to humans, animals, or activities, and introduced preventive duties and emission limits. Although this made the country a leader at the time, the act was repealed in 2012. Although

earlier light pollution legislation was withdrawn, further measures have been introduced.

The Nature and Landscape Protection Act No. 114/1992, updated in 2017, regulates the installation of lighting in national parks to prevent light pollution (§16(1)(j)): 'outdoor lights must not direct beams above the horizontal plane through the light source'. Additionally, from 2024, some aspects of light pollution ale also addressed in the new Building Act No. 283/21, which requires buildings to minimize negative impacts on humans, animals, and the environment, including from artificial lighting (§148(1)). Additionally, the implementing Decree No. 146/2024 specifies that outdoor lighting for non-public roads, open-air workplaces, sports facilities, and advertising devices larger than 8 m^2 must be designed to limit negative impacts, including lighting on building facades (§24).

3.4. Germany

Germany does not have a uniform federal law specifically addressing light pollution or dark sky protection. However, a legal basis for developing public policy in this area can be found in two laws: the Law on Protection against Harmful Environmental Effects Caused by Air Pollution, Noise, Vibrations, and Similar Phenomena (2013) and the Federal Nature Conservation Act (2009). The first law, in §3(2), recognizes 'light' as a possible form of immission but does not establish specific measures to counter light pollution, leaving this responsibility to the governments of the individual federal states. The second law, in §23(4), prohibits the installation of lighting along roads and paths, as well as illuminated or light-emitting advertising devices, within nature reserves. At the same time, it allows exceptions if the installation does not adversely affect the conservation objectives of the area or is necessary for traffic safety or other public safety concerns. Federal law in this area can be seen as evolving, as in 2021 §41a was added to the Federal Nature Conservation Act, introducing detailed provisions to protect animals and plants from the harmful effects of artificial lighting. This represents a significant development in German law. However, the regulation has been postponed, as it will only come into force after the adoption of the required implementing ordinance, which will specify emission and technical standards for individual lighting installations.

Some federal states regulate light pollution at their own level, two of them are especially worth of noting. In Baden-Württemberg, the Nature Conservation Act (2015) was amended in 2023 to require that outdoor lighting avoid harming insect fauna. Any installation must assess its ecological impact, while lighting in protected areas may only be approved in exceptional cases, strictly when necessary for traffic safety (§23). In Bavaria, the Immission Control Act (2011) was amended in 2019 to limit light emissions from public buildings and to ban illuminated or light-emitting advertising devices in outdoor areas, with municipalities authorized to grant exceptions (§9). The Bavarian Nature Conservation Act (2011) was likewise amended to include Art. 11a, establishing rules to prevent negative impacts of outdoor artificial lighting on insect fauna.

3.5. Hungary

In Hungary, certain regulations can be found in Government Decree No. 253/1997 on nationwide requirements for spatial planning and construction — the Hungarian Building Code (OTÉK) — which includes the requirement that lighting be designed and executed in a way that minimizes light pollution (since 2012). This 1997 decree was the legal basis until the end of 2024. Since the beginning of 2025, Government Decree No. 280/2024 has been in force, which contains a precise definition of light pollution (Section 5 § (39)) as artificial disturbing light that is emitted above the horizon or not exclusively onto and in the direction of the surface to be illuminated, or that emits light with color effects at inappropriate times, thereby causing glare, artificial brightening of the night sky, or harmful physiological and environmental effects, including negative impacts on wildlife. The new regulations also cover advertising and illuminations. Above all, the regulation requires that newly constructed buildings and installations do not endanger environmental hygiene or the health of users according to their intended purpose and, among other things, 'do not cause light pollution' (Section 74 § (1)). Furthermore, lighting of buildings, public and decorative lighting, illuminated advertisements and advertising devices should be arranged and designed in such a way that the lighting effect does not cause light pollution (Section 75 § (2)).

In addition, Act XCI of 2008, amending the Nature Conservation Act (Act LIII of 1996) regarding protected areas, provides that: 'In protected areas, permanent outdoor lighting on open spaces or fields where no construction activity is planned — except for lighting necessary for the safe operation of public transport — must be designed so as not to disturb tranquility, nor endanger or harm protected animals or species of Community interest'.

In the case of Hungary, the delegation of provisions to a lower level refers to the reduction of light pollution in the Hortobágy National Park and its immediate surroundings, as introduced by Regulation No. 45/2020 (IX. 21.) of the Minister of Agriculture on the designation of the buffer zone of the Hortobágy National Park. This act is local and sectoral in nature and relates directly to environmental protection, including the protection of the night landscape.

According to § 2(1), in the buffer zone, any activities related to the installation, replacement or construction of outdoor lighting, including public lighting and illuminated advertising, may only be carried out with the consent of the nature conservation authority.

3.6. Italy

There is no nationwide regulation on light pollution or dark sky protection in Italy. Due to the principle of autonomy, these matters are governed by the regions (or provinces) themselves, and they have actively exercised their legislative powers in this area.

Emilia-Romagna: Regional Law No. 19 of 2003 promotes reducing light pollution and energy use, protecting astronomical research and outreach, and sets guidelines,

technical requirements, responsibilities for authorities, and penalties for non-compliance. Light pollution is defined as any artificial light spilling outside its intended area or above the horizon. Friuli Venezia Giulia: Regional Law No. 15 of 2007 focuses on reducing light and optical pollution, saving energy, standardizing lighting for road safety, protecting observatories, natural environments, biodiversity, and the night sky, while promoting public awareness and technician training. The starry sky is considered a natural heritage. Liguria: Regional Law No. 22 of 2007 addresses light pollution mainly through energy efficiency. It regulates regional and local planning, protects observatories, and provides municipal Lighting Regulations to plan, maintain, and upgrade outdoor lighting. Lombardy: Regional Law No. 31 of 2015 replaces the 2000 law and implements the EU Energy Efficiency Directive while addressing light pollution. It requires outdoor lighting to prevent light above the horizon, meet energy and safety standards, preserve circadian rhythms, and protect biodiversity. Piedmont: Regional Law No. 31 (2000, amended 2018) aims to reduce light and optical pollution, optimize lighting and energy use, protect wildlife, observatories, heritage sites, improve road safety, and preserve nightscapes and viewpoints. Bolzano: Provincial Law No. 4 of 2011 promotes preventing and reducing light pollution and energy savings. Resolution No. 477 of 2022 set technical criteria for outdoor lighting. Light pollution is defined as any artificial light spreading beyond its intended area, especially above the horizon, to protect the environment, ecological balance, and public health. Veneto: Regional Law No. 17 of 2009 aims to reduce light and optical pollution, save energy, establish uniform design standards, protect research, the environment, and landscape, safeguard the starry sky, and promote awareness and technician training. Trento: Provincial Law No. 16/2007 regulates outdoor lighting to reduce light pollution, save energy, and ensure sky visibility. Valle d'Aosta: Regional Law No. 17 of 1998 regulates public and private outdoor lighting based on UNI-CEI standards, setting obligations, prohibitions, and penalties to limit light pollution. Veneto (municipal planning): Regional Law No. 17 of 2009 also requires municipalities to adopt a Lighting Plan for the Containment of Light Pollution.

3.7. Poland

Polish law lacks specific regulations addressing light pollution, which could serve to protect the dark sky. Light pollution is not referenced in the Environmental Protection Law. A partial legal basis for protective measures can be found in the 2003 Act on Spatial Planning and Development, which, under Article 37a, authorizes municipal councils to adopt so-called 'advertising resolutions'. These resolutions may establish the principles and conditions for the placement of small architectural objects, advertising boards, advertising devices, and fences, including their dimensions, quality standards, and the types of construction materials that may be used. However, the adoption of such resolutions is not mandatory, and the absence of concrete design guidelines and lighting standards limits municipalities' ability to fully leverage the potential offered by this legislation.

Executive regulation on implementing solution concerning the technical requirements for buildings and their siting (2002) is also minimal. According to §293(6) of this regulation: lighting installations, including advertisements, located on the exterior of a building or in its surroundings must not cause discomfort to the building's occupants, pedestrians, or drivers. If the light is directed at a building façade containing windows, the illumination on that façade must not exceed 5 lux for white light, and 3 lux for colored light or light with variable intensity, flashing, or pulsating effects. Unfortunately, this regulation does not impose any obligation to comply with specific technical standards.

Some protection measures are provided through management plans for sensitive areas, such as Natura 2000 sites, which are comprehensively regulated under the 2004 Nature Conservation Act. However, standards for environmental quality with respect to light pollution are lacking.

3.8. Slovakia

Regulation of light pollution protection is partial. The primary hard-law basis can be identified as the Decree No. 539 on detailed information regarding threshold values of optical radiation and requirements for the measurement of optical radiation in the natural environment (2007). For the purposes of the aforementioned decree, the term 'nuisance light' is defined as artificial light from the surroundings (excluding road and public lighting) that, when shining on the exterior surface of a bedroom window, has a disturbing effect on the residents.

Outdoor lighting installations, such as advertising signs, lighting installations in factory yards, construction sites, parking lots, and similar installations—excluding public lighting—should be designed, constructed, and operated so that light from these installations falls as little as possible on the windows of nearby residential rooms. If it is not possible to prevent light from these installations from reaching residential windows, the permissible levels of nuisance light intensity specified in the table must not be exceeded (§ 5 (1)).The decree sets also emission limits for four environmental zones.

The issue of light pollution is addressed only fragmentarily in the 2007 Act No. 355 on the Protection, Promotion, and Development of Public Health and on Amendments to Certain Acts, which regulates public health protection, disease prevention, and crisis actions of health authorities. The act indicates that physical education and sports facilities should be located in such a way that their operation does not negatively affect the surrounding environment, particularly residential areas, including through light emissions.

3.9. Slovenia

Slovenia has a longstanding legislative approach in this area, exemplified by Regulation No. 81 on permissible levels of light pollution in the environment from 2007. Although fairly technical, the regulation aims to protect the dark sky, establishing the principle that lighting sources, as defined by the regulation, must use lamps that emit no light

upwards (except for certain cases concerning the illumination of public street areas within cultural heritage sites).

The regulation specifies detailed requirements for the emission of outdoor lighting for various categories of facilities, including airports, railways, and ports; industrial plants; office buildings and public institutions; and building façades and monuments. It also takes into account the protection of endangered species.

A key provision sets limits on the annual electricity consumption of all lamps used in municipal road and public area lighting, calculated per resident with permanent or temporary residence. Compliance with these targets, including for national road lighting, is assessed through comprehensive environmental impact evaluations of development programs and spatial planning plans that directly or indirectly affect the annual electricity consumption of such lighting.

In the context of local regulations, light pollution issues are addressed in the Nova Gorica municipal decree on the local spatial plan for the municipality of Nova Gorica (OPN). The document designates protected areas, development areas and rules for lighting these areas. These rules are based on an assessment study of the impact of the municipality's spatial plan on Natura 2000 sites and other protected areas.

Appendix 2. Additional Information on the Current State and Future Prospects of Astro-tourism Development.

Current situation of astro-tourism products – extended version

Dark sky tourism has been developing since the 1990s, when the first areas protecting the natural night sky were established and simultaneously promoted as astro-tourism products: Lake Hudson Recreation Area Dark-Sky Preserve in the United States (1993) and Torrance Barrens Dark-Sky Preserve in Canada (1999). The number of such areas has gradually increased, and by 2025 more than 400 certified dark sky protection sites had been recorded worldwide in databases compiled by the Dark Skies Advisory Group (DSAG[16]). According to the nomenclature used by DSAG, these areas are divided into six main categories[17]:

a) Dark Sky Astronomy Site, comprising areas that include at least one astronomical observatory conducting scientific research, located within a protected area (e.g. within a national park),

b) Dark Sky Park, areas located within various types of protected areas (national parks, landscape parks and others), constituting the largest group (over 200 sites worldwide),

c) Dark Sky Heritage Site, located in the vicinity of cultural heritage sites,

d) Dark Sky Outreach Site, representing relatively small-scale locations dedicated to the popularisation of astronomy (e.g. suburban observatories),

e) Dark Sky Reserve, areas similar to dark sky parks but subject to legal protection of nature or landscape, typically larger in extent and including an additional buffer zone consisting of inhabited areas surrounding the core zone,

f) Dark Sky Community, established within inhabited settlements, ranging from small villages of a few hundred inhabitants to cities with populations exceeding fifty thousand.

The issue of nomenclature for dark sky protection areas is further complicated by the terminology used by certifying institutions. Leading organisations operating at a global level apply their own classification systems. Dark Sky International, for example, awards certifications such as Dark Sky Sanctuaries and Urban Night Sky Places to areas that DSAG most often classifies as Dark Sky Outreach Sites or Dark Sky Communities. The Starlight Foundation operates a certification programme comprising more than a dozen different categories, covering both extensive areas (e.g. parks and reserves) and smaller-scale sites (including hotels, restaurants and wineries). A similar diversity of terminology is observed in certification programmes at the national level, as exemplified

[16] Dark Skies Advisory Group is an expert group within the IUCN (International Union for Conservation of Nature) World Commission on Protected Areas that provides guidance on the protection of dark skies and the management of light pollution, particularly in relation to protected areas.
[17] DSAG. World list of dark sky places. https://darkskyparks.org/dsag/DSAG_word_list.htm (as of 25 May 2025).

by designations used by organisations such as the French Association Nationale pour la Protection du Ciel et de l'Environnement Nocturnes (ANPCEN), the Ciemne Niebo Polska programme, and the Royal Astronomical Society of Canada (RASC). The situation is further complicated by the use of individual naming conventions by designated areas themselves, which often adopt terms such as "Starry Parks", "Dark Sky Refuges" and similar expressions. Moreover, despite the work undertaken by DSAG to catalogue dark sky protection sites, there is no single comprehensive database encompassing all certified areas, the total number of which is estimated to exceed 1,300 worldwide.

A further challenge in discussions of dark sky tourism concerns the definition of its constituent products. In accordance with approaches adopted in tourism research, a tourism product includes both clearly delineated areas—broadly corresponding to certified dark sky protection sites (such as dark sky parks, reserves and other sites recognised by DSAG and certifying institutions)—and a range of additional products. These include hotels and other accommodation facilities, tourist trails, viewpoints, events and festivals (both recurring and occasional), applications, facilities dedicated to the popularisation of astronomy (such as museums, planetaria and science centres), and other locations. Estimating even an approximate total number of such products remains challenging, despite attempts undertaken in various countries. For this reason, and due to the inconsistencies in the nomenclature of dark sky protection areas, this chapter adopts the terminology used by DSAG and the number of dark sky tourism products reported in its database. Selected examples of products beyond this list are also provided.

The establishment of dark sky protection areas, which constitute the foundation of dark sky tourism, is primarily aimed at safeguarding locations distinguished by exceptional nocturnal landscape qualities. Analyses indicate that the proportion of areas with sufficiently high sky quality to allow observation of the Milky Way varies significantly across Central Europe—from more than half of the territory in some countries to less than 10% in others. This underscores the urgent need to protect the most valuable areas from further degradation of the nocturnal landscape. The Central European region has played a significant role in these conservation efforts, as well as in the development of the concept of transboundary dark sky parks. In 2009, the world's first transboundary dark sky park was established in the Izera Mountains in the Sudetes (on the border between Czechia and Poland), along with Europe's first international dark sky park—the Zselic Starry Sky Park in Hungary. Since then, more than a dozen additional parks and reserves, as well as communities and observatories with dark sky protection status, have been established. A particularly noteworthy example is the Bieszczady region, where three parks located within three countries (Poland, Slovakia and Ukraine) converge, forming a unique example of cross-border cooperation in the context of dark sky tourism development. Within this region, on the Polish side, the 'Bieszczady' Starry Sky Park—established in 2013—hosts the only site in Central Europe classified by DSAG as a Dark Sky Astronomy Site. In practice, this site functions as a typical dark sky park;

however, due to its large area and its location within three protected areas (a national park and two landscape parks), it also exhibits characteristics typical of dark sky reserves.

To date, five dark sky reserves have been established in Central Europe, all with international status: three in Germany (Bavarian Forest Star Park, Rhön Dark Sky Reserve, Westhavelland Nature Park) and two in Austria (Eisenwurzen and Attersee-Traunsee Nature Park). The latter is classified by its certifying body (Dark Sky International) as a dark sky park. Two of these reserves have been in operation since 2014 (Rhön and Westhavelland), while the remaining three have been established relatively recently (Attersee-Traunsee in 2021, Bavarian Forest in 2025, and Eisenwurzen in 2026). In terms of astro-tourism offerings, they exhibit similar characteristics: a range of activities is organised at varying frequencies, including guided night walks, night sky observation sessions, meteor shower festivals, and other thematic events and workshops. The most common forms of infrastructure include designated observation sites located in specially prepared areas, as well as other locations identified as optimal for observation (such as parking areas and open spaces with unobstructed horizons).

Against this background, particularly noteworthy from the perspective of astro-tourism development is the Observatory Gahberg in the Attersee-Traunsee reserve, together with a network of nearby hotels and agritourism facilities, which collectively form a local centre for the popularisation of astronomy. Another notable example is the so-called “Nachtraum” in the Bavarian Forest Star Park—a specially designed facility for the presentation of issues related to light pollution.

The most numerous and widespread form of astro-tourism attractions in the analysed region is represented by dark sky parks, of which there are fourteen in total (or twelve when transboundary sites are treated as a single area). They are present in almost all CE countries, including two in Croatia (Petrova Gora-Biljeg and Vrani Kamen), three in Czechia (the Beskyd and Izera parks, both shared with neighbouring countries, and the Manětín park, not included in the DSAG database), three in Germany (Nossentiner/Schwinzer Heide, Kyritz-Ruppiner Heide, and Winklmoosalm), one in Poland (Izera), two in Slovakia (Poloniny and the Beskyd park shared with Czechia), and three in Hungary (Bükk, Hortobágy and Zselic). These parks constitute a diverse group both in terms of their duration of operation and their spatial extent. They include some of the oldest parks on the continent (Izera and Zselic, established in 2009), as well as the most recent ones, designated in the second half of 2025 (Nossentiner/Schwinzer Heide and Kyritz-Ruppiner Heide). Differences are also evident in terms of size, ranging from the Winklmoosalm Park, covering only several dozen hectares, to parks extending over hundreds of square kilometres (e.g. Bükk, Hortobágy or Poloniny).

In terms of astro-tourism, their range of activities does not differ significantly from that observed in dark sky reserves and other comparable designations. In addition to numerous visitor-oriented activities, they offer a variety of tourism infrastructure, including a “planetary trail” in the Izera Park, an astronomical observatory combined

with an education centre in Zselic Park, and a three-star hotel located within the park. Other examples include a dedicated projection facility illustrating the impacts of light pollution (a "darkroom") in the Nossentiner/Schwinzer Heide Park, and the "Heide Tower" observation structure in the Kyritz-Ruppiner Heide Park, where training workshops for astro-guides are also conducted.

A similar role to that of dark sky parks is fulfilled by so-called Dark Sky Outreach Sites, which are typically small, often suburban locations dedicated to the popularisation of astronomy, operating on the basis of existing educational facilities that constitute their primary attraction. Numerous such sites exist in Central Europe; however, only two have so far obtained certification from organisations involved in dark sky protection. The first of these, the Ostrowik Dark Sky Protected Area, joined the Ciemne Niebo Polska programme in 2014. Its core consists of an astronomical observatory building and an adjacent small park. It is managed by the University of Warsaw and, in addition to its scientific activities, has offered astro-tourism services since 2025 in the form of educational programmes for schools and organised groups. The second such site is the Val d'Aosta Starlight Stellar Park in northern Italy. This site obtained international certification from the Starlight Foundation in 2020, and its main features include an astronomical observatory and a planetarium. It attracts thousands of visitors annually, primarily from the northern Italian region.

The final group of dark sky tourism sites comprises Dark Sky Communities, of which there are five in the Central European region. Two of these—Jelsa in Croatia and Sopotnia Wielka in Poland—have obtained international certification from Dark Sky International (in 2022 and 2023, respectively). The remaining three, all located in Poland (Palowice, 2009; Izdebno and Chalin, 2014; and Dobre Miasto, 2019), have received national certification under the Ciemne Niebo Polska programme. Dark Sky Communities differ from the previously discussed forms of protection in that their primary objective is the modernisation of outdoor lighting, through recommendations issued by institutions engaged in reducing light pollution, thereby improving living conditions for local communities while simultaneously preserving the quality of the nocturnal landscape.

In some of these locations, astro-tourism provision is virtually absent (e.g. Palowice and Dobre Miasto), although they remain of interest to those concerned with the history of initiatives aimed at mitigating light pollution. In others, tourism is developed through several key forms, ranging from the organisation of one of the largest thematic events in the country—the Dark Sky Festival (Sopotnia Wielka)—to the delivery of numerous observation sessions, workshops and educational activities for organised groups and visitors (Izdebno and Chalin, Jelsa, Sopotnia Wielka). The tourism offer also includes typical astronomical and astro-tourism infrastructure, such as observation platforms for individual use, as well as scientifically valuable facilities, including an observatory forming part of the Global Astrophysical Telescope (PTSD3 – Poznań Satellite Telescope)

in Chalin, and an astronomical observatory together with a replica of the interior of the Destiny module of the International Space Station in Sopotnia Wielka.

Despite the more than twenty initiatives described and the associated broad range of tourism offerings—particularly in terms of events organised during the summer season—the development of astro-tourism in Central Europe remains uneven in both distribution and character. Some areas function as well-managed, near year-round educational and astro-tourism centres (e.g. Zselic Park, Sopotnia Wielka, Val d'Aosta Starlight Stellar Park), while others remain niche due to limited promotion and infrastructure (e.g. Izera Park, Beskyd Park, or Vrani Kamen). Furthermore, the COVID-19 pandemic significantly slowed the certification process for new dark sky protection areas, with recent growth observed primarily in the number of Dark Sky Communities. However, in the period 2025–2026, four new parks and reserves were established, which may indicate a return to pre-pandemic trends.

Development Prospects of Astro-tourism Products – extended version

Industry forecasts, including those of the World Tourism Organisation (UNWTO) and the United Nations Development Programme (UNDP, 2017), as well as the Organisation for Economic Co-operation and Development (OECD, 2024), indicate that traditional mass tourism will gradually give way to niche tourism based on authentic experiences and high environmental quality. Astro-tourism aligns with this trend, combining astronomical observation with nature interpretation, education and cultural heritage. At the same time, its development contributes to increasing public awareness of light pollution.

For more rapid development of astro-tourism, more effective use of existing transboundary products is required. These should serve as flagship elements of the region, representing a unique value in comparison with dark sky protection initiatives in other parts of the world—namely, the world's first transboundary dark sky park in the Izera Mountains, the Czech-Slovak park in the Beskydy Mountains, and the only tri-national dark sky protection area in the world, located in the Bieszczady Mountains. In addition, other parks located in border regions, such as the Bavarian Forest Star Park extending along the German-Czech border, could strengthen transnational relationships through the development of astro-tourism. At present, however, this transboundary potential remains largely untapped, and partnerships exist mainly at the level of formal documentation, without effective implementation of joint astro-tourism initiatives.

Dark sky tourism in Central Europe will undoubtedly continue to develop. The 25 dark sky protection areas established over the past decade and a half are likely to be complemented by additional sites in the coming years. Current initiatives aimed at establishing new dark sky parks in Austria and Poland may further expand the region's astro-tourism offer. At present, Germany, Poland, Hungary and Croatia lead in terms of the number of such sites. Despite the early introduction of legal regulations aimed at minimising light pollution in Slovenia, no certified dark sky protection site has yet been established there, despite existing potential and preliminary projects supported by EU

funding. Similarly, Italy and Austria appear not to be fully exploiting their potential in this area.

It is likely that a number of the several dozen astro-tourism facilities currently operating in Central Europe outside the network of certified dark sky protection areas would be interested in participating in a “dark sky region” cluster, in order to benefit from shared promotional tools, professional destination branding, access to training packages, and the standardisation of services. Sites holding recognised dark sky certifications, such as IDSP, Starlight or other acknowledged designations, primarily gain increased prestige and credibility, strengthen their image as areas committed to the protection of the nocturnal environment, and are better positioned to attract visitors. Additional benefits include opportunities for the development of environmental education and the consolidation of local stakeholders around a shared sustainable development policy.

From a sectoral perspective, this would enable the development of a recognisable tourism product based on common quality standards (e.g. guidelines for observation infrastructure, lighting policies, competencies of astro-guides, and principles for organising night-time events), as well as the creation of integrated tourism packages in cooperation with local accommodation providers, gastronomy and guides. Such a cluster could also function as a platform for data exchange (e.g. sky quality monitoring, tourism statistics), a shared calendar of events, and a mechanism for applying for funding under national and EU programmes.

At present, however, both cooperation between individual dark sky protection areas and institutions involved in tourism development and light pollution mitigation, as well as the professional promotion of astro-tourism itself, remain among the most urgent areas requiring improvement. There is a lack of a coherent communication strategy, audience segmentation (e.g. astrophotography enthusiasts, families with children, premium tourists, school education groups), effective presence in sales channels and social media, and systematic approaches to certification and quality auditing. Without effective measures integrating the public and private sectors, the future of dark sky tourism may remain stagnant—dominated, as at present, by fragmented initiatives characterised by increased activity during seasonal astronomical events (e.g. meteor shower peaks or solar and lunar eclipses), but lacking a stable, year-round business model and a long-term destination development strategy.

Appendix 3. SWOT Analysis of the Future of Dark Sky Protection in Central Europe.

Strengths

- The presence of areas with high nocturnal landscape tourism value and low levels of light pollution, including certified areas recognised by Dark Sky International.
- Increasing engagement of local communities, non-governmental organisations, environmental protection institutions, and selected business partners.
- Established and ongoing dialogue with local and regional authorities at various administrative levels.
- Long-standing, durable interdisciplinary and transnational cooperation (covering environment, technology, tourism, spatial planning, economy and education).
- Existing cooperation networks and long-term organisational structures (e.g. alliances, working groups, research teams).
- Access to scientific tools and pilot solutions and implementations (e.g. GIS, spatial analyses, demonstration projects).
- Growing scientific consensus regarding the negative impacts of artificial light at night and the need for protection and legal regulation.
- Compatibility of dark sky protection with sustainable and educational tourism, as well as relatively low entry barriers for astro-tourism.
- The significant importance of natural heritage for local communities.
- The establishment of the Sentinel Alliance under the DARKERSKY4CE project as a permanent working group addressing light pollution in Central Europe.

Weaknesses

- Insufficiently developed tourism and sustainable technical infrastructure in peripheral areas.
- Low public awareness of the phenomenon and underestimation of the impacts of light pollution.
- Limited recognition of the issue and uncoordinated promotion at the regional level.
- Limited accessibility of many locations and restrictions on night-time movement.
- Gaps in access to the Internet and mobile networks in certain dark sky areas.
- Shortage of qualified personnel (e.g. astro-guides, experts in nocturnal ecosystems), particularly in small settlements.
- Fragmentary data on light pollution and a limited scale of pilot actions.
- Short-term funding mechanisms not aligned with the long-term processes of ecosystem recovery.
- Cultural resistance to change and reliance on voluntary stakeholder engagement; absence of dedicated governmental enforcement bodies addressing the issue.
- The presence of, at times, conflicting local interests among stakeholders in rural areas.
- Underdeveloped transnational networks and complex international coordination.

Opportunities

- Growing interest in tourism based on authentic experiences, nature, and thematic education.

Threats

- Progressive light pollution associated with urbanisation, suburbanisation and infrastructure development.

- The potential of astro-tourism as a tool for rural development and the diversification of local economies.
- Increasing environmental awareness, particularly among younger generations, and the development of citizen science.
- Technological progress in adaptive and smart lighting systems.
- Advances in outdoor lighting technologies and design.
- High energy costs as an incentive to reduce excessive lighting.
- Integration of light pollution issues into EU policies (e.g. climate, biodiversity, territorial cohesion).
- Availability of EU funding and cross-border cooperation instruments.
- Dedicated funding schemes, transnational and interdisciplinary projects, and commissioned initiatives.
- The possibility of developing a common, pan-European strategy for the protection of the night sky.
- Increasing engagement and a more prominent voice of scientists, educators, science communicators, and public figures.
- The existence of thematic networks (e.g. Dark Sky International, Starlight Foundation).
- Increasingly effective operation of foundations, associations and civic groups active in dark sky protection and in raising awareness of the issue.
- Growing awareness of the benefits of darker skies for ecosystem protection.
- A favourable moment for introducing changes and new regulations within emerging European policy cycles.

- Reducing light use requires changes in habits and ways of thinking, which are difficult to achieve.
- Unequal access to potential benefits (e.g. from astro-tourism) and the risk of superficial or ineffective measures.
- The risk that proposed mitigation measures may not be accessible to all groups (e.g. low-income populations, persons with disabilities, migrants).
- Lack of coherent legal regulations and weak enforcement of existing provisions; absence of uniform lighting standards.
- Fragmentation of actions and insufficient cooperation between institutions, stakeholders and decision-making levels.
- Inappropriate and widespread use of LED technologies leading to increased night-time light emissions.
- Conflicts between environmental objectives and priorities related to urban planning and safety.
- Climate variability hindering certain activities, such as night-time observations.
- Limited financial and human resources following the completion of dedicated projects.
- Risk of declining long-term public interest and fragmentation of institutional actions.
- Political instability and the growing influence of political currents less sensitive to environmental issues.
- The presence of other environmental stressors contributing to ecosystem degradation.
- The widespread perception that other environmental threats are of higher priority.
- The development of astro-tourism and dark sky tourism products without parallel measures to reduce the continuously increasing level of light pollution—i.e. attempts to derive economic benefits from astro-tourism without safeguarding its key resource, namely the dark night sky.

Appendix 4. List of Proposed Forms of Engagement by Target Group.

Target group – Protection of Nocturnal Ecosystems in Central Europe:

a) **Public administration (local, regional, national and European)**
- integrating the protection of nocturnal ecosystems into development strategies and spatial planning documents,
- developing and implementing lighting standards that limit light emissions,
- introducing local regulations concerning public and private lighting,
- financing lighting modernisation programmes.

b) **Managers of protected areas (national parks, landscape parks and other forms of nature conservation)**
- monitoring night sky quality and levels of light pollution,
- implementing pilot projects for lighting modernisation within protected areas,
- conducting educational activities on the importance of natural darkness for ecosystems,
- cooperating with scientific institutions in the implementation of research and conservation projects.

c) **Scientific and research institutions**
- conducting research on the scale and impacts of light pollution on nocturnal ecosystems,
- developing methods for monitoring the night sky,
- providing expert support to public administration and protected area managers,
- participating in pilot projects aimed at reducing light emissions.

d) **Energy sector and lighting equipment manufacturers**
- developing smart lighting technologies and solutions that minimise light emission beyond areas requiring illumination,
- implementing energy-efficient public lighting systems,
- participating in projects for the modernisation of lighting infrastructure,
- promoting best technological practices in sustainable lighting.

e) **Local communities**
- participating in public consultations concerning changes to lighting systems,
- engaging in information campaigns and educational activities,
- cooperating with local authorities in the implementation of initiatives aimed at reducing light pollution,
- supporting pilot actions and demonstration projects.

Target group - Transformation of dark skies into an asset for sustainable tourism development:

a) Local government units (LGUs), including tourism promotion departments
- integrating astro-tourism into local and regional development and promotion strategies,
- financing infrastructure and promotional activities,
- establishing regulations to limit light pollution.

b) DMOs, i.e. Local Tourism Organisations (LTOs) and Regional Tourism Organisations (RTOs)
- coordinating cooperation among stakeholders,
- developing regional astro-tourism products,
- conducting marketing campaigns,
- organising study visits and industry events.

c) Tourism entrepreneurs
- participating in product partnerships,
- developing accommodation and service offers tailored to night-time tourism,
- co-organising astronomical events,
- undertaking professional training in astro-tourism.

d) Managers of astro-tourism facilities
- developing observational and educational infrastructure,
- designing programmes for night sky and nocturnal landscape interpretation,
- coordinating and cooperating with stakeholders in the organisation of astronomical events and activities.

e) Non-governmental organisations (including informal astronomical clubs)
- conducting workshops and night sky observation events,
- contributing to the development of educational programmes,
- providing substantive consultation for tourism products,
- activating and engaging local communities.

f) Scientific community
- providing expert consultation in the siting of facilities,
- cooperating in the development of educational programmes,
- conducting research on the potential of astro-tourism.

g) Local communities
- participating in public consultations on tourism development planning,
- actively engaging in local initiatives and events,
- developing services complementary to astro-tourism,
- fostering local entrepreneurship related to astro-tourism.

h) Protected areas, dark sky parks and reserves
- developing visitor management frameworks,
- introducing visitor limits in sensitive areas,
- monitoring the environmental impacts of tourism.

Target group – Local participation and transnational cooperation in light pollution reduction:

a) Public administration (local, regional, national and European)
- developing regulatory frameworks and standards for limiting light pollution,
- integrating dark sky protection into public policies and development strategies,
- coordinating cooperation among institutions at different levels of governance,
- supporting investment and pilot projects.

b) European Union institutions and executive agencies
- shaping EU policies related to environmental protection and energy efficiency,
- funding research and implementation projects,
- supporting transnational cooperation and the exchange of experience,
- creating synergies between EU funding programmes.

c) Non-governmental organisations and civic movements
- conducting educational activities and public awareness campaigns,
- disseminating best practices for reducing light pollution,
- cooperating with public administration and the scientific community in pilot projects,
- stimulating civic engagement and local initiatives.

d) Scientific and educational institutions
- conducting research and analyses on light pollution,
- developing monitoring methods and analytical tools,
- providing expert support for implementation projects and public policies,
- participating in international research projects.

e) Lighting and energy sector
- developing technologies that reduce light emissions and energy consumption,
- participating in demonstration projects and testing innovative solutions,
- cooperating with research institutions in the development of lighting standards,
- implementing sustainable lighting systems in public spaces.

f) Managers of protected areas
- testing solutions for reducing light pollution in environmentally valuable areas,
- cooperating with public administration and scientific institutions in monitoring the nocturnal environment,
- integrating conservation measures with the development of sustainable tourism.

g) Local communities and property owners
- participating in pilot actions and demonstration projects,
- implementing good lighting practices at the local level,
- engaging in public consultations and decision-making processes.

h) Transnational projects and cooperation initiatives
- exchanging experience and best practices between regions,
- establishing platforms for international cooperation,
- developing joint tools and standards for monitoring light pollution.

Appendix 5. Scenarios Description for Dark Sky Protection in Central Europe.

1. Protection of Nocturnal Ecosystems in Central Europe

Factors influencing the protection of nocturnal ecosystems from light pollution were previously identified in the SWOT analysis (see Chapter 3). These include both enabling factors that support the reduction of light pollution and threats related to infrastructure development, urbanisation, suburbanisation, and the absence of coherent legal frameworks. Based on this analysis, two key uncertainties were identified as having the greatest potential to determine the future of nocturnal environmental protection: the lack of systemic legal regulations at the international level (Factor 1) and ongoing urbanisation and suburbanisation processes (Factor 2). These factors were identified as the most significant threats to the protection of nocturnal ecosystems. Their interaction allows for the definition of different possible future scenarios. In theory, six combinations could be distinguished based on these factors; however, three of the most probable and representative scenarios were selected for further analysis:

- **status quo scenario** - absence of systemic legal regulations with the continuation of current rates of urbanisation and suburbanisation,
- **pessimistic scenario** – absence of systemic legal regulations combined with accelerated urbanisation and suburbanisation,
- **optimistic scenario** – introduction of systemic legal regulations alongside a slowdown in urbanisation and suburbanisation.

1.1. Status Quo Scenario

In this scenario, no coherent and universally applicable legal regulations for limiting light pollution are introduced over the next decade. Actions will continue to be undertaken primarily at the local or regional level by non-governmental organisations, research institutions, local authorities, and managers of protected areas. The absence of harmonised regulations at the European level will result in individual initiatives applying differing standards and technical solutions. Consequently, efforts to reduce light pollution will remain fragmented and poorly coordinated. Although some local communities may achieve positive outcomes, the problem will gradually intensify at the regional scale. At the same time, the continuation of current rates of urbanisation and suburbanisation will lead to further infrastructure expansion and an increasing number of lighting installations. As a result, areas with naturally dark skies will progressively diminish, and pressure on nocturnal ecosystems will increase.

1.2. Pessimistic Scenario

The pessimistic scenario assumes the absence of systemic legal regulations combined with accelerated urbanisation and suburbanisation. Under such conditions, infrastructure development, urban expansion, and increasing demand for outdoor lighting will lead to a rapid rise in light pollution. The lack of regulatory frameworks and technical standards limiting light emissions will result in the widespread use of energy-inefficient and

excessively intensive lighting. Consequently, artificial light will continue to spread throughout the nocturnal environment.

This scenario would lead to the progressive disappearance of dark sky areas, while nocturnal ecosystems would experience accelerated degradation, fragmentation, and the loss of species performing key ecosystem functions. Light pollution, in combination with other environmental pressures, would cause irreversible damage to biodiversity. As a result, it would no longer be possible to maintain dark sky conditions suitable for astronomical observations, whether professional or amateur.

1.3. Optimistic Scenario

The optimistic scenario assumes the introduction of coherent legal regulations at the national or international level, alongside a slowdown in urbanisation and suburbanisation processes. Under this scenario, a systemic approach to reducing light pollution would be established through the definition of standards for the design and use of outdoor lighting. Legal regulations would include, inter alia, limiting light emissions to areas where illumination is required, applying appropriate correlated colour temperature, optimising operating times and light intensity, and the protection of natural areas that are highly sensitive to artificial light.

A slowdown in urbanisation and suburbanisation, combined with improved spatial planning, would reduce pressure on the natural nocturnal environment. As a result, larger areas of dark skies would be preserved, and the protection of nocturnal ecosystems would become more effective. This would enable the restoration of nocturnal ecosystem functioning and the re-establishment of conditions suitable for astronomical observation.

2. The Use of Dark Skies as an Asset for the Sustainable Development of Tourism

The following scenarios take into account potential changes in approaches to light pollution and the development of tourism associated with night sky observation at local, regional, national and transnational levels. Scenario analysis makes it possible to identify potential development pathways for the sector over the next decade and to determine factors that may either support its growth or constitute significant barriers. Three possible future trajectories are outlined: the continuation of current trends in approaches to light pollution and astro-tourism development (status quo scenario), a deterioration of night sky observation conditions resulting from increased light pollution and declining interest in astro-tourism (pessimistic scenario), and the effective reduction of light pollution combined with the dynamic development of astro-tourism as a component of sustainable nature-based tourism (optimistic scenario).

2.1. Status Quo Scenario — “Diffuse Lights, Fragmented Actions”

The status quo scenario assumes the continuation of current trends in the development of astro-tourism in Central Europe. Despite growing public interest in nature-based tourism and experiences related to night sky observation, no significant improvements

occur in the coordination of public policies, financing mechanisms, or stakeholder cooperation. Under such conditions, initiatives related to dark sky protection and astro-tourism development are implemented primarily at the local level by non-governmental organisations, local communities, scientific institutions, and managers of protected areas. However, these activities remain fragmented and are rarely integrated into broader tourism development strategies or environmental policies.

Although the number of dark sky sites gradually increases, many of them remain poorly promoted and have limited recognition among tourists. Only a small number of parks and reserves develop comprehensive tourism offers, including astronomical events, educational programmes, or active promotion through digital channels. By the mid-2030s, the astro-tourism sector in the region remains fragmented and largely dependent on the engagement of individual institutions and communities. The lack of coherent regulations governing outdoor lighting, combined with increasing light pollution, gradually deteriorates observational conditions in many locations. As a result, the potential of astro-tourism as a driver of regional development remains largely underutilised.

2.2. Pessimistic Scenario — "Lost Dark Skies"

The pessimistic scenario assumes a deterioration of conditions for astro-tourism development due to increasing light pollution, weakened international cooperation, and reduced financial support for initiatives related to night sky protection. The expansion of transport infrastructure, urban development, and the widespread use of intensive LED lighting contribute to the gradual degradation of night sky quality, even in peripheral areas that previously offered excellent observational conditions. Consequently, observational conditions in many existing dark sky parks deteriorate, leading to declining interest in astronomical events and night-time tourism activities.

The absence of effective legal regulations and financing mechanisms results in the gradual decline of many astro-tourism initiatives. The number of volunteers and local leaders engaged in organising events decreases, and some protected areas lose their certifications related to night sky quality. Under such conditions, astro-tourism in Central Europe loses competitiveness in comparison with other regions of the world offering better observational conditions, such as Southern Europe or Scandinavia. As a result, the sector contracts and continues to function only through isolated local initiatives that are unable to develop a stable tourism product of regional significance.

2.3. Optimistic Scenario — "A Bright Future for Dark Skies"

The optimistic scenario assumes the successful integration of night sky protection with the development of sustainable nature-based tourism. In this scenario, astro-tourism becomes a significant component of the region's tourism offer, and Central Europe establishes itself as one of the leading astro-tourism destinations in Europe. A key role is played by the development of transnational cooperation and the introduction of more coherent regulations aimed at reducing light pollution. In many countries of the region,

legislation is adopted to regulate the design and use of outdoor lighting, and the protection of the nocturnal landscape is incorporated into environmental policies, spatial planning frameworks, and tourism development strategies. At the same time, a network of interconnected dark sky parks and other areas with high-quality night skies is established. Through coordinated promotion and joint actions, the region develops a recognisable tourism brand centred on experiences related to stargazing and nocturnal nature.

Astro-tourism begins to generate tangible economic benefits for local communities through job creation, the development of tourism infrastructure, and increased visitor numbers. At the same time, public awareness of the importance of protecting the nocturnal natural environment increases, while educational and scientific activities become integral components of the tourism offer. As a result, the natural night sky becomes a key element of regional identity and a symbol of a sustainable approach to tourism development and environmental protection.

3. Local Participation and Transnational Cooperation in Reducing Light Pollution

The analysis indicates that the future of efforts to reduce light pollution depends primarily on two factors. The first is the level of social engagement and environmental awareness among residents, local authorities and non-governmental organisations. The second is the degree of development of transnational cooperation and the capacity to establish durable coordination mechanisms at the European level.

In recent years, there has been a gradual increase in interest in the issue of excessive artificial light at night. In many regions, local initiatives have emerged focusing on dark sky protection, the modernisation of public lighting, and the development of astro-tourism. However, these activities are often fragmented and project-based, and their continuity depends on the availability of funding and the activity of individual institutions. International cooperation also plays an important role, enabling the exchange of knowledge, experience and best practices. Projects implemented under European programmes contribute to the development of cooperation networks between regions; however, in many cases their outcomes are time-limited and do not lead to lasting institutionalisation.

On the basis of these two factors, three development scenarios have been formulated: continuation of current trends, a negative scenario, and a positive scenario.

3.1. Status Quo Scenario – Continuation of Trends

In this scenario, the level of social engagement and the pace of regulatory change remain similar to the current situation. Transnational cooperation continues mainly in the form of projects financed through European funds but does not result in the establishment of durable institutional mechanisms. The absence of common European regulations on light pollution means that actions are undertaken primarily at local or regional levels. These initiatives are often fragmented and vary in terms of standards and methods applied.

At the same time, the number of light sources continues to increase, particularly due to the widespread adoption of LED technology, which is not always used in accordance with principles of nocturnal environmental protection. Local authorities often face limited financial resources for modernising lighting infrastructure, further hindering the implementation of improvements. Under such conditions, public awareness grows slowly and remains relatively low outside expert communities and environmental organisations.

As a result, the level of light pollution in Central Europe gradually increases, leading to biodiversity loss, increased electricity consumption, and a decline in quality of life. The natural night sky becomes an increasingly scarce resource, available mainly in areas distant from highly urbanised zones.

3.2. Pessimistic Scenario

The pessimistic scenario assumes a decline in both social and political engagement with environmental issues. Geopolitical and economic instability shifts policy priorities towards security and short-term economic goals, pushing environmental concerns into the background. In such a context, no new regulations addressing light pollution are introduced, and existing environmental standards may be weakened or abandoned.

The issue of excessive artificial light ceases to be a relevant element of public policy, and transnational cooperation in this area gradually disintegrates. At the same time, urbanisation and suburbanisation intensify, alongside increased investment in outdoor lighting, often justified by safety concerns. Public awareness declines, and environmental education loses importance, reducing societal pressure for change.

The consequences of this scenario include a rapid increase in light pollution, the loss of visibility of the natural night sky, and the degradation of nocturnal ecosystems. This leads to biodiversity decline, the erosion of cultural values associated with the night landscape, and the collapse of astro-tourism development potential. Additionally, environmental inequalities between regions deepen, while efforts to protect dark skies become fragmented and uncoordinated.

3.3. Optimistic Scenario

The optimistic scenario assumes increased public awareness and political stability conducive to coordinated action at local, national and European levels. In this context, it becomes possible to adopt common regulations recognising excessive artificial light at night as a form of environmental pollution.

Comprehensive cooperation develops among local authorities, scientific institutions, civil society organisations and the private sector. Durable transnational cooperation networks are established, along with dedicated funding programmes for actions aimed at reducing light pollution. At the same time, outdoor lighting is progressively modernised in line with energy efficiency principles and requirements for protecting the nocturnal environment. The protection of nocturnal ecosystems and dark skies is incorporated into educational programmes and regional development strategies.

As a result, levels of light pollution stabilise or begin to decline, generating benefits for both human health and the functioning of nocturnal ecosystems. The reduction of excessive artificial light also contributes to decreased electricity consumption and lower CO_2 emissions. The natural night sky increasingly comes to be recognised as a shared natural and cultural heritage of Europe, and its protection becomes an integral element of sustainable development and cross-border and international cooperation.

Appendix 6. Description of DARKERSKY4CE Pilot Projects.

The pilot projects proposed by the partners of the DARKERSKY4CE project are described below. The pilots are at different stages of implementation, and their detailed design, delivery, promotion and preparation of informational materials are the responsibility of their respective initiators and proponents.

Pilot Demo Site 1. Public Lighting System, City of Leipzig, Saxony, Germany

The pilot implemented in Leipzig (Germany, Saxony) focuses on the modernisation of public lighting, aimed at reducing light pollution. The city has pursued a sustainable lighting policy for many years—already in 1999 a municipal lighting concept was developed, while subsequent Interreg initiatives (Lighting Urban Community International – LUCI, PLESS) laid the foundation for sustainable light management. The key document is the 2020 Light Master Plan, which sets out design principles aligned with residents' needs, environmental protection and landscape values.

A central measure is the designation of light-sensitive zones, i.e. areas with restricted or completely eliminated lighting, particularly within Natura 2000 sites and urban riparian forests. Within the DARKERSKY4CE project, the city is testing new luminaires and technologies that minimise scattered light emissions. These measures are implemented in environmentally valuable and recreational areas, in cooperation with local partners.

An important component of the pilot is the engagement of residents and civil society organisations through consultations, educational events and awareness-raising activities. The project strengthens an integrated approach combining biodiversity protection, spatial planning and improvements in quality of life.

Pilot Demo Site 2. Education through astro-tourism in the Kujawsko-Pomorskie Voivodeship

The aim of the pilot implemented in the Kujawsko-Pomorskie Voivodeship is to develop an integrated educational and tourism offer that enhances public awareness of light pollution while emphasising the ecological and social importance of natural darkness. The initiative supports sustainable tourism based on natural resources and promotes environmental education by linking the unique qualities of dark sky areas with regional development strategies. For the implementation of the developed pilot concept, locations characterised by minimal light pollution have been identified within the Kujawsko-Pomorskie Voivodeship, and a potential site for dark sky observation has been selected (the Tuchola Forest region, including Wdecki Landscape Park and Tuchola Landscape Park) as the target area for future educational and tourism activities.

As part of the pilot, a cyclical programme of educational activities in observational astronomy is planned, including issues related to dark sky protection and the reduction of artificial light pollution. Educational activities will be conducted in regional astro-bases and school-based astronomical observatories.

In addition, a comprehensive astro-tourism offer will be developed, based on nocturnal nature walks, educational workshops and astronomical observations carried out at designated dark sky observation sites within the Tuchola Forest area. The pilot activities are targeted at local communities, school groups, astronomy enthusiasts and tourists.

The pilot activities are based on two key ecosystem and cultural services according to the CICES classification: outdoor activities and recreation (ES-3.1.1.1/3.1.1.2) and education and science (ES-3.2.2.2). These ecosystem services are particularly important for engaging local and institutional stakeholders, as they align with the practical priorities and long-term interests of entities involved in environmental protection and the tourism sector. The successful implementation of the pilot depends on stakeholder engagement and an adopted strategy based on close cooperation with landscape park authorities and State Forests, including the co-creation and implementation of the astro-tourism concept, the use of direct links with local communities, schools and educators, as well as the establishment of partnerships with local tourism service providers and cultural institutions.

Pilot Demo Site 3. Stakeholder dialogue in the Pinerolo area, Province of Turin, Italy

The pilot in the Pinerolese region (Italy) focuses on the Fenestrelle Fortress and the issue of light pollution in the Chisone Valley. Its objective is to establish a durable platform for cooperation among stakeholders, including public administration, non-governmental organisations, the tourism sector, local communities and educational institutions. This cooperation is intended to reconcile cultural heritage protection, tourism development and environmental stewardship.

The project applies the concept of ecosystem services, with particular emphasis on pollinator protection (ES-2.3.2.1) and the aesthetic value of nature (ES-3.2.1.4). The theme of pollinators serves as a unifying element linking different stakeholder groups—farmers, beekeepers, environmentalists, schools and tourism operators—demonstrating that reducing artificial light supports biodiversity and ecosystem health.

At the same time, landscape values and dark skies are used as tools for developing astro-tourism, highlighting the beauty of the region and promoting sustainable lighting practices. These elements underpin educational activities, community initiatives and astro-tourism development. Schools, tourism consortia, heritage managers and local residents are actively involved through workshops, consultations and cultural-educational events.

The expected outcome of the pilot is a cooperation model that enhances awareness of the impacts of light pollution and facilitates the development of joint lighting solutions adapted to rural and mountainous areas. This model may be replicated in other regions of Europe.

Pilot Demo Site 4a. Demonstration of monitoring methods in Somogy County, Hungary

The project implemented in Somogy (Hungary) involves the creation of an interactive exhibition demonstrating the impact of artificial light on ecosystems, with a focus on promoting the Zselic Starry Sky Park. A permanent sky quality meter (SQM) has been installed on the roof of a local educational centre, with its readings displayed on screens alongside ecological interpretations and historical data.

A key component of the project is youth education. Students use portable SQM devices during night walks, and their measurements are incorporated into the exhibition and an augmented reality (AR) application. Educational materials support learning in physics, biology and geography, fostering research competencies and a deeper understanding of light pollution.

Zselic Park—a Natura 2000 site—serves as an example of effective protection of dark skies and biodiversity. SQM monitoring and local best practices support planning processes and enhance public awareness.

Pilot Demo Site 4b. Demonstration of monitoring methods in the federal state of Carinthia, Austria

The pilot in Carinthia (Austria) addresses the growing issue of insect population decline, partly associated with light pollution. Carinthia University of Applied Sciences is developing a non-invasive method for monitoring nocturnal insect activity, working in collaboration with national parks, municipalities, experts and local communities.

The project includes educational and outreach activities, as well as citizen science initiatives, highlighting the role of nocturnal insects as key components of trophic networks. Students, university participants and tourists are actively involved. The pilot aims to inspire the adoption of practices that protect dark skies and to promote responsible use of artificial lighting.