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DARKERSKY4CE

Dark Skies in Peripheral Areas:

Solutions to Convey Their Value

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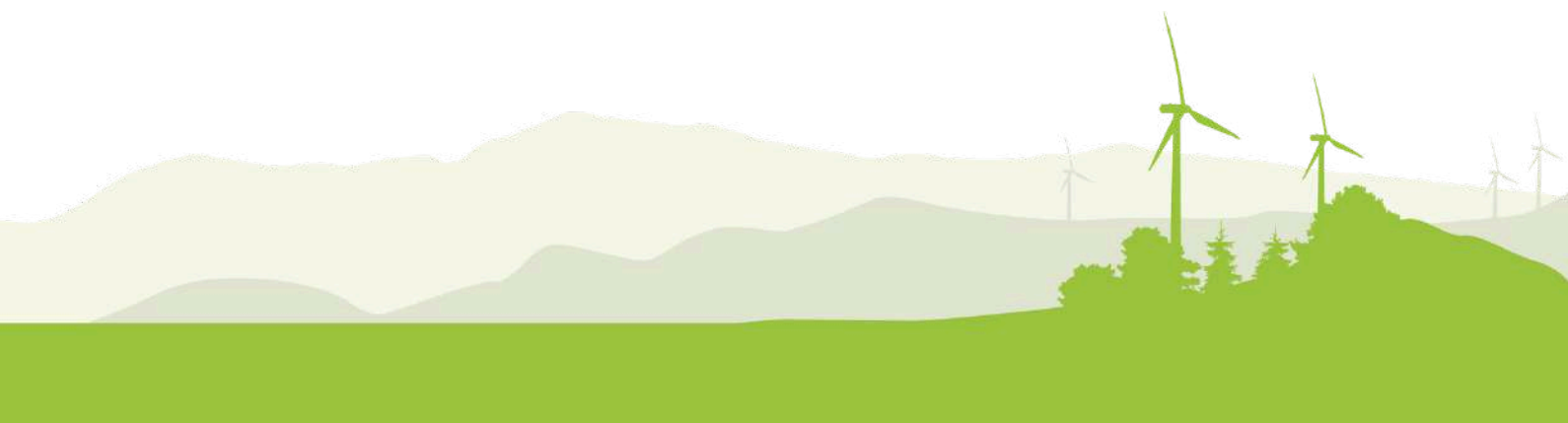

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Project Title	DARKERSKY4CE - Strategic Transnational Approach to Reduce Light pollution in Central Europe
Project ID and Acronym	CE0200765 - DARKERSKY4CE
Name of Project Partner Organisation	Istituto Nazionale di Astrofisica GAL Escartons e Valli Valdesi
Partner Number	LP, PP6

Purpose of this document

This document, titled *Dark Skies in Peripheral Areas: Solutions to Convey Their Value*, illustrates the Solution deriving from the Pilot Action D.1.1.2 and represents the Deliverable D.1.3.3 / Output 1.3 of the DARKERSKY4CE project.

The solution is based on a dynamic monitoring system, which relies on both quantitative data, from the Photometer Network (D.1.3.4), and qualitative data, from the Dynamic Monitoring Tool (D.1.3.2).

The purpose of this document is to provide a measuring, monitoring, and communication methodology of the data gathered in the DARKERSKY4CE Repository (D.1.1.2) in order to measure the impacts of light pollution on the rural areas of Central Europe.

This solution provides knowledge on how to use collected data for scientific/research purposes, but also on how to use them to communicate the relevance of the subject matter, namely light pollution, and the threats it poses for the social, economic, and ecological value of dark skies.

In order to do so, the present document was divided into the following three main sections:

1. *The Repository - Data Format* → after providing a general overview of the project Repository, this first section illustrates in detail both the Photometer Network (i.e. newly acquired photometers and already existing networks in Central Europe) and the Dynamic Monitoring Tool (i.e. target specific surveys, Call to Action, and desk research), by means of which the DARKERSKY4CE partnership was and is able to collect the needed set of, respectively, quantitative and qualitative data on light pollution and its impacts. Furthermore, this first section ends with a detailed presentation of the project Geographic Information System Map (GIS Map) on Ecosystem Services.

2. *Methodology* → using the data gathered in the Repository, this second section provides a methodology for: the measuring of quantitative data (e.g. ground-based instruments vs space-based instruments, photometry vs radiometry, radiance vs luminance, etc.); the monitoring of qualitative data (e.g. categories, indicators, and parameters of the DMT surveys, Call to Action, and desk research); and the communication of impacts, results, and solutions.

3. *How to Use the Data* → this third and last section illustrates how the set of quantitative and qualitative data of the DARKERSKY4CE Repository, respectively gathered via the Photometer Network and the Dynamic Monitoring Tool, can be useful to help identify trends in light intensity measurements and in the perception of the light pollution problem by the target groups. Finally, this last section also provides some suggestions on how to use the Ecosystem Services GIS Map as a

decision-support and strategic planning tool for private citizens, policy makers, and environmental stakeholders.

Acknowledgments

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1. The Repository - Data Format

1.1 Repository Overview

The main focus of the DARKERSKY4CE Repository (D.1.1.2) is to collect, compare, elaborate, and homogenise the already available, but incohesive data on light pollution, with a specific focus on Central Europe. Indeed, not only is there not a standardised collection of said data, but the two main types of commonly collected data usually regard sky brightness and ALAN (i.e. Artificial Light At Night) and can vary greatly according to dependent parameters such as time, geographical position, and light colour.

Therefore, the DARKERSKY4CE Repository aims to become a transnational compendium of relevant and standardised data on light pollution in Central Europe. Such a useful tool will allow municipalities, research institutes, private citizens, and whomever else is interested in learning about light pollution to be able to gather the most important information on the topic, to compare the data collected on the territory of Central Europe, and to make well-informed decisions when it comes to regulating light pollution in said region of Europe.

In particular, the DARKERSKY4CE Repository is articulated in the following three main sections:

- *Measurements and Data*, a collection of data gathered from both ground-based and satellite instruments
- *Photometer Network*, a collection of data gathered from the project network of photometers as well as from already existing networks in Central Europe
- *Dynamic Monitoring Tool (DMT)*, a series of surveys, a desk research, and other engaging data gathering tools, part of a Call to Action, meant to reach the general public and relevant stakeholders in order to raise awareness about the topic of light pollution

Furthermore, the Repository also includes the following additional sections:

- *Light Pollution*, a compendium detailing the main sources of light pollution, its impacts on ecosystems and ecosystem services (complete with the DARKERSKY4CE GIS Map showing the main sources of Ecosystem Services in Central Europe), and some of the existing European policies on light pollution
- *Glossary*, a collection of definitions for the most used and technical terms

1.2 Quantitative Data

The set of quantitative data of the DARKERSKY4CE Repository is gathered via the Photometer Network (D.1.3.4), consisting of a series of newly acquired photometers and already existing networks in Central Europe. For both new and existing networks, the repository reports the data available according to the table below. Given that both ground-based and space-based devices are considered, some of the items may apply to both or just one of the device types.

Item	*Description*	*Ground based*	*Space Based*
Instrument/Network Name	The name of the Instrument or Network	YES	YES
Type of Instrument	The type of device used to monitor light pollution, *e.g.* SQM (Sky Quality Meter) or all-sky camera for ground-based instruments, infrared imaging radiometer for space-based instruments	YES	YES
N° of Stations	The number of instruments belonging to the network (1 in case of a single instrument)	YES	NO
Location	The region(s) and/or country(ies) where the instrument(s) is/are located. In case of a single instrument, coordinates of position (i.e. longitude, latitude, altitude)	YES	NO
Measurement Point	The type of location where the instrument is situated (e.g. city centre, suburban area, rural area, isolated place, astronomical observatory, etc.)	YES	NO
Status	Whether or not the instrument/network is active (if available, additional information such as when the measurements will start, when they stopped, etc.)	YES	YES
Data Availability	Whether or not the data can be accessed (e.g. online, upon request, etc.)	YES	YES
Time Range	Time frame of the measurement (e.g. from year to year)	YES	YES
Frequency of Measurement	The time between two consecutive measurements (e.g. every 5 seconds, every minute, once per day, on-spot, etc.)	YES	YES
Data Publishing Frequency	How often are data published (e.g. once per day, once per month, once per year, live, etc.)	YES	YES
Data Publishing Delay	The time delay, if any, after which the data is published (e.g. a month, a year, multiple years, etc.)	YES	YES

Owner	The institution, association, company or private citizen that owns or is in charge of the instrument/network	YES	YES
Contacts	How to contact the owner or where to find the contact information	YES	YES
Map of the Stations	Embedded map with pins for each station	YES	NO
Calibrated Data	Whether or not data are calibrated to a standard measurement unit	YES	YES
Measurement Unit	The unit in which the data, calibrated or not, are available (e.g. mag/arcsec^2, nW/cm^2/sr, etc.)	YES	YES
Wavelength Range	The specific interval of wavelengths (e.g. 300-600 nm) describing the observed range of the light spectrum or the spectrum range itself (e.g. ultraviolet, visible, infrared, etc.)	YES	YES
Field-of-View	The portion of the sky observed by the ground-based instrument (e.g. 20°, 20° x 20 °, all-sky, etc.) / The extension (e.g. 100 km^2) or the dimensions (e.g. 10 km x 10 km) of the area observed by the satellite	YES	YES
Observed Area	The area of the Earth that can be observed by the satellite (e.g. from -60° to +60° of latitude)	NO	YES
Spatial Resolution	The spatial dimension of 1 pixel in a satellite image	NO	YES
Orbit Type	The average altitude of the satellite orbit around the Earth, e.g. Geostationary Orbit (GEO), Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Polar Orbit (PO), Sun-synchronous orbit (SSO), etc.	NO	YES
Pointing direction	The direction the instrument is pointed at in standard working conditions (e.g. for ground-based instrument zenith (upwards), to the North (Polaris); satellites: nadir (downwards), off-nadir (at a specific angle); etc.)	YES	YES
Data Visualisation	If and how the data are displayed on the owner's website	YES	YES
Data Format	The digital format in which data are available, e.g. spreadsheet (csv, xml), text file (txt, dat), image (jpeg, png), etc.	YES	YES
Data Download	Whether or not the data can be downloaded from the owner's website	YES	YES

Data Policy	The policy regulating how data can be used, reproduced, and shared, e.g. Creative Commons (CC), Open Access, etc.	YES	YES

The list and description of existing networks, single measurement devices, as well as space-based instruments is available on the dedicated webpage of the DARKERSKY4CE Repository.

Regarding the new photometers, the DARKERSKY4CE partnership acquired Unihedron SQM-LE devices and mini-PCs to operate them. Following the testing of the photometers, the devices were found to be easy to install on a Windows mini-PC and able to run for 4 days in continuous mode (i.e. 1 observation every 5 mins) without any problems.

For an easier and more adaptable installation, it is possible to consider buying the Unihedron SQM-LE unit with the waterproof housing and the Power Over Ethernet (PoE) kit included. The PoE kit allows a single cable going from inside (where the mini-PC will be installed) to outside (e.g. the rooftop of the building, where the SQM will be installed).

Furthermore, concerning the acquisition software, the partnership decided to use, after successful testing, PySQM, i.e. a freeware written in Python and developed by the Universidad Complutense de Madrid, which has been implemented and adapted to fulfill project specific requirements.

1.3 Qualitative Data

The set of qualitative data of the DARKERSKY4CE Repository is gathered via the DMT, namely the Dynamic Monitoring Tool (D.1.3.2), which is articulated in a series of surveys, a social media Call to Action, and a desk research.

The DMT is meant to measure the change, generated by the DARKERSKY4CE project, in the perception and awareness of light pollution in Central Europe. Indeed, despite light pollution being a growing threat to the ecosystems and despite the wide already existing scientific literature on the environmental and health concerns posed by the excess of artificial light at night, it is possible to affirm that the overall awareness of light pollution and of its impacts remains limited, much more so than with other sources of pollution.

The phenomenon of light pollution concerns a wide range of actors who, from the general public to economic operators and public administrators, can both suffer the consequences of light pollution and play a central role in its increase.

In particular, in the framework of this Interreg Central Europe project, the DARKERSKY4CE partnership chose to address the following selected target audiences:

- *Citizens* → the general public is an important target because the change in the perception of light pollution must be as deep and wide as possible and because the citizens' opinions are what drives administrators' choices. Among all citizens, *economic operators* are of particular interest because their businesses represent an additional source of light pollution and a possible source of misuse or good practice of lighting systems.

- *Schools* → students are a sensitive audience and it is important to introduce them to the phenomenon of light pollution, filling the information gap on this topic, while addressing in class the issue of nature conservation and preservation.

- *Local Bodies* → public administrators have not only the responsibility, but also the tools to properly implement the change in the perception of light pollution, by educating the population and by working on new regulations and the practical application of already existing ones.

Since the aforementioned selected targets are very different from one another, the DARKERSKY4CE partnership highlighted different ways to reach all three of them. Indeed, for instance, social media, public events, and developing contacts with associations sensitive to DARKERSKY4CE project-related topics are considered to be the preferred way to reach and interact with the general public, namely with citizens. In order to reach students and to directly follow the change in the attitude of young people towards light pollution, more structured and interactive activities, such as a cycle of workshops or conferences during school hours, are to be preferred. Finally, public administrators or similar entities with decisional power should be contacted directly in order to properly present the issue, help with any obstacles that may arise, and share good practices already implemented elsewhere.

DMT Surveys

In light of the already existing literature in this field of research[1], the DARKERSKY4CE partnership identified the survey as the preferred method and tool to investigate the awareness and the personal opinions of the selected target groups on the topic of light pollution. Indeed, surveys represent an immediate way of communicating with and addressing different target audiences within a wider population, since they can be

[1] C.f. Lyytimaki J, Rinne J, "Voices for the darkness: online survey on public perceptions on light pollution as an environmental problem", Journal of Integrative Environmental Sciences, vol. 10, n. 2, 2013, http://dx.doi.org/10.1080/1943815X.2013.824487
Coogan, A et al, "Perceptions of Light Pollution and its Impacts: results of an Irish Citizen Science Survey", International Journal of Environmental Research and Public Health, 17, 5628, 2020, doi:10.3390/ijerph17155628
Kyung Hee, K et al, "A study on the risk perception of light pollution and the process of social amplification of risk in Korea", Environment Science Pollut Res, 2015, 22, doi:10.1007/s11356-015-4107-5

administered via several media and tailored to address different segments of a population and cover different aspects of the light pollution issue with a fair amount of depth.

Of course, the use of surveys entails limitations too. Indeed, while it can be easy to reach a certain number of people, it is not as easy to have them start filling in your questionnaire, let alone completing it. Nevertheless, the interviewed sample of people should fulfil set requirements of representativity of the target population, with a random selection criterion and sufficient sample dimension. Furthermore, the completion of the questionnaire requires time and attention on the part of the survey participants, just like the careful planning of each question and answer option requires time and attention on the part of the survey authors, who are also responsible for the post-analysis meant to identify false answers, preconceptions, biases.

In particular, in developing the three surveys of the Dynamic Monitoring Tool, the partnership identified a set of qualitative indicators meant to measure the change in light pollution awareness of the above-mentioned three specific target audiences, i.e. private citizens, school students, and local administrators.

Hereafter the links to the three DMT surveys:

- Citizens
- Schools
- Local Bodies

Since the goal of these questionnaires is to monitor the change in the relevant target audiences towards the threat that light pollution represents, the DARKERSKY4CE partnership focussed in particular on questions that can be statistically analysed with indicators able to understand this change. Nonetheless, other characteristics of the population can be of interest too, in order to have a more in-depth view of the population and the situation themselves.

Finally, in order to reach the target respondents, different communication channels can be used. Indeed, surveys can be published in local, if not national newspapers, integrated in promotional campaigns, shared on social media and through sponsored posts with a view to reach the wider possible audience of potential respondents. In addition to all this, another possible channel to push the DMT surveys is represented by local activity groups, located in the countries of the DARKERSKY4CE project partners, e.g. associations dealing with nature, environmental protection, mountains, as well as social issues.

Call to Action

In addition to the use of target specific surveys, which represent a valid tool to acquire detailed information on the perception of light pollution, the DARKERSKY4CE

partnership, after consulting with experts, developed further tools meant to reach an even wider audience.

In particular, the DARKERSKY4CE partnership designed a Call to Action (CTA) meant to establish an interactive social media presence for the project. Indeed, through sponsorships and CTAs, the project hopes not only to reach the already detailed target audiences but also to attract new people and therefore broaden the number of users and followers.

A Call to Action can be defined as a marketing device designed to prompt the immediate and active response of the target audience. Whether it is clicking on a link, filling in a form, making a purchase or seeking further information, CTAs represent clear and direct invitations for the user to take immediate action, as per definition.

In particular, the DARKERSKY4CE social media Call to Action was designed as follows:

- Social media quiz
- Short Instagram surveys
- Prize to win by filling in the DMT survey
- Competition
- Spotify playlist or podcast
- ASMR video

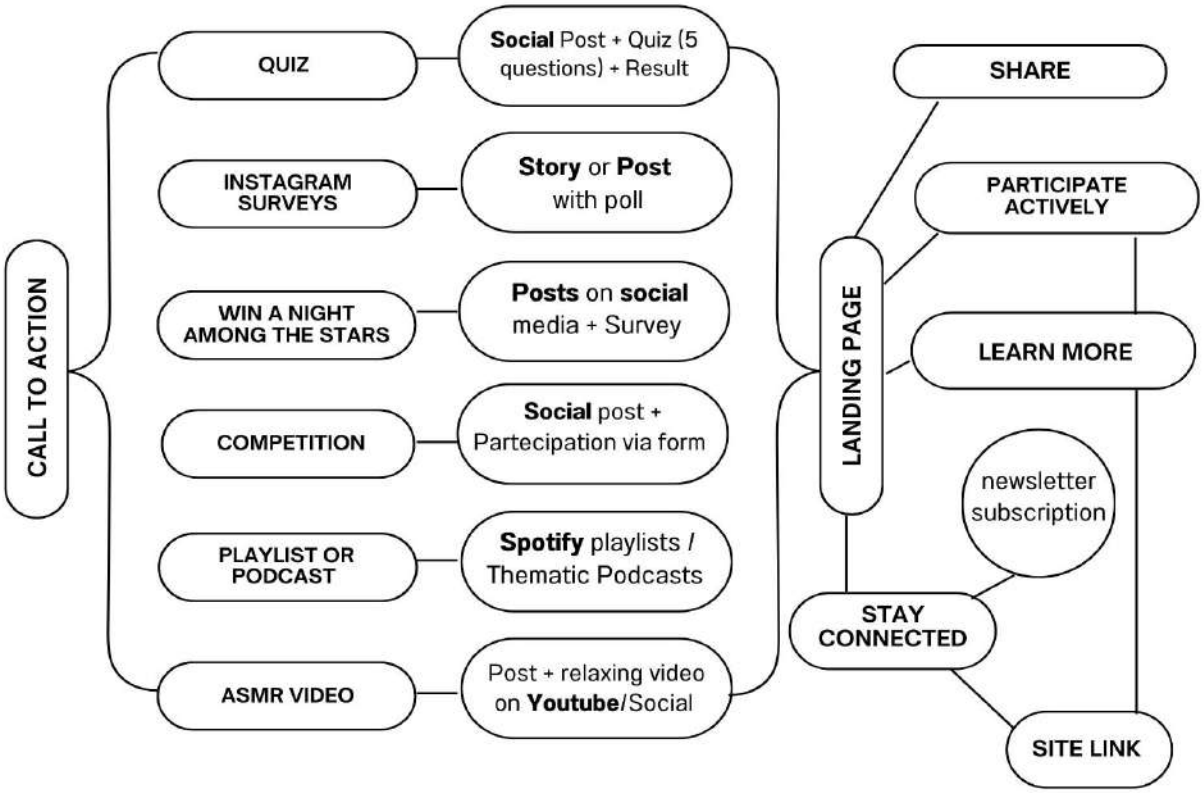


Figure 1.3.1 - A breakdown of the design for a DARKERSKY4CE Call to Action.

All the abovementioned Call to Action activities are to be analysed as means of collecting, quickly and on a large scale, relevant and specific data, thus allowing the DARKERSKY4CE project to reach social media communities of previously unforeseen recipients and stakeholders.

Furthermore, after selecting the most suitable Call To Action activities, it is important to foresee their publication, and possibly repetition, throughout the project lifetime and to maintain a consistent stylistic and graphic format in order to give them recognisability through different media and over time.

Desk Research

The desk research of the DARKERSKY4CE Dynamic Monitoring Tool was designed to analyse existing actions put in place by stakeholders in order to transform dark skies into an asset for sustainable local development.

Indeed, the DARKERSKY4CE partnership agreed on the valuable input that could derive from conducting a brief but clear desk research in order to monitor the activities put in place locally and to understand how active stakeholders in a given area are on the specific issue of light pollution and dark sky protection (e.g. astrotourism, nocturnal wildlife conservation, etc.).

1.4 Ecosystem Services GIS Map

The DARKERSK4CE partnership also developed an Ecosystem Services GIS Map meant to show the main ecosystem services in Central Europe. In particular, the DARKERSKY4CE Geographic Information System Map is meant to identify relevant light pollution sources and related factors in order to inform policy makers of both the challenges and the potential that they represent for a given area, thus hopefully inspiring a change in policies and encouraging an optimisation of the level of light pollution.

Indeed, the project Ecosystem Services GIS Map shows both good practices areas, i.e. low light pollution areas already providing different types of ecosystem services, and areas with strong light emissions that should be addressed raising awareness among private citizens and policy makers. In addition, the GIS Map will also gather and show all relevant data on the DARKERSKY4CE Pilot Areas, i.e. Northern Italy, Carinthia, non-urban surrounding of Leipzig, Kujawsko-Pomorskie Voivodeship, Somogy county, Cross-border area of Nova Gorica.

In alignment with the EU ecosystem assessment of the MAES initiative (Mapping and Assessment of Ecosystems and their Services), dark sky areas in Central Europe were mapped and integrated into the interactive online map of the project, designed and

managed by the South Transdanubian Regional Innovation Agency (STRIA), project partner of DARKERSKY4CE.

The overlay of light pollution data and relevant information on ecosystem services (e.g. biodiversity, carbon storage, water regulation, cultural or recreational value, etc.) allows for the identification of priority areas to protect, thus hopefully allowing decision-makers to pinpoint regions where ALAN is most disruptive to ecological functions and where maintaining darkness would provide the greatest environmental benefit.

Furthermore, it is possible to affirm that the DARKERSKY4CE GIS Map supports sustainable land-use planning by highlighting zones where human activity can be adapted to reduce light pollution without compromising economic or social development. Urban planners could therefore use the map to create buffer zones around ecologically sensitive areas, to adapt lighting regulations in specific regions, or to designate new dark sky reserves that align with both conservation and tourism goals.

After a thorough consultation with all project partners, the layers and point-like data of the DARKERSKY4CE GIS Map are the following:

1. LOCAL ADMINISTRATIVE UNITS	
The Local Administrative Unit (LAU) boundaries help to provide orientation, further allowing information to be collected at the municipal level and to be evaluated. A tool can be found in the header to collect and print out the most relevant information at the municipal level.	DATA SOURCE: This layer is based on the Local administrative units (LAU) dataset. LINK: https://ec.europa.eu/eurostat/web/gisco/geodata/statistical-units/local-administrative-units LICENCE: (C) EuroGeographics for the administrative boundaries.
2. MEASUREMENTS	
In addition to remote sensing data, we also have information on light pollution from other sources, perhaps the most accurate of which is local measurement, where information is generated either by instrumentation or human perception. This layer combines data from several inventories into one map.	DATA SOURCE: Several sources are aggregated into this layer. LINK: https://globeatnight.org/ LICENCE: Globe at Night data is made available under a Creative Commons Attribution 4.0 International License.

3. VIIRS RADIANCE DATA	
VIIRS radiance data, prominently featured on light pollution maps like lightpollutionmap.info, provides a crucial perspective on the extent and intensity of artificial light emitted across the Earth at night. Captured by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument, particularly its Day/Night Band (DNB), aboard satellites like the NOAA-NASA Suomi NPP and NOAA-20, this data measures the amount of low-light visible and near-infrared radiation leaving the Earth's surface.	DATA SOURCE: lightpollutionmap.info
4. NATURA 2000 SITES	
Natura 2000 is an ecological network of protected areas, set up to ensure the survival of Europe's most valuable species and habitats. Natura 2000 is based on the 1979 Birds Directive and the 1992 Habitats Directive. Natura 2000 is the key instrument to protect biodiversity in the European Union. The European database of Natura 2000 sites consists of a compilation of the data submitted by the Member States of the European Union and is generally updated once a year. Natura 2000 sites areas are home to sensitive species and habitats that can be harmed by light pollution. Including these sites helps raise awareness of where dark sky protection is especially important. This is why it is a priority to protect and maintain natural darkness in Natura 2000 areas and identify hotspots where light pollution is higher.	DATA SOURCE: This layer is produced using EEA, "Natura 2000 (vector) - version end 2023" dataset. LINK: https://www.eea.europa.eu/en/datahub/datahubitem-view/6fc8ad2d-195d-40f4-bdec-576e7d1268e4?activeAccordion=1095296 LICENCE: EEA, Copenhagen, 2025.

5. LOCAL PROTECTION SITES	
In addition to the EU level listed nature protection sites, there are other nature protection areas at Member State level which are also of high priority for protection against light pollution. It is therefore worth being aware of the location of these areas when gathering information about our environment.	DATA SOURCE: Several sources are aggregated into this layer.
6. ARTIFICIAL SKY BRIGHTNESS	
The World Atlas of Artificial Night Sky Brightness is a widely cited global atlas of light pollution published in 2016 by Falchi et al. It shows, based on remote sensing data and model calculations, the extent to which light pollution can be detected, i.e. the extent of artificial sky brightness. In summary, it tells us how bright we can see the sky when we stand at a point.	DATA SOURCE: lightpollutionmap.info

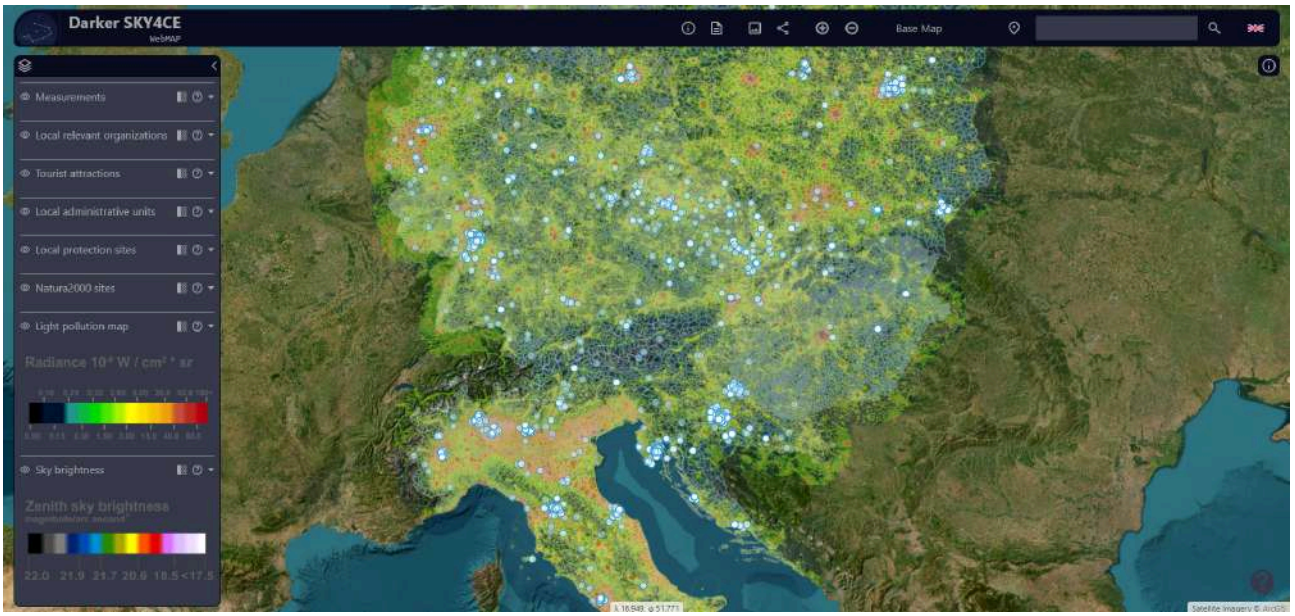


Figure 1.4.1 - A screenshot of the DARKERSKY4CE Ecosystem Services GIS Map.

Finally, since the goal of the DARKERSKY4CE GIS Map, whose menu and functions are available in all languages of the partnership, is not only to identify areas with high levels of light pollution in order to draw attention to the need for its reduction, but also to identify dark sky areas which might be eligible for Dark Sky Park accreditation, the GIS Map also presents a reporting tool.

This tool allows for the download of users' research results in the form of a report providing adequate and concise information meant to support the decision-making process. Since the users of the GIS map will be local decision makers, local enterprises, and private citizens, the report will collect the information available within specific public administration borders.

Hereafter the information provided in the local administrative unit report.

1. Local MAP, basically map canvas content
2. LAU base data:
    a. LAU Name
    b. LAU population
    c. Total Area
3. Basic World Atlas 2015 statistics
    - Percentage of area from specific class of sky brightness calculated from World Atlas 2015) Min/Max, StDev or Histogram using: https://www.handprint.com/ASTRO/bortle.html
4. Natura2000 Sites
    - List, and basic data, probably links for more information
5. Land Cover, Natura2000, VIIRS statistic:
    - Corine Land Cover Classes Aggregated to the following categories:
        i. Settlement
        ii. Agriculture
        iii. Grassland, and lower vegetation sites
        iv. Forest
        v. Water bodies
6. Measurements intersecting the current LAU
7. Any other point data: Dark Sky Park, ETC (where data can be provided)

2. Methodology

2.1 Measuring (Quantitative Data)

The first important thing to keep in mind when dealing with measurements from the Photometer Network is that each instrument is measuring the amount of light that falls onto the detector, that is produced by both artificial and natural sources. Therefore, the instrument is not directly measuring ALAN (i.e. Artificial Light At Night), but rather a mixture of artificial and natural light. Among natural sources of light at night we can list, with different levels of intensity, the Moon, bright planets and stars, the Milky Way, the Zodiacal light, the airglow and auroras. The light produced by natural sources should be in principle removed from the measurements in order to obtain the exact amount of ALAN, but this is a difficult task. Apart from the contribution of the Moon and auroras, which can significantly affect the measurements, the rest of the sources are usually so faint that they have to be accounted for only in case of a very dark night. The conditions of the atmosphere (e.g. humidity, the presence of clouds or mist, etc.) are also very important as they can significantly change the measurements. Indeed, these conditions can be a problem for single on-spot measurements, where the contribution of the moonlight or the cloud coverage, for example, has to be carefully taken into account and removed, while in case of periodic monitoring (e.g. once per night or even with higher frequency) they can be more easily factored.

Another important aspect is that ground-based and space-based instruments are measuring two different things. The light emitted by sources located on the Earth and travelling upwards (either directly, or because reflected by the ground or other surfaces) is partially scattered by the atmosphere, thus producing the so-called skyglow, i.e. the diffuse luminance of the night sky responsible for the light pollution. This light is collected by ground-based instruments together with direct light coming from other sources, if present. The amount of light that does not undergo the scattering escapes out of the atmosphere and can be collected by space-based instruments. Therefore, space-based instruments are not measuring ALAN, but rather the amount of light produced on the Earth's surface that escapes the atmosphere. Nevertheless, this measurement is somewhat related to the level of light pollution in a given area that can be (and usually is) much larger than the area of the source, reaching sizes of tens or even hundreds of kilometres. Resolution and coverage can be quite different: space-based instruments can provide a wide coverage of the Earth's surface with variable spatial and temporal resolutions (from tens to hundreds of meters), while ground-based instruments can measure at higher frequency but only in a limited area.

A third relevant issue is the spectral feature of light. Light (or better said the electromagnetic radiation) may have an infinite spectrum of frequencies (and

wavelengths). In particular, wavelengths ranging from about 400 nm to 700 nm are the ones that can be perceived by the human eye, corresponding to all the colours of the rainbow, from red (larger wavelengths) to blue (shorter wavelengths). This is usually called the "visible spectrum". However, electromagnetic waves can have wavelengths larger than 700 nm, called infrared radiation, as well as shorter than 400 nm, called ultraviolet radiation. Both the light source and the observer (either human or instrumental) have a specific sensitivity for each wavelength.

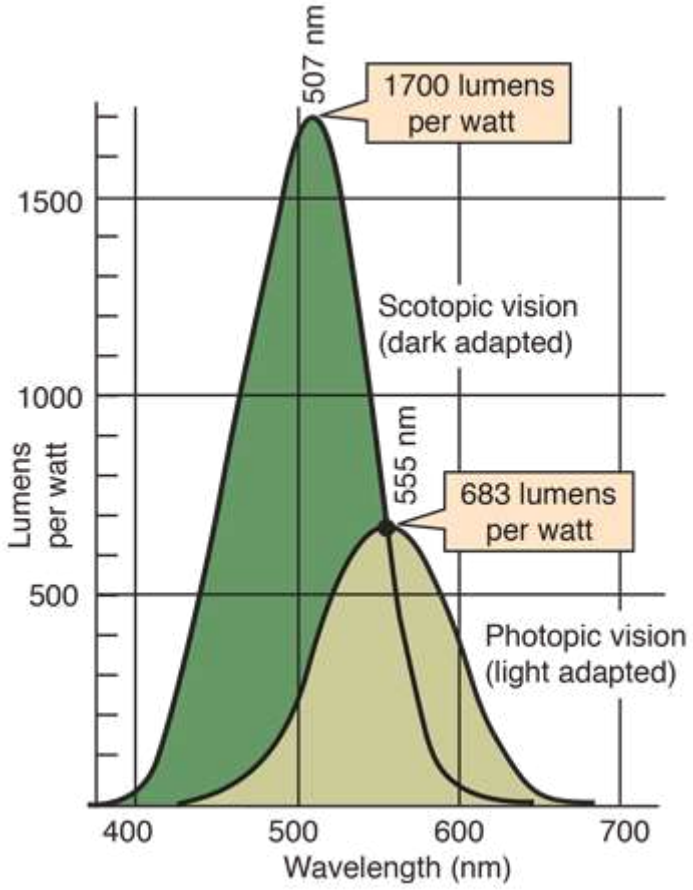


Figure 2.1.1 - Photopic and scotopic sensitivity curves of the human eye[2].

Figure 2.2.1 shows the so-called ***photopic*** and ***scotopic*** **curves**, representing the mean sensitivity of the human eye to the visible wavelengths. The photopic curve refers to high-level illumination regimes (i.e. daylight or artificial illumination) and is dominated by the cones, while the scotopic curve refers to low-level illumination regimes (i.e. night vision), which are dominated by the rods. These curves have been obtained by averaging on a representative sample of human beings. The human eye photopic vision sensitivity is maximum around 555 nm, and drops to zero at the limits of the photopic curve range. Scotopic vision is shifted to bluer wavelengths, with maximum at 507 nm. The total amount of perceived light is therefore the sum of all the wavelengths weighted with the corresponding sensitivity (mathematically speaking, considering the sensitivity curve a

[2] From http://hyperphysics.phy-astr.gsu.edu/hbase/vision/bright.html, Georgia State University

continuous function, this is called the integral of the photopic curve over all the wavelengths). Observers other than human beings (i.e. animals) will have a different sensitivity curve, with a different shape and not necessarily confined in the 400-700 nm range, they will therefore measure a different amount of light coming from the same source. The same is true for artificial detectors that can have a wide variety of sensitivity curves, e.g. RGB filters, astronomical standard bands (U,B,V,R,I), or radiometric bands that extend in the infrared and ultraviolet domains.

Given the different possible sensitivity curves, it is necessary to discriminate between ***luminance***, which is the intensity of a source of light emitted or reflected in a given direction as seen by the photopic human eye, and ***radiance***, which is the intensity of the same source as seen by a detector with a different sensitivity curve. Radiance is usually expressed in physical units as [W / m^2 sr] (watt per square meter per steradian), while the corresponding unit for luminance is [lumen / m^2 sr] (lumen per square meter per steradian) or, most commonly, [cd / m^2] (candela per square meter). The formal equivalences for photopic vision 1 W / m^2 sr = 683 cd / m^2 and for scotopic vision 1 W / m^2 sr = 1700 cd / m^2 are true only at exactly 555 nm and 507 nm, respectively. Therefore, these equations are not generally valid and cannot be used in our context to convert luminance into radiance values and vice versa.

Measurements from ground-based instruments are often reported as ***sky brightness*** at Zenith (i.e. the point in the sky exactly above our heads). The physical units for sky brightness are [Mag / as^2] (magnitudes per square arcsecond). Magnitude is a logarithmic scale used by astronomers to quantify how bright an astronomical object is. On account of its definition, the larger the magnitude the weaker the intensity. Moreover, as a logarithmic scale, the magnitude does not increase or decrease linearly: a difference in magnitudes of 5 means that the weaker object is 100 times fainter than the brighter one. Vega is a very bright star with Mag = 0, while the weaker Polaris is about Mag = 2. The faintest stars that can be seen by a trained naked eye are around Mag = 7. Venus at its maximum is as bright as Mag = -4.6, almost 100 times the luminosity of Vega, while the full Moon can reach Mag = -12.6, almost 1.000.000 times brighter than Polaris. [Mag / as^2] measures the magnitude of (light emitted by) a very small square portion of the sky, 1 $arcsecond^2$ being 1/3600 x 1/3600 square degree (for comparison, the diameter of the Moon is roughly 30 arcminutes, with an angular area of about 700.000 as^2). The darkest sky on Earth is characterised by a brightness of 22 Mag/ as^2. In the scientific literature[3], a correspondence between [Mag / as^2] and [cd / m^2] has been defined as follows:

$$22.0\ \text{Mag/as}^2 = 1.71 \times 10^{-4}\ \text{cd/m}^2$$

It is possible to convert any value of [Mag / as^2] to [cd / m^2] and vice versa by using the following formulae:

[3] Crumey A., MNRAS (2014) - http://mnras.oxfordjournals.org/content/442/3/2600.full.pdf+html

$$[\text{value in cd/m}^2] = 10.8 \times 10^4 \times 10^{(-0.4*[\text{value in Mag/as}^2])}$$

$$[\text{value in Mag/as}^2] = -2.5 \times \text{Log}_{10}(10.8 \times 10^{-4} \times [\text{value in cd/m}^2])$$

An online converter is also available[4].

The transition between scotopic and photopic visions happens in the range between 0.01 and 10 cd/m²; this regime is called mesopic vision and is characterised by a combination of the scotopic and photopic curves. In terms of sky brightness, scotopic vision is therefore active above 17.58 Mag/as², while the mesopic regime is in the range between 17.58 and 10.08 Mag/as². For sky brightness values brighter than 10.08 Mag/as², photopic vision is active. A sky brightness of 17.58 Mag/as², at the limit of the scotopic vision, corresponds to an already very light polluted site of the highest grade (8-9) according to the Bortle scale (e.g. an urban area). To quantify the amount of light perceived by the human eye we shall therefore consider the scotopic, mesopic, or photopic curves according to the appropriate sky brightness regime.

Hereafter other units that may be used in such measurements and their brief definition.

- **Spectral radiance** is the radiance per wavelength. Units are usually [W / m² sr nm] (watt per square meter per steradian per nanometer).
- **Instrumental units** are provided when data are uncalibrated. These are the internal units of a specific measuring instrument and cannot be compared with those of other instruments.
- **Naked Eye Limiting Magnitude (NELM)** is a quantitative indication of the sky brightness provided as the faintest star that can be discerned by the naked eye.
- **Bortle scale** is a nine level qualitative description of the sky brightness.

Last but not least, the dependence of the measurements on the spectrum of the light source is of outstanding importance. As an example, Figure 2.1.3 shows the spectra of several types of street lamps that can be found in Madrid. The spectrum of some lamps extends to the whole visible range, while in many cases only specific element lines are present, such as sodium or mercury vapor lamps. The emission spectrum of the light source is combined with the sensitivity curve of the eye or the instrument detector. As a result, the same detector usually measures only a portion of the total light emitted by the sources, providing different values for sources presenting a different spectrum but the same intensity. To better understand this concept, we carried out and now present the following simple simulation.

[4] https://unihedron.com/projects/darksky/magconv.php

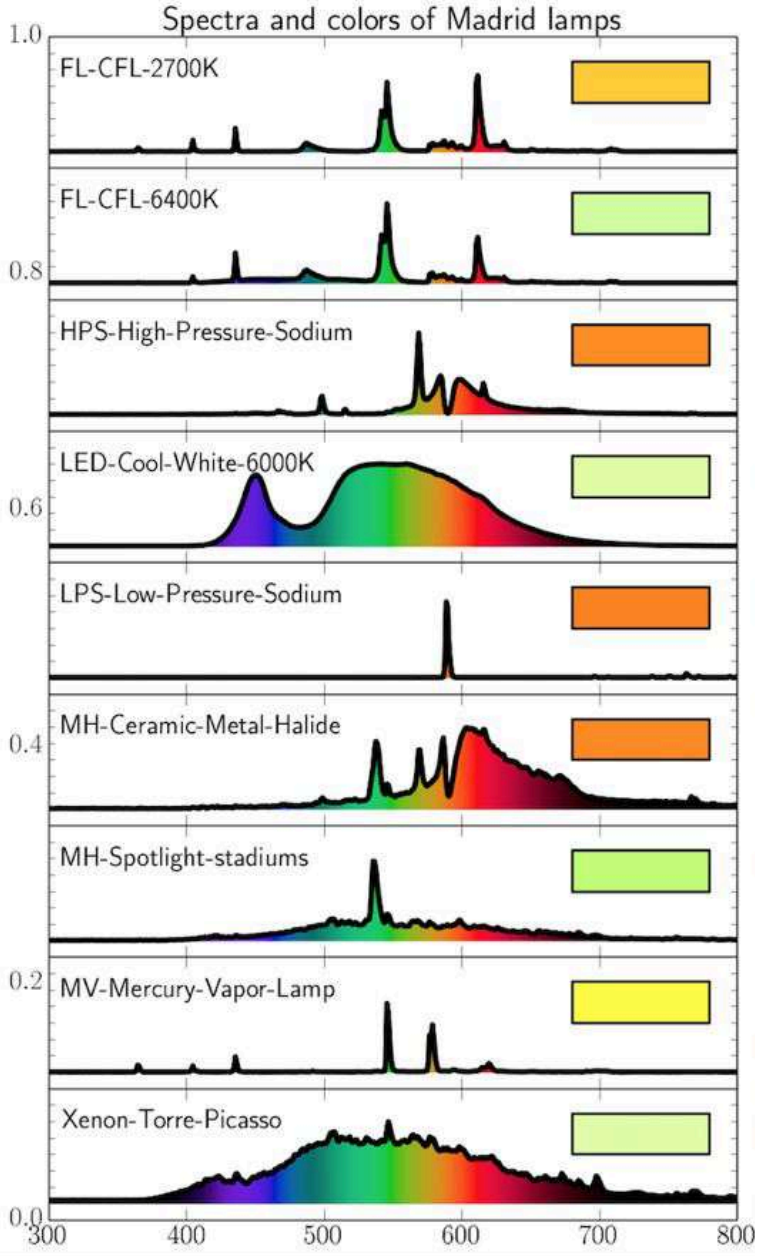


Figure 2.1.2 - Examples of spectra from Madrid street lamps[5].

Figure 2.1.4 shows four **sensitivity curves**, namely the already mentioned photopic (green) and scotopic (blue) sensitivities, plus the SQM[6] (violet), which encompasses the ranges of both the scotopic and the photopic curve and extends towards the blue end, and the VIIRS-DNB[7] (red), which has a wider wavelength span considerably shifted towards the red end. Curves are normalised to provide 100% sensitivity at maximum peak wavelength.

[5] https://guaix.ucm.es/wp-content/uploads/2020/01/StreetSpectra_manual.pdf
[6] https://darkersky4ce.inaf.it/measurement-devices/
[7] https://darkersky4ce.inaf.it/instrument-sheet-viirs-dnb/

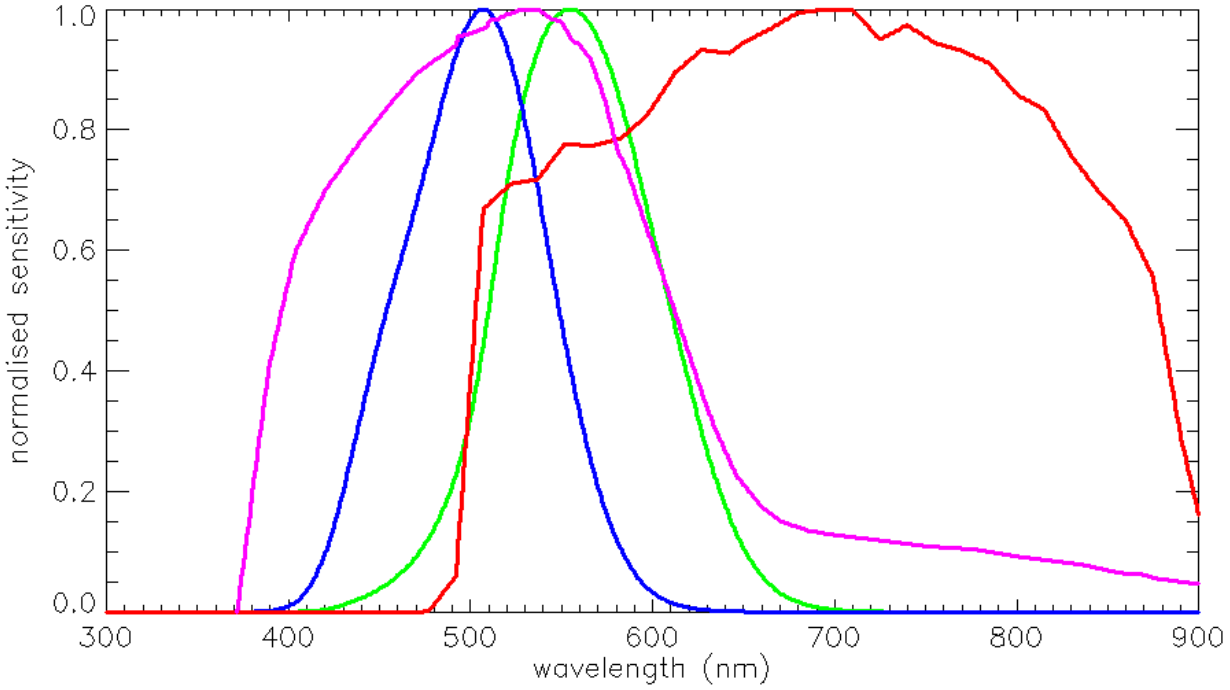


Figure 2.1.4 - Photopic (green), scotopic (blue), SQM (violet) and VIIRS-DNB sensitivity curves.

Figure 2.1.5 shows **emission spectra** of five different types of illuminating sources used for street lighting[8]. The results of the combination of emission spectra with sensitivity curves are reported in Table 2.1.1 as the percentage of detected radiation assuming 1) that all sources are emitting the same total radiance and 2) all sensitivity curves are normalised to a maximum value of 1. The first assumption allows us to compare the different sources. The second assumption implies that it is not possible to directly compare among different detectors, as we do not know the overall sensitivity. Nonetheless, it is possible to compare the response of the detectors to the different emission spectra of the sources.

	Incandescent	Red LED	Blue LED	HPS	LPS
Photopic	13% (1.0)	46% (3.5)	42% (3.2)	46% (3.5)	69% (5.3)
Scotopic	7% (1.0)	22% (3.1)	41% (5.8)	10% (1.4)	6% (0.9)
SQM	24% (1.0)	59% (2.5)	75% (3.1)	51% (2.1)	64% (2.7)
VIIRS-DNB	76% (1.0)	77% (1.0)	52% (0.7)	80% (1.1)	79% (1.0)

Table 2.1.1 - Comparison of the response of selected instrument or eye to lamps with different spectra, assumed emitting the same total radiance.

[8] Spectra are taken from a database available at https://guaix.fis.ucm.es/lamps_spectra

Our simulation is extremely simplified, so the numbers presented in Table 2.1.1 are only a rough approximation. Nevertheless, it is possible to derive some interesting general conclusions. In particular, it has to be noted that moving from incandescent to red and blue LED has the consequence of increasing the scotopic signal by, respectively, 3 times (red LED) and almost 6 times (blue LED). This means that a blue LED with the same power of an incandescent light generates 6 times more light pollution perceived by human eyes adapted to nighttime vision (and, by the way, 3 times more light pollution by human eyes adapted to daytime vision). This increase in light pollution is not completely tracked by SQMs, which will measure only an increase by 2 times (red LED) and almost 3 times (blue LED), thus providing an underestimate of the increase in light pollution levels. The situation is even worse for space-based VIIRS-DNB measurements, which will record a decrease of about 30% for blue LED with respect to incandescent light, while it looks remarkably stable for red LED and sodium lamps. At the same time, SQMs, with respect to sodium lamps, will detect an increase of more than 2 times compared to a rather stable response of the scotopic vision.

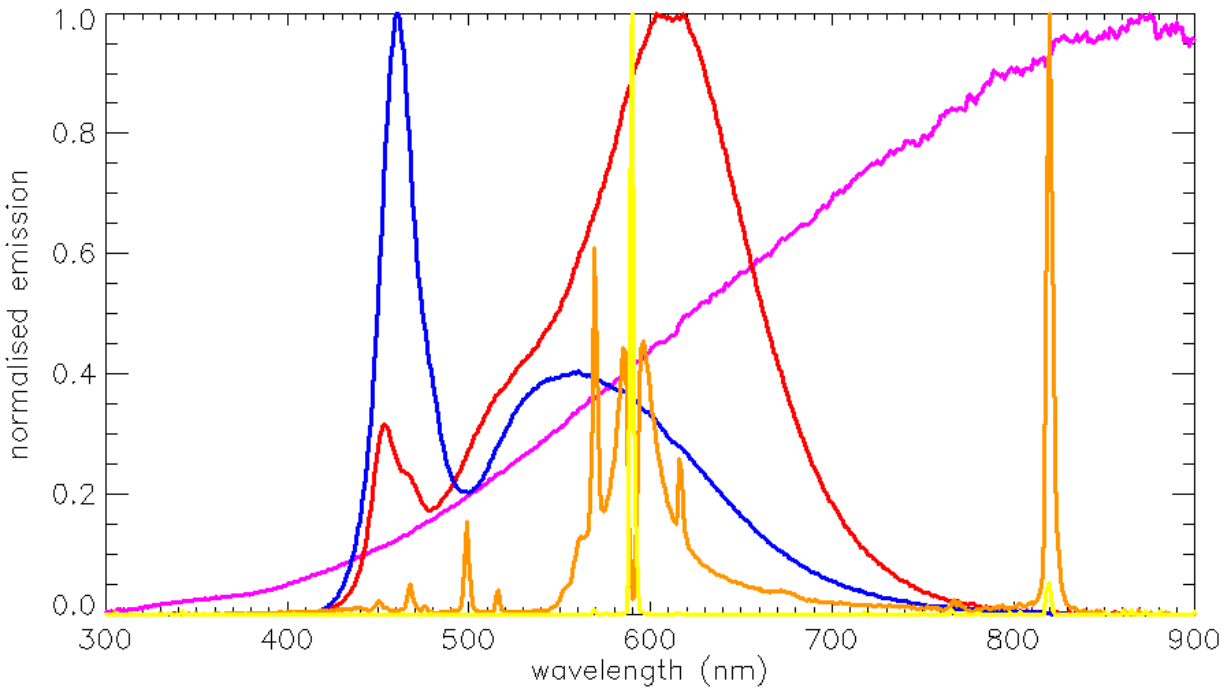


Figure 2.1.5 - Emission spectra of five different types of street lamp light sources (from https://guaix.fis.ucm.es/lamps_spectra). Incandescent (violet): I_Incandescent_Tungsten_2805K_LICA_Philips. Red LED (red): LED_2618K_LICA_Ryet_Ikea_2700K. Blue LED (blue): LED_7043K_LICA_Deco_LED_7000K. High Pressure Sodium (HPS, orange): HPS_High_Pressure_Sodium_2005K_F_Fisicas. Low Pressure Sodium (LPS, yellow): LPS_Low_Pressure_Sodium_1701K_LICA.

A deeper insight into the effect of the source spectrum and the specific sensitivity curve would have to take into account several additional factors (e.g. weather conditions, atmospheric absorption, and diffusion properties); this would go, however, beyond the

scope of this document. Studies are available in the scientific literature, see for example:

- https://doi.org/10.1016/j.jqsrt.2025.109378
- https://doi.org/10.1093/mnras/stx145
- https://doi.org/10.3390/s25020516

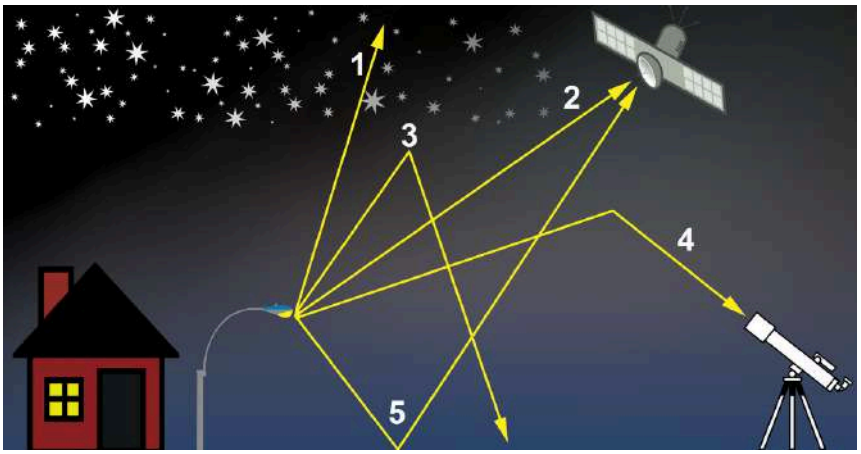


Figure 2.1.6 - Schematisation of the different phenomena leading to the measurement of light pollution with ground and space-based instruments (darksky.org).

2.2 Monitoring (Qualitative Data)

The monitoring of the qualitative data of the DARKERSKY4CE Repository is meant to be continuous and mainly achieved through different phases of survey administration and the progressive gathering of relevant data throughout the lifetime of the DMT surveys, the Call to Action, and the related social media campaigns.

DMT Surveys

The DMT surveys are to be administered at different times, in order to have a first photograph of the audiences' understanding of the concept of light pollution to be compared, later on, with the same audience's awareness following the DARKERSKY4CE project activities, e.g. communication and dissemination events, social media campaigns, meeting with local administrators, school workshops, etc. Indeed, the different stakeholders will be questioned on the definition of light pollution, as well as on the threats it poses for and the impacts it can have on human life.

Furthermore, the DARKERSKY4CE project also provides for four Pilot Actions in five distinct Pilot Areas located in the different countries of the partnership and meant to cover different topics related to light pollution. The presentation of said Pilot Actions will be accompanied by awareness-raising events, during which the DMT surveys will be administered once more.

Once collected, the answers of each survey can be analysed and compared. Based on the types of indicators, the statistical analysis of the collected data can foresee different techniques.

For percentages, the difference between batches can be confirmed by statistical tests, using the normal approximation of the binomial distribution when the size of the sample is sufficient. Similar tests can be used to test if a percentage is dependent on categorical variables, such as age, gender or geographical origin.

For a question where the variable is an attitude and the answer is designed as a Likert-like scale, with a set of scores (from "negative" to "positive" in usually 5 to 7 steps), it is possible to evaluate the distribution of the variable, and monitor how it changes along different batches of data.

Moreover, for the same question different answers can be proposed with simpler scales, to be able to establish an order based on respondents agreement/disagreement. A typical example of this is represented in the figure below, where the three answers can be ordered based on the score of the preference.

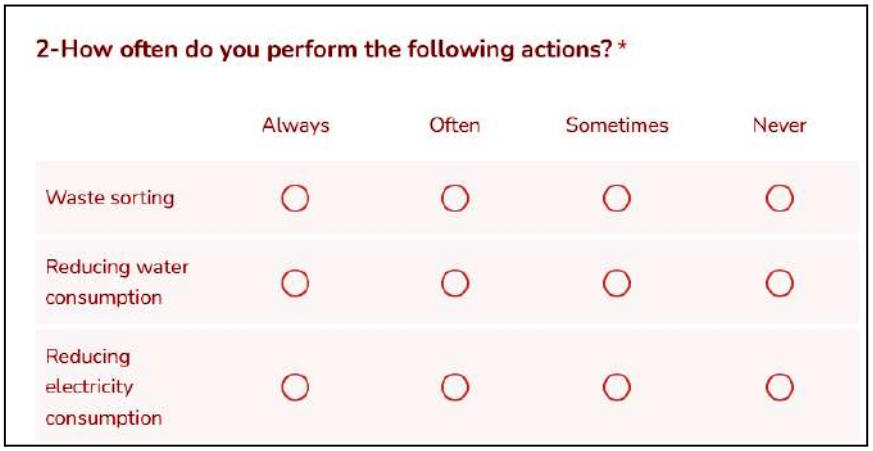


Figure 2.2.1 - The screenshot of a question of the DMT survey for citizens.

Furthermore, advanced techniques, such as the analysis of the variance of indexes on subsamples generated by the categorical attributes or a regression analysis to link together variables in a model, can also be performed if dealing with a sufficient number of responses.

For each survey, the DARKERSKY4CE partnership identified a set of indicators that can be suited to give a measure of the change in the perception of the threat posed by light pollution. Not all questions are to be considered direct indicators; nevertheless, it can be useful to categorise data in subsamples, to double-check key indicators, to force the respondent to focus on the topic with practical examples, or to define future strategies.

Hereafter the analysis of the categories of questions and indicators of the three DMT surveys, complete with what to look out for in order to monitor the change in the perception of light pollution:

1) *The knowledge of the light pollution issue.*

- We can investigate whether or not people have already heard about light pollution.
- A typical indicator for the change is the percentage of people aware of the issue, percentage that we clearly expect to rise.
- Knowing through which information channel the audience learned about artificial light at night can help identify the most used channels and use them to effectively communicate news about project events, the DARKERSKY4CE Call to Action, etc.

2) *The presence of artificial lighting in common life.*

- Artificial lights are everywhere and people get used to their presence.
- The survey questions can help us focus on:
    - what are the most predominant sources of lights (e.g. streetlights, residential and/or commercial lighting, traffic lights, private houses indoor/outdoor lighting, temporary events lights such as festivals lighting);
    - whether or not they changed in the last years: are people paying attention to the level of lighting?
- Answers can help describe the sources of artificial light linked to the geographical area of the respondent.
- Indicators for the change are especially linked to the rise of the level of awareness of people and of attention to their surrounding environment.

3) The feelings about the effects of artificial lighting.

- The effects of artificial lighting on the natural environment and its species are still poorly accepted by the population, although described in detail in an ever-growing literature.
- Questions can cover the following topics:
    - how artificial light affects human health, in particular pre-sleep habits (e.g. exposure to white artificial light) and sleep quality, as perceived by people;
    - how artificial light affects animal behaviour, in particular the quantity of nocturnal species around inhabited areas, as perceived by humans, and the knowledge of the effects of light pollution on wild species.
- Answers to these questions can give insight on the perception of the negative effects that light overexposure has on human health and on the natural environment we live in.
- Indicators for the change are, for instance, the percentage of people aware that light pollution has effects on nocturnal species, and what they are.

4) *Is artificial lighting beneficial for humans?*

- Commonly, light is often considered as a form of progress, and closely linked to security, safety, and nightlife.
- We can investigate what are the perceptions of:
    - the use of artificial light for commercial purposes (e.g. advertising, shopping centres and streets, night clubs);
    - the use of artificial light for cultural purposes (e.g. monuments, historic buildings);
    - the personal feeling someone has when crossing dark areas;
    - the correlation between crime and lighting, since, although in the literature this correlation is not proven, people generally equate more light with feeling safer.
- In this case, there are different indicators for change:
    - for the commercial use of lighting, it is important to understand the thoughts of commercial operators, checking the percentage of those who think that the lighting of their premises is essential for sales, but also of those who are willing to install sustainable lighting, or already did it;
    - for safety and security issues, we can monitor the percentage of people that associate more light to more security, but also work with public administrations, who are typically the ones in charge of public lighting (including cultural buildings). Their willingness to contemplate the issue of light pollution during their decision process is often subject not only to technical difficulties, but also to electoral evaluation.
- Indicators can easily monitor the level of knowledge of local regulations and their applicability subject to financial constraints. They can also check for political willingness, even though the analysis of these latter indicators is difficult because it is influenced by hidden variables such as electoral expectations.

5) *Cultural aspects*

- Dark skies are connected to night experiences, such as professional and amateur astronomical observations, or night events, such as walks at the discovery of night environments and others.
- We can have questions about:
    - the availability of starry skies in the area where the respondent lives (clearly linked to the geographical information of the respondent);
    - the awareness of the benefits of dark sky experiences on someone's physical and mental health;
    - the knowledge of and attitude towards astrotourism and other sustainable economic activities.
- Indicators for the change can monitor the percentage of people already aware of the importance of dark skies and of those interested in experiencing a sustainable tourism involving the dark skies.

6) *Are people willing to change?*

- The sensitivity towards the issue of light pollution should tend to a change in habits.
- We can have questions about the willingness to change in:
    - the private context (e.g. outdoor lighting, participation to public events, availability to support campaigns for public interventions);
    - the public context (e.g. local public lighting, local regulations, support for national regulations).
- In this case, indicators for change can monitor the types of public and private illumination used, the percentage of private and public institutions willing to update their lighting systems, or that already did.

7) A set of questions not directly related to indicators of the change in perceptions are useful to further interpret the respondents' way of thinking.

- In compliance with current privacy regulations, in this set of personal information we can ask for and use the following information:
    - gender;
    - age;
    - qualification;
    - geographical position of respondent, and we can expect different approaches for people coming from rural rather than urban areas;
    - attitude towards environmental sustainability, in order to understand the background of respondents.
- The categorisation using the above-mentioned additional information can be done only if each category is sufficiently numerous.

Call to Action

The DARKERSKY4CE Call to Action is an important part of the project Repository because it allows for the social media user to become the protagonist. Indeed, users are invited to perform a specific action, or a series of actions, that follow the vision of the content published. Therefore, in addition to viewing the content material proposed, users are allowed and encouraged to actively show interest, to deepen their knowledge on the topic of light pollution (e.g. through quizzes and questions), and to share said content even further.

Moreover, it is important to highlight how the DARKERSKY4CE social media Call to Action provides for collecting data both faster and in greater numbers than with the DMT questionnaires, allowing at the same time to reach previously unforeseen possible recipients.

Hereafter a schematisation of the key categories identified for the DARKERSKY4CE Call to Action in the region of Northern Italy, but applicable in all other regions of the project partners countries. In particular, it is possible to observe how relevant interests,

values, motivations, and possible specific CTA activities have been matched to a series of demographic and target audiences, acting as specific social media communities.

DEMOGRAPHIC DATA	INTEREST	VALUES AND MOTIVATIONS
Age: 18 - 45 years (main target group), but also parents 45 - 60 years old Gender: all, with a slight predominance of women if focusing on families Location: geographical area of interest (e.g. Val Chisone, 50km radius, Piedmont, IT)	Environment and sustainability Nature, wildlife, hiking Photography (especially night and nature photography) Astrophotography Astronomy and science Well-being, conscious lifestyle	Environmental sensitivity Desire for authenticity and simplicity Interest in protecting nature for oneself and one's children Involvement in local social/environmental causes Nostalgia for the starry sky / search for 'connection' with the cosmos

Category	Example	Type of CTA	Hashtags
Eco-conscious	Young greens following @greenpeace, @lifegate	2-Short surveys 3-Receive a prize 4-Dark Sky Competition 5-Listen to the Stars 6-Video ASMR	#luminous pollution #cielibui #darkness #defend the dark #protectthenight #watching the sky #NightWithoutLight #respectamolight #celostellar #salviamolestelle #naturaenotturno #environmental education #photographianotturna (English) #LightPollution #DarkSkies #DarkSkyMovement #SaveTheNight #ProtectTheNight #StarrySkies #SeeTheStars
Family explorer	Parents seeking slow activities with their children	1-Short quiz 4-Dark Sky Competition 5-Listen to the Stars	
Nature lover	Hikers, landscape, nature and animal photographers	1-Short quiz 2-Short surveys 3-Receive a prize 4-Dark Sky Competition 5-Listen to the Stars 6-Video ASMR	
Local curious	People linked to the territory	2-Short surveys 3-Receive a prize 4-Dark Sky Competition	

Educators & Teachers	Teachers or disseminators	1-Short quiz 2-Short surveys 3-Receive a prize 4-Dark Sky Competition 5-Listen to the Stars	#NightSkyLovers #NoLightPollution #RewildTheNight #AstroPhotography

Desk Research

The DARKERSKY4CE desk research can be considered an additional tool for evaluating the actions put in place by stakeholders in order to transform dark skies into an asset for sustainable local development.

The desk research is a classic research strategy that allows to investigate which activities, related to a certain topic of interest, have been carried out in a given geographical area and during a specific period of time. Therefore, it also allows to assess over time whether or not various types of events, related to a certain topic of interest, are being organised.

In order to carry out a successful desk research, with sufficient objective value, the parameters of said research must be clearly defined beforehand. Hereafter the relevant parameters of the DARKERSKY4CE desk research.

Parameter	Description
Geographic area	The geographical area must be specific and should not be too large, in order to facilitate research (maximum at regional level).
Period	The period must be specified. Given the niche nature of the topic, the period analysed cannot be too short, as the information found would be too limited. At the same time, if the period analysed is too long, there is a risk of not finding the information sought. We recommend considering a period of time between 6 and 24 months.
Tools to be used	We can use the following tools: search engines and channels, keywords/key phrases, planning the use of AI, etc.

Focus on the main topic of the survey	In our case, light pollution and the exploitation of dark skies or everything closely related to it: stargazing evenings, events on lighting, etc.
Search for activities proposed by the main local or international actors	E.g. associations or astronomical observatories, international organisations, nature parks, hotels, etc.

The tangible advantage of choosing to carry out a desk research is that it does not require too much time and resources and that it allows you to use existing data (i.e. data on activities carried out by actors in a given territory).

A desk research can potentially be used in two ways. The first way is to monitor the situation at the beginning of an awareness-raising process or specific actions (e.g. a pilot action). This provides a better understanding of whether there are actors active on the issue, which events are already proving successful and which ones have not yet been explored. The second way is to monitor changes in the perception among economic operators and other stakeholders after an action has been carried out on the issue of light pollution.

By setting two equal research time frames, before and after awareness-raising activities, it is possible to assess whether the number of activities organised in a given area has increased or not. If the number of events and activities organised has increased by a significant percentage, it can be assumed that the actions carried out have had an effect on stakeholders' perceptions of the relevance of activities on the topic (e.g. night-time observations, information evenings, tourist packages).

2.3 Communication

In light of the experience of the DARKERSKY4CE project, it is possible to affirm that communication is an essential aspect of elaborating solutions to convey the value of dark skies in peripheral areas. Indeed, light pollution entails negative effects on the flora and fauna of an ecosystem, including on human beings, e.g. biodiversity loss, disorientation of wildlife, energy consumption and waste, alteration of circadian rhythm, sleep disorders, disruption of melatonin production, etc. It is therefore important to engage people in the discussion surrounding light pollution policies in order to allow them to make informed decisions.

When communicating about light pollution, two important and seemingly contradictory factors must be taken into account: the significant direct and indirect impacts that light pollution can have on human beings and the general lack of interest among citizens in

forms of pollution that are not clearly visible. It is therefore important to find strategies to overcome public indifference by highlighting the impacts that can affect people's lives.

Addressing light pollution means confronting an issue that often goes unnoticed by the public, despite its documented effects on human health, biodiversity, and ecosystem services. One of the main challenges is therefore to make the invisible visible — framing the absence of darkness as a presence with ecological and cultural significance.

Within the DARKERSKY4CE project, communication is conceived as a strategic, cross-cutting dimension that amplifies the project impact and supports its broader goals. The project approach to outreach combines information, awareness-building, and active engagement. Central to this is the Dynamic Monitoring Tool (DMT), which goes beyond data collection in order to serve as a platform for reflection and participation, as a true communication and dissemination tool. Through surveys and visual outputs, it helps disseminate knowledge about Artificial Light At Night (ALAN) and invites people to take part in ongoing conversations.

Complementing this, the Call to Action (CTA) targets social media audiences using interactive formats — such as quizzes, challenges, playlists, and short videos — to reach a broad and diverse public in a playful yet meaningful way. Furthermore, participation in international and national initiatives — including the International Dark Sky Week 2025, Dark Sky Advocate, and M'illumino di Meno — further expands visibility and builds alliances across sectors, reinforcing a shared commitment to protecting the night sky.

The ultimate goal is twofold: to raise consciousness about the impacts of artificial lighting at night, and to foster more sustainable choices — both personal and institutional — towards environmental stewardship and collective well-being. To support this, the project employs a consistent, data-informed narrative enriched with visual materials like the DARKERSKY4CE GIS Map that translates technical content into a clear, engaging experience.

Communication in this project is not merely informational, but relational: it opens up space for dialogue, co-creation, and discovery. It invites a renewed perspective on darkness — not as emptiness, but as a shared resource — and promotes ecological literacy rooted in wonder and responsibility.

This vision finds a concrete expression in the project Repository website that provides comprehensive materials related to light pollution and sky brightness measurements for Central European citizens, the scientific community, and indirectly, policy makers and tourism professionals.

To make this content approachable, the site includes explanatory sections on the causes and consequences of ALAN, emphasising the ecological benefits of preserving dark skies,

especially in non-urban areas. Its structure is simple and intuitive, with sections including:

- an overview of light pollution sources, effects, and relevant EU policies;
- a core section featuring three main resources: the Dynamic Monitoring Tool, Measurements and Data, and the Photometer Network;
- a glossary to support non-expert users in navigating key terminology.

The modern design of the Repository — balancing dark and light tones — evokes the theme of the night while enhancing usability. Infographics and visuals complement the text, ensuring clarity for both expert and general audiences.

By weaving together science, storytelling, and participatory tools, DARKERSKY4CE transforms light pollution from an abstract issue into an emotional and cultural concern. In doing so, it encourages communities to reconnect with the night sky and recognise darkness as a vital, endangered heritage worth protecting.

3. How to Use the Data

3.1 Identifying Local Trends in Light Intensity Measurements

The set of quantitative data of the DARKERSKY4CE Repository, gathered via the Photometre Network, is useful to help identify trends in light intensity measurements.

Besides being able to measure the current amount of light produced at night in a given place, it is of course of the utmost importance to be able to identify possible trends, in order to evaluate whether the level of nocturnal light is increasing, decreasing or is somewhat stable over time. Here we provide some examples on how to interpret time series of measurements coming from the Photometre Network.

In the following, we make reference to data produced by the already mentioned VIIRS-DNB instrument. Data are available all over the world with a resolution of 1 value per month (or per year), in the time frame 2012-2023, spanning over 12 years, which is long enough to discuss possible trends. Visualisation has been recently made easy through the website www.lightpollutionmap.info under the *VIIRS trend* layer. A colour coded map provides areas where radiance is increasing (orange, red) or decreasing (green, dark green). By clicking on the map, a graph is shown with yearly radiance values and an estimate of the mean increase/decrease in percentage per year.

Let us take as a first example the small town of Lusernetta, in the alpine Pellice valley, in Piedmont (Italy).

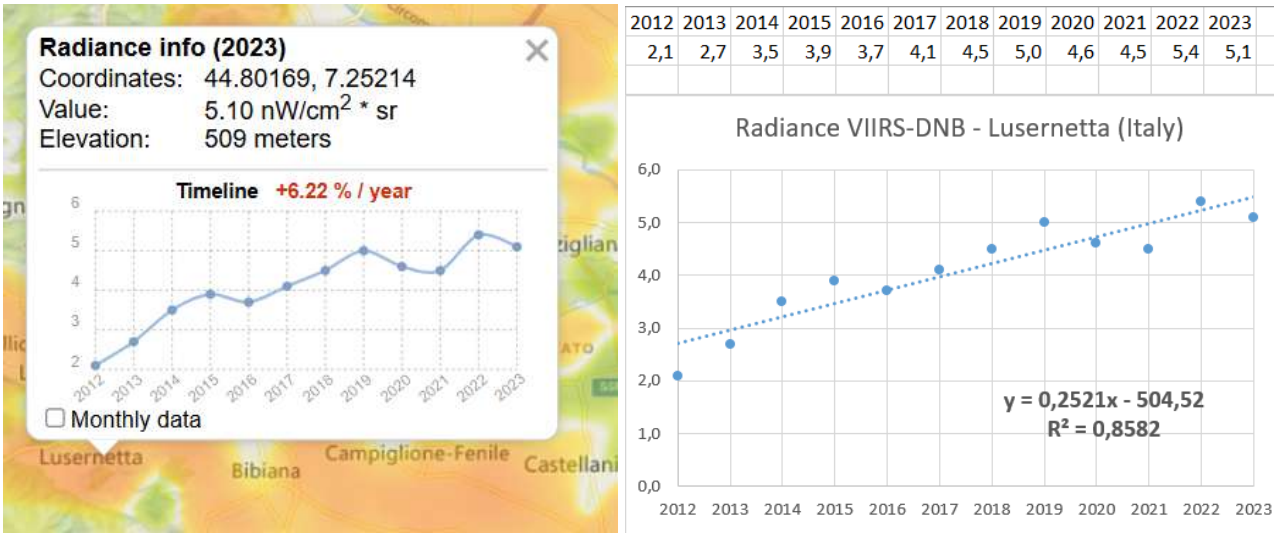


Figure 3.1.1 - Example 1 - Increase of light emission in Lusernetta, in the alpine Pellice valley, in Piedmont (Italy). Left panel: map and radiance graph from VIIRS trend; right panel: linear fit to identify trend characteristics.

The map colour is orange and, in fact, the graph shows an increasing trend that can be clearly noted. An increase of +6.22% per year is also reported (Figure 3.1.1, left panel).

However, the blue curve is not a straight line, so the question arises if the value of 6.22%/year is really representative of the actual annual trend. In order to verify this, we can compute this trend on our own, using for example a spreadsheet. By pointing the mouse on each one of the dots of the graph, we can read the radiance value for every year, and report it down on the spreadsheet. Most spreadsheet programs allow to compute a "linear trend" as the line that better fits, represents, the data points. In Figure 3.1.1, right panel, we show the result: a straight line, representing the linear trend, is drawn. The characteristics of this line are shown in the lower right corner of the graph. They are the **analytical equation of the straight line** (first row), where the number before the ***x*** is the absolute mean increase per year (in this case, about 0.25 nW/cm²sr), and the **coefficient of determination R²**, which provides an estimate of how well the straight line mimics the measurement. The value of R^2 is always confined between 0 and 1. The higher the value of R^2, the better the linear approximation (usually, a value down to $R^2 = 0.80$ is considered acceptable). In our case, a value of $R^2 = 0.85$ means that the trend is globally almost linear, with some change in slope (a steeper increase in the time frame 2016-2019, for example) and some temporarily decrease. It is important to underline the fact that **"small" variations can be due to measurement conditions rather than a change in the light emission level**. As a further remark, to compute your own increase in percent/year, you can use the formula of the CAGR (Compound Annual Growth Rate), but keep in mind that this number represents a trend that is not strictly linear, but rather exponential:

[CAGR%] = ([V_max/V_min]^(1/N_time_intervals) - 1) x 100

Where:

V_max = value of the analytical approximation (straight line) in x_max

V_min = value of the analytical approximation (straight line) in x_min

N_time_intervals = number of time intervals

Using the values V_max = 5.41, V_min = 2.78, and N_time_intervals = 11, we get a value of CAGR = 6.6%/year increase, in good agreement with the value of 6.2%/year reported by the website. This small discrepancy is due to possible differences in the formulae used for computation.

A second example is shown in Figure 3.1.2. Here the measurements are taken in a food provider deposit area south of the city of Vercelli, in Piedmont (Italy). The left panel shows a steeper increase in light emission, while in the right panel the trend can be considered linear with a **R^2** = 0.95 with an increase of 4 nW/cm²sr per year and a corresponding CAGR = 24.3%/year.

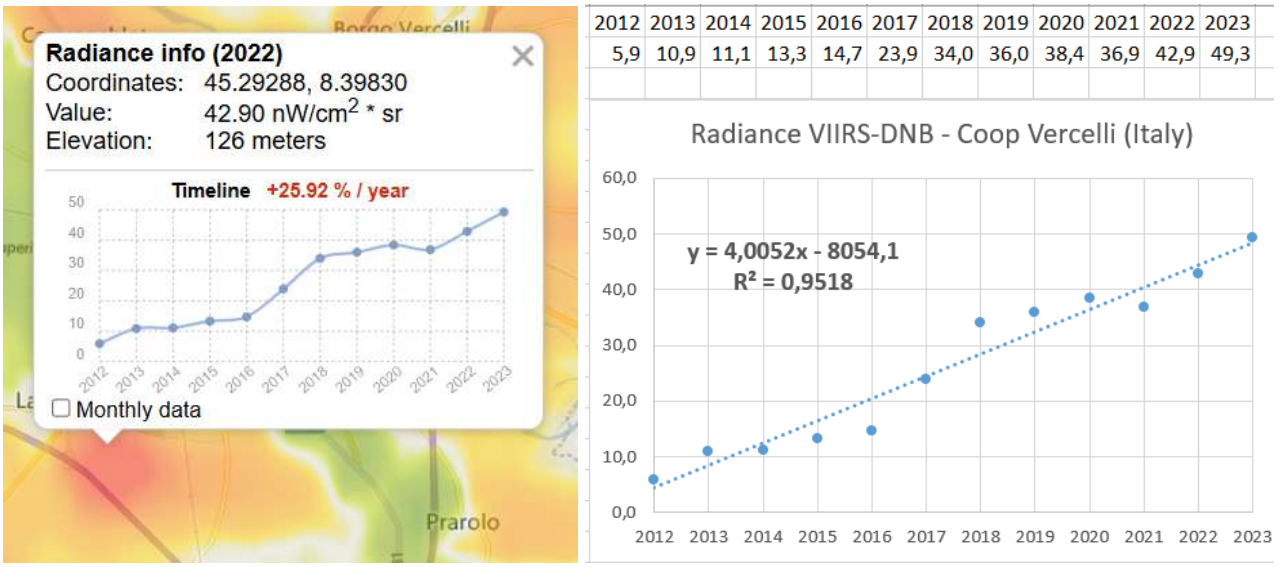
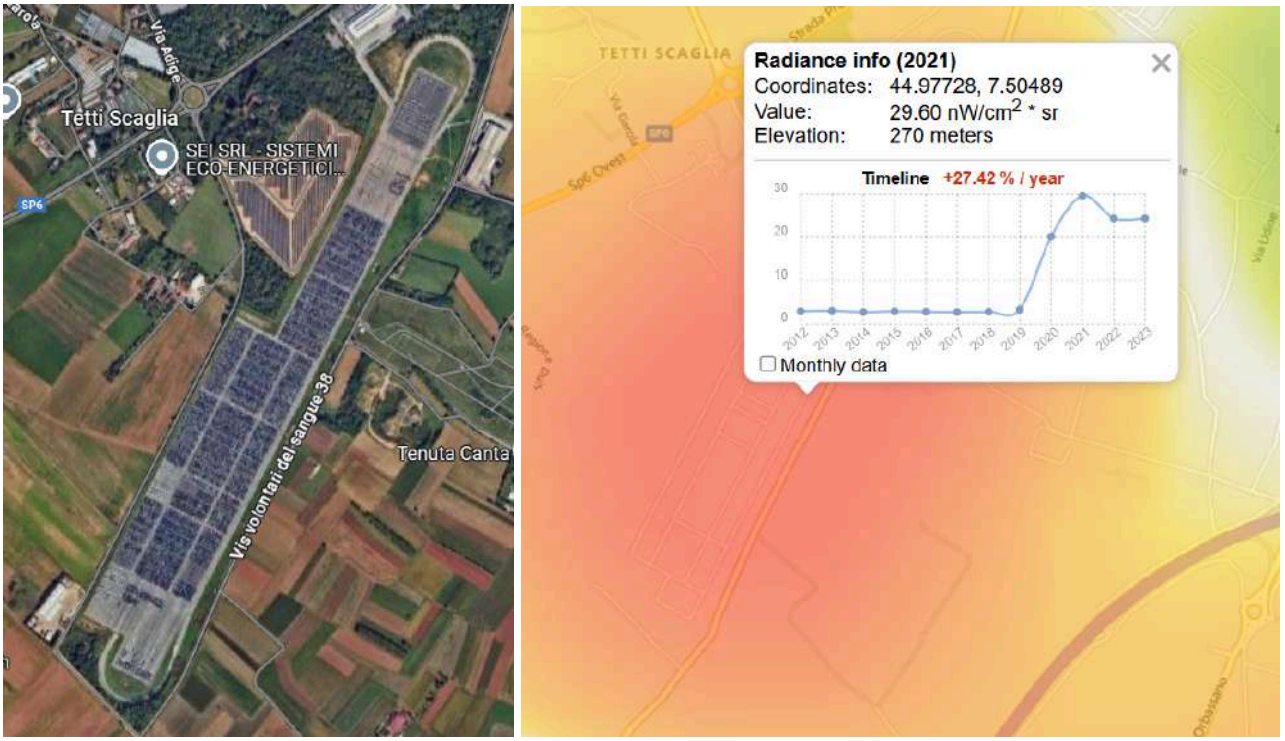


Figure 3.1.2 - Example 2 - Increase of light emission in food provider deposit south of Vercelli, Piedmont (Italy). Left panel: map and radiance graph from VIIRS trend; right panel: linear fit to identify trend characteristics.

Figure 3.1.3 reports the result of a third example, taken from a large parking lot where new cars are stored before shipping, near the city of Piossasco, Piedmont (Italy). The trend in light emission is quite different from the previous examples: the level remains quite stable from 2012 to 2019, then it suddenly increases and moves to a new threshold. It is clear that this behaviour is far from being a constant and linear increase over the years, and in fact the linear approximation provides a value of R^2 = 0.66, below the threshold.



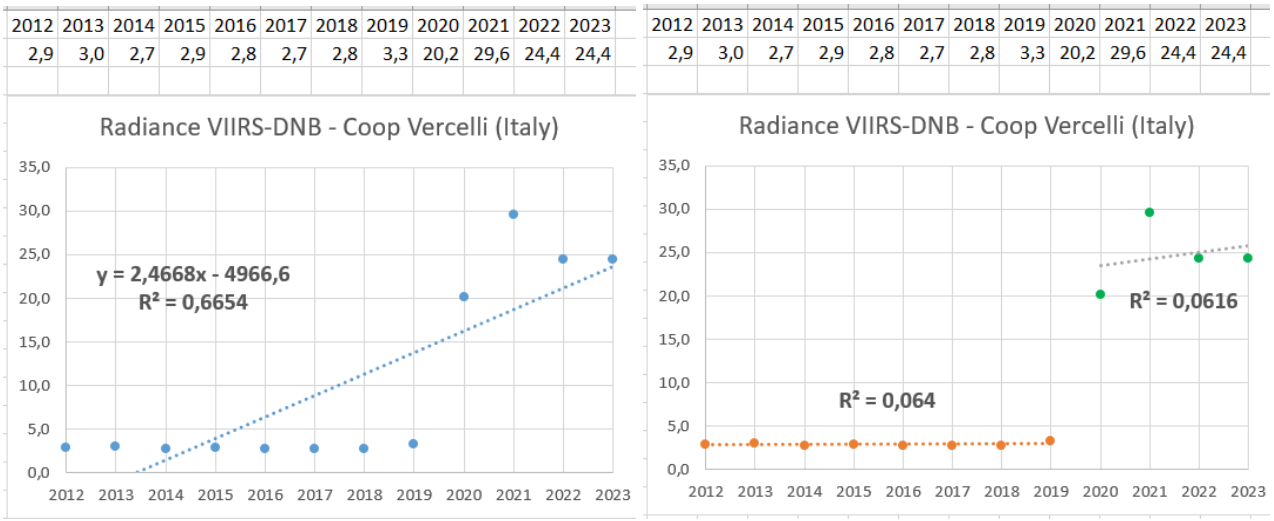


Figure 3.1.3 - Example 3 - Increase of light emission in a deposit of new cars near Piossasco, Piedmont (Italy). Upper-left panel: satellite snapshot of the area; upper-right: map and radiance graph from VIIRS trend; lower-left panel: global linear fit results; lower right-panel: two linear fits to identify trend characteristics.

The two time frames do not show a linear trend (R^2 < 0.80 in both cases), so the right way to deal with such a behaviour is to compute the mean value of the thresholds before the increase from 2012 to 2019, which is V_before = 2.9 nW/cm²sr, and after the increase, which is V_after = 24.6 nW/cm²sr. Obviously, something happened around the year 2020, causing a sudden increase of light emission (of ~ 850% !). The reason could be investigated, but it is likely due to the installation of a lighting system in the parking lot.

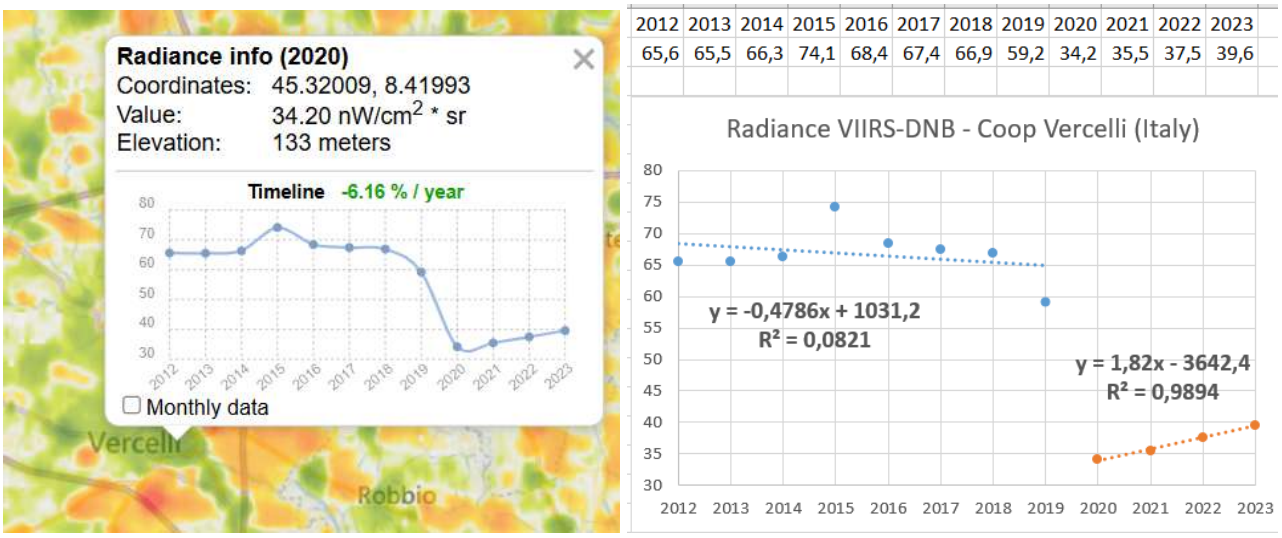


Figure 3.1.4 - Example 4 - Sudden decrease of light emission in the city of Vercelli, Piedmont (Italy). Left panel: map and radiance graph from VIIRS trend; right panel: linear fits to identify trend characteristics.

Another example is shown in Figure 3.1.4. Here the area under analysis is the city centre of Vercelli. Again, the behaviour of light emission over time cannot be considered linear (R^2 = 0.66), but it is rather characterised by two distinct regimes, one before and one after the year 2019. A linear approximation for the period 2012-2019 is not applicable as R^2 < 0.80 (Figure 3.1.4 right panel), so the trend is not describing the actual evolution.

We shall instead compute the mean of the values V_mean = 66.7 nW/cm²sr. After the sudden decrease in 2019, the new emission drops to about one half of the previous value, with a small increase in the following years of 1.8 nW/cm²sr per year.

Again, something happened in 2019. By searching the internet, we find that precisely that year the municipality of Vercelli changed 7 thousands of the 9 thousands public lighting points switching to red LED technology[9]. The VIIRS-DNB measurements should therefore reflect an effective reduction of light emission. Local ground-based measurements should be performed anyway to verify the impact on light pollution.

Of course, the linear approximation is only one of the possible models to be applied to the measured data, meaning a constant absolute increase every year. Other analytical models could better fit the data, for example an exponential curve (describing a percentage increase every year, the one corresponding to the CAGR) or other more complicated or suitable models. The value of R^2 can be a driver to accept ($R^2>0.8$) or exclude ($R^2<0.8$) one or more models.

Very often data are made available without any pre-processing or even without being calibrated. Ground-based instruments usually provide sky brightness measurements at high frequency, i.e. one value every 1 to 10 minutes. In this context, values are highly influenced by environmental conditions. Figure 3.1.5 shows an example of measurements done with a PRISMA all-sky camera in Pino Torinese from 2016 to 2019. In the left panel Mag/as² are reported vs. the height of the Moon at measurement time, while in the right panel the same measurements are plotted as a function of the Moon phase (Moon phase of 0.0 means New Moon, while a Moon phase of 1.0 means Full Moon). In both graphs it is possible to distinguish two distinct regimes separated in the left panel by a red curve. Measurements in the upper part are those made in good weather conditions, i.e. no clouds and clear atmosphere, while in the lower part the higher values of sky brightness (i.e. lower Mag/as²) are due to a sky partially or totally covered with clouds. Another clear feature of the left panel graph is the fact that when the Moon is up over the horizon (positive values on the x-axis) the measurements strongly depend on the Moon height, while this does not happen when the Moon is below the horizon. The right panel shows a similar behaviour regarding the lunar phase. Therefore, to obtain a reliable value of the mean monthly or yearly sky brightness, it is necessary to remove at least the effects of weather conditions and of the presence of the Moon light. In principle, these effects can be corrected by carrying out a specific analysis. In this case, we find that for a Moon height h (measured in degrees) and a Moon phase φ, it is possible to correct the measurements by adding the quantity $\Delta mag = 0.026 \cdot \varphi \cdot h$; however, in general, such correction can be avoided simply by removing the measurements affected by the presence of the Moon and of bad weather conditions.

[9] https://www.infovercelli24.it/2019/04/04/leggi-notizia/argomenti/attualita-7/articolo/vercelli-a-led-nuova-luce-in-tutti-i-quartieri-della-citta.html

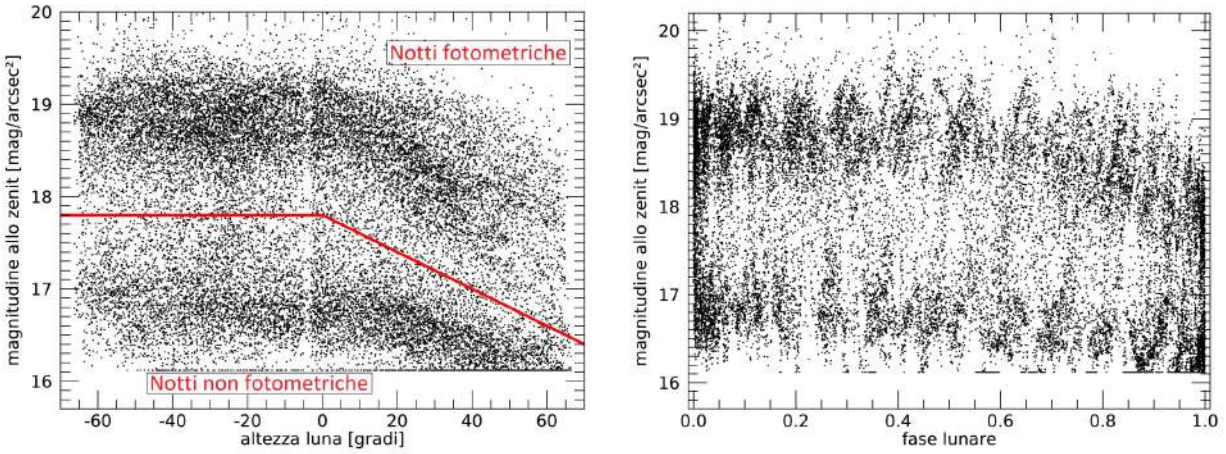


Figure 3.1.5 - left panel: sky brightness in Mag/as² as a function of Moon height above the horizon. Right panel: sky brightness in Mag/as² as a function of Moon phase. Data refer to the PRISMA camera in Pino Torinese (Italy) in the time frame 2016-2019.

Hereafter useful reminders when comparing data from different instruments:

- it is not possible to merge or directly compare ground-based data (quantifying, basically, the airglow) with space-based data (providing the light that escapes from the Earth's surface);
- it is not possible to merge or directly compare data from instruments with different sensitivity curves;
- be careful with trends: based on what is described in section 2.1, a negative trend does not necessarily mean a decrease in the light pollution perceived by the human eye.

Figure 3.1.6 shows an example of sky brightness reported from an SQM during one night (i.e. the night between the 25th and the 26th of May 2025). In this example, while the night falls around 9 P.M., sky brightness values increase and then start to oscillate between 18 and 19 Mag/as². Around midnight the brightness reaches a short plateau around 20.5 Mag/as² lasting a fraction of an hour, and soon after midnight the oscillating behaviour continues until the morning. This is very likely due to clouds affecting the measurement all night long, with a short exception just before midnight. Therefore, it would be possible to assume 20.5 Mag/as² to be the probable measurement value during a clear night. Note that the report provides the Moon phase (a negligible 2%) and the Moon maximum height (61°). The dotted lines enclose nighttime and, more specifically, they indicate the astronomical sunset and sunrise (i.e. when the Sun is below the local horizon by -18°), while the red shaded area indicates when the Moon is below the horizon, namely the time range when the most reliable measurements can be found, not being influenced by Moon light.

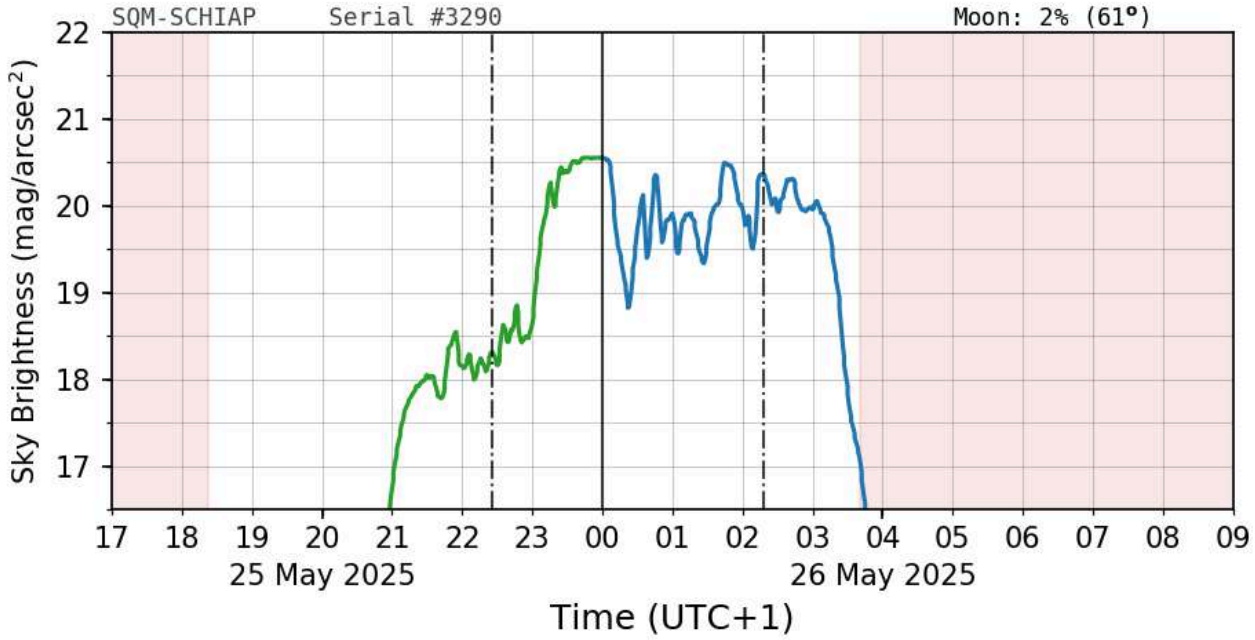


Figure 3.1.6 - Example of the sky brightness plot measured by a SQM located at the Astronomical Observatory "G.V. Schiapparelli" in Campo dei Fiori (Varese, Italy), founded by Salvatore Furia[10].

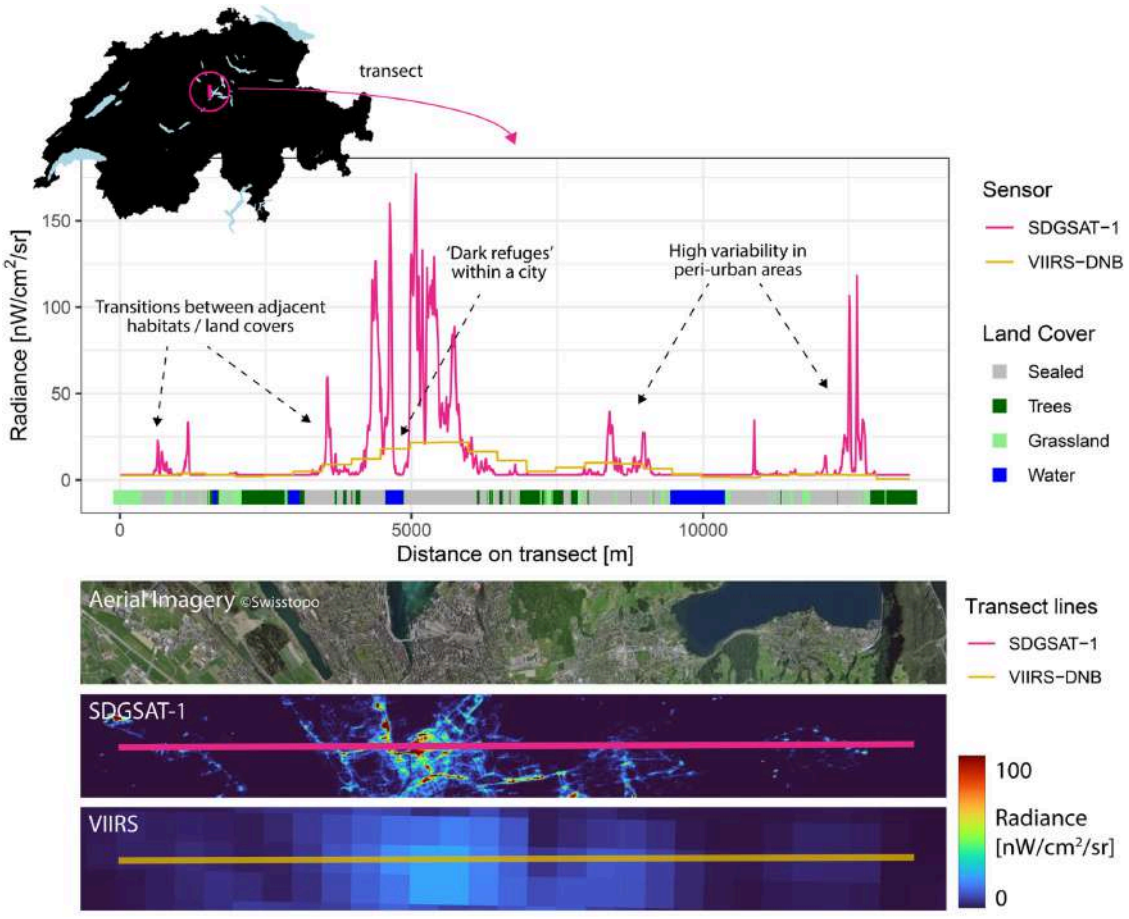


Figure 3.1.7 - Comparison between spatial resolutions of VIIRS and SDGSAT-1 data. Taken from Weber D. et al. (2025).

[10] https://darkersky4ce.inaf.it/instrument-sheet-sqm-schiapparelli/

Among the space-based observations, it is worth mentioning that recently, in November 2024, SDGSAT1 measurements have been used to produce a map of light emission from Earth in the European countries with an unprecedented linear spatial resolution of 40 metres[11], i.e. about 20 times better than VIIRS-DNB data (see Figure 3.1.7). These measurements are considered promising for ecological applications given the enhanced spatial resolution enabling assessments of small-scale variability in light intensity, which is not captured by VIIRS (D.Weber et al.[12]), even though there are some limitations due to the sampling time and frequency. Another caveat is that, being SDGSAT1 a space-based instrument, it measures light emission rather than light pollution, which, as we know, can extend to larger regions with respect to emission areas (the same applies to VIIRS data as well).

3.2 Identifying Trends in the Perception of the *Light Pollution Problem* by the Target Groups

The set of qualitative data of the DARKERSKY4CE Repository, gathered via the Dynamic Monitoring Tool, is meant to help identify trends in the perception of the *light pollution problem* in the relevant specific target groups identified by the partnership, i.e. private citizens, school students, and local administrators, and in the relevant social media communities reached by the project Call to Action.

DMT Surveys

Hereafter a schematisation of the survey-specific indicators of the three DMT questionnaires, complete with a *How to analyse and measure the change* column meant to help identify the above-mentioned trends.

- *Citizens*

Topic	*Indicator*	*How to analyse and measure the change*
Knowledge of the "ALAN" (question #3)	P_1 = percentage of "Yes"	Expected a raise of P_1, to be checked with a statistical test on proportion.
In your opinion, how much can artificial night light affect the following areas?	Six answers (one related to energy waste) to be classified as "Strong impact",	The "energy waste" answer should be marked as "Little to no impact". P_2 and P_3 should increase.

[11] https://darkersky4ce.inaf.it/instrument-sheet-sdgsat-1/
[12] https://doi.org/10.1002/rse2.70011

(question #6)	"Moderate impact", "Little to no impact". No "I don't know" option. P_2 = percentage of "energy waste" marked as "Little to no impact" on the total of answers P_3 = percentage of "energy waste" marked as "Little to no impact" on the total of "Little to no impact" answers	To be checked with statistical tests on proportion.
Has the level of night lighting near your home increased in the last three years? (question #7)	P_4 = percentage of "I don't know" P_5 = percentage of "Yes"	P_4 should decrease (more people pay attention to ALAN) P_5, categorized on area information, can state if ALAN is increasing or not in a certain area.
In your opinion, how much do the following sources contribute to light pollution? (question #8) Note: #5 is similar, but based on the personal experience of the respondent	Eight answers. No "I don't know" option. Not an indicator.	
Does the light entering your bedroom at night affect the quality of your sleep? (question #9)	P_6 = percentage of "I don't know"	P_6 should decrease (respondents pay more attention to inappropriate light). Use a statistical test on proportion. The areal location of answers is an added info.
Effects on human health of light	Five answers (one is "Vision problems (e.g.	In general, the classification by importance level can give

pollution (question #10)	eye strain, glare, reduced night vision)") to be classified as "Strong impact", "Moderate impact", "Little to no impact". No "I don't know" option.	a vision of how people understand light pollution and its effects on human health.
Do you feel discomfort or fear when walking through unlit places at night? (question #11)	P_7 = percentage of "yes"	Even if P_7 should decrease, it is not expected due to its psychological aspect
If it were possible to reduce and/or improve public lighting at night, would you be in favour? (question #12)	P_8 = percentage of "yes" P_9 = percentage of "I don't know"	P_8 should increase P_9 should decrease Use a statistical test on proportion
Do you think that dark areas can increase the risk of crime and therefore be dangerous for human safety? (question #13)	P_{10} = percentage of "yes" P_{11} = percentage of "I don't know"	P_{10} and P_{11} should both decrease Use a statistical test on proportion
If you have outdoor lights outside your home, how do you use them at night? (question #14)	Four answer, one is not desirable ("they are always on") P_{12} = percentage of "always on" answer	P_{12} should decrease. To be checked with statistical tests on proportion
Have you already taken any actions to reduce light pollution in your daily life? (question #15)	P_{13} = percentage of "I don't think is necessary" answers	P_{13} should decrease Use a statistical test on proportion

Would you support measures to reduce light pollution in your community?(question #16)	P_{14} = percentage of "No, I don't think is a priority"	P_{14} should decrease Use a statistical test on proportion
Can you see the stars at night where you live? (question #17)	Five answers (four linked to the Bortle scale, and "I don't know") P_{15} = percentage of "I don't know"	P_{15} should decrease Use a statistical test on proportion Useful to assess if awareness arises. With country categorization, can give information on the pollution of different areas.
Have you ever had the experience of observing the sky in a very dark place? (question #18) What topics could interest you in an astrotourism experience? (question #19)	Not an indicator	Useful to point the respondent attention to the following question
How important do you think it is to protect the starry sky for future generations? (question #20)	P_{16} = scale from 1 ("Not at all important") to 7 ("Very important")	The distribution of P_{16} should tend to 7 Use moments and distribution plots
Final question: "Has this survey increased your interest in light pollution?"	P_{17} = scale from 1 ("Not at all") to 5 ("Greatly")	The distribution of P_{17} should tend to the maximum. Use moments and distribution plots

A special section of this survey is dedicated to *economic operators*:

How important do you consider lighting (illuminated signs, shop windows, etc.) to be for the promotion of your business?	Four answers, from "Not at all" to "Very important" P_{18} = scale from "Very important" to "Not at all important" in 4 steps	The distribution of P_{18} is an indicator of the use of artificial light for advertisement, not directly an indicator of the change.
During which time slot do you leave the advertisement lighting of your business on?	P_{19} = percentage of "Also some hours outside regular opening hours"	P_{19} should decrease To check with statistical tests on proportion
In your opinion, how positive for your business could be the development of dark sky tourism in your area (stargazing, night walks, astrophotography courses, tastings under the stars, etc.)?	Four answers, from "Negative" to "Very positive". P_{20} = scale from "Negative" to "Very positive" in 4 steps	The distribution of P_{20} should tend to "Very positive" (operators see dark skies as an additional value)

Upon the collection of a sufficient amount of data, the following set of questions is used to target the survey respondents, to categorise the data, and to collect ancillary information.

First section on personal information Questions about age, gender, qualification, family composition, environment in which people live, or attitude towards sustainability.		
Where did you hear about ALAN?	Not an indicator, but useful to decide the	

(question #4)	best way to reach people with communication	
How strong are the following sources of artificial light near your home? (question #5)	Six answers (one for private, four for public lighting and "others") to be classified as "Very strong", "Moderate", "Weak or not noticeable". No "I don't know" option.	Not expected a change, useful for categorization
If you have outdoor lights outside your home, how do you use them at night? (question #14)	Four answers, with one "bad habit" ("They are always on")	Not an indicator subject to change easily However, it can be related to approach to sustainability

- *Schools*

The DMT survey for students is similar to the one for private citizens but designed in a simpler way and focuses on first-hand situations that children between 6 and 12 or 13 years old could have experienced. The DARKERSKY4CE partnership foresees administering this questionnaire in a controlled environment, i.e. during school workshops.

The questions range from the general concept of "light pollution" and its effects on humans and wild species to the students' personal feelings about darkness and their willingness to change.

Topic	*Indicator*	*How to analyse and measure the change*
Feelings toward nature (question #1)	P_1 = Likert-like scale, from 1 (not at all important) to 7 (very important)	The distribution of P_1 should increase the asymmetry toward higher values
Knowledge of the "ALAN" (question #2)	P_2 = percentage of Yes P_3 = percentage of "I don't know"	Expected a raise of P_2 Expected a decrease of P_3 ("unaware students") Both to be checked with a

		statistical test on proportion
Meaning of "light pollution" (question #4)	Four answers (one related to energy waste) with a single choice P_4 = percentage of "energy waste" P_5 = percentage of "I don't know"	P_4 and P_5 should decrease Both to be checked with a statistical test on proportion The other two questions can give a hint on how light pollution is perceived by young people.
What are the main effects of ALAN? (question #5)	Four answers (one related to energy waste and one negative - "no effects") with multiple choice P_6 = percentage of "increase of energy consumption" P_7 = percentage of "no effects"	P_6 and P_7 should decrease Both to be checked with a statistical test on proportion The other two questions can give a hint on how light pollution is perceived by young people.
What are the main effects of ALAN? (question #8) more detailed w.r.t. #5	Six answers (one is "Air quality - more smog") to be classified as "strong impact", "moderate impact", "little to no impact". No "I don't know" possibility P_8 = percentage of "Air quality" marked as "little to no impact" on the total of answers P_7 = percentage of "air quality" marked as "less important" on the total of "less important" answers	P_6 and P_7 should increase (it indicates that respondents are not aware of the ALAN properly). Use a statistical test on proportion. In general, the classification by importance level can give a vision of how young people understand light pollution and its causes. The areal location of answers is an added info.
Effects of ALAN on wild species	Three answers (one is correct, one is a wrong	P_9 and P_{10} should decrease (it indicates that respondents

(fireflies - question #7 bird migration - question # 9 frogs - question #11)	effect, one is negative - "I don't know" or "no effects") P_8 = percentage of "correct effect" P_9 = percentage of "wrong effect" P_{10} = percentage of negative answers	are not aware of the ALAN properly). P_8 should increase (its increase alone is not sufficient to distinguish on the other two indicators) To be checked with statistical tests on proportion. Answers can be summed together, or the indicators can be multiplied on each answer, to distinguish the knowledge of students of different natural phenomena.
Effects of ALAN on wild species (nocturnal animals - question #10)	Four answers, one is wrong, with multiple choice. P_{11} = percentage of wrong answers	P_{11} should decrease To be checked with statistical tests on proportion.
What can we do to reduce light pollution? (question #12)	Four answers, one correct, one wrong (reduce energy waste), two negative ("I don't know", "nothing to do") P_{12} = percentage of correct answer P_{12} = percentage of "wrong effect" and "I don't know" P_{13} = percentage of "nothing to do"	P_{12} and P_{13} should decrease (it indicates that respondents are not aware of the ALAN properly). P_{12} should increase (its increase alone is not sufficient to distinguish on the other two indicators) To be checked with statistical tests on proportion.
Where you live, can you see the stars? (question #13)	Five answers (four linked to the Bortle scale, and "I don't know") P_{14} = percentage of "I don't know"	P_{14} should decrease Use a statistical test on proportion Useful to assess if awareness arises.

Are you afraid when you go through dark places? (question #16)	Four answers ("yes", "no", "somewhat", "no if I'm not alone") P_{15} = percentage of "yes"	Even if P_{15} should decrease, it is not expected due to its psychological aspect
Would you like to have an astrotourism experience? (question #17)	P_{16} = percentage of "yes"	P_{16} should increase Use a statistical test on proportion

The following set of ancillary questions is foreseen:

First section on personal information Questions about school level, gender, environment in which students live		
Where did you hear about ALAN? (question #4)	Not an indicator, but useful to decide the best way to reach people with communication	
Have you ever experienced stargazing in a very dark site? (question #14)	Not an indicator	
What are the strongest sources of artificial light near your house? (question #15)	Five answers (one for private and four for public lighting) to be classified as "very important", "important", "unimportant". No "I don't know" possibility	Not expected a change, useful for categorization

- *Local Bodies*

The DMT survey for local administrators focuses on their knowledge of the current regulations, on their willingness to carry out awareness-raising actions with the population and to make an effort, also from an economic point of view, to reduce light pollution. Moreover, several questions are about the relationship between lighting and safety, which is a delicate topic for a political entity such as a local administration.

Topic	*Indicator*	*How to analyse and measure the change*
When was the last upgrade (other than routine maintenance) of the street lighting system in your municipality? (question #1)	P_1 = percentage of "I don't know"	P_1 should decrease The answers ("less than 2 years", "between 2 and 5 years ago", "more than 5 years ago") can give a map of the actions already done.
Are you aware of regional (or national) regulations on public lighting and light pollution reduction? (question #2)	P_2 = percentage of Yes P_3 = percentage of "No"	Expected a raise of P_2 Expected a decrease of P_3 Both to be checked with a statistical test on proportion
What do you think are the main impacts of light pollution? (question #3)	Five answers (one related to energy waste and one negative - "not an important problem") with up to three choices P_4 = percentage of "waste of energy and high costs" P_5 = percentage of "not an important problem"	P_4 and P_5 should decrease Both to be checked with a statistical test on proportions. The other questions can give a hint on how light pollution is perceived by administrators.
Has your municipality already taken specific measures to reduce light pollution?	P_6 = percentage of "Yes" P_7 = percentage of "I don't know"	Both P_7 and P_8 should decrease, while P_5 should increase. They are not mutually

(question #4)	P_8 = percentage of "No"	exclusive. To be checked with statistical tests on proportions.
To what extent do you consider light pollution to be a problem in your municipality? (question #5)	Four answers, ranging from "To a large extent" to "it is not a problem". P_9 = distribution of answers	The distribution of P_9 should show an asymmetry toward "to a large extent" To be evaluated with moments, distribution plots
What type of public lighting is predominantly used in your municipality? (question #7)	P_{10} = percentage of "I don't know" answers	P_{10} should decrease To be checked with statistical tests on proportion. The other answers give a map of the type of lighting usage.
Were devices to reduce light pollution installed in your municipality (e.g. LEDs with appropriate colour temperature, shielded lighting, night switch-off)? (question #8)	P_{11} = percentage of "No"	P_{11} should decrease To be checked with statistical tests on proportion.
What is the economic impact of public lighting on the energy costs of your municipality? (question #9)	P_{12} = percentage of "I don't know"	P_{12} should decrease To be checked with statistical tests on proportion. The other answers give an indication of the load of lighting costs on the overall economic balance.
Has your municipality ever considered switching off or reducing public lighting during certain	P_{13} = percentage of "Yes" P_{14} = percentage of "Yes, but is not a viable solution"	Both P_{14} and P_{15} should decrease, while P_{13} should increase. They are not mutually exclusive.

time slots in order to reduce consumption and light pollution? (question #10)	P_{15} = percentage of "No, there is no interest"	To be checked with statistical tests on proportions.
What are the main difficulties in taking measures against light pollution in your municipality? (question #11)	Not an indicator of the change	It gives a hint on the perceived obstacles to a reduction of light pollution
Has your municipality ever considered astrotourism (e.g. sky observation events, creation of areas protected from light pollution,etc.) as an opportunity for economic and tourism development? (question #16)	P_{16} = percentage of "No"	P_{16} should decrease Use a statistical test on proportion

In the following table is presented an in-depth analysis of the indicators of the survey questions tackling in particular the correlation between lighting and safety.

In your experience, do the citizens of your municipality perceive public lighting as an important safety factor? (question #6)	Three answers P_{17} = percentage of "yes, but balanced with environmental sustainability"	P_{17} should increase To be checked with statistical tests on proportion.
Has your municipality done an assessment of the balance between public safety and light pollution reduction? (question #12)	P_{18} = percentage of "Yes"	P_{18} should increase Use a statistical test on proportion While P is a direct indicator of the change, the percentage of two other answers ("No, never addressed" and "Safety

		is a priority on light pollution") should be monitored to evaluate the security issue
Can light pollution be reduced without compromising citizens' perceived safety? (question #13)	P_{19} = percentage of "No, more light is equal to more security"	P_{19} should decrease
Has your municipality carried out any citizenship initiatives on street lighting? (question #14)	P_{20} = percentage of "No"	P_{20} should decrease Use a statistical test on proportion

The following set of ancillary questions is foreseen:

First section on information about localization and number of inhabitants of the municipality, role of the respondent in the council		
Which tools do you consider most effective in raising public awareness of light pollution? (question #15)	Not an indicator, but useful to decide the best way to reach people with communication	
Final personal questions: age and gender of the respondent		

As already mentioned, throughout the project lifetime, as well as, potentially, after its end, different batches of data will be collected and a thorough analysis will be performed. In particular, this analysis is meant to be performed focusing, firstly, on each

country of the DARKERSKY4CE partnership, in order to be able, later on, to mix and compare all collected data.

In this way, it will be possible to provide both country-specific and more general overviews of the collected data and, therefore, to identify on both levels the trends in the perception of the *light pollution problem* across the three specific target groups identified by the partnership, i.e. private citizens, school students, and local administrators.

In particular, the indicators will be compared looking for statistically significant differences that will indicate whether or not a change occurred in the desired direction, and whether or not the activities carried on have been as useful as anticipated.

If enough data are collected, answers can be categorised and new perspectives can be gained. For instance, it is possible to expect a different initial behaviour and a different capability to absorb new attitudes on the basis of age, gender or qualification. Indeed, although it would also be possible to expect people who live in a rural country, who are sensitive to sustainability-related topics, or who have children to raise, to already be more attentive to ecological issues, the initial survey could reveal this assumption to not be justifiable, thus requiring awareness-raising actions.

Call to Action

In marketing, CTAs are considered crucial for guiding user behaviour, improving engagement, and measuring the effectiveness of campaigns. In order to do so, CTAs must be clear and concise (e.g. posts with eye-catching colours). Indeed, the effectiveness of a CTA depends on its ability to communicate the value of the proposed action and the ease with which the user can perform it. Then, the degree of involvement and the growth of interest for the topic in question, or lack thereof, can be assessed over time and by means of specific indicators.

Hereafter the relevant indicators of the DARKERSKY4CE Call to Action activities meant to help identify the trends in the perception of the *light pollution problem* in the relevant social media communities:

- Number of users reached
- Number of users clicking on the post/video
- Number and % of likes
- Number and % of users participating in the CTA
- Number and % of users following the links and reaching the landing page
- Type of answers (knowledge of the phenomenon % personal opinion about it %)
- Number and % of clicks to the final link proposed on the landing page (which may refer to a site, to a more in-depth page, to the general questionnaire or to a box for collecting addresses to be updated on dark sky events etc.)
- Number and % of shares with mention or hashtag

The DARKERSKY4CE partnership also attributed specific indicators for the monitoring and the identification of light pollution awareness trends through all six proposed activities of the Call to Action.

NAME	**DISCOVER WHAT ANIMAL OF THE NIGHT YOU ARE - (CTA1)**
TYPE	Short and Fun Quiz
SOCIAL	Facebook - Instagram - (Linkedin: possible post following an article)
TARGET	Family explorer, Nature lover, Educator & prof
ACTION	🦉 What animal of the night are you? 🌙 Find out how much you know about light pollution and which nocturnal animal represents you most! _____ **1- At night you like it:** A) Being outdoors and observing the sky ⭐ B) Staying at home with a light on 🏠 C) Sleeping deeply 😴 _____ **2- Do you know what light pollution is?** A) Of course! Too much light at night damages nature and the sky 🌍 B) More or less... it has to do with illuminated cities, right? 🤔 C) No, but I want to know more! 📖 _____ **3- Have you ever gone out somewhere very dark to see the stars?** A) Yes, and I have seen incredible things! ✨ B) Sometimes, but I don't think about it often 💡 C) Never, but I'd like to try! 🚀 _____ **4- Which of these statements is true?** A) Light pollution alters the rhythms of animals and plants 🦉🌿 B) Bright lights make cities safer at night 🚦 C) Darkness is always a problem and must be eliminated 🌑 _____

	🌟 RESULTS 🌟 Majority of A → YOU ARE AN OWL! 🦉 Wise and nocturnal, you love the starry sky and know the value of darkness. Keep spreading the message! _____ Majority of B → YOU ARE A LIGHT! ✨ You are curious and observant, but sometimes you get distracted by artificial lights. Switch off more and observe the sky! _____ Majority of C → YOU ARE A LIZARD! 🦎 You love the sun, but the night world is still a mystery to you. It is time to discover the beauty of the dark! _____ 🔦Final challenge: For one night, try turning off all the unnecessary lights you can and look at the sky. What can you see or what do you feel? Share it with us! How? _____ You can create a video, interview or selfie and tell us what you experienced, or you can write your thoughts and inspirations in the comments, but also take a shot from where you live both outside and inside, the important thing is to use the mention and/or the hashtag: a) the material will be selected for a collective video b) win the night among the stars (see under prize proposal 2)
STRUCTURE	**Social posts + Quiz (5 questions) + Result + Challenge + Landing Page**
RESULT	Participation in the quiz and final challenge invitation to switch off unnecessary lights for one night and share the experience = increased awareness
INDICATORS	-number of users reached -number of users clicking on the post/video -number and % of likes -number and % of users participating in the CTA

	-type of answers (knowledge of the phenomenon % personal opinion about it % only possible with option c) -number and % of clicks to the final link/landing page (which may refer to a site, to a more in-depth page, to the general questionnaire or to a box for collecting addresses to be updated on dark sky events etc.) -number and % of shares with mention or hashtag
OPTIONS	A. Format Stories Create a sequence of stories with the question in the first slide and in the following stories the correct answer and a brief explanation. B. Post with Carousel (succession of slides) First slide = question, next slide = answer options, last slide = correct answer, etc. C. Using an External Link Create an eye-catching image for the post inviting people to take the quiz. Put a link to a quiz made with Google Forms
IN PRACTICE HISTORY OR CAROUSEL	Post inviting participation in the quiz A slide for each quiz question Slide with quiz results Slide with final challenge (optional) Slide landing page

NAME	**SHORT SURVEYS (CTA2)**
TYPE	Polls
SOCIAL	Instagram
TARGET	Eco-conscious, Nature lover, Local curious, Educators & Teachers

ACTION	Polls on Instagram are very attractive and used 'call to action' because they are quick and offer an immediate sense of gratification. Polls can be placed within the daily history of one's profile, require a background image or video and are essentially designed for one's followers, are quick and easy, being in stories only last 24 hours, but the data collected remains in the archive. It is possible in stories to ask both open questions (but often there is not much participation) and specific questions in the form of simple 'polls' with a variable number of answers, the latter usually being more popular and with them it is possible to assess interest and/or knowledge of a certain topic. Recently, the possibility was introduced to make polls in posts that remain in one's feed (which can therefore also be sponsored) and kept for a period of time that one deems suitable. Polls on Instagram are not anonymous, which means you can see who has voted and which option they have chosen. The only limitation of post polls is that they only have short answers (YES/NO). For the polls in the daily stories, on the other hand, you can choose to use some of the questions in the generic (citizens) questionnaire, or you can create some lighter and funnier ones.
STRUCTURE	**Story or Post with survey + Link to Landing Page**
RESULT	Quickly engaging the public and collecting data on knowledge and perceptions of darkness Deepen topic on site
INDICATORS	-number of users reached -number of users clicking on the post/video -number and % of likes -number and % of users participating in the survey -type of answers (knowledge of the phenomenon % personal opinion %) -number and % of clicks to the final link/landing page -number and % of shares with mention or hashtag -number and % of users who continue with the landing page link
IN PRACTICE POST, STORIES	Post with question Enter the 2 or 3 possible answers for the survey Slide with landing page

NAME	**WIN A NIGHT AMONG THE STARS - (CTA3)**
TYPE	Competition: receive a prize if you fill in our questionnaire
SOCIAL	Facebook - Instagram - (Linkedin: possible post following an article)
TARGET	Eco-conscious, Nature lover, Local curious, Educators & prof
ACTION	In most of the proposals inviting people to fill in forms and questionnaires on social media, a 'final gift' is proposed, i.e. the possibly immediate prize. The prize is the best incentive for people to take the time to answer the questions in a questionnaire. Users will then be invited with a catchy post to fill in the 'general public questionnaire', motivating them with the prospect of a prize upon completion.
STRUCTURE	**Social media post + Questionnaire + Link to Landing Page**
RESULT	Collecting data and encouraging questionnaire completion, collecting email addresses, offering a prize
INDICATORS	-number of users reached -number of users clicking on the post -number and % of likes -number and % of clicks on the link -number and % of users participating in the questionnaire -type of answers (knowledge of the phenomenon % personal opinion %) -number and % of clicks to the final link/landing page -number and % of users leaving their addresses -number and % of shares with mention or hashtag
AWARDS	All participants will receive a PDF stargazing guide (prepared by INAF). Each partner can decide on the amount and type of the prize according to its own particularities ITALY = drawing of No. X winners of free entry tickets with guided tour of local planetarium and/or observatory
IN PRACTICE POST, STORIES	Post inviting participation in the competition: "Would you like to win a night among the stars?" fill in the questionnaire! Link to google form with questionnaire

	(NOTE: plan to add on the questionnaire the wording related to how the prizes will be drawn specifying the obligation to enter e-mail) Link at the end of the questionnaire to the landing page

NAME	**DISCOVER THE DARKEST SKY - (CTA4)**
TYPE	Competition
SOCIAL	Facebook - Instagram - (Linkedin: possible post following an article)
TARGET	Eco-conscious, Family explorer, Nature lover, Local curious, Educators & Teachers
ACTION	A competition open to all to identify and map the places in the area with the darkest skies, where light pollution is minimal. With this CTA, in addition to collecting useful scientific data on the area and other indicators related to the perception of the value of dark skies, it is an active and therefore direct way of raising awareness of the protection of the night sky. The competition is an invitation to go out and rediscover the night, people are encouraged to move away from over-lit areas and invited to observe the sky to search for the darkest places in their area. Then, in order to join the competition, one must fill in a special form (e.g. buio non ti temo) that allows one to collect useful data on location (GPS coordinates of google maps) and other information, such as measuring light with special Apps (Loss of the Night/Dark Sky Meter).
STRUCTURE	**Social post + Form participation + Link to Landing Page**
RESULT	Mapping the darkest skies and encouraging people to rediscover the beauty of the night, participate in the prize draw, share
INDICATORS	-number of users reached -number of users clicking on the post -number and % of likes -number and % of clicks the form link -number and % of users participating in mapping -number and % of clicks to the final link/landing page -number and % of users leaving their addresses -number and % of shares with mention or hashtag

AWARDS	One winner per prize (or several prizes to be defined with INAF as in the case of the CTA2 proposal)* will be drawn from all participants. All participants will receive a PDF stargazing guide (prepared by INAF). Each partner can decide on the amount and type of the prize according to its own particularities *ITALY = X number of free entries with a guided tour of the local planetarium and/or observatory
IN PRACTICE POST, STORIES	Post inviting participation: 'Discover the darkest sky' fill in the form! Link to google form (describe how prizes will be drawn, e-mail entry required) Link at the end of the form to the landing page Landing page

NAME	**LISTEN TO THE STARS - (CTA5)**
TYPE	Playlists or Podcasts
SOCIAL	Promotion by post: Facebook - Instagram - (Linkedin prior article)
APP	Spotify
TARGET	Playlist: Eco-conscious, Nature lover Podcast to: Eco-conscious, Nature lovers, Educators & Teachers Podcast b: Eco-conscious, Family explorer
ACTION	Creation of one or more **playlists** containing both Italian and international songs related to stars, dark skies and the moon. _____ Creation of 6/10 episode **podcasts** dedicated to specific target groups: a) 6 episodes to "lift up your eyes and appreciate the dark skies" e.g. content: astronomy lessons, excerpts from famous books, relaxing suggestions b) 10 “in the dark you sleep better” episodes with storytelling (or parts of stories dedicated to children with topics related to dark nights and stars _____

	Organise a storytelling contest? the best stories about the preciousness of the night and dark skies will perhaps be included in a special podcast? to be evaluated
STRUCTURE	**Spotify Playlists / Thematic Podcasts + Link to Landing Page**
RESULT	Creating an immersive experience for those who love music and storytelling, listening, sharing
INDICATORS	-number of users reached -number of users clicking on the post -number and % of likes -number and % of clicks to the link leading to spotify -number of tracks entered by users (playlists only) -number and % of clicks to the final link/landing page -number and % of users following the audio channel -number and % of shares
IN PRACTICE POST, STORIES (promotion) AUDIO CONTENT	Post with links to promote audio content on Spotify: PLAYLIST: Create a music playlist containing both Italian (or your own country's) and international songs related to stars, dark skies and the moon. Invitation to collaborate in the creation of playlists (i.e. those who receive the link can add tracks to enrich it). Invitation to share, download, follow PODCAST: a) make 6 episodes to "lift up your eyes and appreciate the dark skies". b) making 10 'in the dark you sleep better' episodes Invitation to share, download or follow

NAME	**IS THE DARK SCARY OR GOOD? - (CTA6)**
TYPE	ASMR Video
SOCIAL	Promotion by post: Facebook - Instagram - (Linkedin previo articolo)
APP	YouTube
TARGET	Eco-conscious, Nature lover,

ACTION	Create and share on our main channels a video with ASMR (Autonomous Sensory Meridian Response) features, i.e. a relaxing video of dark, starry skies with sounds from space or a soundtrack and/or slow voice telling why darkness is precious to humans. The ASMR technique, coined in 2010, refers to a relaxing, often sedative sensation that starts on the scalp and spreads to the rest of the body. These videos are widely used to relax and especially to help people sleep. Example ASMR: https://www.youtube.com/watch?v=eimBu-yuWis https://www.youtube.com/watch?v=B5unCXpegAw https://www.instagram.com/reel/C-B-7cDuNGy/?igsh=MXQ5dHpzaWZneHV3bA==
STRUCTURE	**Post + relaxing video on Youtube/Social + Link to Landing Page**
RESULT	Showing the value of dark skies through relaxing images and sounds and sharing the video
INDICATORS	-number of users reached -number of users clicking on the post -number and % of likes -number and % of clicks to the link leading to youtube -number and % of clicks to the final link/landing page -number and % of users following the channel -number and % of shares
IN PRACTICE POST, STORIES (promotion) AUDIO VIDEO CONTENT	Posts with links to promote audio and video content on YouTube Creating a video with ASMR features Sharing the post and videos in our main channels

Desk Research

Hereafter two examples of desk research activity, complete with their respective results, in order to provide examples of search parameters that can help identify trends in the perception of the problem of light pollution.

- *Example n°1*

Search parameters

Area	Period	Words/Phrases/Key	Tools/Channels
Turin and Piedmont	01/01/2024 30/04/2025	astronomy events/ walks in the dark skies	Google/FB

What did we find?

Title	ALAN	Exploitation of dark skies	Type	Link
new lighting	*x*		*article*	https://www.lastampa.it/torino/2025/04/07/news/nuova_illuminazione_strade_buie_passerella_olimpica-15091634/
Heritage to be preserved		*x*	*project*	https://www.interreg-alcotra.eu/it/exo-eco-esopianeti-ecologia-il-cielo-e-le-stelle-delle-alpi-patrimonio-immateriale-delleuropa
Energy saving	*x*		*article*	https://www.piazzapinerolese.it/2025/02/08/mobile/leggi-notizia/argomenti/attualita-18/articolo/la-luce-costera-meno-anche-sotto-i-portici-di-luserna-san-giovanni.html?sfnsn=scwspwa
observing stars		*x*	*event*	https://planetarioditorino.it/sotto-un-cielo-di-stelle
street lighting	*x*		*project*	https://webthesis.biblio.polito.it/3385/
Criticism of the event	*x*		*article*	https://www.valsusaoggi.it/lettera-le-critiche-al-fascio-di-luce-della-sacra-di-san-michele/
Reflections ALAN	*x*	*x*	*conference*	https://www.esero.it/evento/

				sotto-un-cielo-di-stelle-riflessioni-sullinquinamento-luminoso-millumino-di-meno-xxi-edizione-16-02-2025/
Astronomy and art		*x*	*event*	https://fondoambiente.it/eventi/astronomi-per-una-notte-al-castello-della-manta
Space festival		*x*	*event (4 days)*	https://www.compagniadisanpaolo.it/it/news/torino-space-festival-2024/
Astronomical events		*x*	*article*	https://www.torinotoday.it/social/eventi-astronomici-agosto-2024-superluna-storione-stelle-cadenti-san-lorenzo.html

- *Example n°2*

Search parameters

Search on Google: "2024 events and evenings astronomy piemonte"

What did we find?

Type of event	**n°**	**Link**
Evenings FAI	*6*	*https://langhe.net/evento/sere-fai-destate-14-08-2024/*
Evening of observation	*1*	*https://www.diocesi.torino.it/site/wd-appuntamenti/dal-parco-alla-luna-e-oltre-festival-g-astronomico-ed-2024/*
Abbonamento Musei in collaboration with Infinito - Evening of observation	*4*	*https://abbonamentomusei.it/evento/serate-osservative/*
Tasting evenings and observation with telescope	*7*	*https://www.astronomitaly.com/blog/astronomitaly-in-tour-eventi-esperienze-osservazioni-astronomiche-telescopio-italia-pianeti-stelle-cadenti-nebulose-stargazing*

Night walks	*19*	*https://www.ecomuseodellerocche.it/it/news/12/notturni-nelle-rocche-2024*
night of San Lorenzo	*1*	*https://www.mentelocale.it/torino/56443-la-notte-di-san-lorenzo-alla-precettoria-di-sant-antonio-di-ranverso.htm*
Observation, study and tasting evenings	*11*	*https://www.osservatorioalpette.it/eventi/2024/*
Astronomy day	*1*	*https://planetarioditorino.it/astronomy-day-2024*
Evening observation	*5*	*https://liceocuneo.it/evento/osservatorio-astronomico-planetario/*
Summer camp "ass. astrofili"	*1*	*https://www.gawh.it/main/events/campo-estivo-2024/*
TOTAL	***56***	

3.3 Use of Ecosystem Services GIS Map

By integrating data on both ecosystem services and light pollution levels, the DARKERSKY4CE GIS Map serves as a decision-support tool for private citizens, policy makers, and environmental stakeholders. Indeed, providing a visual representation of both light pollution and the main sources of ecosystem services in Central Europe, the project GIS Map allows users to visualise how ALAN (i.e. Artificial Light At Night) can affect ecosystems and pose a threat for high-value natural areas. Furthermore, by tracking changes in light pollution and ecosystem service provision over time, the GIS Map enables authorities to evaluate the impact of mitigation strategies and adjust them as needed.

The visual nature of GIS maps makes them an effective means of engaging a wide range of users and helps communicate, in a compelling and easy way, the value of darkness as a natural resource and how reducing light pollution can support biodiversity, promote sustainable tourism, and enhance regional identity.

The goal of the DARKERSKY4CE GIS Map is to create a shared platform for cross-sectoral collaboration and long-term strategic planning in order to analyse both the potential and challenges of a given area and to get as close as possible to an optimal level of light pollution. Therefore, if the visualised data are positive, it will be possible to consider the area in question as a good practice; otherwise, if an area presents several facilities

with strong light emission, it will be possible to properly identify and consequently address its challenges.

The project GIS Map presents static data. Static data upload refers to the one-time integration of datasets that remain unchanged over time unless manually updated. These datasets represent a snapshot of information at a specific moment and are typically used for background or reference purposes (e.g. administrative boundaries, land cover classifications, elevation models, SQM measurements, ecosystem service assessments from a given year). The DARKERSKY4CE partnership agreed to the update of the data, when and if needed, throughout the lifetime of the project.

Hereafter the list of the header icons and a brief explanation on how to use them.

- *Info icon*: click on this icon and then click on the map. You'll see all relevant information (info from the layers that are switched on) in a pop-up window.
- *Sheet icon*: this is the reporting tool. Click on it and then click on the map. A report will be generated about the administrative unit where the location can be found.
- *Image icon*: click on it to create a print screen about the analysed area.
- *Share icon*: you can share your work (selected area with layers) with your colleagues if you want to ask them to check/contribute to your analysis. You can close these functions by clicking on them once more.
- *Zoom icons*: the map can be zoomed to the level at which the satellite image remains interpretable.