# The Light Pollution Mapping Framework of the DARKER SKY Project

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## Kurzfassung

Das Interreg-Nordsee-Projekt DARKER SKY zielt darauf ab, die Lichtverschmutzung zu verringern und die biologische Vielfalt im Nordseegebiet zu fördern. An dem Projekt sind Partner aus Frankreich, den Niederlanden, Deutschland und Dänemark beteiligt. Im Fokus des DARKER SKY Projekts steht unter anderem, Kommunen und Häfen mit innovativen Methoden zur Messung und Überwachung von Beleuchtungsanlagen mit dem Ziel der Reduzierung von Lichtverschmutzung zu unterstützen.

DARKER SKY implementiert umweltfreundliche Pilot-Beleuchtungsanlagen an acht Standorten, um ihre Eignung für Gemeinden und öffentliche Dienstleister im Nordseeraum zu evaluieren. Die Erfassung der Beleuchtung und der Lichtverschmutzung vor und nach der Umrüstung sind dabei von entscheidender Bedeutung. Um sicherzustellen, dass trotz variierender Fachkenntnisse und Bedingungen an allen Standorten eine einheitliche Methodik angewendet wird, haben die Partner einen gemeinsamen Rahmen vereinbart.

Die Aufgabe bestand darin, eine Methode zu finden, die für Laien durchführbar ist und zuverlässige Daten für die Bewertung des Pilotprojekts liefert. Dazu mussten die Lichtmesspraxis für Außenbeleuchtung und die für die Erfassung der Himmelsaufhellung aus der Sicht eines Laien reflektiert und gegebenenfalls vereinfacht werden. Zusätzlich dazu sollten auch Expertenansätze für professionelle Vergleiche dokumentiert werden. Das „Light Pollution Mapping Framework“ verwendet daher einen zweistufigen Ansatz: 1) Die Laienebene bietet vereinfachte Verfahren (z.B. Beleuchtungsstärke, Himmelsaufhellung im Zenit) für Personen mit begrenztem Wissen und Ressourcen. 2) Die Expertenebene richtet sich an Fachleute und umfasst etablierte Verfahren (z.B. Spektral- und Leuchtdichtemessungen, Langzeitaufnahmen der Himmelsaufhellung).

Der Rahmen für die Messung der Lichtverschmutzung wurde fertiggestellt und wird bereits an den Demonstrationsstandorten angewandt, sodass erste Erfahrungen vorliegen. Er wird jedoch während des gesamten Projekts bis Oktober 2026 weiterentwickelt werden. Das Projekt wird von der Europäischen Union im Rahmen des Interreg-Nordsee-Programms kofinanziert.

## Abstract

The Interreg North Sea project DARKER SKY aims to reduce light pollution and boost biodiversity in the North Sea Area, involving partners from France, the Netherlands, Germa-ny, and Denmark. It focuses on providing municipalities and ports with innovative methods for measuring and monitoring light reduction solutions.

Within DARKER SKY, environmentally-sound lighting techniques will be implemented at 7 demonstrator sites to explore replication for North Sea Region municipalities and public service providers. Monitoring the lighting infrastructure and light pollution before and after the intervention is crucial. Partners agreed on a common Light Pollution Mapping Framework to ensure a comparable methodology across all demonstrator sites and partners with varying expertise and conditions.

The mission is to find a methodology that is feasible for non-experts and provides reliable data for evaluating the pilot project. This required examining the discipline's practices for measuring outdoor lighting and sky brightening from a layperson's perspective and critically reviewing procedures, timeframes, and equipment. Additionally, expert approaches should be considered for professional comparisons. The Light Pollution Mapping Framework uses a two-level approach: 1) The non-expert level offers simplified procedures for measuring illuminance and zenith sky brightness, suitable for those with limited knowledge, equipment, and budget. 2) The expert level caters to professionals in lighting or astronomical measurements, incorporating best practices like spectral analysis, luminance, and long-term all-sky images.

The Light Pollution Mapping Framework has been finalized in terms of agreed methodology and is already being applied at the demonstrator sites, allowing us to learn initial lessons. However, it will continue to be developed throughout the project until October 2026.

The project is co-funded by the European Union in the framework of the Interreg North Sea Programme.

## 1 The DARKER SKY project

Light pollution, the excessive, misdirected or inappropriate use of artificial light at night, is increasingly recognised as a cross-regional challenge and serious environmental stressor causing biodiversity loss & habitat fragmentation. A proper reduction of light pollution & biodiversity protection calls out for transnational exchange and intergovernmental management.

Several EU countries, for the first time, consider light pollution in national legislation and strengthen its containment as a mandatory task for municipalities. However, no technical specifications for concrete environmentally sound, cost- and energy-efficient lighting solutions for urban planners and lighting engineers nor a cross-regional strategy guiding public authorities in maintaining and restoring ecological connectivity across the NSR are given.

The EU Interreg North Sea project DARKER SKY is aiming at reducing light pollution & increasing biodiversity and ecological connectivity in the North Sea Area by

a) providing municipalities with innovative measuring, monitoring and co-design methods for the implementation of new light reduction solutions;

b) fostering the interdisciplinary transnational exchange with good practices and lighthouse demonstrators, i.e. environmentally-sound lighting techniques and systems on 8 demonstrator sites in pilot regions in Brest (France), Groningen (The Netherlands), Lower Saxony (Germany) and Hamburg (Germany) with replication potential for North Sea region municipalities and public service providers (e.g. Wadden Sea ports);

c) establishing dialogue among local, regional & national public authorities to develop concrete regional action plans and a transnational strategy for a sustainable policy uptake of light reduction solutions across the NSR.

By doing so, DARKER SKY joins efforts among geographically scattered regions and initiatives to create and strengthen wider transnational dark ecological corridors, thus following the EU Zero Pollution Action Plan and EU Biodiversity Strategy to mitigate the fragmentation of natural habitats.

The DARKER SKY project is structured in three work packages (WPs). The aim of WP 1 is to co-develop transferable frameworks for effective regional and transnational policy uptake in WP 3, and for light pollution mapping, environmental monitoring and assessment to be tested at demonstration sites in WP 2 and rolled out across the North Sea region in WP 3. Figure 1 illustrates the three frameworks (Lighting, Biodiversity and Sociology) developed and applied to monitor the before and after situations at the demonstration sites.

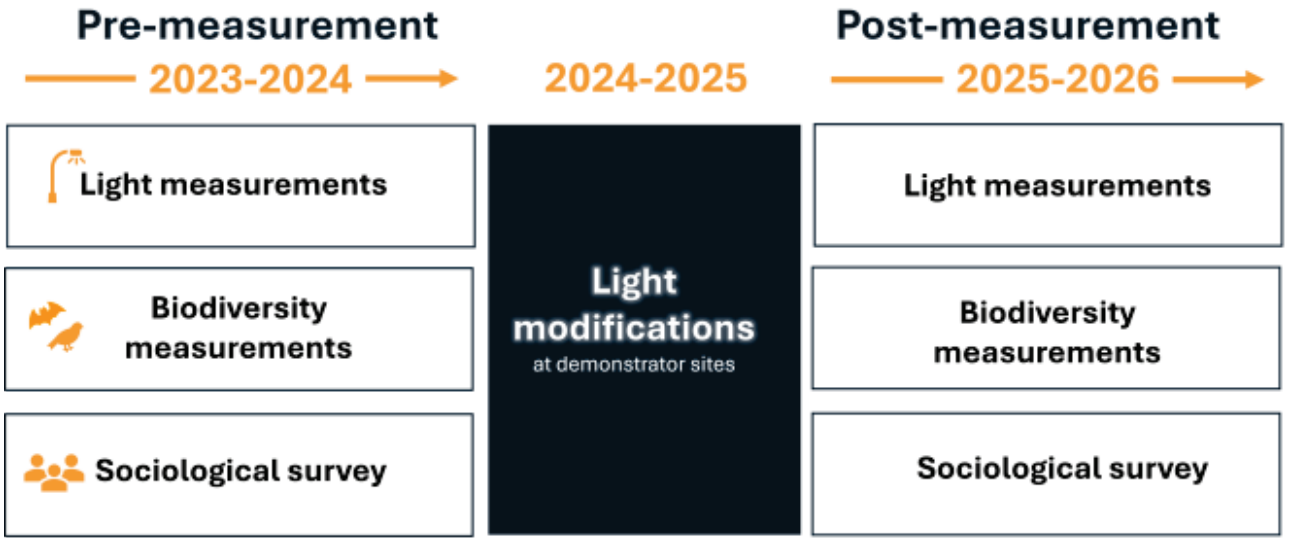


Fig. 1: Three transferable frameworks regarding lighting, biodiversity and sociology are developed to gain a comprehensive understanding of the impact of the light modifications within the DARKER SKY project. [1]

This paper introduces the joint measurement strategy within the DARKER SKY project for lighting- and sky-related measurements in the context of light pollution monitoring and discusses challenges of the process developing a mapping framework.

## 2 Developing a Measurement Framework

Lighting measurements are essential to gain insights into the effects of measures to prevent light pollution, for example when renewing lighting systems. The DARKER SKY project uses seven pilot projects as models for lighting refurbishments. These projects are evaluated through before-and-after comparisons.

The goal of the Light Pollution Mapping Framework is to apply a joint monitoring strategy to all partners within the DARKER SKY project to have a comparable transnational light monitoring approach and gain knowledge on the feasibility of the procedure and quality check of the results and documentation.

In the wider context, the Light Pollution Mapping Framework may serve as a blueprint for European municipalities seeking a viable monitoring method for their local dark sky efforts. In order to achieve a good starting position for this, it is planned in the final part of the project that a critical reflection of the framework will be carried out by the partners, collaborating institutions and the professional communities in order to document lessons learnt.

To develop the Light Pollution Mapping Framework, project partners from different countries with professional backgrounds in astronomy, physics and lighting engineering, either from practical or academic environments, formed a multidisciplinary working group.

In a first step, the members of the working group exchanged measurement methods and typically used devices from their different areas. This was followed by an exchange of experiences on pre-project activities in the dark sky context, in particular on obstacles and challenges. In a third phase, the working group discussed the methods to be combined and included in the framework, in particular the extent to which measurements should be carried out. It is important to emphasise that the focus is not on developing new measurement methods, but on using best practice approaches and combining ‘on the ground’ lighting measurements (i.e. measurements of the lighting situation at installations) with ‘in the sky’ measurements in an easy-to-use way for wide acceptance and application.

The Light Pollution Mapping Framework is documented in a digital, still internal, project report and will be made available on request for non-profit purposes and reviews. It will be continuously updated and completed during the project period. After completion of the project, it will be freely accessible to all interested parties.

# 3 The Light Pollution Mapping Framework

The following subsections inform about the target group and structure of the framework and give insight into selected contents of the report.

## 3.1 Target Group and Recipients

The framework for measuring light pollution is designed for use by local authorities to monitor their lighting installations. Procurement procedures and the parties involved may vary depending on the local political structure. However, local authorities need a measurement framework on which they can base the refurbishment of their lighting assets. The Light Pollution Mapping Framework is intended as a guide for council staff and contractors on what type of measurements should be taken, when and under what environmental conditions (weather, time of year and others) before and after refurbishment.

For the duration of the DARKER SKY project, the target group is limited to the project partners, in particular the municipalities among the partners. The framework was developed with knowledge of the partners' personnel, time and financial constraints. Beyond the project, however, it is planned that the framework can be applied by many municipalities, which can build on the results of the evaluation and documentation, resulting in added value for municipalities compared to a single, local approach.

## 3.2 Structure

In view of the target group, the report of the Light Pollution Mapping Framework is structured in such a way that it provides clear information at a low threshold and functions as a practical reference work with little prior knowledge. Descriptions of specific measurement types, devices and measurement planning are documented from various perspectives and information requirements and are also presented in tabular form, see Tables 1 and 2.

More precisely, in the introduction, an overview of the DARKER SKY project is given, the aim of the Light Pollution Mapping Framework work package is and principles for environmentally sound lighting are addressed. The main part is divided into three chapters. Firstly, Chapter 2 ‘Quality Framework’ shows how to ensure that the same information is documented transnationally in all pilot projects. Chapter 3 focusses on all methodological overarching information on the implementation of the measurements, while Chapter 4 provides detailed information on the individual process and scope of the activities. All measurement types are clearly presented in fact sheets and brief instructions. The chapters are supplemented by examples and detailed information, which can be found in the appendix of the report, for example see Figures 2 and 3.[2]

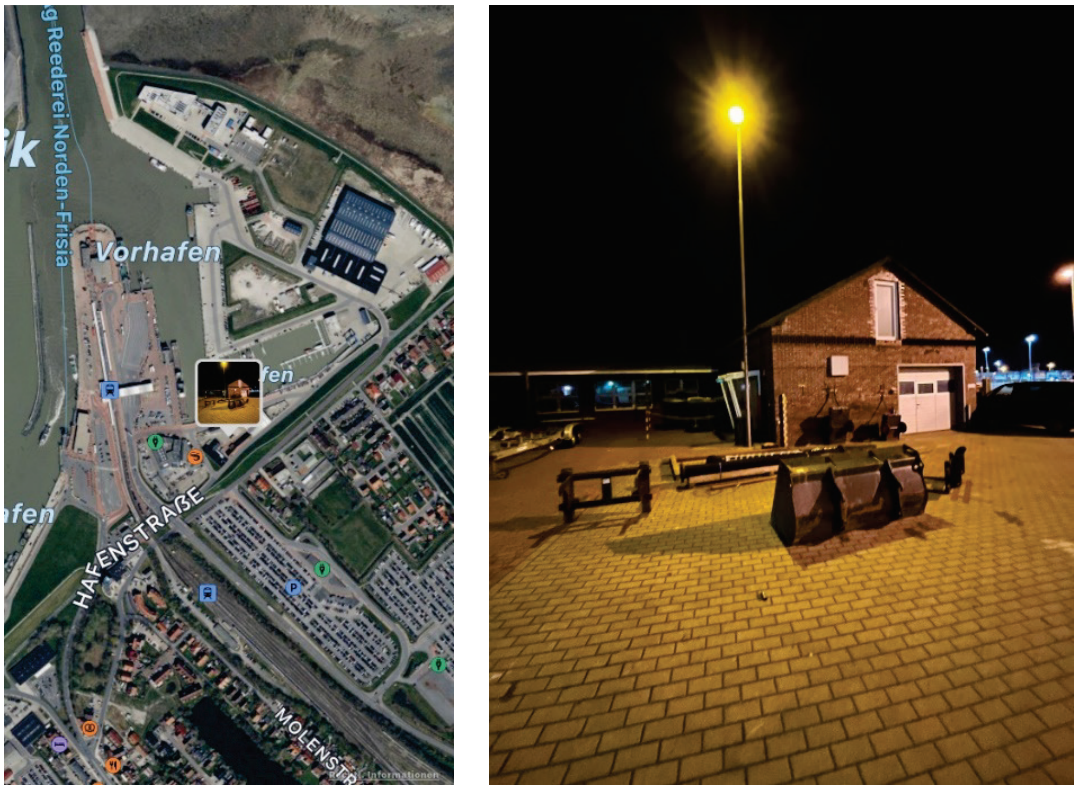


Fig. 2: Sample for the documentation of a Point of Interest (POI). (Credits: B. Poppe) [2]

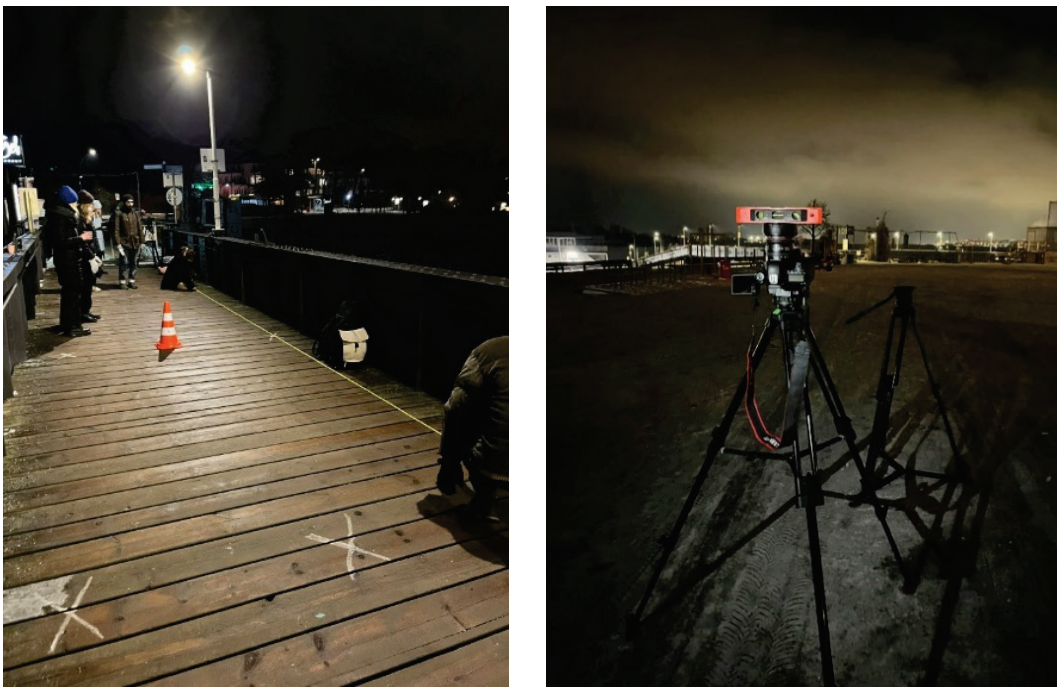

Fig. 3: The report offers guidance to lay persons by illustrating measurement preparations.
Left: Preparation of a simple measurement grid. Right: Using a level for correct horizontal orientation.
(Credits: HAW Hamburg) [2]

### 3.3 Two-Level Approach

Since the measurements shall be conducted by as many people as possible, the working group has agreed on a framework at two expert levels. A non-expert level describes the framework conditions for the measurements to be carried out with the simplest and most affordable measuring equipment possible. The expert level includes measurements with more complex methods, which are recommended depending on the possibilities and availability of equipment.

The Light Pollution Mapping Framework report provides guidance in form of a decision scheme which level to apply for the pilot project. The pilot project coordinator decides, which level to apply for the refurbishment project. Subsequently, all light measurements before and after the retrofit should be carried out according to the chosen level. Criteria for selecting the level are, for example, professional background and number of persons to conduct measurements, budget and time capacities. The choice of level then has an effect on the type of measurements to be carried out (see Table 1), the measuring device (see Table 2) or the number of measuring points (e.g. illuminance measurement grid).

Tab. 1: The types of measurements summarized for non-expert and expert level with information on the location the measurement is valid for. POI stands for Point of Interest and may be a specific location within the pilot-site. CCT stands for correlated colour temperature. [1]

| Type of Measurement | Non-Expert Level | Expert-Level | Location |
|---|---|---|---|
| **Illuminance (Ground Level)** | x | x | Per POI |
| **Vertical Illuminance** | x | x | Per POI |
| **Luminance (Ground Level)** | - | (x) | Per POI |
| **Luminance Distribution** | - | (x) | Per POI |
| **CCT (Ground Level)** | (x) | x | Per POI |
| **Spectra (Ground Level)** | - | (x) | Per POI |
| **Zenith Sky Brightness (one-time)** | x | x | Per Pilot-site |
| **Zenith Sky Brightness (long-term)** | (x) | (x) | Per Pilot-site |
| **Sky Brightness (one-time)** | (x) | x | Per Pilot-site |
| **Sky Brightness (long-term)** | - | (x) | Per Pilot-site |

"-" Measurements are not expected, but definitely allowed.
"(x)" Measurements are not mandatory but recommended if possible.
"x" Measurements are expected.

### 3.4 Lighting Measurements

The lighting measurements aim to describe the direct luminous environment around the installation, for example on the street level, at a level of a standing person and in the surroundings. Lighting measurements in the Light Pollution Mapping Framework therefore cover measurements of the horizontal and vertical illuminance, luminance on the street level and as luminance distribution, as well as CCT and spectral measurements.

All types of lighting measurements are to be conducted per Point of Interest (POI), i.e. at pre-defined points within the pilot project area. For example, a seafront promenade may have a long row of luminaires, but the geometries of the walkways may differ at some points and need to be considered separately. The same applies if a commercial harbour area consists of different lighting installation geometries.

The two-level approach allows a simplified setup for the non-expert level by reducing the required measurements to those of horizontal and vertical illuminance and also recommends the measurement of the correlated colour temperature (CCT).

### 3.5 Sky-related Measurements

The sky-related measurements aim at a characterisation of the artificial illumination of the night sky. Sky-related measurements in the Light Pollution Mapping Framework cover the parameters 'zenith sky brightness' and the 'sky brightness distribution'. Depending on the extent of the refurbishment and the immediate surroundings, a before-and-after comparison of these measures can provide information on the effect of the light pollution prevention activity, for example the refurbishment or the implementation of a dimming protocol.

Apart from that, these measures always document the current state of artificial light at night at the respective location, which is a value that is typically underestimated[1]. The quality of the sky-related measurements depends very much on the atmospheric conditions, especially humidity and clouds. It therefore makes the most sense to monitor these parameters for as long as possible, which makes the monitoring effort larger than most people would expect.

# 4 Challenges

During the creation and further development of the Light Pollution Mapping Framework, the working group identified various challenges. These are presented below, along with the approaches to solving them.

### Combining methods from different backgrounds

A foreseeable challenge was to combine the methods from various professional backgrounds (astronomy, physics, engineering) and working environments, either in practice or in academia. At the same time, this is a strength for the framework, because it enables interdisciplinary dialogue to take place at an early stage and opposing positions can be negotiated in advance. There were major differences of perspective, for example, in the assessment of the validity of the measurement results between illumination measurements and sky-related measurements, on what basis (e.g. number of measurements or measurement points) which statement can be made. In addition, there is the well-known challenge between science and practice as to how much effort should and can be put into a good quality measurement. The conflicting opinions were largely resolved through interdisciplinary dialogue within the working group. Other differences remained and could be moderated by the two-level expert approach.

### Understand the level of information and guidance needed

Another challenge was to understand what types of information were needed for the planned measurement types and to what depth and how they should be documented. The internal interdisciplinary dialogue within the working group has already highlighted the need for explanations to other people with an affinity for technology. It is therefore much more difficult to address technical laypersons.

In order to tackle this challenge, students on the Media Technology engineering programme at HAW Hamburg were involved in proof-of-concept test measurements as part of a regular lighting and colour course. The students had prior knowledge of basic lighting parameters, but largely no experience with light measurements, especially not outside of a laboratory environment. A measurement exercise was carried out in class with the task of preparing a ‘street measurement’ in a team (illuminance and luminance measurements) according to the standard procedure in EN 13201-3 [4]. This already showed the difficulties in implementing the information provided. Later, at a suitable measurement time, the group of students had the task of carrying out all types of measurements included in the Light Pollution Mapping Framework practically outside at an example location.

[1] Measurements of the zenith sky brightness and the sky brightness distribution in form of a false colour all-sky image feed large scale light pollution mapping initiatives, visit for example: https://www.lightpollutionmap.info .

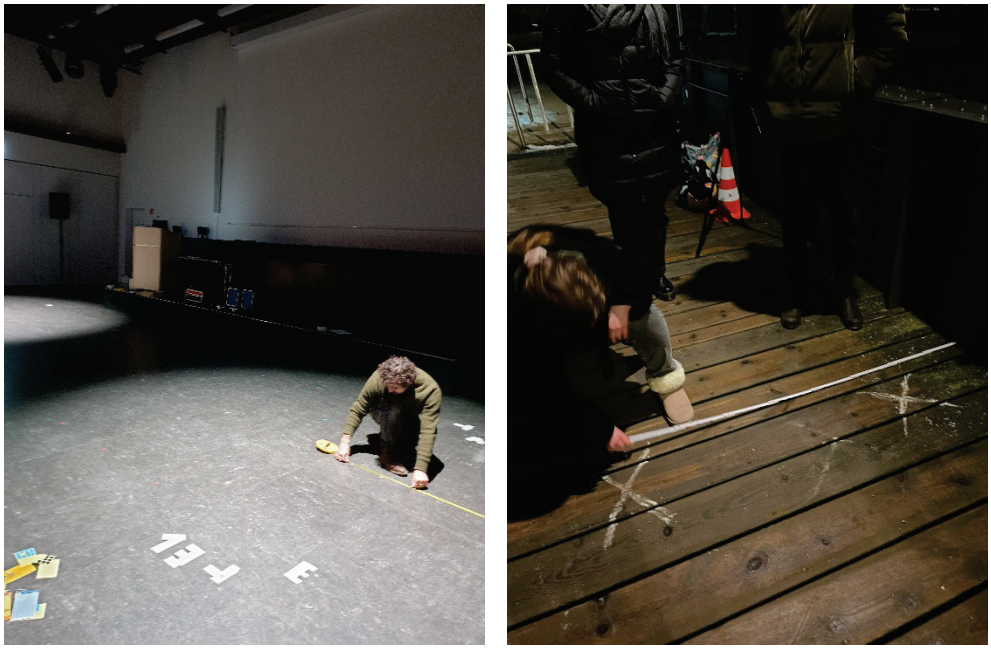

Fig. 3: Impressions of the class activities for the proof-of-concept measurements: Preparation of a measurement grid on the ground indoors (left) and outdoors (right), Credits: HAW Hamburg

Teufelsbrücker Platz in Hamburg Altona was chosen as the location because it offers suitable measurement geometries for all the measurement types to be carried out. Many practical questions and uncertainties could be observed from the students work, which can also occur with laypersons of the target group. This observation could therefore be incorporated directly into the documentation. A positive side effect was that the test measurements resulted in photos that could be used to illustrate the framework.

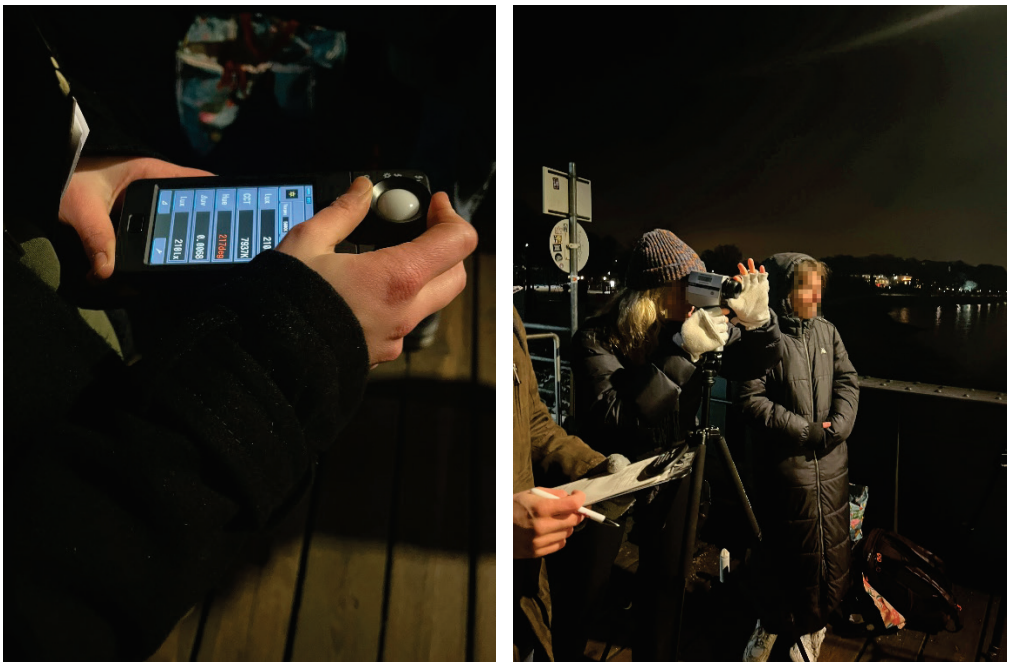

Fig. 4: Proof-of-concept measurements at Teufelsbrücker Platz, Hamburg, January 2023, Left: Using a chroma meter, Right: Measuring the luminance with a luminance spot meter, Credits: HAW Hamburg

Another point that the proof-of-concept measurements showed is how much explanation and guidance is needed to familiarise non-experts with the correct operation of the measuring devices. This is not currently documented in writing in the Light Pollution Mapping Framework. For the measurements within the DARKER SKY project, the members of the working group use the biannual physical partner meetings to demonstrate devices, and their operation as required.

### Equipment Costs

Particularly with a view to later use in local authorities after the end of the project, the cost of the measurement equipment including accessories was and remains a significant challenge. Although the working group was very open to simplifying the measurements, the quality of the measuring devices used should not fall below a certain minimum requirement. For light measurements, for example, this refers to uncertainty class B according to DIN 5032-7 [3] for illuminance and luminance measuring devices. Although the measuring devices for the sky-related measurements are not high-end devices either, the total measuring device costs (without peripherals and accessories) are approx. 2500 € for the minimum equipment for the non-expert level and approx. 6000 € for the expert level measurements without optional measurement types. The added value of one approach compared to the other from the perspective of a municipality will be assessed at the end of the project.

Tab. 2: Overview of the measuring devices to use at non-expert and expert level. [1]

| Measuring Devices | Non-Expert Level | Expert-Level |
|---|---|---|
| **Illuminance Meter** | x | x |
| **Luminance Meter** | - | (x) |
| **Imaging Luminance Measuring Device** | - | (x) |
| **Chroma Meter** | (x) | x |
| **Spectroradiometer** | - | (x) |
| **Sky Quality Meter** | x | x |
| **Sky Quality Camera** | (x) | x |

"-" Measuring device is not required
"(x)" Measuring device is recommended
"x" Measuring device is required

### Measurement Grids and their Necessity

Those unfamiliar with lighting measurements often underestimate the importance of a measurement grid and the necessary resolution. It is clear that in uncomfortable conditions (e.g., weather, time of day), the idea to simplify or shorten the measurement often arises on site. Above all, the desire to avoid using a defined measurement grid that has to be transferred is evident. The Light Pollution Mapping Framework solves this by offering a simplified grid compared to the standard EN 13201-3 [4] measurement grid, minimizing the effort required

at non-expert level. This grid was derived from van Bommel [5] and is intended for preliminary measurements only. However, the framework emphasizes that the full grid should be used whenever feasible to ensure accuracy. The effects of this simplification will be evaluated in retrospect at the end of the project.

**Measurement uncertainties of devices**

Good quality measurements are challenging to carry out when conducting practical measurements outdoors, especially for non-experts. The devices used and their uncertainties must be well known and documented. Due to cost constraints, it is not feasible for all project partners to purchase the same models of the measuring devices, resulting in some not having the model-specific uncertainties available. (Exemplary models are briefly presented in the appendix of the framework.) Additionally, many so-called illuminance measuring devices on the market lack or provide incorrect information on measurement uncertainty. The working group will analyse the model-specific data as far as possible and also draw conclusions about the repeatability of the measurement by means of comparative measurements by several partners with "their" devices at joint meetings. This procedure is randomised and carried out on the basis of the members of the working group's awareness of the problem. The challenges relating to measurement uncertainty in practical application at local authorities will persist until a practical and affordable procedure is found.

# 5 Conclusion and Outlook

This article describes how lighting measurements and sky-related measurements in the DARKER SKY project are used to evaluate the effect of retrofitted lighting systems in terms of lighting quality and the potential for sky brightening. In order to achieve this in the pilot projects within the DARKER SKY project, measurements have been agreed in a 'Light Pollution Mapping Framework'. This contains information, understandable for laypersons, which must be observed when light and sky-related measurements are carried out by staff or authorised persons for the before/after comparison in the municipalities. The information includes the quality framework (e.g. measurement preparations or the scope of the documentation) as well as the measurements themselves with measuring devices and procedure. The standardised way allows the methodology to be evaluated and continuously adapted within the DARKER SKY project. The synchronised monitoring of the pilot projects means that challenges can be quickly identified on site and generally dealt with. Standardisation of the evaluation and presentation of the results, as well as retrospective reflection on the procedure, are still outstanding. Overall, the work on the development of the Light Pollution Mapping Framework can be rated as very instructive for those involved and as an excellent starting point for breaking down barriers to lighting and sky-related measurements in municipalities with the aim of reducing light pollution.

## DARKER SKY Project Partners

University of Brest - Université de Bretagne Occidentale (Lead Partner)
REM Consult GmbH
Brest Métropole
Municipality Hamburg-Altona (Freie und Hansestadt Hamburg, Bezirksamt Altona)
Hamburg University of Applied Sciences (HAW Hamburg)
Landmakers Cooperatie U.A.
Municipality of Heerenveen – Gemeente Heerenveen
Van Hall Larenstein - University of Applied Science (VHL)
Carl von Ossietzky University Oldenburg (CvO)
Lower Saxon Wadden Sea National Park Authority (Nationalparkverwaltung Niedersächsisches Wattenmeer, NLPVW)
Niedersachsen Ports GmbH + Co.KG (NPorts)
University of Groningen – Rijksuniversiteit Groningen (RUG)
Aarhus University (AU)

The project is co-funded by the European Union in the framework of the Interreg North Sea Programme.

## DARKER SKY Pilot Project Areas

Valley of Sainte-Anne, Brest, France
Moulin Blanc beach, Brest, France
Elbe cycling and hiking path, Hamburg, Germany
Sülldorf, Hamburg, Germany
Commercial Wadden Sea Port, Norddeich, Germany
Harbour of Lauwersoog, Lauwersoog, the Netherlands
Pier, industrial area and city centre, Holwerd, the Netherlands

For details, please visit https://www.interregnorthsea.eu/darker-sky/pilots

## References

[1] https://www.interregnorthsea.eu/darker-sky/news/light-biodiversity-monitoring, 14 February 2025

[2] Light Pollution Mapping Framework, DARKER SKY report, draft November 2024

[3] DIN 5032-7:2024 Photometry - Part 7: Classification of illuminance meters and luminance meters

[4] EN 13201-3:2015 Road lighting - Part 3: Calculation of performance

[5] van Bommel, W., 2015, *Road Lighting*, fig. 14.17