International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

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Pharel, A., et al.

DOI 10.25039/x051.2025/mrvwkq

This article is also published as part of:

Proceedings of the CIE 2025 Midterm Meeting Vienna, Austria, July 4-11, 2025:
Scientific Conference (July 7-9, 2025)

DOI 10.25039/x051.2025

in

Proceedings of the CIE (International Commission on Illumination)

ISSN no. 3061-015X (print), 3061-0168 (online)

The paper has undergone double-blind peer review and its final version has been presented at the CIE 2025 Midterm Meeting, Vienna, Austria, July 4–11, 2025.

CIE Central Bureau
Babenbergerstrasse 9/9A
A-1010 Vienna, Austria
Tel.: +43 1 714 31 87
e-mail: ciecb@cie.co.at — www.cie.co.at

LIMITING THE IMPACT OF LIGHTING AT NIGHT ON BIODIVERSITY: A MULTI-EXPERTISE METHODOLOGY FOR ADAPTING LIGHTING TO LOCAL CHALLENGES

Pharel, A.[1], Teklal, M.[2], Brabant, C.[3], Deswert, J.-M.[1], Van Der Wijden, B.[4], Brison, N.[4], Corten, I.[5], Bel, P.[6]

[1] ENGIE Laborelec, Linkebeek, BELGIUM, [2] Sibelga, Brussels, BELGIUM, [3] Natagora, Brussels, BELGIUM, [4] Bruxelles Environnement, Brussels, BELGIUM, [5] Radiance35, Liège, BELGIUM, [6] Commune de Jette, Jette, BELGIUM

agathe.pharel@engie.com

Abstract

Growing awareness about the multiple impacts that artificial lighting at night has on natural ecosystems and the pressing necessity for protecting biodiversity is conflicting with the need for ensuring a safe and accessible nighttime environment for human beings and societies. In this project, the collaboration between multiple expertise among which ecology, sociology and lighting, has led to the elaboration of a methodology and an onsite measurement protocol for determining how the lighting characteristics could be tuned in order to limit the harm on the local biodiversity. Using the bats population as an umbrella species for nocturnal biodiversity assessment, the measurement protocol consists in mapping the lighting characteristics (illuminance, spectrum, light points height) versus the presence of various light-sensitive and opportunistic bats species, using dynamic onsite measurements that are repeated several times a year according to seasonality. This results in recommendations for the local lighting infrastructure adaptation to fit local biodiversity.

Keywords: Artificial lighting at night, biodiversity, collaboration, multi-expertise

1 Introduction – light pollution and municipalities objectives

The multiple impacts that lighting at night has on biodiversity has been more and more documented over the past years and especially from 2010s (Hölker, et al., 2010). Starting from scientists and ecologists, the awareness has been progressively growing among the lighting industry, lighting societies and the municipalities to reach the status of a common concern. In 2023, the LUCI association (international network of cities on urban lighting) declares that 'Minimising light pollution for all living beings' is one of its first objectives (LUCI Association, 2023). From a legislative perspective, the 2024-published European Nature Restoration law considers light pollution as one of the main issues that member states need to address in order to restore 30% of threatened habitats by 2030 (The European Parliament and the Council of the European Union, 2024).

At the same time, the public lighting world is pursuing its technological revolution with cities progressively replacing their traditional light sources for LED lighting (Research and Markets, 2025). On the one hand, the lower energy consumption of LED lighting lead ecologists to fear of an increase in the number of light points (Pawson & Bader, 2014) and moreover of an increase in blue content of artificial lighting (Sanchez de Miguel, et al., 2022). On the other hand, LED lighting can also be seen, mostly by lighting operators and municipalities, as a great opportunity for saving electricity, thus carbon dioxide emissions (Barraza Garcia, et al., 2014). Some common ground can be found as LED lighting also introduces new possibilities for tuning the lighting colour temperature and the emitted light intensity over time and seasons, therefore allowing a better control on light pollution (Macgregor & Evans, 2020).

For these reasons, lighting refurbishment works are accelerating and making a number of questions more pressing: how to renovate lighting properly, i.e. how to protect vulnerable

 DOI: 10.25039/x051.2025/mrvwkq

habitats while lighting remains mandatory for social reasons? Which light sources should be chosen, especially regarding their spectral content, in order to limit their harm on sensitive species? Which systems should be favoured in order to control the light emissions over time? As was concluded in 2019 after a transdisciplinary research project on the challenges and potential of LED lighting, '"sustainable LED lighting" goes far beyond energy efficiency as it raises complex design issues that imply stakeholder negotiation. [The expert feedback] suggests that the LED paradox may be solved in context, but hardly in principle' (Schulte-Römer, et al., 2019). This summarises the challenge that this work proposes to tackle and offers one solution, among others.

This study presents a methodology, including an onsite measurement protocol, which has been developed in collaboration between multiple expertise with the aim to provide recommendations to lighting operators and municipalities on the lighting solutions to select and their operation regime. This onsite protocol has been tested for four years in a pilot city located in the Brussels Capital region, where Natura 2000 areas are standing alongside residential neighbourhood and hospitals and where light-sensitive species of bats are the subject of protection policies.

2 Objectives of the project

2.1 General objectives of the developed methodology

The project named 'Bat Light District' started in 2021 with a triple objective. First, to comply with the applicable nature protection and restoration regulations in the Brussels Capital region, especially the 2012 Nature Conservation Ordinance (Parlement de la Région de Bruxelles-Capitale, 2012) and related decrees (Van der Wijden & Fain, 2020). Among these regulations, the transposition of the European Habitats directive (Council of European Communities, 1992) has especially led to the delimitation of Natura 2000 areas on the regional territory. Second, to control and guide the evolution of urban lighting in Brussels region at the time of a massive replacement of traditional light sources for LEDs (Sibelga, 2022). Finally, the third objective has been to formalise the collaboration between several competencies of the regional urban development in a project mode.

The methodology presented in this paper aims at addressing this triple objective.

The municipality of Jette, located in the North-West of Brussels Capital Region, has been the laboratory for this methodology development and associated Bat Light District pilot project: first because of the high density of Natura 2000 protected areas it encloses, second to take advantage of the 2021-2025 street lighting replacement plan in this area.

2.2 Objectives related to the study of bats as biodiversity indicators

The specific objective of the Bat Light District project has been to improve the conservation status of bats, solely focusing on the public lighting adaptation. Indeed, bats are subjected to specific monitoring activities in the Brussels Region and their conservation status is thus well documented (Bruxelles Environnement, 2022). The repartition of bats population in the region shows an important presence in and around the regional Natura 2000 habitats, where twenty of the twenty-six Belgian bats species have been contacted (**Figure *1***): the darker area in the North-West part of the map locates the Bat Light District pilot project.

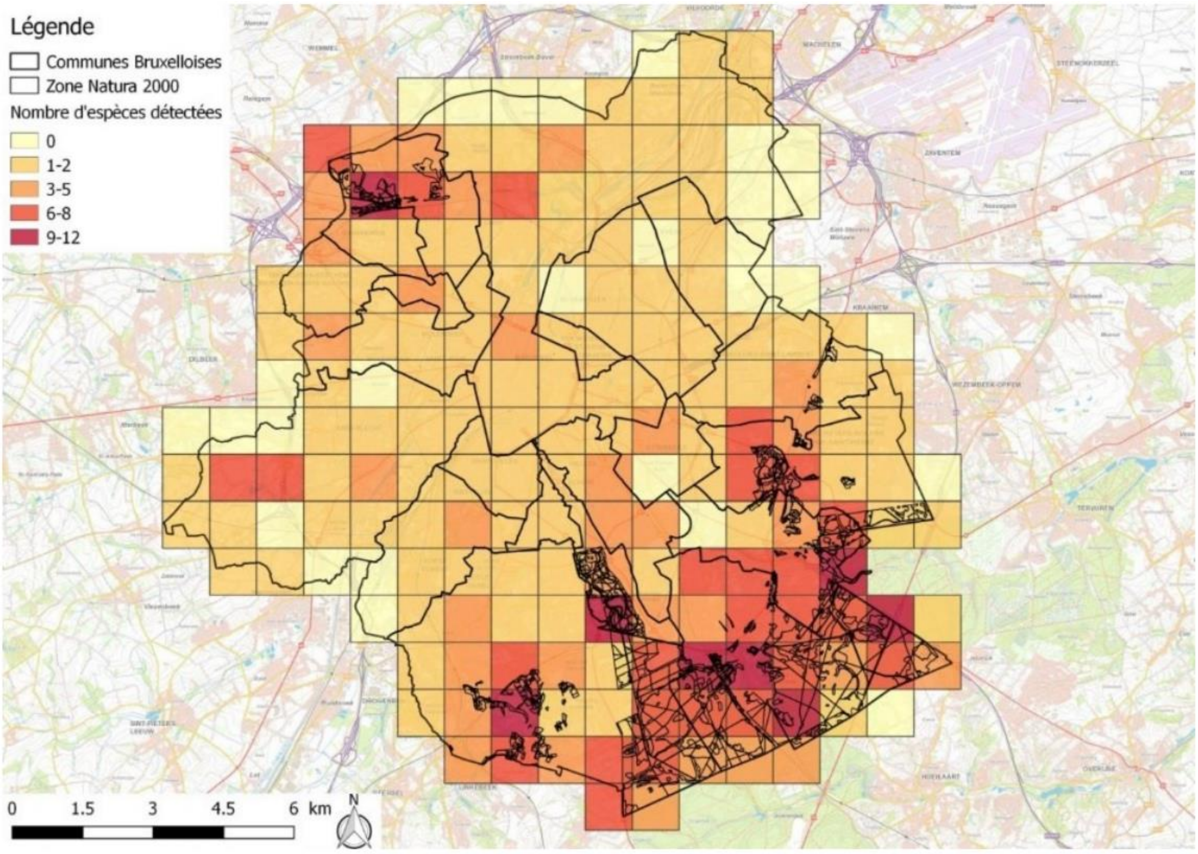

Figure 1 - Bats species diversity in Brussels Capital region over the 2001-2018 period on a 1x1km grid (Brabant, et al., 2019)

More, bats are often considered as umbrella species, i.e. as ‘a species whose conservation is expected to confer protection to a large number of naturally co-occurring species’ (Roberge & Angelstam, 2004), and the impact of artificial lighting at night on bats have been investigated from different perspectives. For almost twenty years, many sources have been reporting on the detrimental effect of light at night on bats, either from natural sources (e.g. moonlight) (Saldana-Vazquez & Munguia-Rosas, 2013) or from artificial sources (Boldogh, et al., 2007). In these research, the degree of impact varies depending on the bats species; however most of them conclude that light at night acts as a deterrent for bats (Bhardwaj, et al., 2020) (Laforge, et al., 2019) and recommend switching-off or decreasing light levels to the minimum (Azam, et al., 2018).

Nevertheless, the pilot project named ‘Bat Light District’ being conducted in a dense and highly connected urban environment, switching off the lighting is currently not an option for safety and social reasons. Alternative solutions must be experienced, one of which being changing the urban lighting spectrum. Indeed, some research tend to show that different artificial light spectra impact bats presence and activity differently: monochromatic-green and cold white lighting are reported to repel bats while monochromatic-orange light does not (Limpens, et al., 2011). This conclusion has been discussed in later studies, especially for Myotis and Rhinolophus bat species which are present in Brussels region (Zeale, et al., 2018) (Spoelstra, et al., 2018).

It has therefore been decided to focus on how artificial lighting spectrum modifications could benefit local bat species abundance and activity within the perimeter of the Bat Light District project. Different ‘lighting solutions’ have therefore been implemented on specific locations aiming at improving the ecological connectivity between different Natura 2000 areas (see 2.3).

2.3 Specific objectives of the pilot project

The Bat Light District pilot study has been designed and carried out in order to foster the cooperation of different stakeholders in choosing, placing and operating ‘light solutions’ aiming at increasing local bats population and activity. These solutions have been placed on spots that were suspected to be ecological corridors for bats in between different Natura 2000 areas.

The “light solutions” considered were urban lighting systems available on the market in 2020 and specifically designed to reduce light pollution and the impacts of artificial light on biodiversity. Among them were: colour temperature-switching LED luminaires (2200 to 2700 K), monochromatic-amber (592-594 nm peak) and monochromatic-red (630 nm) LED luminaires (**Figure *2***). An additional lighting solution used consisted in wrapping MHHP luminaires (those which were not replaced for LEDs as part of the refurbishment plan) with red filters.

Figure 2 – Before/after the installation of monochromatic-red LED luminaires – Avenue Henri Liebrecht, 1090 Jette, Brussels

2.4 Dissemination of the methodology

In order to further test the methodology developed and implemented in the above-mentioned pilot project, a deployment at the regional level as part of the LIFE B4B European project has been started as of 2024. This deployment plans on the extension of the methodology in the South-East part of Brussels Region, as highlighted on **Figure *1***.

In parallel, the methodology gives way to the development of a GIS-based digital tool named NightWatch: this tool is aiming at involving different stakeholders and expertise in the building of recommendations for the public lighting of a given territory, using local lighting, biodiversity and social data.

3 Methodology

3.1 Involved stakeholders

The methodology development and the associated pilot project have been from the very beginning gathering a number of stakeholders equally involved as project partners and representing expertise in lighting, ecology and sociology. Typically, actors involved have been the lighting operator, regional and municipal authorities, an environmental NGO and lighting specialists. These project partners shared similar interests in developing a methodology aiming at assessing and comparing the impact of different ‘lighting solutions’ on local biodiversity. This multi-expertise taskforce, while sharing a common objective, forms the very basis of the methodology and ensures that the diversity of viewpoints, languages and working methods is taken into consideration.

3.2 Study parameters and indicators

The multi-expertise methodology necessarily involves gathering data on the lighting parameters, biodiversity indicators and sociological factors.

As a common baseline for each project using the methodology, light levels, spectral composition of light and position of the light points in three dimensions are collected. In the case of the Bat Light District pilot study, lighting parameters have been collected during the course of the project to document the implementation of new lighting solutions in the neighbourhood (see 2.3) and to characterise the diversity of lighting solutions implemented in the area. Illuminance levels, spectral content and height of the light points have been mapped using the tools and protocol described in 3.3.1 and 3.3.2.

When it comes to the biodiversity indicators used in the methodology, they can partly be from various sources, including local, regional or global databases (e.g. Natura 2000, GBIF or other trustworthy sources). It is however necessary to complement this data with measurements of biodiversity indicators performed during the course of the project. In the case of the Bat Light District project, the chosen biodiversity indicator has been the local population of bats as explained in 2.2. The abundance (number of contacts) and the diversity (number of distinct species) of the bats have been recorded during the project.

About social indicators, multiple data can be gathered following diverse protocols. Urbanistic classification of roads, neighbourhoods and buildings already allow to geographically understand and deduce the needs of street lighting users. However, modifications in the nighttime lighting environment must be accompanied by proper communication and education: in that matter, local authorities, environmental NGOs and lighting design experts are playing a key role in explaining and sharing the story behind the adaptation of the lighting landscape. With that aim, specific communication campaigns and sociological studies have been performed as part of the Bat Light District in order to collect the feelings and thoughts of street lighting users over the course of the project.

3.3 Measurement protocol

3.3.1 Tools and data gathered

The data gathered during the onsite measurements is aiming at characterising the presence and activity of bats and the quality of the artificial lighting at the same moment in time. Therefore, the tools used in this protocol are positioned on a car in order to perform dynamic measurements.

A specialist ISO 17025 accredited illuminance meter composed of five luxmeter cells is mounted on the hood of a car and is complemented by an embedded GPS (see **Figure *3***). Following EN 13201 protocol for road lighting illuminance measurements, the tool records the road illuminance level at a 25 Hz sample rate. It creates a map of the road illuminance at ground level by correcting the measurement performed at the car's hood height thanks to a manually-entered correction factor. The tool is also equipped with a camera aiming at detecting the position of a light source: it records the light points' height and GPS position and associates these coordinates with a calculated average illuminance.

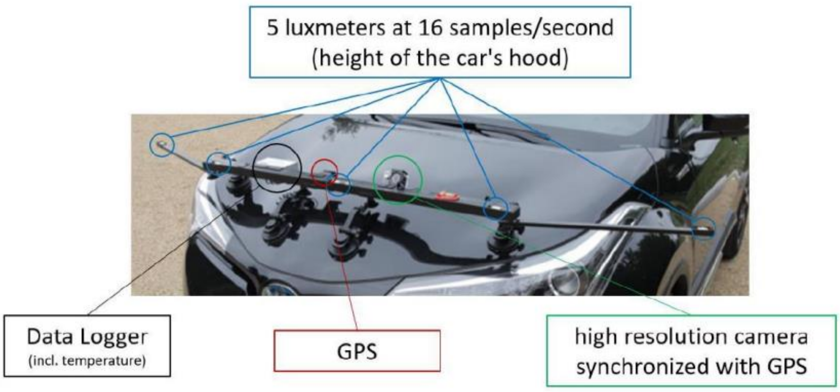

Figure 3 - ISO 17025 illuminance mapping system

On the roof of the same car is positioned a spectrometer that is recording the ambient light spectrum in the visible and near-visible range (360 nm to 780 nm), using 10 nm steps. Spectral measurements are triggered as soon as the measured illuminance level is above 0,1 lux. The sample rate depends on the illuminance level, lowest illuminance levels being associated with lower sample rates (from 0,6 measurements per second under 5 lux to over 10 measurements per second above 95 lux). The spectrometer also records the GPS location, time and date, and computes the colour temperature of the detected white light.

Last, a Batlogger M is also embedded during these dynamic measurements, the microphone of which is positioned on the roof of the car. The Batlogger M is an ultrasounds recorder that allows to locate and identify bats as a function of the GPS position of their 'contact'. The precise identification of the bats species is performed after the measurement campaign by ecologists of the partner environmental NGO.

3.3.2 Measurement protocol

The measurement protocol consists in the performance of precisely defined transects across the area of interest, using the car equipped with the above-mentioned tools and continuously recording the above-mentioned data.

These transects are repeated three times a year at different seasons depending on the bats' activities (breeding of youngsters, foraging, migrating and mating seasons). The transects are performed in the exact same order and are always starting half an hour after the sunset. They are not lasting for more than two hours in order to capture the very beginning of the bats' night activity.

The measurements are always performed in dry and not windy conditions.

3.3.3 Measurements results

The lighting data gathered during the measurements is later analysed by the lighting experts and the bats-related data is analysed by the environmental NGO. This step results in the mapping of the surveyed area where lighting-related characteristics and bats-related data can be displayed, season per season and year per year.

Measurement results are then shared among the project partners and discussed in dedicated meetings, which are aiming at deriving recommendations for the local lighting infrastructure and its eventual refurbishment to LED lighting.

3.3.4 Pilot project specifics

The collaboration between the different expertise has started with a specific pilot project focusing on an about 250 hectares zone where Natura 2000 areas are standing alongside densely urbanised neighbourhoods. There, the above-described measurement protocol has been performed for four years. During this timeframe, the renovation to LED of the public lighting has been carried on: this has been the opportunity to progressively implement the different lighting solutions mentioned in paragraph 2.3 and especially to test the influence of different colour temperatures and spectra on bats behaviours.

In order to validate the relevance and consistency of the three-times a year measurements from a naturalistic point of view, complementary fixed ultrasound recorders and bats recording surveys have been used during the first three years of the project. The comparison between the data gathered using these different methods allowed to assess the precision of the results obtained thanks to the protocol described in section 3.3.2.

Additionally, a sociological study has been conducted in November 2023 in the targeted neighbourhood to assess the social acceptance of the new lighting configuration. Nighttime pedestrians' opinions have been collected thanks to questionnaires and analysed by one of the consortium partners.

3.4 Results

The analysis of the pilot study's four years of data is currently undergoing, however some trends have already been observed over the past years: first, the bats have been contacted in a growing number of locations and therefore seem to spread more evenly in the neighbourhood. Second, the detection of light-sensitive bats has been fluctuating over the years but the general trend is on the rise.

The social acceptance survey carried out amongst some of the neighbourhood's nighttime pedestrians shown that half the respondents were rather positive regarding the changes in lighting colour temperatures while 27% did not pay attention and 23% felt anxious. There was no clear correlation between the lighting colour and the feelings of the respondents. Regarding the understanding of the project, most of the respondents poorly knew about the protection of biodiversity in urban areas. However, after some information was provided, about two third of the respondents were supporting the adaptation of the lighting colour temperature for biodiversity conservation purpose.

More complete results, especially on the analysis of colour temperature and illuminance effects on bats behaviours, are expected in the upcoming months.

4 Discussion

The methodology developed allows a smooth collaboration between different stakeholders and complementary expertise and introduces a more comprehensive way of dealing with a complex and multifaceted issue.

The use of dedicated tools for performing dynamic measurement surveys helps to reduce the time and effort spent performing the onsite audits, while ensuring a degree of consistency by repeating measurements under precise seasonal, time to sunset and weather conditions. As it is the case for any study involving biodiversity surveying, the multiplicity of factors influencing biodiversity behaviour cannot be neglected and therefore conclusions can only be derived from long-term observed trends.

The application of this methodology to three new urbanised areas has started in 2024 and is to be continued in the upcoming three years.

5 Acknowledgments

We would like to express our gratitude to Ms Bénédicte Collard, Mr Ben van der Wijden and Mr Bernard Van Nuffel for instigating the Bat Light District project. Their involvement at the very beginning of this project brought its stakeholders together and cement their collaboration.

We also would like to thank Romain Bruffaerts for his help collecting and analysing data for several measurement campaigns.

Finally, we thank Synergrid, the Belgian federation of electricity and gas grid operators, for partially funding this project.

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