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Light Pollution

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Summary

- *Light pollution is a massive and growing phenomenon all over the world, especially with the development of LEDs.*
- *By disrupting the natural cycles of light and dark that structure our living world, and by segmenting habitats in space and time, artificial light at night, along with other anthropogenic pressures, contributes to a decline in biodiversity. It also raises serious public health concerns.*
- *An effective campaign against light pollution requires a paradigm shift from systematic lighting to fine-tuning lighting according to the context. It can only succeed if everyone commits to reducing the use of artificial light, which is related to, but not the same as, reducing our energy consumption.*

Mrs. Annick Jacquemet, Senator

The characteristics of light pollution

Pollution linked to the development of artificial lighting at night

Fear of the night comes from the fear of being attacked by wild animals. Since the discovery of fire, man has invented the shared lighting of a public space, the forerunner of public lighting.[1] However, it wasn't until the end of the 17th century that modern public lighting was introduced in cities to demonstrate the public authorities' ability to extend daylight and eliminate darkness.[2]

In the centuries that followed, urban lighting expanded. Originally designed for security and surveillance,[3] it also facilitates travel and contributes to territorial marketing and the attractiveness of cities.[4]

In addition to urban lighting, artificial light has enabled an increase in private night-time human activities, whether economic, sporting, cultural, etc.

Today, **public lighting[5] accounts for about 70% of all lighting**, compared to 30% for private lighting, although the proportion varies by geographical area.[6]

A complex form of pollution that is still difficult to measure

Light pollution can take many forms[7]:

- **over-illumination** (excessive use of light). Two parameters can be used to measure over-illumination: the number (or density) of light points within a given area, and the illuminance[8] (through its flux and duration);
- **glare** due to too much luminance or too much contrast between light and dark colours. Luminance increases as the light-emitting area decreases, which is why LEDs are particularly dazzling compared to other lighting. Luminance[9] measures the risk of glare to wildlife from artificial lighting;
- **the light halo** caused by the omni-directional light emitted into the sky by urban lighting. This can be seen tens of kilometres away from where the artificial light is produced[10].

The effect of artificial light at night also varies according to its spectral composition[11] [12] and therefore its colour temperature.

Several techniques have been developed to measure light pressure (satellite data, ground zenith measurements, modelling, etc.), each with its advantages and disadvantages[13].

Massive and growing pollution worldwide

The continued growth of the world's population, coupled with increasing urbanisation, the development of human infrastructure, reduced lighting costs and the emergence of new technologies, have led to an explosion in man-made light emissions, particularly in major cities and industrialised countries.

In 2014, artificial light affected 23% of the earth's surface and 88% of industrialised areas such as Europe[14] (85% of metropolitan France).[15] Between 2012 and 2016, the area of the Earth illuminated by external artificial light increased by 2.2% per year, with an increase in radiance[16] of 1.8% per year.[17] A

more recent study based on participatory science shows that between 2011 and 2022, the brightness of the sky caused by artificial light has increased globally at a rate of 10% per year, doubling in less than eight years.[18] **Since the 2000s, the replacement of incandescent or discharge lamps with LEDs[19] has had a rebound effect**[20] on light pollution through the development of lighting in new areas and the proliferation of public and private lighting.[21]

In France, the number of public lighting points has increased from 7.2 million in 1990 to 9.5 million in 2015, and now stands at 11 million,[22] representing an increase of +53% since 1990.[23] On the other hand, the number of hours public lighting is on in France has fallen by 12% since 1990,[24] as almost 12,000 towns and cities have switched off public lighting in the middle of the night. **The recently published light pollution maps, from 2014 and 2021,[25] show a slight decrease in light pollution in the middle of the night, but these data do not give an indication of light pollution at the beginning and end of the night.**

The effects of light pollution

Light pollution affects nocturnal landscapes and our relationship with the night.

35.9% of the world's population is no longer able to see the Milky Way at night. This figure rises to 60% for Europeans and 80% for North Americans.[26] **Light pollution not only affects stargazing,[27] it also contributes to disconnecting individuals and societies from their environment.** The night remains one of the rare opportunities for humans to escape from their anthropocentric view of the universe and to experience the non-human living world. Such experiences are essential to ensure education for "environmental citizenship".[28]

For thousands of years, darkness has influenced our sensory understanding of the world. Light pollution has weakened our relationship with darkness in its artistic, cultural, historical, philosophical and religious aspects.[29]

Light pollution contributes to energy waste and climate change.

According to the ADEME, annual electricity consumption for public lighting and lighting in buildings is 2900 TWh worldwide, i.e. 13% of total electricity production, and 56 TWh in France.[30] **Light pollution wastes significant amounts of energy[31] and contributes to greenhouse gas emissions.**[32]

Given the energy efficiency of LEDs, retrofitting lighting systems with LEDs should result in a significant reduction in energy consumption.[33] However, this reduction may be less than expected if the number of light points and the amount of light emitted is increased, as has been seen in the past.[34] In addition, LEDs are mainly produced in China using highly carbon-intensive electricity and require the extraction of rare earths, a process that emits a lot of CO_2 and causes pollution, which puts their carbon footprint into perspective.[35]

Light pollution contributes to the decline of biodiversity

The cycle of day and night is a structuring element in the evolution of life.

There are two basic needs for darkness:[36]

- **spatial needs for darkness:** 28% of vertebrates and 64% of invertebrates are partially or entirely nocturnal[37] and have adapted perfectly to the dark to navigate and move around[38]. The light in the environment influences their movements either by **repulsion** (Negative Phototaxis) or by **attraction** (Positive Phototaxis).[39] Plants and fungi also react to the direction of light;[40]
- **temporal needs for darkness**: time is one of the fundamental dimensions of ecosystems.[41] **Time can be expressed as days** (when hunting, feeding, moving, sleeping, singing, opening flowers, etc.). It is therefore regulated by the circadian system which governs a multitude of metabolic, physiological and behavioural processes.[42] **Time can also be expressed by seasons** (when hibernating, reproducing, moulting, migrating or pollinating, and so on) through the Circannual cycle. **The alternation between light and dark is the most powerful exogenous synchroniser of circadian and circannual cycles with natural periodicities.**[43] When artificial light disrupts this pattern, it has a negative impact on biodiversity - from individual species to entire ecosystems.

✓ **Light pollution disrupts individual behaviour and physiology**

Artificial light at night changes individual behaviour in several ways.

It hinders the movements of nocturnal species. The mechanisms involved vary according to the phototaxis of the species.[44] **Artificial lighting disrupts the orientation mechanisms of migratory birds**, which can be attracted to large light sources. Moths, for example, are attracted to and trapped by light sources. Artificial lighting restricts the movements of light-avoiding species, forcing them to deviate from their usual path or even preventing them from accessing vital areas because they are illuminated.

By interfering with the orientation and movement of organisms, **light pollution is directly responsible for the death of hundreds of millions of birds and trillions of insects**[45] **every year.** These losses can be explained by a number of mechanisms: individuals become exhausted, collide with obstacles, or are attracted to areas with inadequate resources or increased risk of predation.

Artificial light at night is particularly harmful during certain stages of life (egg laying and nesting for birds;[46] hatching for sea turtles,[47] etc.) and can lead to significant population declines.[48]

Artificial light at night can prevent certain species from acquiring food, which is reduced or delayed in time and can hinder their individual development[49] and the growth of their offspring.[50]

Artificial light at night also alters instraspecific communication, in particular disrupting breeding activities. For example, fireflies rely on the exchange of bioluminescent signals to attract mates, which are obstructed or suppressed by artificial light to the extent that females under streetlights are not seen by males.[51] Other species, such as amphibians and birds, communicate through song, which can also be disturbed by artificial light, with negative consequences for reproduction.[52]

The degradation of darkness by artificial light prevents the secretion of melatonin, disrupts the synchronisation of the central circadian clock and alters sleeping patterns. **It disrupts a wide range of physiological and metabolic functions in both fauna and flora.** Common examples include effects on body mass,[53] reduced fertility[54] and sleep, changes in neural structure, changes in immune responses, developmental speed,[55] and even effects on the expression of certain genes.[56] **Artificial light at night also causes phenological shifts**[57] that can have dramatic consequences for reproduction and population conservation.[58]

Artificial lighting is therefore a real threat to biodiversity, with LED lighting systems having a particularly high impact due to their high proportion of blue light.[59] [60]

These effects on biodiversity are significant, even at low levels of light intensity.[61]

✓ **Light pollution changes how ecosystems work**

Light pollution disrupts the relationships between species.

Some daytime (diurnal) species[62] take advantage of artificial light to increase their period of activity because it gives them greater visibility. They therefore interfere with and compete with the activities of nocturnal species.

Artificial light at night also unbalances the prey-predator relationship, with a disproportionate presence of predators in illuminated habitats (such as insect-eating bats, rats, birds, reptiles and spiders).[63]

Among nocturnal species, light pollution will favour those whose behaviour is least affected by artificial light.[64] It therefore acts as a filter and could become a new natural selection factor.

For many species, light pollution appears to be a factor in the degradation, dispersal and even suppression of their habitats, with consequences for the way their communities are structured.[65]

If such changes were to occur on a larger scale, they could alter the balance and functioning of ecosystems, with cascading effects on species that are not typically affected by artificial light. Light pollution has been shown to disrupt nocturnal pollination networks, negatively affecting the reproductive success of plants, as well as having a negative impact on daytime pollinators.[66]

Light pollution can therefore jeopardise certain ecosystem activities such as pollination and the natural nutrient cycle.

Long underestimated, artificial light is now seen by ecologists as a major man-made threat to biodiversity. It is present in all ecosystems: terrestrial - light pollution affects 23% of the land surface (instead of "only" 3% for land artificialisation), but also marine:[67] 22% of coastal areas are exposed to artificial light, particularly around the Mediterranean, the Red Sea, the Persian Gulf and the seas surrounding South-East Asia. In addition, 42% of protected areas are reported to have been exposed to an increase in light pollution since the early 1990s.[68]

How blue light affects human health

As in other animal species, light exposure is the main synchroniser of the biological circadian rhythm in humans. **Its sensitivity is mainly based on the melanopsin ganglion cells (MGCs) of the retina, which are strongly stimulated by blue light, with a peak sensitivity around 480 nm.** The MGCs send their messages to the suprachiasmatic nuclei of the hypothalamus, the home of our biological clock. It controls the timing of a wide range of biological processes and functions involved in waking, sleeping, thinking, mood, metabolism, cell division, DNA repair, etc. Our central biological clock also controls the production of a hormone, melatonin,[69] whose secretion is inhibited by exposure to light. However, our current lifestyle tends to expose us to multiple sources of blue light (lighting, screens, etc.) in the evening and at night, leading to a disruption in circadian cycles[70] and physiological disturbances.

Disturbances in circadian cycles lead to varying degrees of disturbance in humans, including altered sleep patterns, delayed sleep onset, poor memory, mood swings and lack of attention, as well as cardiovascular risks and increased risk of breast[71] and prostate cancer, diabetes and obesity.[72]

Finally, **some LED lighting systems[73] are phototoxic[74] to the retina.** The Regulation requires that only lights (especially LED lights) with a photobiological risk group of 0 (no risk) or 1 (low risk) should be authorised for use, but some light sources are exempt from this regulation, such as torches and car headlights.[75] The most vulnerable populations include infants, children and young adults,[76] as well as people with eye diseases or abnormalities.[77]

■ For an effective fight against light pollution

A wide range of actions with a variety of results

✓ **An ambitious yet poorly implemented national regulation**

The disturbance caused by artificial light depends on several technical parameters: the duration of the light, its intensity, its density, its orientation and its light spectrum. **France has developed ambitious regulations to limit light pollution.** A number of outdoor lighting systems, both public and private,[78] are subject to these regulations, which impose **three types of measures**:

- **it regulates the timing of the lighting concerned**, which must be switched off either one hour after the end of the working day or after closing time (indoor lighting of business premises, parks and gardens, outdoor construction sites; the obligation to switch off is two hours after the end of the working day for car parks used for business purposes) or at the latest by 1 a.m. (lighting for historic monuments and buildings, shop window lighting, advertising and illuminated signs).[79] The lights should not

be switched back on before 7 a.m. or 1 hour before the start of the working day if this is earlier. For advertising and illuminated signs, the switch-on time is 6 am;

- **it sets out technical requirements to avoid illuminating the sky,[80] to limit lateral glare, to reduce colour temperatures[81] and to regulate the surface density of the installed luminous flux;[82]**
- it sets some generic rules, such as prohibiting direct lighting of water surfaces.

However, there are several obstacles that weaken the effectiveness of these measures. Firstly, the lack of publication of certain implementing decrees has **limited the application of the legislation**.[83] **Moreover, although sanctions are provided for in the event of non-compliance with the regulations, they are not always applied in practice due to a lack of control**.[84] **Finally, the current regulation is far from complete.** Public and private street lighting is not subject to contrast reduction requirements and its timing is left to the discretion of local authorities. In addition, outdoor events and sports facilities are included in the scope of the Decree of 27 December 2018, but are not subject to any timing or technical requirements.[85] Similarly, requirements for light emitted into the sky currently only apply to street lighting and car parks. The technical requirements are only extended to other lighting categories within the perimeter of astronomical observation sites and in nature reserves.[86]

✓ **A growing quest for light conservation that goes beyond energy conservation at the local level**

Creating areas of darkness through the use of "Black Grids".

The fight against the fragmentation of habitats by artificial light is primarily focused on eliminating lighting and removing as many light points as possible in nature reserves and suburban areas.[87] The "Black Grid" (trame noire),[88] similar to the Green and Blue Grids[89] that allow animals to move freely in terrestrial and aquatic environments, aims to recreate a "nocturnal continuity" to preserve fauna and flora that need the night.[90]

Labels, charters and awareness-raising actions

Several associative labels have been developed to safeguard the quality of the night-time environment,[91] such as the American label "International Dark Sky Reserve" (RICE - Réserve Internationale de Ciel Étoilé)[92] or the French label "villes et villages étoilés" (starry cities and villages).[93] A number of associations have launched awareness-raising campaigns for local authorities and citizens,[94] while some cities have adopted charters[95] to encourage the transition to reducing our energy consumption, particularly with regard to lighting.

Renovating public lighting to achieve "fair lighting".[96]

40% of lighting installations are more than 25 years old and are particularly energy-intensive. Public lighting renovation projects are expected to generate savings of between 40% and 80%,[97] particularly through the use of LED technology.[98] Given the weight of public lighting in the electricity bill of towns and cities (37%) and the increase in energy prices, the rate of upgrading outdoor lighting installations has accelerated: it is now between 5 and 7% per year, up from 3% a few years ago.[99] **However, light conservation is not the same as energy conservation** - two concepts that can in fact be contradictory.[100] [101] **Energy renovation can only be effective in the fight against light pollution if it is accompanied by prior consideration of the purpose of the lighting and its actual use in relation to the proven needs of the population.** The decision to switch off street lighting in the middle of the night, which currently concerns more than 12,000 towns and cities, can be taken independently of any energy renovation.[102] On the other hand, LEDs make it easier to implement fair lighting by optimising the duration and quantity of lighting (dimming, the use of presence detectors or lighting on demand) and by optimising the illuminated surfaces, which limits the amount of light emitted into the surrounding natural environment.

Recommendations

- **Enforce existing regulations** on timing and technical rules for public and private lighting.
- **Change the paradigm from systematic lighting to context-specific lighting**: design the lighting according to the real needs of the users,[103] adapt the lighting according to the uses[104] and then consider the equipment required.
- **Develop comprehensive legislation to address the phototoxicity risks of certain light sources[105]** and strengthen policies to raise awareness of the dangers of circadian disruption associated with exposure to artificial light in the evening and at night.

The Office's websites:

http://www.assemblee-nationale.fr/commissions/opecst-index.asp
http://www.senat.fr/opecst

Références

[1] *See the General Council for the Environment and Sustainable Development (Conseil général de l'environnement et du développement durable) (November 2018) - À la reconquête de la nuit: la pollution lumineuse, état des lieux et propositions https://igedd.documentation.developpement-durable.gouv.fr/documents/Affaires-0010973/012301-01_rapport-publie.pdf;jsessionid=D3B8344A72C967707EC0E66228F46C45*

[2] *Hearing with Alain Cabantous on 14 November 2022. Until the middle of the 18th century, the authorities were unable to control nocturnal activities, and promoted fear of the night to discourage people from going out. However, given the relative effectiveness of this policy, another approach emerged: making the night an extension of the day. Lighting has played a key role in achieving this policy.*

[3] *Artificial lighting contributes to the physical safety of people by making it easier to see the obstacles that have become increasingly common on public roads over the years. However, the scientific evidence linking lighting and crime is mixed. An initial analysis by the Direction Centrale de la Sécurité Civile (Central Directorate of Public Security) on the impact of switching off public lighting on crime did not reveal any particular trend in the evolution of criminal activity in the areas affected by these measures. On the other hand, the representatives of the Direction Centrale de la Sécurité Civile interviewed on 2 December 2022 highlighted the problems that the removal of night lighting posed for their ability to intervene quickly and safely. During the hearings, several speakers pointed out that the concepts of safety - an objective fact - and the feeling of safety - a subjective fact - are often confused in public debate, and that the lack of scientific research into the relationship between lighting and safety perpetuates this confusion.*

[4] *See Samuel Challéat (2019). Sauver la nuit. How darkness disappears, what its disappearance does to the living, and how it can be reclaimed. Premier Parallèle.*

[5] *Public lighting illuminates public spaces, mainly along the roadside and in public squares. It also contributes to the enhancement of the architectural heritage of public buildings or spaces.*

[6] *A study carried out by the Paris City Council in 2018 shows that 58% of the light emitted at night within its territory comes from private lighting, compared to 35% from public lighting and 7% from vehicles. On Réunion Island, public lighting accounts for 45.8% of all lighting, compared to 54.2% for private lighting (including 13.7% for sports fields).*

[7] *See Jean-Philippe Siblet (2008). Impact de la pollution lumineuse sur la biodiversité. Literature review Ministry of Ecological Transition/National Museum of Natural History agreement, sheet n°2.*

[8] *Illuminance measures the amount of light received by a surface. It corresponds to the luminous flux (expressed in lumen) in relation to the illuminated surface and is expressed in lm/m2 or lux.*

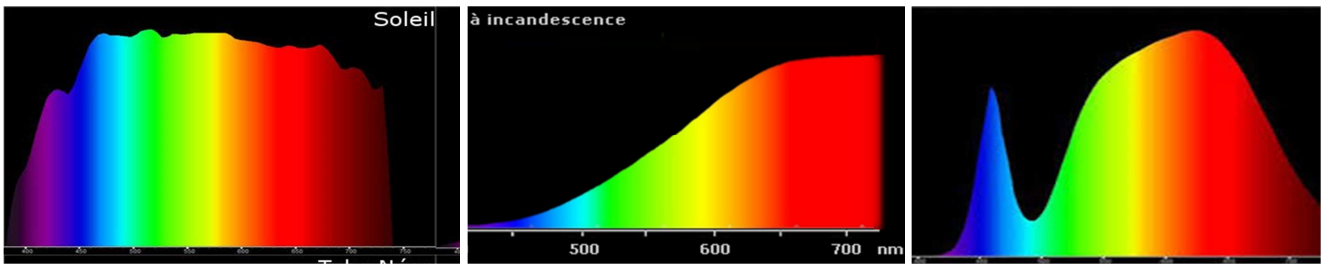
[9] *Luminance is the intensity of light relative to the light-emitting surface and is measured in candela per m^2 ($cd.m^2$).*

[10] *The light halo is accentuated by air pollution, which increases the number of particles in the atmosphere, and by certain weather conditions such as clouds, haze and fog.*

[11] *See Sordello et al. (2018). Developing national indicators on light pollution, preliminary reflections. UMS Patrimoine naturel. The spectral composition of light is the proportion of different wavelengths in the emitted light. A light source whose wavelengths are distributed over the entire spectrum visible to the human eye will produce white light and, conversely, coloured light if the wavelengths are localised or if certain wavelengths are missing. The colour temperature of light is determined by the proportion of blue and red in the light spectrum. The colder the light (high proportion of blue), the higher the colour temperature (measured in Kelvin).*

[12] *Examples of spectra:*

Sunlight *Incandescent lamp* *LED*



[13] *Satellite data gives an indication of the light emitted into the sky by all public and private lighting. However, they are subject to severe time and weather constraints (the satellite must pass over the area at night and in clear weather to measure the artificial light emitted into the sky), while the spectral coverage rarely allows the blue light emitted by LEDs to be taken into account. For example, NASA's satellite sensors cover a range between 500 and 900 nm, while the blue wavelength is between 400 and 500 nm. It should be noted that the Chinese satellite Jilin 1 captures the red, green and blue spectral bands. The zenith measurements, taken with a photometer on the ground, allow us to measure the darkness of the night sky and, conversely, the light halo. However, for a detailed analysis of light pollution, it would be necessary to multiply the number of photometers taking continuous measurements, to take into account the landscape, to better integrate weather conditions and to increase the spectral sensitivity of the sensors. Modelling can be used to simulate the light pollution produced in a given area more realistically. The Otus software, developed by the private consulting firm DarkSkyLab, is based on data on the number of inhabitants in urban areas, radiance data from the VIIRS-DNB satellite and geo-*

located light sources (luminaires with their power and ULOR - Upward Light Output Ratio - which represents the proportion of luminous flux emitted by a street lamp below the horizontal). However, some data, such as the number and characteristics of public lighting at night, are still patchy and inconsistent.

[14] See Falchi et al. (2016). The new world atlas of artificial night sky brightness. Science Advances. Vol 2, N° 6

[15] Figures from 11 October 2021 provided by the National Biodiversity Observatory (Observatoire national de la biodiversité), which publishes a light pollution indicator. https://www.ofb.gouv.fr/actualites/un-nouvel-indicateur-pour-mesurer-la-pollution-lumineuse

[16] Radiance is the amount of light emitted from a given surface and detected by the photographic sensor used to take satellite or aerial photographs.

[17] Kyba et al. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. Science Advances. Vol 3, N° 11

[18] *Kyba et al. (20 January 2023). Citizen scientists report global rapid reductions in the visibility of stars from 2011 to 2022. Science 379. As part of the* Globe at Night *project (https://www.globeatnight.org), more than 50,000 star observations were made by members of the public to identify the darkest stars visible to the naked eye. The brighter the sky, the brighter the stars need to be to be seen. Over an 18 year period, the number of stars detected at the same location fell from 250 to 100.* This change in the number of stars detected is equivalent to the sky getting brighter by 9.6% per year.

[19] LEDs (Light Emitting Diodes) are electronic components that emit light when an electric current is passed through them. Their luminous efficacy is extremely high, allowing them to produce much more light than an incandescent or discharge lamp using the same electrical power.

[20] Increasing the efficiency of lighting tends to increase its use rather than save energy.

[21] The increase in the number of light points has also been stimulated by the introduction of simple and free lighting (solar LEDs) in places where fixed lighting would have been impossible or too expensive. The use of LEDs by private individuals has increased significantly: Christmas decorations, path lighting, garden lighting, etc.

[22] Figures from the ADEME (the French Agency for Ecological Transition): https://www.ecologie.gouv.fr/pollution-lumineuse However, the exact number of light points is not known and figures vary between 9.5 and 11 million. Consequently, the INRAE (French National Institute for Agricultural Research) has been asked to define a standard for public lighting databases with the aim of homogenising existing and future databases in order to centralise them at national level. During a hearing held on 17 October 2022, those responsible for this programme at the INRAE highlighted the slow progress made in setting up this national database. It took a year and a half of negotiations to validate the data standard, and the challenge now is to make its existence known to all those involved in public lighting and convince them to use it.

[23] Growing urbanisation is also responsible for increasing the number of light points.

[24] Figures provided by the French Lighting Association (Association française d'éclairage) at a hearing on 4 November 2022.

[25] Revue Ciel et Espace, August/September 2022, issue 584.

[26] See Kyba et al. (2017). Article cited above.

[27] In fact, it was astronomers who began to denounce light pollution in the 1970s.

[28] See Victor Cazalis and Anne-Caroline Prévot (2019). Are protected areas effective in conserving human connection with nature and enhancing pro-environmental behaviours? Biological conservation. Volume 236. French people who live close to a nature reserve tend to be more "environmentally friendly" than others. Protected areas certainly offer 'wilder' landscapes than elsewhere, but most importantly, they stimulate people's interest in and sensitivity to nature through a variety of awareness-raising activities on preserving the environment and protecting biodiversity. In fact, re-establishing the links of daily proximity between humans and non-humans seems to be a condition for creating a less "egocentric" way of life.

[29] See Challéat et al. (2021). Grasping darkness: the dark ecological network as a social-ecological framework to limit the impacts of light pollution on biodiversity. Ecology and Society. 26 (1)

[30] In France, lighting accounts for between 10 and 11% of the country's total electricity consumption.

[31] According to the International Dark-Sky Association, at least 30% of outdoor lighting is wasted in the US, costing $3.3 billion a year and emitting 21 million tonnes of CO_2.

[32] It is estimated that lighting is responsible for the emission of 1.15 billion tonnes of CO_2 per year worldwide and 5.6 million tonnes in France. In addition, public lighting in our country alone emits 670,000 tonnes of CO_2 per year. This is equivalent to 41% of urban electricity consumption for 9.5 to 11 million light points.

[33] According to the French Energy Association (Association française de l'énergie), an LED can save up to 70% of electricity per light point compared to a conventional light bulb. The energy efficiency of an LED (ratio of luminous flux emitted to electricity consumed) is currently 130 to 150 lm/W, compared with 55 to 70 lm/W for a compact fluorescent lamp or 17 to 30 lm/W for a halogen lamp.

[34] Today, one LED produces the same amount of light as 3 CFLs and 15 incandescent bulbs.

[35] For an LED produced in China and used in France, the life cycle analysis shows that 30% of the greenhouse gas emissions are generated by the extraction of materials, 5% by their manufacture and 65% by their use. For an incandescent bulb, the figure is around 25% for extraction and production and 75% for use under the same conditions.

[36] *See Samuel Challéat (2019). Book cited above.*

[37] *See Hölker et al. (2010). Light pollution as a biodiversity threat. Trends in Ecology and Evolution. 25 (12). It should be noted that classifying a species as nocturnal or diurnal is a simplification, as many species are active at dusk and dawn, two times when they are most active. As a result, some diurnal species end their activities at sunset while some nocturnal species begin them, and vice versa at dawn.*

[38] *Furthermore, many movements occur at night, including those of species that are generally considered diurnal (e.g. migrating birds).*

[39] *See Romain Sordello et al. (2018), article cited above. Some animals exhibit positive phototaxis: they are spontaneously attracted to light sources. This is because, in normal nocturnal conditions, these animals orientate themselves using naturally illuminated structures. For example, some insects can be identified using the light of the moon. Beetles use the starry sky and in particular the Milky Way to guide their movements. For other species, however, light is a repellent factor. Negative phototaxis is explained by the fact that the eyes of nocturnal animals are not tolerant to light. It is also a behavioural strategy to make them less visible to their predators. The attractive or repulsive effect of light sources is manifested with a very small amount of light.*

[40] *This is called phototropism (the growth of an organism in response to a light stimulus), which is positive for the stems and negative for the roots.*

[41] *See Gaston et al. (2014). Human alteration of natural light cycles: causes and ecological consequences. Oecologia. 176 (4).*

[42] *See Falcón et al. (2020). Exposure to Artificial Light at Night and the Consequences for Flora, Fauna and Ecosystems. Frontiers in Neuroscience. 14.*

[43] *The range of natural lighting is enormous: 100,000 lux is measured under the midday sun compared to 0.1 to 0.3 lux under a full moon on a clear day.*

[44] *See Romain Sordello et al. (2014). Fragmenting effect of artificial light. What are the impacts on the movement of species and how can they be taken into account in ecological networks? Muséum national d'histoire naturelle (the National Museum of Natural History), Centre de ressources Trame verte et bleue.*

[45] *Some studies suggest that a third of the insects attracted to stationary artificial light sources die before daylight, either through exhaustion or predation, amounting to between 400 and 1,600 insects per night per lamp post. 2,000 billion insects are said to be killed each year in France by public lighting. For migratory birds, the International Dark-Sky Association estimates that 100 million are killed each year in the United States as a result of collisions with illuminated buildings.*

[46] *See Siblet (2008). Human Health Impacts Related to Light Pollution Literature review Ministry of Ecological Transition/National Museum of Natural History agreement. During the nesting season, adult and juvenile birds may be attracted to extraneous light sources, preventing them from returning to their nests or from being able to navigate.*

[47] *See Sordello et al. (2014), report cited above. Once they have hatched, juvenile turtles find the sea by looking at the night horizon, which is clearer at sea than on land. Light pollution creates unwanted light sources that disorient them. Sea turtle hatchlings born on the beach crawl towards the land where the shoreline is lit, instead of going out to sea, and eventually die from predators and heat after daybreak.*

[48] *See Le Corre et al. (2002). Ligh-induced mortality of petrels: a 4-year study from Réunion Island (Indian Ocean). Biological Conservation. Volume 105. This study concludes that for the Bareau's Petrel, an endemic species of Réunion Island, the main threat of mortality is artificial lights.*

[49] *See Rich & Longcore (2006). Ecological consequences of artificial night lighting. Island Press. Darwin's leaf-eared mice exposed to increased ambient light showed a 15% reduction in food intake, a 40% reduction in the amount of food taken to the nest and a 4.4 g loss in body weight at night.*

[50] *See Azam et al. (2016). Disentangling the relative effect of light pollution, impervious surfaces and intensive agriculture on bat activity with a national-scale monitoring program. Landscape Ecology. 31 (10). Artificial lighting in bat "nurseries" has major impacts on the health of juveniles by desynchronising the period when bats go hunting from the "peak of abundance" of insects.*

[51] *See Avalon et al. (2020). Light pollution is a driver of insect declines. Biological Conservation. Volume 241.*

[52] *Light pollution can affect breeding success by making individuals less selective in their choice of mate. For example, strong lighting can inhibit mating calls in amphibians. Females are then less selective in their choice of mate in order to speed up the mating process and limit the risk of predation.*

[53] *The impact of artificial light on body mass varies between species: body mass increases in mice and decreases in buffalo toads.*

[54] *In insects, several mechanisms can lead to reduced fertility, including sterilisation of males, suppression of pheromones secreted by females and inadequate oviposition.*

[55] *Prolonged exposure to artificial light delays the development of insects that hibernate as juveniles, such as crickets, while it accelerates the development of some multivoltine ladybirds.*

[56] *See Touzot et al. (2022). Transcriptome-wide deregulation of gene expression by artificial light at night in tapdoles of common toads. Science of Environment. 818. This study has demonstrated that exposure to artificial light leads to changes in the expression of immune-related genes in this group of amphibians.*

[57] *The following examples illustrate the phenological shifts caused by light pollution: early singing for certain species of birds; changes in the timing of bud burst and leaf yellowing or flowering; inhibition of plant dormancy; advanced (e.g. for blue tits) or delayed (e.g. for kangaroos) peak birthing periods.*

[58] *Early bud burst creates a risk of increased loss in the event of late frost. In addition, juvenile development is hindered by the misalignment of birth peaks with peaks in food availability. Some insect species also synchronise various developmental activities to specific times of the day: for example, the Drosophila jambulina fly hatches before dusk when temperature and humidity are optimal. Similarly, intertidal midges - Pontomyia oceana - hatch when the tide is out. Artificial light can cause midges to hatch at the wrong time, causing them to dry out or drown.*

[59] *See Romain Sordello (December 2017). Pollution lumineuse: longueurs d'ondes impactantes pour la biodiversité (Light pollution: wavelengths impacting biodiversity). Based on the literature review by Musters et al. (2009). UMS Patrimoine naturel. 220 publications were reviewed, covering 10 biological groups (plants, insects, crustaceans, arachnids, fish, amphibians, reptiles, birds, non-bat mammals and bats). When looking at the types of effects of artificial light on living organisms, the authors looked at four categories with a total of 11 types of effects:*

- *"Physiological", including growth, hormonal regulation, circadian rhythms and circannual cycles;*
- *"Behavioural", including activity, phototaxis and orientation;*
- *"Ecological/population", including reproduction, mortality and population distribution;*
- *And "inter-species interactions", corresponding to the relationships between predators and prey.*

The results were summarised as follows:

	Ultraviolet (<380nm)	Violet (380-450nm)	Bleu (450-500nm)	Vert (500-550nm)	Jaune (550-600nm)	Orange (600-650nm)	Rouge (650-750nm)	Infrarouge (>750nm)
Plantes	• Croissance	• Croissance	• Croissance	• Croissance			• Croissance • Horologe circadienne	• Croissance • Horologe circadienne • Horloge circannuelle • Rapports proies/prédateurs
Crustacés				• Phototactisme			• Activité • Phototactisme	
Arachnides		• Phototactisme	• Horologe circadienne • Phototactisme	• Phototactisme	• Horologe circadienne • Phototactisme	• Horologe circadienne • Phototactisme	• Horologe circadienne • Phototactisme	
Insectes	• Phototactisme • Orientation		• Phototactisme • Orientation	• Phototactisme	• Phototactisme		• Phototactisme	
Amphibiens	• Activité	• Horologe circadienne • Orientation • Phototactisme	• Horologe circadienne • Orientation • Phototactisme	• Horologe circadienne • Orientation • Phototactisme	• Orientation • Phototactisme	• Orientation • Phototactisme	• Phototactisme	
Oiseaux	• Régulation hormonale • Orientation	• Orientation	• Croissance • Horloge circannuelle • Phototactisme • Orientation	• Croissance • Horloge circannuelle • Phototactisme • Orientation	• Orientation	• Orientation	• Horloge circannuelle • Phototactisme • Orientation	• Croissance
Poissons			• Régulation hormonale • Croissance • Phototactisme	• Croissance • Phototactisme	• Phototactisme		• Phototactisme	
Mammifères (hors chauves-souris)	• Horologe circadienne	• Horologe circadienne	• Régulation hormonale • Horologe circadienne		• Horologe circadienne • Activité • Phototactisme	• Horologe circadienne • Activité • Phototactisme	• Horologe circadienne • Activité	• Horologe circadienne
Chiroptères		• Horologe circadienne	• Horologe circadienne	• Horologe circadienne	• Horologe circadienne	• Activité	• Horologe circadienne	
Reptiles		• Phototactisme	• Phototactisme	• Phototactisme	• Activité			

Tableau 2 : Types d'impacts par plage de longueur d'onde pour chaque groupe biologique d'après Musters *et al.* 2009

Légende :

1 type d'impact | 2 types d'impacts | 3 types d'impacts | 4 types d'impacts

SORDELLO R., 2017, UMS PatriNat. *Longueurs d'onde lumineuses impactantes pour la biodiversité. Exploitation des résultats de Musters et al., 2009.* Page 11/18

Fauna and flora are affected by all wavelengths. However, when looking at the number of biological groups affected and the number of effects observed, blue and red stand out as the most problematic wavelength ranges.

[60] *See Clémentine Azam's thesis (2016). Impacts of light pollution on bat spatiotemporal dynamics in France: implications for outdoor lighting planning. A white LED lamp attracts 48% more insects than a sodium-vapour lamp.*

[61] *See D.R. Dixon et al. (2006). Lunar-related reproductive behaviour in the badger (Meles meles). Acta Ethol. Some species reduce or even stop their activities under the influence of the full moon, even though its illuminance is very low (less than 1 lux).*

[62] *For example, night activity has been observed in passerines and peregrine falcons.*

[63] *See Davies et al. (20 March, 2017). Street lighting changes the composition of invertebrate communities. Biology Letters.*

[64] *This is particularly true for chiropterans: some bats (such as the Least Rhinolophus) do not fly in lit areas, or do so with altered behaviour, while other chiropterans (such as the Pipistrelle) do.*

[65] *See Davies et al. (23 October, 2012). Street lighting changes the composition of invertebrate communities. Biology Letters. This study demonstrated how artificial lighting changes the composition of terrestrial invertebrate communities. Two groups of carnivores are over-represented in brightly lit communities: predators and scavengers (spiders, carabids, woodlice, ants and amphipods). This finding proves that artificial lighting has a permanent effect on the composition of invertebrate communities and does not simply attract certain species at night that would disperse again during the day.*

[66] *See Knop et al. (2017). Artificial light as a new threat to pollination. Nature. 548. By studying flowers in artificially lit areas 24 hours a day, the researchers observed a 62% reduction in visits by nocturnal pollinators such as moths and certain beetles, compared to areas without light pollution. More importantly, this resulted in a 13% reduction in the amount of fruit produced by a local plant species, the cabbage thistle, despite numerous visits by daytime pollinators such as bumblebees, bees and flies.*

The researchers demonstrated that the cascading effects of light pollution do not stop at plants and their reproduction, but can also spread to daytime pollinators. As light pollution reduces the reproductive success of plants on which daytime pollinators feed, this could eventually lead to a decrease in the food resources available to daytime pollinators.

[67] *See Marangoni et al. (2022). Impacts of artificial light at night in marine ecosystems – a review. Global Change Library. Volume 28.*

[68] *See Duffy et al. (2015). Mammalian ranges are experiencing erosion of natural darkness. Scientific Reports 5, 12042.*

[69] *Melatonin secretion begins in the evening as soon as the retina is in darkness. It peaks in the middle of the night and returns to very low or undetectable levels in the morning and during the rest of the day with exposure to light.*

[70] *The intensity of the circadian disturbance seems to depend on the intensity of light, the time and duration of exposure, but also on the individual's history of exposure to light during the day. It has been shown that an intensity of 2-10 lux or 5 minutes exposure to 200 lux light is sufficient to inhibit melatonin secretion and sleep (see Prayag et al. (2019). Melatonin suppression is exquisitely sensitive to light and primarily driven by melanopsin in humans. Journal of Pineal Research. Volume 6). These levels are much lower than what we are exposed to in our daily lives via our household appliances. However, it takes 45 minutes for melatonin to return to the level where it should have been before being interrupted by light (see Gronfier et al., July 2004. Efficacy of a single sequence of intermittent bright light pulses for delaying circadian phase in humans. American Journal of Physiology-Endocrinology and Metabolism. 287). The disruption of circadian rhythms, mainly associated with the suppression of melatonin, is even more pronounced in children, adolescents and young adults (up to the age of 20) because their lenses are more transparent than those of adults, allowing more blue light to pass through. The widespread use of LED screens among adolescents, as well as the behavioural, hormonal and circadian changes that occur at this age, also explain their particular sensitivity to circadian rhythm disturbances. Finally, some toys that are supposed to put babies to sleep or certain nightlights for children emit blue light and thus run the risk of altering sleep by disrupting melatonin production.*

[71] *See J.L Dufier & Y. Touitou, on behalf of a working group attached to the XIV Committee (Health Determinants, Prevention & Environment), National Academy of Medicine. Report 21-10. Light pollution and public health. The link between exposure to artificial light at night, our internal clock and melatonin, and the significantly increased risk of breast cancer in women who work night shifts was demonstrated in the Nurse Health Study (where 115,000 American nurses were studied for a period of 10 years). It revealed a significant increase (79%) in the relative risk of breast cancer in women who worked at least 3 nights a month for 20 years. In 2007, the International Agency for Research on Cancer (IARC) classified shift and/or night work as a Group 2A probable carcinogen because it involves circadian de-synchronisation. The conclusion of the Anses report (Assessment of health risks related to night work, June 2016), which is based on three times as many epidemiological studies, is similar but achieves a higher level of evidence.*

[72] *See the Anses report (April 2019). The effects on human health and the environment (fauna and flora) of systems using light-emitting diodes (LEDs). In humans, artificial light has been linked to obesity and susceptibility to certain hormone-dependent cancers (such as breast and prostate).*

[73] *LEDs have three main characteristics (according to the Anses hearing of 18 October 2022): the light spectrum emitted by LEDs is generally dominated by blue light; due to their high luminance, LED lights can be more dazzling than lights emitted by other technologies; and LEDs are very sensitive to fluctuations in their supply current. As a result, the intensity of the light may vary depending on the quality of the power supply.*

[74] *See J.L Dufier and Y. Touitou (report 21-10 cited above): "Retinal phototoxicity results from cellular photochemical lesions under the influence of chronic exposure to light pollutants without visible damage to the fundus".*

[75] *In 2017, Anses commissioned the Scientific and Technical Centre for Building (CSTB - Centre Scientifique et Technique du Bâtiment) to carry out a study on dipped headlights, which concluded that the new LED dipped headlights belong to risk group 2 and that there is a phototoxic risk once the exposure time exceeds 20 seconds (continuously or cumulatively). Babies and very young children are particularly at risk because they do not yet have the reflex to avoid light sources. In general, the eyes of a child in a pushchair are at the same height as the headlights of a car and can be dazzled by the headlights of cars travelling at low speed (e.g. at a pedestrian crossing).*

[76] *Infants, children, teenagers and young adults have a clear lens that filters less light. Pregnant women are also at risk due to the potential health effects on the unborn child.*

[77] *Especially people with aphakia (no lens) or pseudophakia (with an artificial lens). Night workers and people with sleep disorders are also at risk.*

[78] *For example, the French Decree of 27 December 2018 on the prevention, reduction and limitation of light pollution covers outdoor lighting intended to promote the safe movement of people and goods and the comfort of the public (excluding vehicle lighting and signalling devices); lighting for enhancing cultural monuments and buildings, parks and gardens; lighting for outdoor sports facilities; building lighting, including both the lighting of building facades and the interior lighting emitted to the outside of the same buildings; lighting for uncovered car parks; temporary lighting (outdoor events and outdoor construction sites). In addition, Decree No. 2022-1294 of 5 October 2022 amending certain provisions of the French Environmental Code relating to the rules for the extinguishing of illuminated advertising and illuminated signs harmonises the rules for the extinguishing of illuminated advertising and illuminated signs.*

[79] *The aforementioned Decree No. 2022-1294 of 5 October 2022 extends the obligation to extinguish to illuminated advertising supported by street furniture, while postponing the date of applying this measure to 1 June 2023. Illuminated advertising on street furniture used for transport services (e.g. bus shelters) may remain lit during the operating hours of these services. During the hearing of representatives of the direction de l'habitat, de l'urbanisme et du patrimoine (Directorate of Housing, Urban Planning and Heritage) on 9 January 2023, it was clarified that communal information panels fall within the scope of Decree no. 2022-1294 insofar as they are considered, depending on their content, either as street furniture or as illuminated advertising. Finally, it was recalled that Article 18 of Law N° 2021-1104 of 22 August 2021 on combating climate change and strengthening resilience to its effects allows local authorities with local advertising regulations to regulate illuminated advertising and illuminated signs inside shop windows and intended to be visible from the outside in terms of switch-off times, surface area, energy consumption and the prevention of light pollution.*

[80] *By 1 January 2025, all lighting installations intended to promote the safe movement of people and goods in public and private spaces, as well as lighting installations in uncovered car parks, with a ULR (Upward Light Ratio: the ratio of the light emitted by the luminaire in the upper hemisphere to the total light emitted by the luminaires) of more than 50% must be replaced with compliant lighting. In addition, new lights used for public and private street lighting should have an ULR of less than 1%.*

[81] *In view of the danger of blue light to the retina, the colour temperature is limited to 3000 Kelvin for all outdoor lighting, to 2700 Kelvin in the "built-up" areas within national park boundaries and to 2400 Kelvin in nature reserves and in the "non-built-up" areas within national park boundaries.*

[82] *For this purpose, a new value has been created: the installed luminous flux density (DSFLI - densité surfacique de flux lumineux installé), which corresponds to the total number of lumen of all the lights in the same installation, divided by the surface area to be illuminated. The DSFLI is measured in lumens per m². The French Decree of 27 December 2018 authorises the installation of 35 lumens per m² of surface to be illuminated for the lighting of traffic lanes. For car parks, building façades and park and garden lighting, the above-mentioned Decree provides for a DSFLI of less than 25 lumen per m² in built-up areas and less than 20 lumen per m² outside built-up areas. This is a kind of authorised "allowance" that results in an obligation to illuminance levels (lux). Unlike lux, DSFLI cannot be measured. It is calculated according to the lighting plan, eliminating the need for time-consuming and costly night-time illuminance measurements by the regulatory authorities. However, there is currently no standard way of calculating the DSFLI and each consulting firm may calculate it differently.*

[83] *The "Grenelle 1" Law of 3 August 2009 and the "Grenelle 2" Law of 10 July 2010 introduced the prevention, reduction and limitation of light pollution into the French Environmental Code. Decree 2011-831 of 12 July 2011 on preventing and limiting light pollution entrusted the Minister for the Environment with the task of limiting the operation of seven categories of lighting installations over time and laying down technical requirements for them. However, the implementing decrees were not adopted and it was not until 2018, when the State was condemned by the Council of State, that the Decree of 27 December 2018 on the prevention, reduction and limitation of light pollution was published. On the other hand, the Decree laying down the maximum luminance thresholds for illuminated signs and advertisements and the luminous efficacy of the light sources used has not yet been published. According to the Directorate of Housing, Urban Planning and Heritage (Direction de l'habitat, de l'urbanisme et du patrimoine) of the Ministry of Ecological Transition, two versions of this Order (a "minimum" version, close to the current practices of professionals, and a "maximum" version, more ambitious in terms of limiting the nuisance caused by advertising and illuminated signs) have been drafted and are awaiting approval by the Cabinet of the Minister for Ecological Transition. The decision-making process would also involve preliminary discussions with the Ministry of Economy, Finance and Industrial and Digital Sovereignty. In its 4th National Health and Environment Plan, the government undertook to regulate the nuisance caused by advertising and illuminated signs in terms of health and the environment by setting technical standards for the installation of advertising and illuminated signs. The obligation to extinguish illuminated advertising and signs was introduced by Decree 2012-118 of 30 January 2012 concerning outdoor advertising, signs and billboards. Its application has been very uneven, especially in the absence of monitoring by the competent authorities. A new Decree, No. 2022-1294 published on 5 October 2022, harmonises the rules for switching off illuminated advertising, regardless of whether the area is covered by a local advertising regulation or not and regardless of the size of the urban unit to which it belongs.*

[84] *In September 2022, a study carried out by the Inter-ministerial Directorate for Public Transformation sought to understand why the regulation on the extinction of businesses at night was poorly applied, even though it dates from 2013. The findings of the study are as follows. On the one hand, shopkeepers lack the motivation to switch off their shopfronts and signs (biodiversity is not seen as an issue, LED technology is considered to limit the impact of commerce on the environment, lighting management methods are often complex, while the motivation to switch on is high as it is seen as an advertising gesture). On the other hand, the regulations are not well known and seem difficult to apply: not only is controlling night-time extinction difficult and tedious, requiring inspections between 1am and*

7am, but it is not a priority for local authorities who prefer to avoid conflict with shopkeepers. The study suggests that both local authorities and retailers should take action to encourage the switching off of lights in shops at night. The aim is to make local authorities aware of the regulations and their role through a simple and easily accessible information medium, to highlight the reputational benefits of taking action, given that the vast majority of French people are in favour of switching off lights in shops at night, and to provide local authorities with tools for communicating with shopkeepers (practical guide, standard letters, etc.). With regard to actions aimed at shopkeepers, it is advisable to remind them of the regulations and the penalties for failure to comply with them, to raise their awareness at key moments (when building or setting up new shops, when applying to the town hall for assistance in setting up, etc.), and even to support their efforts to change by providing them with personalised advice and assistance (e.g. installing timers or improving their lighting system).

[85] With the exception of sports facilities, which must have a colour temperature of 2700K in built-up areas and 2400K outside built-up areas in nature reserves.

[86] Consequently, outside the perimeter of astronomical observatories and nature reserves, there are no requirements on the light emitted towards the sky for outdoor heritage lighting (even though these are all typically bottom-up lighting), lighting in parks and gardens, sports facilities or the lighting of the facades of non-residential buildings.

[87] See the hearing of Christian Kerbiriou, Kevin Barré and Isabel le Viol on 21 October 2022.

[88] See Challéat et al. (2021). Article cited above. The Black Grid is based on the concept of the dark ecological network, which emphasises the importance of darkness as a new dimension of 'ecological connectivity'. In doing so, it puts the preservation of ordinary biodiversity at the forefront of the fight against light pollution. By integrating the ecological processes associated with nocturnal landscapes into biodiversity conservation planning, it offers a twofold perspective for the comprehensive conservation of the night-time environment: on the one hand, combating landscape homogenisation and habitat fragmentation, and on the other hand, integrating conservation theories into normal land-use planning practices.

[89] See Article L. 371-1 of the French Environmental Code, which states: "The aim of the Green and Blue Grids is to combat the loss of biodiversity by helping to preserve, manage and restore the environments necessary for ecological continuity, taking into account human activities, in particular agricultural activities, in rural areas, as well as the management of artificial light at night".

[90] Many territories have already identified their Black Grid, but the legal and regulatory framework remains precarious as the Black Grid is not mentioned in the French Environmental Code.

[91] The notion of night-time environment is commonly used for linguistic convenience, but it is also a research topic in its own right. See the work of the CNRS night-time environment observatory, led by Samuel Challéat. https://observatoire-environnement-nocturne.cnrs.fr/fr_fr/

[92] This label, issued by the International Dark-Sky Association and based on a logic of exceptionality, recognises territories where measures have been taken to preserve the remarkable quality of the starry sky. Four French sites have been awarded this label: RICE Pic du Midi, RICE Cévennes National Park, RICE Alpes-Azur Mercantour and RICE Mille Vaches Regional Nature Park in Limousin. In practical terms, the RICE strategy aims to define a core zone of exceptional sky quality and a buffer zone where local authorities commit to improving their public lighting and preserving the night-time environment.

[93] This label, issued by the National Association for the Protection of the Night Sky and Environment (ANPCEN - Association Nationale pour la Protection du Ciel et de l'Environnement Nocturnes), recognises the actions carried out by towns, cities and regions to improve the quality of the night and the night-time environment.

[94] The "La nuit des étoiles" (Night of stars) organised each year by the French Astronomy Association or "Le jour de la nuit" (day of night) by the Agir pour l'environnement (action for the environment) association, to name but two examples.

[95] One example is the "Tous unis pour plus de diversité" (All united for more diversity) charter launched by the city of Strasbourg.

[96] See the ADEME, AFE, Syndicat de l'éclairage (lighting union) (2010). Eclairer juste (Fair lighting). https://www.syndicat-eclairage.com/wp-content/uploads/2014/09/eclairer_juste.pdf

[97] According to the Government's Energy Plan of 6 October 2022, upgrading France's public lighting to LED lighting with automated control would result in energy savings of 40-80% in the first few months, with a full return on investment in 4-6 years.

[98] The penetration rate of LEDs for public lighting in France is estimated at 15% (2019). More than 99% of lighting renovations and new installations are carried out using LEDs.

[99] See the hearing of the French Lighting Association on 4 November 2022: 45% of the 10 million lighting points in France are over 25 years old.

[100] Two mechanisms are involved here: the rebound effect (the low energy consumption of LEDs encourages an increase in the number of light points) and the fact that the energy efficiency of LEDs is inversely proportional to their impact on biodiversity due to their high proportion of blue light. One study looked at different lighting scenarios to see how technological changes to meet energy-saving objectives might affect communication between pipistrelles. One of the scenarios involves changing the entire lighting system from numerous Sodium-vapour lamps to LEDs with a colour temperature of 3000K, while maintaining the same illuminance and number of light points. This scenario reduces the movement of Chiroptera in the three cities studied (Paris, Lille and Montpellier). Replacing current lighting systems with this LED model would significantly increase the amount of blue light emitted. Bats are particularly sensitive to

these wavelengths. The development of LEDs must therefore be accompanied by a reduction in their colour temperature. However, switching from a 3000K LED to a 2200K LED, for example, results in a 30% loss in energy efficiency.

[101] The use of energy saving certificates (CEE - Certificats d'Economie d'Energie) is a key factor in the purchasing decision of those responsible for modernising lighting installations. However, this certification process focuses on energy efficiency and excludes alternatives to the "standard" LED, such as "amber" LEDs, which are much hotter, or high-pressure sodium-vapor lamps at 1800K (i.e. a lower colour temperature than LEDs), which are considered to have a lower impact on biodiversity but are also less energy efficient. However, in August 2022, the government launched the Green Fund, which aims to accelerate the ecological transition within the territories. Its subsidies (available from January 2023) can be used for renovating public lighting installations, provided that they contribute to the protection of biodiversity, the reduction of light pollution (Black Grid) and energy efficiency. One of the eligibility criteria is "greater protection of biodiversity: the colour temperature of the luminaires installed must not exceed 2700 K both inside and outside built-up areas and 2400 K in protected areas as defined in Article 4 of the Order of 27 December 2018". In this way, the Green Fund enables the impact of technologies on biodiversity to be taken into account in the debate on energy efficiency.

[102] There are many solutions to reducing light pressure that do not require a switch to LED technologies, such as reducing the installed wattage when replacing high-pressure sodium lighting, or re-embedding the light source in the light fitting to improve the photometry of the lighting itself.

[103] Protecting the night-time environment must be territorialised, taking into account the needs but also the concerns, whether scientifically justified or not, of the public, which vary according to gender and place of residence (for example, women and people living in built-up areas are more concerned about darkness than men and people living in rural areas). However, several studies have shown that there is real public support for reducing the intensity and number of light points. When it comes to switching off in the middle of the night, the period between 1am and 5am seems to be the easiest to apply. In the interests of efficiency and acceptability, the extension of switch-off times should be phased in gradually, starting with areas where there is strong support for switching off, namely rural and suburban areas.

[104] This policy must be implemented in consultation with local residents and the authorities responsible for the safety of people and traffic.

[105] Exposure limit values (ELVs) for blue light are defined internationally by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). During their hearing, the ANSES representatives pointed out that the ELVs were last updated in 2013 and did not take into account the particular vulnerability of children and young people. The 4th National Health and Environment Plan foresees a French ban on LEDs with a risk group higher than 1 for products intended for children and for headlamps, subject to compatibility with European legislation. It also states that France will submit a request at European level to ban LED car headlights with a risk group higher than 1.

Persons consulted

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Mrs. Anne-Marie Ducroux, Honorary Chair of the National Association for the Protection of the Night Sky and Environment (ANPCEN - Association Nationale pour la Protection du Ciel et de l'Environnement Nocturnes)

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