one

Light Pollution

1.1.

Introduction

Our planet, since its origin some 4.5 billion years ago, has undergone multiple changes on a global scale. It is a changing planet. At the present time, we are immersed in one of these processes of change, however, this one is quite different. Its origin derived from human activity, the speed at which it is occurring, the magnitude of each threat and the interaction between them (synergies) means that we are facing unprecedented global change with dire consequences for life as we know it today. Two of the main threats that are causing this anomalous change are habitat transformation and degradation. And behind them are different forms of pollution, of which light pollution stands out as having a faster annual rate of increase than any other driver of global change.

Light pollution is defined as the disturbance of the natural nighttime darkness caused by artificial light. Light pollution is a growing phenomenon. Every year, the world's illuminated area and the intensity of artificial brightness in the night sky grows by around 2.2%, although recent studies suggest that this percentage could be higher. In 2021, the CSIC participated in a study that showed that light pollution has grown by around 50% in the last 25 years. Other studies that do not use information from satellites, but instead use data taken from the ground, point to an annual increase of 9.6%. And, let's not deceive ourselves, even if it is not tangible, does not smell or make a noise, it is pollution in the strict sense of the word and poses a threat to astronomical observations, to the balance of ecosystems and to our health.

Light pollution is an imminent risk to which we must respond in the same way as we deal with other threats such as waste management, drought or the protection of the oceans.

When we talk about pollution, we refer to the presence of elements or substances (pollutants) that should not be in the environment and that alter its natural conditions. In the case of light pollution, the polluting agent is artificial light and the medium is

night. And it is not just any pollutant. There is one characteristic that makes artificial light a very dangerous pollutant: its ability to propagate in all directions and the high speed at which it does so, 300,000 kilometres per second.

The main source of artificial light that causes light pollution is outdoor lighting. Indeed, when we think of it, our mind pictures long rows of street lamps along streets and avenues in our towns and cities. But outdoor lighting is not only limited to the light points that flood streets and roads, it goes beyond that: it also includes pedestrian street and park lighting, sports and recreational lighting (football stadiums, athletics tracks, etc.), industrial lighting (work areas) and ornamental and decorative lighting (statues, buildings, shopping centres, shop windows, etc.).

There is a key moment in the history of mankind when artificial light begins to threaten the night: the industrial revolution. From 1870 onwards, several events came together, such as massive industrialisation, increased agricultural production (which led to an improvement in the population's diet), medical advances and hygienic-sanitary improvements that caused the world's population to double in barely a century. This, coupled with the increasing popularity of electricity, led to an explosion in the number of light points. Night became day.

Light pollution, from its origin, is an environmental problem with a huge social component. The problem, and at the same time the solution, lies in the social perception of artificial light. Culturally, artificial light is synonymous with well-being, beauty, advanced societies, status and security. And this means that light pollution is a global environmental problem that we do not perceive as a threat, but as an unmistakable sign of well-being and progress.

Street lighting in an urban area. / ADOBE STOCK

Light pollution is an environmental problem that requires a direct approach. Measures derived from strategies that address other environmental challenges are not sufficient. This environmental problem needs to be tackled from a joint scientific, political, social and legislative perspective. It also requires an extra effort to make society aware of its existence and the true extent of this serious threat.

Responsibility for this challenge must therefore be shared. The scientific community, politicians and economic and social players must all assume our share of responsibility. It is essential that we join forces in favour of a responsible lighting model. Outdoor lighting in our towns and cities should help us to walk without tripping, avoid possible accidents, guarantee our safety, promote economic activity in the sunless hours or enhance the beauty of our most emblematic buildings, but it should never alter the scientific activity of astronomical observatories, prevent us from enjoying the spectacle of a starry sky, alter our health or the balance of ecosystems. Nor should we forget that the sky can become a driving force for sustainable economic development in rural areas, helping to halt depopulation phenomena.

The Universal Declaration of Human Rights of Future Generations explicitly states that "people belonging to future generations have the right to an unspoilt and unpolluted earth". The La Palma declaration, signed by leading institutions such as the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the International Astronomical Union (IAU) among others, also recognises "the right to an unpolluted night sky as an inalienable right of humankind, equal to all other environmental, social and cultural rights". And the Sustainable Development Goals (SDGs) of the United Nations (UN), specifically numbers 3 (health and well-being), 11 (sustainable cities and communities), 12 (responsible production and consumption), 14 (underwater life) or 15 (life of terrestrial ecosystems) are threatened by light pollution.

Stopping the massive illumination of our planet must become a common goal, for us and for those to come.

Example of urban sources of light pollution. / AIRAM RODRÍGUEZ

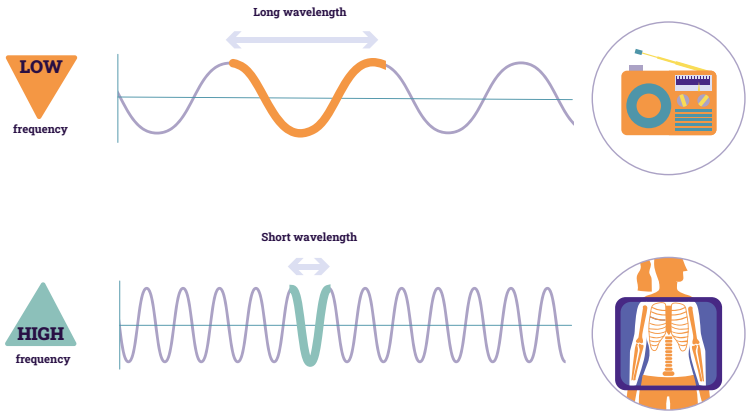
1.2.

Some concepts to understand the problem

What is light?

Light (also called electromagnetic radiation) is a set of electromagnetic waves that propagate at high speed. Each of these electromagnetic waves is characterised by its frequency (measured in hertz -Hz-) and its wavelength (in nanometres -nm-; one billionth of a metre).

Figure 1 Electromagnetic wave



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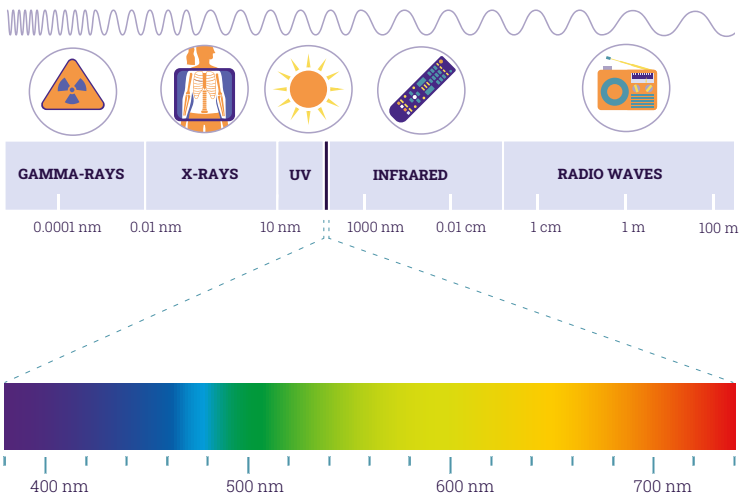
Depending on their frequency and wavelength, there are different types of electromagnetic waves, which together are called the **electromagnetic spectrum.**

Figure 2 Electromagnetic spectrum highlighting the visible band



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Our everyday understanding of "light" is only a narrow range within this vast electromagnetic spectrum. Specifically, the range between 400 nm and 700 nm. This is the so-called "visible" range or "visible light", the only one to which the human eye is sensitive. For the rest of the electromagnetic radiation, we are blind, although thanks to ingenuity and the development of technology we are able to "hear" radio waves, heat our breakfast with a microwave oven, change channels on the television with our infrared remote control, analyse a crime scene with ultraviolet light, perform clinical tests with X-rays and gamma rays, and use telescopes and detectors to reveal the Universe in each and every one of these wavelengths.

Characterisation of an artificial light source

Artificial light can be characterised, among other parameters, by luminous flux, colour temperature and light direction.

Luminous flux is the amount of light emitted by a light source (measured in lumens -lm-).

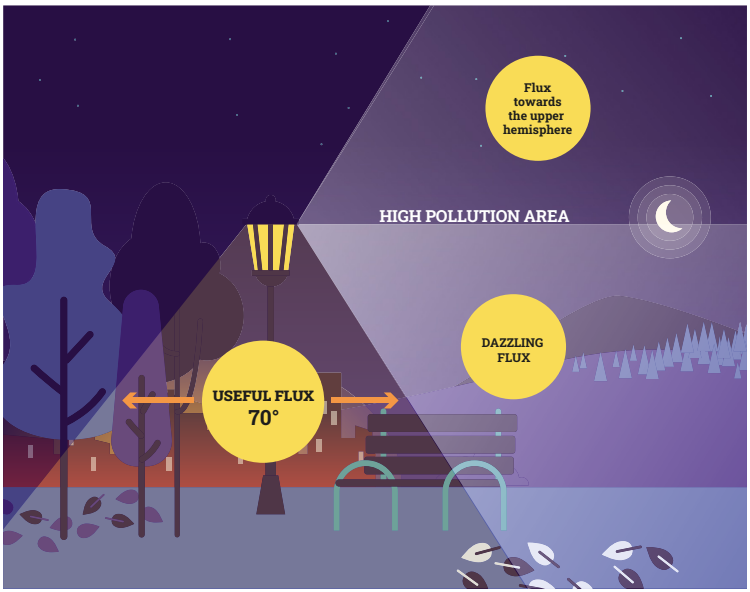
The colour temperature (measured in kelvins -K- formerly called Kelvin degrees) indicates the colour of the light emitted. The value of this parameter denotes whether the light source tends towards warmer or colder colours. The lower the colour temperature value, the warmer the light emitted by the source.

The direction is the angle at which the light is emitted from the light source and can range from 0° (pointing directly towards the ground) to 180° (if the luminous flux is aimed entirely at the zenith). Considering that the densest layers of the atmosphere, those that contain the most particles, are found in the first kilometres from the surface, the artificial light emitted by a light source will experience a greater dispersion if the angle of emission is close to the horizontal plane (70º-130º), and can reach distances of hundreds of kilometres.

This implies that the artificial sky glow we observe anywhere in the world not only comes from light points in the nearest urban areas, but is the result of the sum of scattered light from light sources located at great distances. In the predominant urban design of our cities, surrounded by large metropolitan areas, approximately 20% of the artificial brightness we see in the night sky comes from sources in neighbouring towns. So, when we talk about light pollution, we are talking about a global environmental problem that therefore requires a joint response.

When the angle of emission is close to the zenith (angles between 130° and 180°), scattering is not as intense. Light points emitting at this angle will predominantly contribute to the increase in sky brightness locally.

Figure 3 Emission angles



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The upper hemispheric flux (UHF) is the amount of light emitted towards the upper hemisphere. This parameter has been included in all current regulations concerning outdoor lighting and light pollution, such that a small UHF is associated with low polluting luminaires. But its usefulness is questionable because it does not take into account the direction in which the light is emitted. A luminaire may have a small UHF, but if all the light, however small, is emitted at an angle close to the horizontal plane, it is a highly polluting light source. In other words, a small UHF value is not synonymous with low pollution.

Lamps and luminaires

Outdoor lighting features two key parts that play an important role in the environmental problem at hand: lamps and luminaires. Both are decisive in controlling light pollution levels.

Lamps are responsible for emitting light. In outdoor lighting, there are different types depending on the way in which the artificial light is generated: incandescent, discharge or LED *(Light Emitting Diode)*.

Incandescent lamps emit heat-induced light when a very thin conductive filament increases in temperature. Discharge lamps, which include fluorescent lamps, produce artificial light by means of an electric discharge inside a bulb that is filled with gases or metal vapours. There are different types of discharge lamps depending on the gas used and the pressure of the gas. Thus, there are high- or low-pressure discharge lamps. As for the gas used, it can be sodium vapour or mercury vapour, although the latter was banned in the European Union in 2015.

Another type of lamp that has been used extensively in outdoor lighting in recent years is the LED lamp. In this type of lamp, light is generated by the phenomenon of electroluminescence when an electric current passes through a semiconductor material.

The luminaire is the structure that supports one or more lamps. It is responsible for distributing, filtering, transforming the light emitted and directing the luminous flux in the direction of the object or area to be illuminated.

Figure 4 Types of lamps

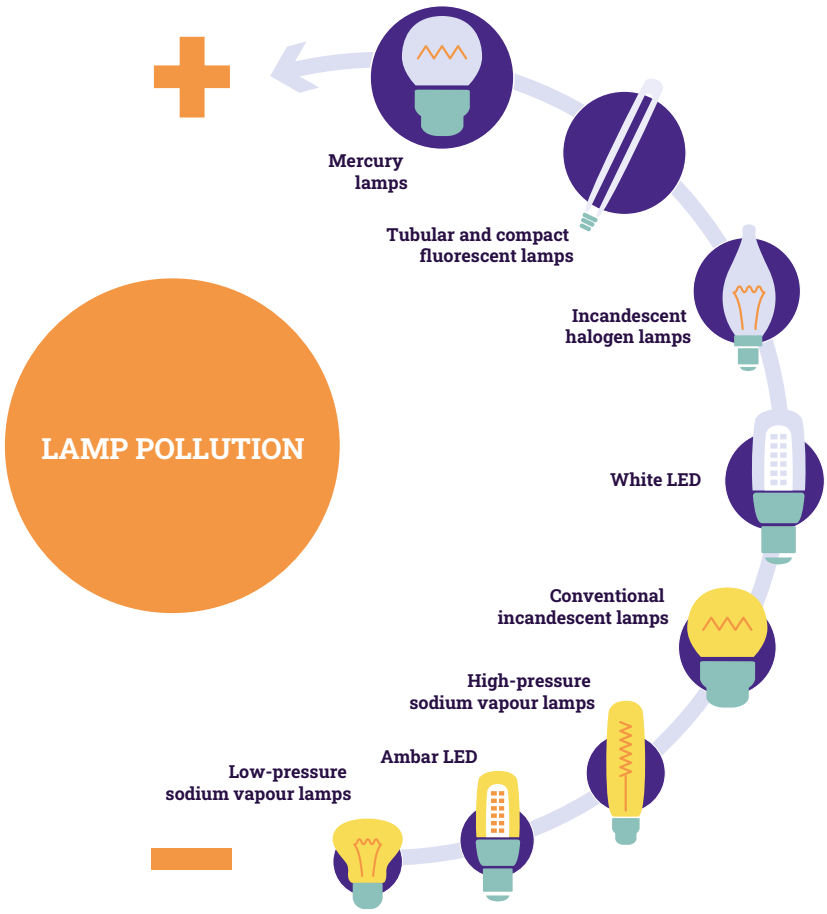

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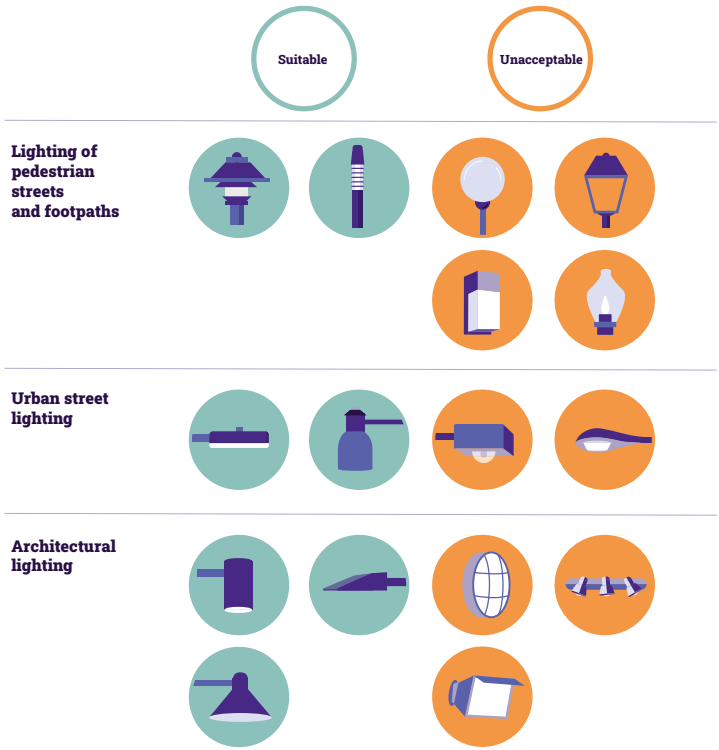
Figure 5 Types of luminaires



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The luminaire design determines the direction in which the light is emitted from the lamp into the environment. This angle of emission is a determining factor in the level of artificial sky glow and the intrusiveness of the artificial light. Another important factor linked to luminaires is the height at which they are installed. The lower the height, the better we can control the dispersion of light and achieve the same level of illumination using lower wattage lamps.

Forms in which light pollution is manifested

Most of us associate light pollution with "that luminous glow" that floods our skies at night. Indeed, what is known as artificial night sky glow (or skyglow) is the most popular manifestation of light pollution, but not the only one. The fact that astronomers were the first to express their growing concern about this form of light pollution in the 1970s has probably made it the most widely known manifestation of light pollution in society. But light pollution has other ways of showing itself that go beyond the diffusion of light into the sky causing artificial glow. Light intrusion and glare are also another side of the same coin.

Skyglow: When artificial light points directly at the sky or reaches it reflected from pavements and building facades, we encounter the most aggressive and well-known side of light pollution: artificial skyglow, which directly affects astronomical observations, disturbs the night landscape, preventing us from enjoying starry skies, and greatly disturbs nocturnal animals.

But what happens when artificial light reaches the sky? The particles in the atmosphere will interact with the light and the light will be scattered in all directions. It is as if the atmospheric particles act as a kind of secondary light source. The way visible light propagates in the atmosphere will depend on the wavelength of the emitted light and the type of particle it interacts with, which may be a gas molecule or an aerosol. The shorter the wavelength of the light hitting the gas molecules (blue light), the greater the scattering effect. Conversely, longer wavelength light (red light) has less scattering ability. With regard to the range of the emission spectrum of the light source, the greater the range, the greater the increase in artificial sky brightness, since the light emitted covers a greater number of wavelengths and increases the chances of light meeting particles in the atmosphere. The scattering capacity of artificial light also increases with the presence of atmospheric particles.

Artificial sky glow in a natural landscape. / JOSE JIMÉNEZ

The level of air pollution, humidity and the presence of clouds intensify the number of particles in the atmosphere. This results in an increased scattering of artificial light in the atmosphere and greater artificial sky brightness. Between January and April 2020, during the most severe lock-down period caused by the COVID-19 pandemic, several studies were carried out in different cities around the world to investigate the impact of confinement on the levels of artificial sky brightness. A study carried out by CSIC in the city of Granada concluded that, due to the significant decrease of pollutant particles from urban traffic in the atmosphere, the levels of artificial skyglow were lower than in the previous months.

Light intrusion: This occurs when the luminous flux exceeds the space to be illuminated and floods other areas. In general, it is due to the use of luminaires that are too high or positioned close to areas that should not be illuminated, such as, for example, the light that enters homes through balconies and windows. This is one of the forms of light pollution that people perceive as most annoying, although we are not aware that it is a manifestation of this environmental problem. Intrusive light is also very common in coastal areas where large stretches of water are illuminated by the endless rows of street lamps along the promenades.

Spherical luminaires, such as street lamps hanging from façades, the spotlights that illuminate our monuments, large illuminated signs in shopping centres, shop windows, night clubs, etc., are pollutants responsible for light intrusion.

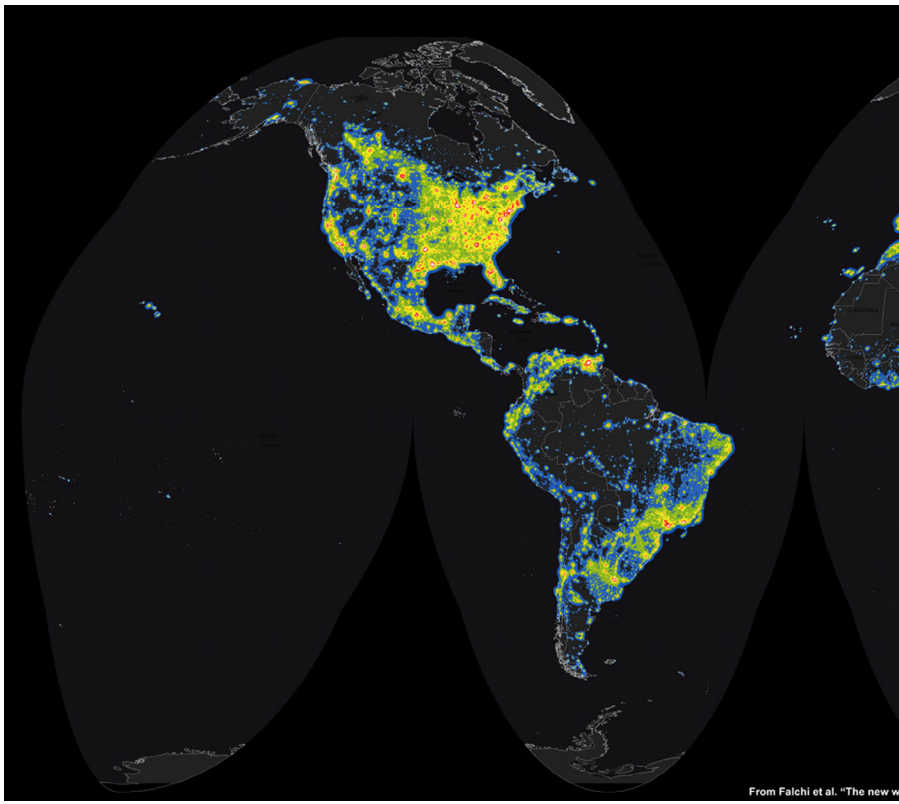
Glare: Either because luminaires are poorly aimed and point the light directly into our eyes (or at the photosensitive organs of other organisms), thus breaking into our field of vision (direct glare), or because an excess of light on a given surface reaches our vision (reflected glare). Glare is a particularly important manifestation of light pollution in road lighting, where special attention should be paid to prevent excessive power, sudden changes from brightly lit areas to dark areas or poorly directed luminaires to avoid glare.

1.3.

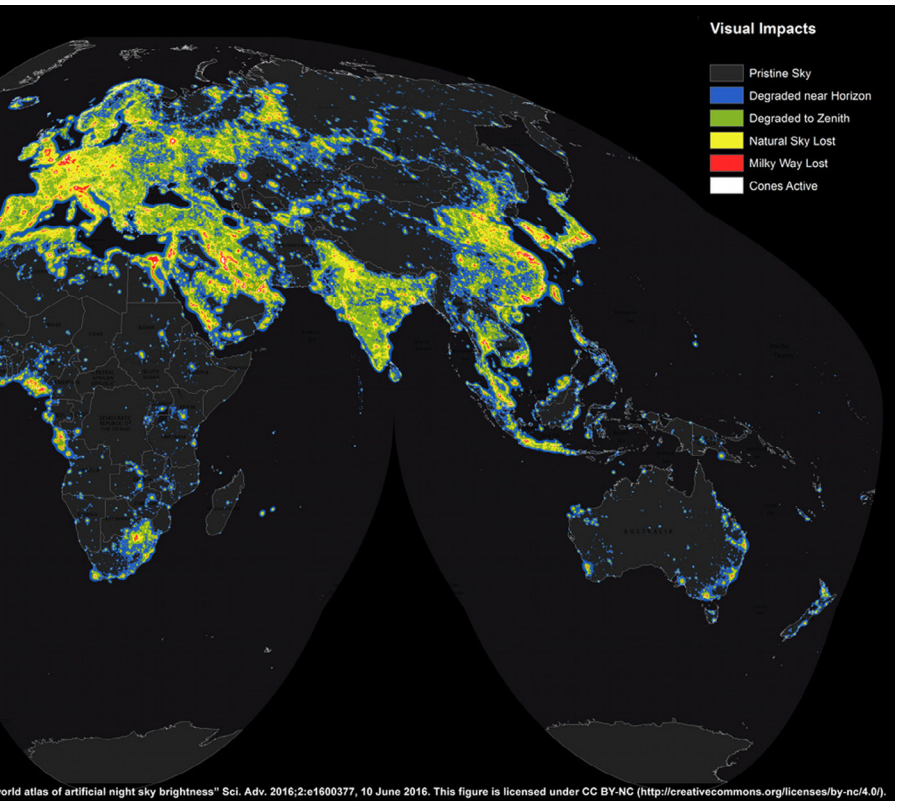
Current situation

Light pollution is a global environmental problem. The ability of light to scatter allows it to reach long distances from the actual light sources, so light pollution should not be considered a purely urban problem. This is demonstrated by data from the International Union for Conservation of Nature (IUCN), according to which two thirds of the key biodiversity areas of our planet are exposed to light pollution.

Providing specific figures for this global problem is difficult due to the variability in data collection methods, the lack of a standardised methodology for measuring and characterising the problem and the absence of comprehensive global official reports.

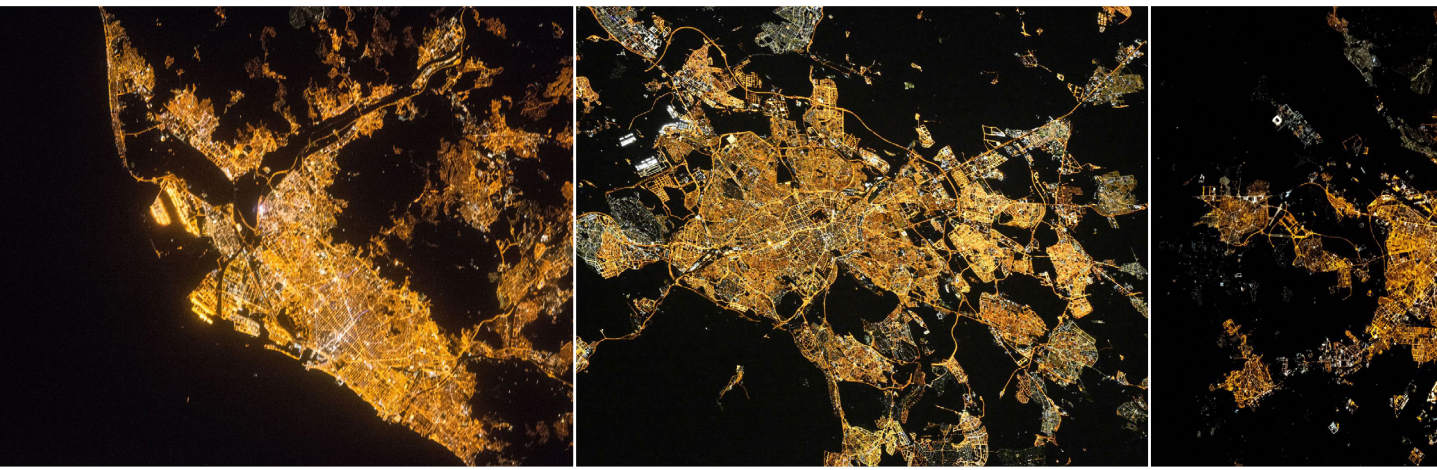


One of the most widely used tools by the international scientific community from which to extract data on this environmental problem is the World Atlas of Artificial Night Sky Brightness published in 2016. This map, as its name suggests, collects information on the most visible manifestation of this environmental problem, artificial sky brightness, caused by the dispersion of artificial light in the atmosphere due to the excessive lighting of our towns and cities. According to the World Atlas of Artificial Night Sky Brightness, 85% of the world's population lives under polluted skies. If we live in Europe or the United States, the figure rises to 99%. A figure that contrasts with the more than 1.3 billion inhabitants of the planet who have no access to electricity.



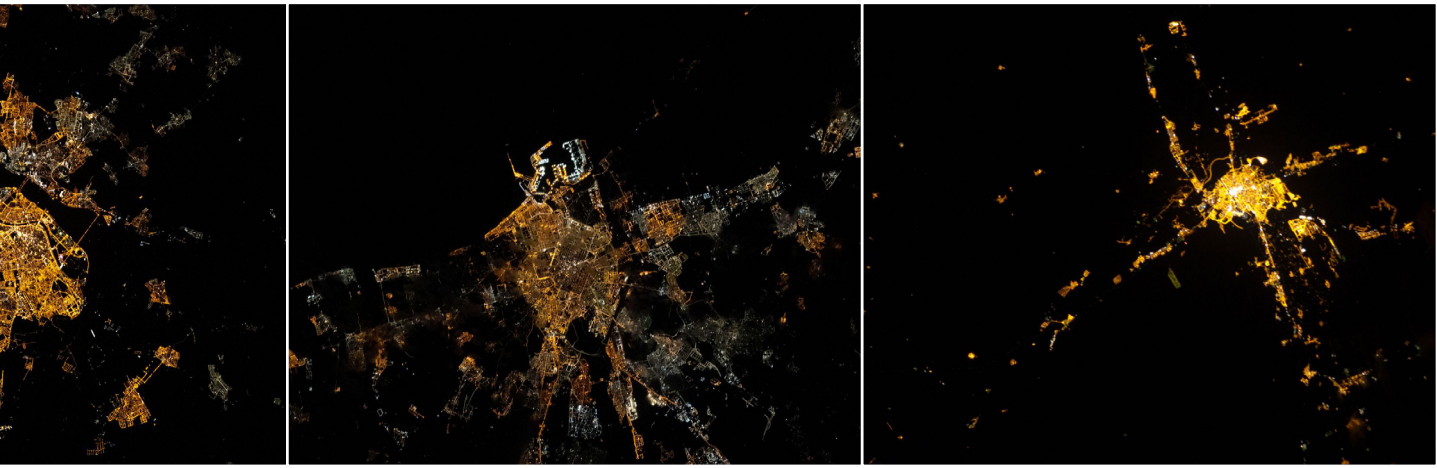
World Atlas of Artificial Night Sky Brightness

FALCHI *ET AL.*, 2016



Chad, Central African Republic and Madagascar are the countries least affected by light pollution. Three quarters of their inhabitants live under a night sky completely free of artificial glow. Singapore, on the other hand, is the most light-polluted country in the world. Its entire population lives under a night sky so bright that the human eye cannot fully adapt to the darkness. It is followed by Kuwait, Qatar, the United Arab Emirates and Saudi Arabia. The strong oil industry that these countries share guarantees them an energy supply that favours the proliferation of points of light.

Europe is the most light-polluted continent on the planet. The most critical cities are Madrid, Paris, Milan, Amsterdam, Brussels and London. Our country, Spain, is the third country in the European Union, only surpassed by Greece and Malta, in terms of light pollution levels and where there is the highest expenditure on public lighting per inhabitant, with average consumption values per inhabitant per year of 116 kilowatt-hour (kwh) compared to Germany's 43 kwh or France's 91 kwh.



Madrid is the city with the highest power emission and, therefore, the one that emits the most light into the sky, followed by Zaragoza, Seville, Barcelona and Valencia. However, if we look at the most polluting light sources (white lights, flow to the upper hemisphere and angles of emission close to the horizontal plane) the ranking is headed by Bilbao, followed by Hospitalet de Llobregat (Barcelona) and Barakaldo (Bizkaia).

Images taken from the International Space Station (Barcelona, Madrid, Seville, Valencia, Zaragoza)
ESA/NASA. LOCATION CITIES AT NIGHT

14.

How does light pollution affect us?

UNDERSTANDING the negative consequences of light pollution can help us to be more aware of the real problem of excessive lighting in our towns and cities. Artificial light is an indispensable element in our current social model, but it is important that we are aware of the consequences of its inappropriate and extreme use.

Light pollution has an impact on four main areas: on the balance of ecosystems, on astronomical observations, on cultural heritage and on our health.

Ecosystem balance

Despite seasonal variations, the cycles of light and dark have remained more or less unchanged for millions of years. Life has developed and evolved under this predictable pattern of light and dark, so that essential biological functions, such as reproduction, foraging, migration and flowering, are adapted to these cycles of light and dark.

Light pollution, however, has burst into ecosystems with force to break these cyclical and ordered patterns to which living beings are adapted.

Biological impacts have been documented for virtually every taxonomic group on the tree of life, making artificial light a risk factor for the balance of our planet's ecosystems and biodiversity. Impact has been detected on the physiology and behaviour of individuals, on the abundance and distribution of species, and on the structure and function of communities and ecosystems.

Despite the great diversity of impacts identified, we can highlight four that may be key to understanding the problem:

- Artificial lighting, even at very low intensities, suppresses the secretion of important hormones such as melatonin. This hormone is involved in the regulation of sleep, circadian rhythms, oxidative stress and immune response. It is also an inhibitor of cancer cell growth.

- Light pollution changes seasonal and daily light signals, altering essential functions in the life cycles of organisms, such as reproduction, migration, flowering, feeding and survival.

- Artificial light points interfere with the orientation and movement of organisms, either by confusing their own natural orientation systems or by acting as an element of attraction or repulsion, even when these light points are located at distances of hundreds of kilometres.

- Light pollution, because it can modify the timing and frequency of biological functions of species, can alter the relationships between species, a key aspect of biodiversity, such as the link between pollinator and plant, predator and prey or parasite and host, among other examples. Through cascading effects, light pollution affects even species that are not directly under the influence of artificial light.

Light pollution therefore triggers responses that affect all levels of ecological organisation from individuals through populations and communities to ecosystems.

Astronomical observations

Advancing our knowledge of the Universe is not possible if we do not guarantee a dark sky. Much of astronomical activity is based on observing a celestial object and measuring the amount of light per wavelength interval emitted by the object, which is known as its emission spectrum. We could say that the emission spectra of celestial objects are like their QR codes, which are then *read by* astronomers using all the physical laws and mathematical models at their disposal, thus obtaining information about the nature of the observed object.

And for the sky to be a good laboratory for science, from an astronomical point of view, it must fulfil three criteria that condition the search for the best sites in the world to locate and build telescopes:

1. No cloud masses or aerosols should be present.

2. It must be very stable atmospherically, i.e., it must not form air bubbles (similar to those created in boiling water) that act as unstable lenses, which are quickly created and destroyed, and which blur the image of the object we are observing.

3. No artificial brightness. The more the sky is artificially brightened at night, the lower the contrast between the colour of the sky background and the astronomical object observed. Therefore, in very light-polluted skies we will only be able to observe extremely bright bodies that are able to contrast with the brightness of the luminous sky, and we will miss an infinite number of objects.

We cannot jeopardise the scientific and technological development linked to observatories. Modern science owes much to the observation of the sky and the study of astronomical phenomena. Advances in knowledge allow us to respond to social priorities such as health, communications, poverty eradication and environmental protection.

Cultural heritage

The magnificence of the night sky has aroused the curiosity and interest of mankind since its origin. In addition to enjoying the fascinating beauty of the firmament, mankind has, since ancient times, looked at the sky with eyes full of questions: we need to look at the sky to know who we are.

The study of the firmament has gone hand in hand with the development of different civilisations and has been, and continues to be, an important source of knowledge. Its observation was decisive for, among other things, the development of navigation by sea and for determining the beginning of the sowing season in

1.23-metre telescope dome. Calar Alto Observatory. / DOMINIQUE JOUBERT

agricultural societies. It has allowed us to establish the position of our planet in the galaxy, to discover that we share chemical composition with the stars or that they move in that dome over our heads while the earth rotates on its polar axis, thus offering us a majestic stellar spectacle.

A spectacle that, today, is a fantasy for more than 80% of the planet's population; 99% of the population if we live in Europe or the United States. Do we want to give up enjoying the breath-taking scenery of a starry sky?

We cannot look the other way, we cannot allow this indescribable landscape, a fundamental part of our cultural and historical heritage, to disappear. A landscape common to all the cultures of the world, a landscape that has accompanied us silently since prehistoric times, that forms part of our daily lives, of our beliefs, of our culture, and that is and has been a source of creative inspiration.

Human health

Humans have also evolved in this rhythmic context of alternating light and dark, which has been altered with the advent of artificial light that has flooded the 24 hours of the day. This is not harmless to our organism, evolutionarily adapted to the natural light pattern of day and night.

The presence of artificial light during the night has two direct and immediate consequences on our organism: the alteration of our biological clock and the suppression of melatonin synthesis. These impacts can, in the long term, translate into disease.

Milky Way from Calar Alto Observatory. / ALEJANDRO SÁNCHEZ DE MIGUEL

Biological clock: Our body has an internal clock that regulates a series of biological parameters that are not constant, but vary depending on whether it is day or night. These fluctuations, which are repeated day after day every 24 hours, are known as circadian cycles. For example, the secretion of cortisol, the hormone that makes us feel stressed, is regulated by this clock, and is higher in the morning than at night. Melatonin secretion or blood pressure also respond to these day-night fluctuations.

The main synchroniser of our internal clock is the alternation between natural light and darkness in a 24-hour period, signals received by the body through our eyes. Therefore, excessive exposure to artificial light at night prevents our clock from synchronising with the environment. It is necessary for day to be day and night to be night, otherwise our internal clock will not function properly.

When the natural light-dark cycle is disturbed due to the abusive use of artificial light at night (either by the glare of our mobile device screens, light intrusion or night shift work), our internal clock is not synchronised with the external clock, it starts sending signals at night that it should be sending in the morning and our circadian cycles are disrupted. This chaos is known as chronodisruption. Epidemiological studies show a link between chronodisruption and an increase in metabolic disturbances (which increase the risk of hypertension, diabetes, obesity and high blood cholesterol levels), as well as cardiovascular disease, cognitive impairment, affective disorders and accelerated ageing.

To maintain a proper state of health, it is essential that our body keeps its circadian rhythms in order.

Melatonin synthesis: Melatonin is a hormone secreted in the pineal gland, or epiphysis, which plays important roles in our body. It is responsible for transmitting the internal clock message to the rest of the body, is an important antioxidant and inhibits the growth of cancer cells, thereby reducing the risk of tumours.

Free radicals, which appear as residues of the oxidation-reduction reactions through which our body obtains most of the energy it needs, can damage our macromolecules (lipids, proteins, carbohydrates and nucleic acids). This damage can disrupt key cellular processes such as membrane functionality, enzyme production and cellular respiration, leading to diseases such as atherosclerosis, premature ageing, high blood pressure and senile dementia, among others. Many debilitating diseases, such as Alzheimer's disease or Parkinson's disease, especially in the elderly, include as part of their degenerative process the accumulation of oxidative damage by free radicals. This is why melatonin's antioxidant capacity to neutralise these free radicals, which are so harmful to us, is so important.

Melatonin is only secreted at night. The presence of natural light during the day or artificial light at night suppresses the synthesis of this hormone. The ability of artificial light to inhibit the production of melatonin makes it a very dangerous pollutant for our health because of the key functions of this hormone in our body.

Other studies: Epidemiological studies associate continuous night shift work (high exposure to artificial light) with an increased risk of breast cancer in women. Other studies have shown a positive correlation between exposure to high levels of artificial light and breast, prostate and thyroid cancer.

The study of the impact of light pollution on our health is not as advanced as that of the effects on biodiversity. Although more and more scientific research is linking light pollution with adverse effects on our health, the volume is still small and, in most cases, they are observational studies and do not establish a causal relationship. It is therefore necessary to deepen this field of research in order to know the real extent of the effects of light pollution on human health.

15.

The challenges of sustainable lighting

Light pollution is caused by the use of artificial light, so the solutions involve reviewing the way we use it. The aim is not to "switch off" cities, but to light them in a more sustainable way.

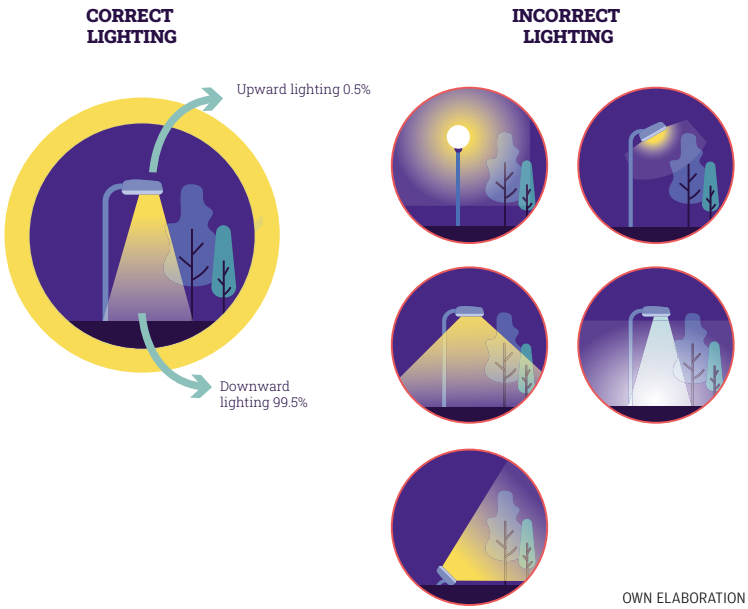
Sustainable lighting that respects the environment, our health, the advancement of knowledge and the right to enjoy a dark sky, must illuminate what we want to see only when and as it is necessary. Let us take a look at each of these assumptions.

Light directed towards the sky increases artificial brightness and wastes energy. Globe-type luminaires, without any shielding, emit light in all directions and waste at least 50% of the electricity they consume. Since, for the time being, humans do not perform any activity in the sky that requires such lighting, it is necessary to avoid directing the light towards the upper hemisphere by always directing the light beam downwards, towards what needs to be illuminated, by using luminaires that are shielded.

In addition to always shining downwards, angles of emission close to the horizontal plane should be avoided as they contribute most to the dispersion of light in the atmosphere. The least polluting angles are those between 0º (corresponding to the base of the lamp) and 70º. Let us also try to respect the darkness of our homes by avoiding the use of luminaires that are very close to our windows or that emit in directions greater than 70º, which could reach windows and balconies and cause light intrusion.

Technological developments have made dimmers, motion sensors and timers available to us, which are very useful in fulfilling the second precept of sustainable lighting: light only when necessary. The use of these devices makes it possible to adapt the lighting system to traffic levels or the type of activity taking place in the illuminated space. In addition to using these elements, it is necessary to limit the lighting schedules of monuments, building façades, advertising signs, etc.

Figure 6 Correct and incorrect uses of lighting



In order to comply with the third premise of sustainable lighting, it is essential that we take into account the lighting levels recommended by international organisations such as the International Commission on Illumination (CIE) depending on the area or activity in question.

Only lamps that emit light in the visible range of the spectrum, which, as stated above, is the only light that our eyes can perceive, should be used. It makes no sense to use lamps that emit light in wavelengths that are not sensitive to the human eye, such as fluorescent lamps. And, among the lamps that emit light within the visible spectrum, we should choose those that have a lower colour temperature and therefore emit light of a longer wavelength (orange-red) as opposed to lamps that emit light of a shorter wavelength (blue) and a higher colour temperature. The bright white light emitted by many of the light points in our cities contains the highest amount of blue radiation. This

type of light illuminates the night sky the most and has a major impact on astronomical observations, and is the most dangerous to our health and to the balance of ecosystems. In addition, this blue-rich white light is the one that causes the most glare problems, causing serious road safety incidents for pedestrians and drivers.

Are LED lamps the solution to light pollution?

LED technology experienced a major breakthrough in the second decade of the 21st century and has begun to replace traditional high- and low-pressure sodium vapour lamps and metal halide lamps. We are currently witnessing a gradual transition in public lighting towards LED lighting, which will be the majority light source by 2030, although the percentage of LED street lighting will vary by country, region and local policies.

LED lamps were proposed as a solution to the energy wastage in public lighting. However, the widespread belief that LED lights save a lot of energy has its nuances. Public lighting only offers very high energy efficiency if we use LED lamps that emit white light, which is extremely polluting for our ecosystems and has proven impacts on our health. It therefore became necessary to manufacture LED lamps that emit warmer light.

The energy efficiency of LED lamps that emit warmer, and therefore less polluting, light is not much higher than that of the sodium lamps we already had on our streets: the energy efficiency of a high-pressure sodium vapour lamp is around 100 and 120 lumens per watt, almost the same as that of an LED lamp of the same colour (amber). The energy expenditure and carbon dioxide emission (CO_2) into the atmosphere is also very similar.

Rebound effect of the use of LED technology: The energy savings that have resulted from the massive installation of white LED lighting have meant that with the same expenditure on electricity bills, local councils have been able to multiply the number of light points or keep those they already had on for longer. This rebound effect has led to over-lighting above the real needs, with a consequent increase in the level of light pollution. LED lamps also have other environmental disadvantages, as they require more raw materials during the manufacturing process and contain high concentrations of metals, which means that their waste is classified as hazardous.

Advantages of using LED lighting: What we cannot ignore are the advantages offered by this technology. One of them is that it allows us to choose the colour of the light they emit; the semiconductor diodes can be combined and filter their light so that, unlike other types of lamps with inflexible emission spectra, we can obtain *customised* emission spectra and colour temperatures that adapt to different needs. This is the case with PC-amber LEDs, which have very low blue light emissions (below 500 nm). Other advantages are, for example, their instant-on capability, which means that the lights can be switched on and off and quickly reach their maximum brightness level; the directionality of the light, which allows the beam to be better directed towards what is to be illuminated; and finally, the possibility of regulating their intensity, thus being able to reduce the amount of light to a minimum when the street is deserted.

For these advantages to be translated into a more sustainable form of lighting, the installation of LED lamps must be accompanied by the design of a digital system that helps to apply them and a plan that assesses the real need for light in each space according to the time of day and activity. And, above all, environmental intelligence and awareness.

Laws and regulations

The existing regulations in our country are mainly aimed at limiting the type of lamp used in order to minimise the most harmful wavelengths, controlling lighting levels (lux), limiting the time of day to avoid wasting energy and avoiding the flow of light to the upper hemisphere, which contributes so much to the increase in light pollution in several of its facets (skyglow and light intrusion). Could we go a step further? Of course.

When we refer to other pollutants, such as noise or CO_2, current regulations always set restrictions on the emission level of the pollutant in question. It is widely assumed that the maximum limit of sound emitted by a source cannot exceed 55 decibels (dB) between 6:00 a.m. and 10:00 p.m., or that CO_2 emissions must be reduced by 35% by 2030. However, when the pollutant is artificial light, there are no maximum permissible levels in any law limiting both pollutant radiation and luminous flux. An international consensus is needed, involving governments and the scientific community, to set limits on light pollution levels and to standardise a methodology and set of parameters for measuring these levels.

Proper regulatory development is one of the solutions to the problem of light pollution. But it must be more than a set of obligations and limitations. Proper regulation is the result of political and scientific compromise.

Italy and France are the European countries with the most advanced dark sky protection laws in the world. In Spain the situation is different. We are still without a state law on light pollution, although this is on the way. At the end of 2021, the draft decree law on light pollution was submitted for public consultation. The scientific community has requested that the results of research on the effects of light pollution on the environment and health, as well as the recommendations of organisations such as UNESCO, UN (COPUOS and UNOOSA), IAU and Dark Sky, be considered in the drafting of the final document of this future decree.

In Spain, the development of legislation on light pollution has been bottom-up, with the legislative efforts of autonomous communities such as the Canary Islands and Catalonia being particularly noteworthy.

And very importantly, let us not forget that when it comes to environmental issues, a country's legislation is a reflection of the awareness and social commitment of its inhabitants. The greater the social commitment, the greater the pressure exerted at the political and legislative level. This is why raising social awareness and sensitising the population to the existence of this environmental problem is an indispensable condition for tackling light pollution.

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Other hazards

Light pollution is not an isolated threat. Climate change, drought, overexploitation of resources, deforestation, plastic pollution or the use of chemical pollutants, among others, make up a wide range of factors that threaten natural ecosystems and our health.

For its part, the sky, considered both as a key space for science and the advancement of knowledge and as a unique heritage resource for humanity, not only faces the threat of light pollution. The mega-constellations of artificial satellites in Low Earth Orbit, their re-entry into the atmosphere or radioelectric pollution, which is increasing due to the proliferation of devices that artificially emit radio wavelengths, are other threats that are endangering a resource that has inspired humanity for millennia and that has been and is key to modern science.

The challenge is not to characterise and quantify the effects of these risks individually. The challenge is to study the cumulative impact of the set of hazards that may interact with each other and aggravate their effects.

3D representation of the global communication network around the planet Earth in space. Elements of this image provided by NASA. / ADOBE STOCK