TAB OFFICE OF TECHNOLOGY ASSESSMENT AT THE GERMAN BUNDESTAG

Light pollution – extent, effects and approaches

TAB-Fokus no. 25 regarding report no. 186 June 2020

Summary

- In addition to the intended effects, the increasing use of artificial outdoor lighting also entails a number of undesirable side effects referred to as light pollution.
- Artificial lighting can disturb the circadian rhythms of humans and animals, which are controlled by the change of day and night, and is suspected of being involved in the development of various diseases.
- Moreover, the increasing illumination of the night influences the natural behaviour of animals. Besides habitat changes, the consequences are ranging from changes in hunting or reproductive behaviour to the deadly attraction effect of light sources, e. g. for insects. However, the long-term consequences of these changes for entire populations, communities or landscapes are still poorly understood.
- Options for reducing light pollution exist both technologically and in terms of regulation and approval of lighting installations.

What is involved

Artificial light is one of the greatest achievements of mankind with considerable significance for the way we work and live. However, artificial lighting also influences the biological rhythm of day and night and thus the overall structure of natural balance. In Germany, a naturally dark night sky has become rare. Moreover, stars and the Milky Way are hardly recognisable due to light domes over urban areas. In addition to the increased brightness of the sky, light can also unintentionally brighten the immediate surroundings. Light is an important »zeitgeber« (literally: time giver) to the natural rhythm of which humans, animals and plants have adapted over thousands of years. Thus, it is assumed that light conditions that are permanently or periodically changing – due to increasing artificial lighting – have negative effects on human health and also lead to ecological impacts.

Against this background, the Office for Technology Assessment at the German Bundestag (TAB) was commissioned to summarise the current state of scientific knowledge with regard to the extent and trends of light pollution and its sociocultural, human medical and ecological effects and to derive options for action in order to support a reduction in light pollution.

What is light pollution and how is it measured?

Light pollution refers to all unintended effects of artificial lighting, i. e. the proportion of artificial light that has effects beyond the pure purpose of lighting, either spatially (direction and area), temporally (time of day and season, duration, periodicity) or through its intensity or spectral composition (e. g. ultraviolet or blue component) (fig. 2).

The various types of light pollution can be measured using different methods. Direct light emissions can best be analysed based on the properties of the light sources, which are registered in so-called lighting cadastres. Unfortunately, the necessary information is often missing or only known for public (street) lighting. Vertical photographs allow getting a lateral perspective of the lighting situation and are particularly suited for studying the temporal variability of light emissions. Light emissions radiated in upward direction can be determined using horizontal aerial and satellite images. However, the informative value depends on the resolution of these images and is also influenced by factors such as foliage or cloud cover. The brightness of the sky can be determined indirectly by detecting the faintest stars that are just barely visible. As an alternative, it can be modelled using data from lighting cadastres and remote sensing.

What is the extent of light pollution and how is it developing?

Based on satellite data, a worldwide increase in the area illuminated at night and in the intensity of illumination of about

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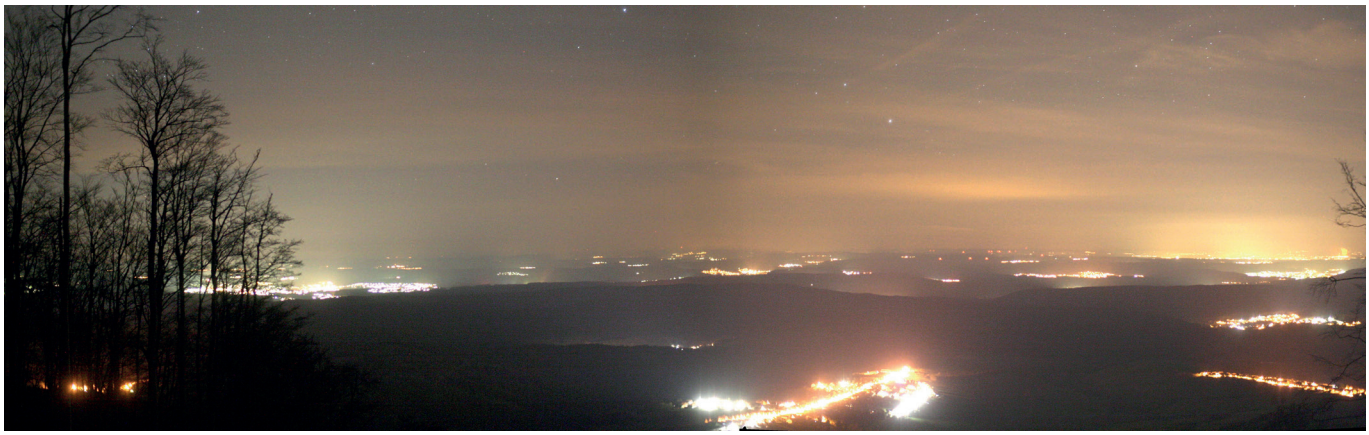
Fig. 1 Light pollution in a panoramic view from the Kreuzberg (Rhön Mountains) looking south



2 % per year each can be observed. In many rapidly developing countries in Africa, South America and Asia, the increase is above average, whereas in already brightly lit countries, such as e. g. Germany, it is often only moderate or in some cases even slightly negative.

Within Germany, most of the Länder show increasing values both for the illuminated area and the intensity of the illumination – Bavaria and Schleswig-Holstein being particularly noteworthy. The exception is Thuringia with a decrease both in the illuminated area and intensity of illumination. A scientifically sound analysis of the causes behind this observation is not yet available. It is assumed that the increase is caused by settlement growth and land use as well as by an increasing use of private outdoor lighting, while the decrease is rather an artefact of measurement, because light emissions of newer LED lighting systems are only insufficiently detected by satellite sensors.

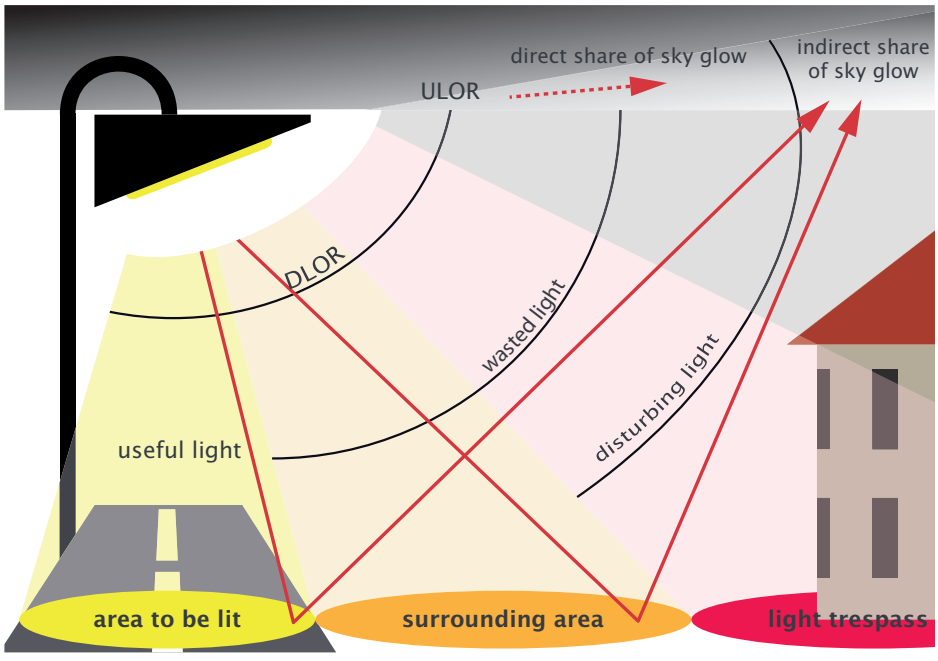
Does light pollution make you sick?

On the one hand, medically relevant effects of light at night result acutely from suppressing the release of the hormone melatonin, which is involved in the regulation of sleep and the temporal coordination of many body processes. On the other hand, these effects result from the associated disturbance of the circadian rhythm (i. e. characterised by the change of day and night within a cycle of 24 hours) of the body's own metabolic processes.

Studies in sleep labs have shown that both acute and circadian light effects can lead to physiological states that are similar to a clinical manifestation – e. g. that of diabetes or cardiovascular disorders. It is unclear, however, from which extent the shift in circadian rhythms poses a threat to health. This is why there are no thresholds or reference values for light intensities or for the extent and duration of the temporal shift.

Some scientific studies have found a statistical correlation between the two variables by using satellite data on light pollution and data on the incidence of cancer. However, a causal relation between light pollution and the risk of developing a disease cannot be proven, since the

Fig. 2 Types of light pollution



DLOR (downward light output ratio) = proportion of light emitted into the lower half space
ULOR (upward light output ratio) = proportion of light emitted into the upper half space
Sky glow = artificially increased sky brightness due to emitted or reflected light scattered back by the Earth's atmosphere

Image page 1: Craig Mayhew/Robert Simmon, NASA GSFC; fig. 1: A. Hänel;
Fig. 2: adapted from Deutsche Lichttechnische Gesellschaft e. V. 2011 and Lang 2013

individual light exposure of the affected persons as well as the parameters of the circadian rhythm or of the melatonin release have not been surveyed. Thus, although there are scientific indications, there is no scientific evidence of adverse health effects of light pollution.

How do animals and plants react to increasing artificial lighting?

Animals and plants depend on regular differences in their light environment to synchronise their seasonal and diurnal behaviour. Moreover, two thirds of all invertebrates and one third of all vertebrates are nocturnal species and thus directly affected by a brightening of night landscapes.

Depending on the species, different effects of light pollution can be observed (fig. 3). Thus, artificial lighting can cause behavioural changes, e. g. a temporal shift of hunting, resting or reproduction phases. The local radius of activity of individuals can also be changed if e. g. insects are attracted by artificial light sources or if illuminated areas are avoided by animals and e. g. street lighting becomes a barrier.

There are major differences between individual species with regard to spectral sensitivity. In general, the number of species affected and the extent of the effects increase the brighter the lighting and the higher the blue and ultraviolet spectral components.

Plants react to artificial lighting, e. g. with a delayed leaf shedding or altered flowering times. Thus, frosts can damage the plant tissue or the synchronisation of flowering with the occurrence of pollinators can be impaired.

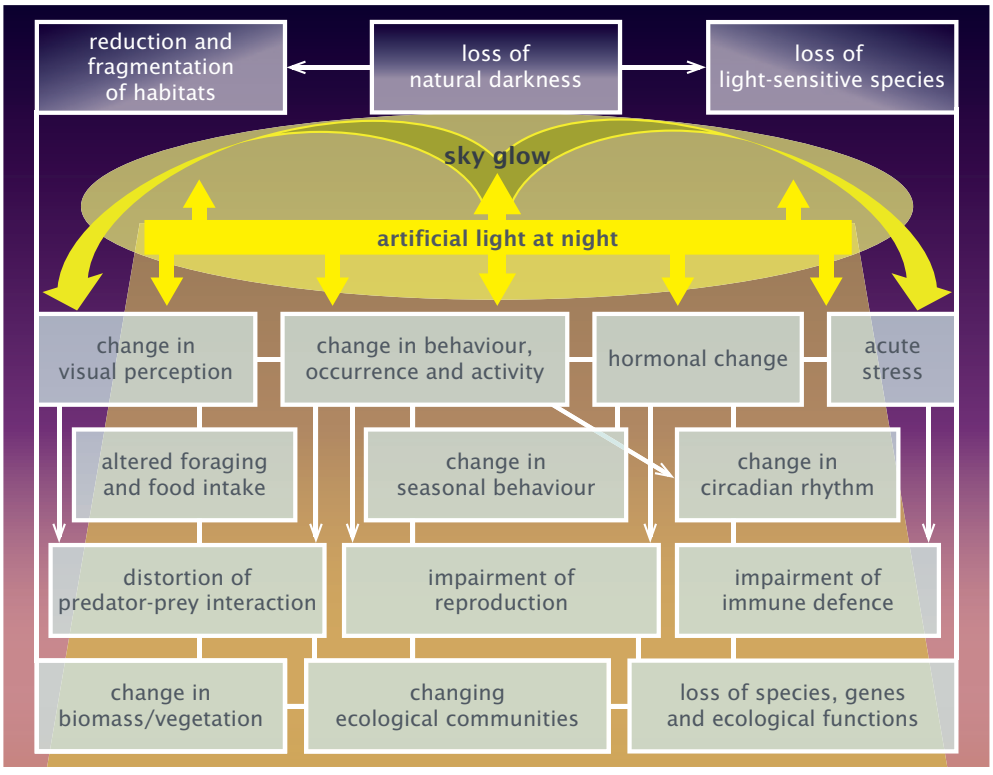
Although individual effects of artificial lighting on some animal and plant species have been well studied, it is not possible to make scientifically sound statements on the effect of an increasing illumination of the night with regard to populations or biotic communities or to derive tangible dose-response relationships. It is often unclear how adaptable species are in the long term or what consequences might result from this adaptation for other plants and animals. Moreover, it is unclear what significance light pollution has as a risk factor alongside other strains (urbanisation, landscape fragmentation, nutrient and biocide inputs, climate change, changes in species composition, etc.).

Will it all get better with LEDs?

In addition to the high energy efficiency involved, LED lighting offers the potential to use light more effectively and avoid light pollution thanks to its controllability. By shifting the spectral composition of the generated light towards typically higher blue components, LED lighting also appears brighter to the human eye than lighting with lower blue components, so that a certain desired brightness could be achieved using a lower intensity of illumination.

However, the short-wave blue light spectrum of LEDs is suspected of causing adverse effects with regard to human health and ecological aspects. Moreover, the availability of low-energy LEDs at a low cost is leading to an ever-increasing use of light both in public lighting and in private households. And finally, when converting to LED technology, often only the light sources are replaced, whereas the opportunities of intelligent lighting control, the use of optimised lamp types and adapted distances of street lamps remain unused. For this reason, the theoretical potential of converting outdoor lighting to LED technology or making better use of other light sources in terms of saving energy and avoiding light pollution is far from being realised.

Fig. 3 Effects of light on flora and fauna



How can light pollution be reduced?

As already indicated, the innovations in the field of lighting and control technology open up new technological opportunities. However, there is a lack of binding or at least universally accepted criteria (such as e. g. industry standards for street lighting) that provide guidance for specific functions (e. g. safety or commercial lighting), locations (e. g. city centres, rural areas or nature conservation areas) and the time of lighting (e. g. more or less intensive times of use).

For a stronger regulation of lighting, there are some starting points in the fields of immission control, nature conservation and urban land use planning. At the local level, municipal lighting statutes or lighting master plans can be used both to initiate a public debate on the negative side effects of artificial outdoor lighting and to provide guidance for the design of public and private lighting systems. Among the European neighbour states, there are some pioneers, such as e. g. France, Italy or Spain, that have adopted national or regional laws against light pollution. These laws stipulate limit values for lighting intensities or timed shutdowns for specific lighting systems.

At present, because of a lack of legal regulation, industrial standards are usually used as a guide for the installation and operation of street lighting systems. Although, at a formal level, these standards are not legally binding, they are in fact highly influential. However, unintended side effects of street lighting on human health, ecology, climate protection or the cityscape are currently hardly or not at all taken into account in the development of standards. A clarification of whether a (implicit) need to refer to the standards actually arises from jurisdiction could give local authorities more planning security and open up opportunities to prevent light pollution from street lighting.

Which options for action exist?

In order to strengthen possible regulatory approaches, we should not wait for the complex research of relevant parameters and thresholds. To counteract the trend of brightening night landscapes, light emissions should rather be assessed in a precautionary manner. Based on this, guidelines for action can be concretised using current knowledge and state-of-the-art technology. In doing so, it is also possible to benefit from the experience of other European countries. Thus, measuring and monitoring systems could be established to monitor the development of artificial illumination, e. g. by the mandatory use of a lighting cadastre. The Länder and local authorities would benefit from the provision of guidance to remove legal and planning uncertainties, e. g. with regard to the significance of industry standards for street lighting.

For federally owned buildings and facilities, lighting guidelines could be developed and implemented to minimise light pollution. The development of integrated local and regional lighting concepts can be advanced by means of funding programmes, awards and competitions for sustainable lighting. Finally, limit and guide values could be established as a basis of assessment in order to be able to evaluate light emission protection in already existing formal planning and control instruments. It is also worth considering the option of developing an independent regulation to limit light pollution.

TAB report no. 186
Lichtverschmutzung – Ausmaß, gesellschaftliche und ökologische Auswirkungen sowie Handlungsansätze

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www.tab-beim-bundestag.de/en/research/u30500.html

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