

# A SUSTAINABLE WORLD REQUIRES DARKNESS AT NIGHT

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**ABSTRACT:** Multiple environmental challenges face today's world. One of the most damaging but least widely recognized arises from artificial light at night (ALAN). Light pollution is now known to be harmful to human health, mainly through disruption of hormone production and of human circadian rhythm, which causes sleepless nights, depression, anxiety, hypertension, diabetes and contributes to some types of cancer. ALAN is also bad for the environment. Almost all species of animals and plants are adversely impacted by light pollution, and not just nocturnal animals. Light pollution also wastes large amounts of energy, and as much as 35% of exterior lighting energy costs could be saved by better lighting. Light pollution also prevents astronomers and astrotourists being able to see so many stars. Astrotourism is booming in several countries and is beneficial for the local economy, especially so in parts of New Zealand, but this niche form of tourism is endangered by ALAN.

**Keywords:** Light pollution, environment, human health, energy costs, astronomy, astrotourism.

## FOUR GREAT ENVIRONMENTAL CHALLENGES

The world currently faces four great environmental challenges. Three of these are very well known, and are in the news media on an almost daily basis. They are:

- Greenhouse gases and global warming ( $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ )
- Plastic in the oceans, including micro-plastics
- Air pollution in mega-cities (especially from car exhausts, smoke and dust particles).

The fourth great environmental challenge is much less widely recognised, yet it is pervasive in urban communities in all countries, especially so in the developed world. This is the challenges arising from light pollution coming from artificial light at night (hereinafter ALAN).

Even though the multiple adverse impacts of light pollution are much less recognised than the other environmental challenges listed, the solution to the impact of ALAN is by far the easiest to resolve. Simply switching off external lights, or shielding them appropriately, using the latest technology of lighting with minimal blue emission and ensuring lights are no brighter than required and are only on when and where required would dramatically reduce the environmental impact of ALAN.

## LIGHT POLLUTION AND ITS CAUSE

Light pollution can be defined as the alteration of light levels in the external environment that are due to manmade sources of light. Three consequences of light pollution which are often cited are:

- the brightening of the night sky, known as skyglow
- the shining of light from a source directly into our eyes, known as glare

- and light spill, also known as light trespass, in which light shines on areas that were not targets for illumination.

Skyglow results in fewer stars being visible, and it thus impedes astronomical research, stargazing by amateur astronomers, astrotourists and anyone who wishes to appreciate the beauty of the pristine dark night sky.

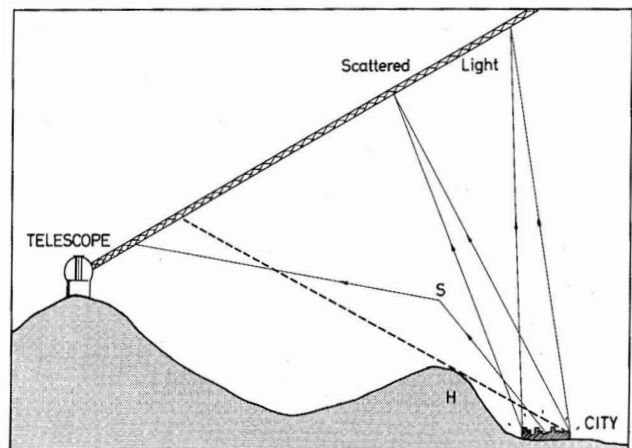


Figure 1: How ALAN brightens the night sky and impedes astronomical observations. From Cayrel et al. (1980), IAU/CIE Report No. 1.

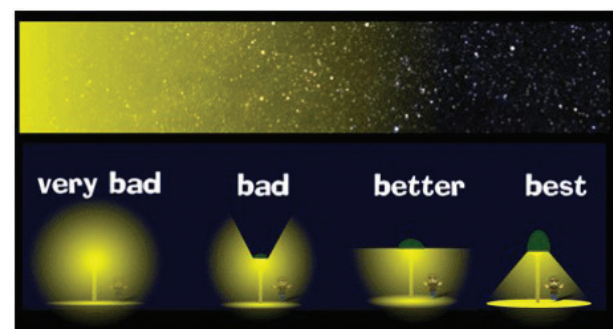


Figure 2: Light pollution results from poorly shielded exterior lighting.



Figure 3: Glare is caused by light shining directly into our eyes, causing reduced contrast and loss of dark adaptation.



Figure 4: Light trespass is light shining where it is not needed (including into bedroom windows at night).

Glare causes a partial loss of dark adaptation and the result is scattering of photons within the eye, resulting in a loss of contrast in the illuminated scene. This in turn reduces the visibility of objects being viewed, and hence there is a reduction of safety in the external environment, including safety on the roads.

Light trespass is especially harmful in the case of trespass into bedroom windows at night, which causes a disruption of normal sleep patterns and may disrupt the production of melatonin, a hormone only produced at night in the absence of blue light. Melatonin deficiency has many serious human health problems, as outlined by the American Medical Association in recent reports (Blask et al. 2012; Brainard et al. 2016) and as noted by the Royal Society of New Zealand in its report *Blue Light Aotearoa* (Harland & Rands 2018).

The worldwide movement to protect dark skies was started by professional astronomers, especially from the 1970s. However, the last 20 years (since about 2000) has seen a significant shift in emphasis. Dark skies are now promoted also to help provide good human health, to protect the environment, to save money by using less light and more efficient lighting, to increase safety at night using well-installed lights, and to promote astrotourism. This represents a significant shift in emphasis; dark skies are still advocated for astronomy, but the loudest voices are probably those for human health and the environment.

#### BLUE LIGHT AND THE PROBLEM WITH LEDS

A key discovery in 2002 was the role played by intrinsically photosensitive retinal ganglion cells in controlling the human circadian rhythm (Hattar et al. 2002). These cells in

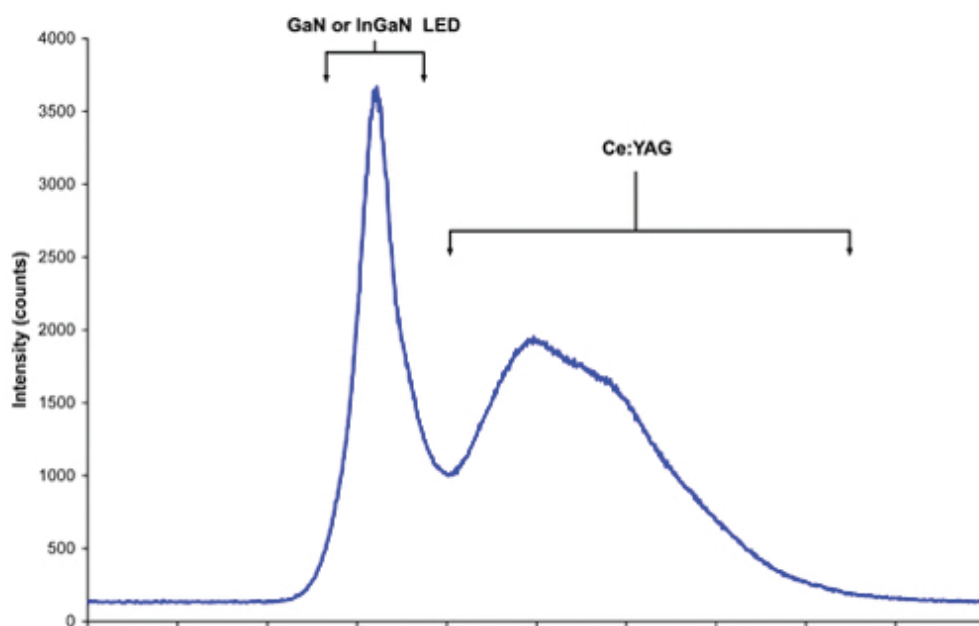


Figure 5: The spectrum of a blue-rich (4000 K) LED showing the GaN or InGaN blue peak at 450 nm.

the retina are especially sensitive to blue light at about 465 nm wavelength. The absence of blue light at night sends a signal to the pineal gland for the production of melatonin, which in turn ensures that all cells in the body follow the same circadian cycle in their metabolism. Quite small amounts of blue light at night suffice to disrupt melatonin production, with many adverse health consequences.

Since 2006, many streetlights have been replaced with light-emitting diode (LED) light sources, and the much favoured orange high-pressure sodium (HPS) streetlights have been phased out. HPS have lower efficacy (they produce less light per unit of electrical energy, or fewer lumens per kilowatt) and their maintenance costs more than LEDs, mainly because of a reduced lifetime.

The problem with the early models of LED luminaires is a strong peak in the blue produced by gallium nitride used in the solid-state light source. The light appears as a harsh white blue-rich illumination. The GaN peak is just at the wavelength where the intrinsically photosensitive retinal ganglion cells are most sensitive, thereby causing the greatest possible adverse effect on human circadian rhythm.

More recent models of LED give a warmer more yellow light colour. These are the phosphor-converted amber LEDs (pc-amber LEDs), in which a phosphor coating absorbs some of the blue emission and converts it into longer wavelength yellow light.

The correlated colour temperature (CCT) of a streetlight indicates the relative amount of blue-light emission. The earliest LEDs had CCT of about 4000 K to 5000 K with over 30% of the energy in the blue (wavelength less than 500 nm). Pc amber LEDs are now available with CCT less than 3000 K and with 10% blue emission. These are much better for not disrupting melatonin production, but they still emit much more blue light than the HPS luminaires.

Blue light scatters far more readily in the atmosphere than longer wavelengths, so blue emission from LEDs can contribute to skyglow some four to five times as much per lumen than for HPS luminaires. Blue light from blue-rich LEDs also contributes more to intraocular scattering causing excess glare. And as mentioned, blue-light trespass is more harmful to human health than yellow-light trespass.

Certainly, LED streetlights are not the only source of blue light at night. LCD screens from television monitors, cell phones and other electronic devices also emit in the blue and can contribute to the suppression of melatonin.

#### ENVIRONMENTAL IMPACT OF ALAN

ALAN has an adverse impact on almost all species of animals and plants, and not just on nocturnal animals. Some of the ecological effects of artificial light at night are listed below:

- Insects cluster around lights and hence expose themselves to predation from birds or bats.
- Birds that migrate using the stars for navigation cannot do so if the skyglow from artificial light prevents them from seeing so many stars or conceals the Milky Way.
- In urban environments, birds collide with the windows of lit buildings, especially so for office buildings where interior lights are on after dark.
- Turtles that lay their eggs in the sand on seashores have hatchlings which need to make their way immediately to the ocean; artificial light near the sea shore can attract them in the opposite direction, and they do not find the water. The hatchlings often die from exhaustion or predation.
- Light at night can hinder the metamorphosis of tadpoles into frogs, and hence it results in reduced reproduction of frogs.
- Trees require light for photosynthesis in their leaves. During this process, tree leaves take in carbon dioxide through stomata and release oxygen during the day. Normally the stomata close at night, but with artificial light they can stay open, which eventually causes leaf necrosis (the leaves die).
- Most plants are sensitive to the changing length of day and hence to the seasons. Artificial light at night can disrupt this sensitivity to the season and mean that a deciduous tree may retain its foliage in the autumn and is unable to hibernate properly for the winter months.

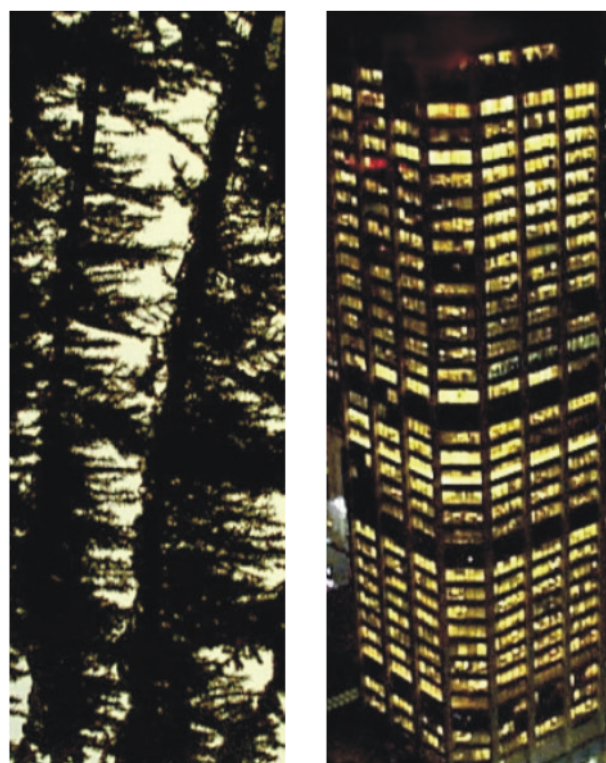


Figure 6: Birds in a forest navigate towards the light. But in an urban environment, they are often stunned by flying into lit windows at night.

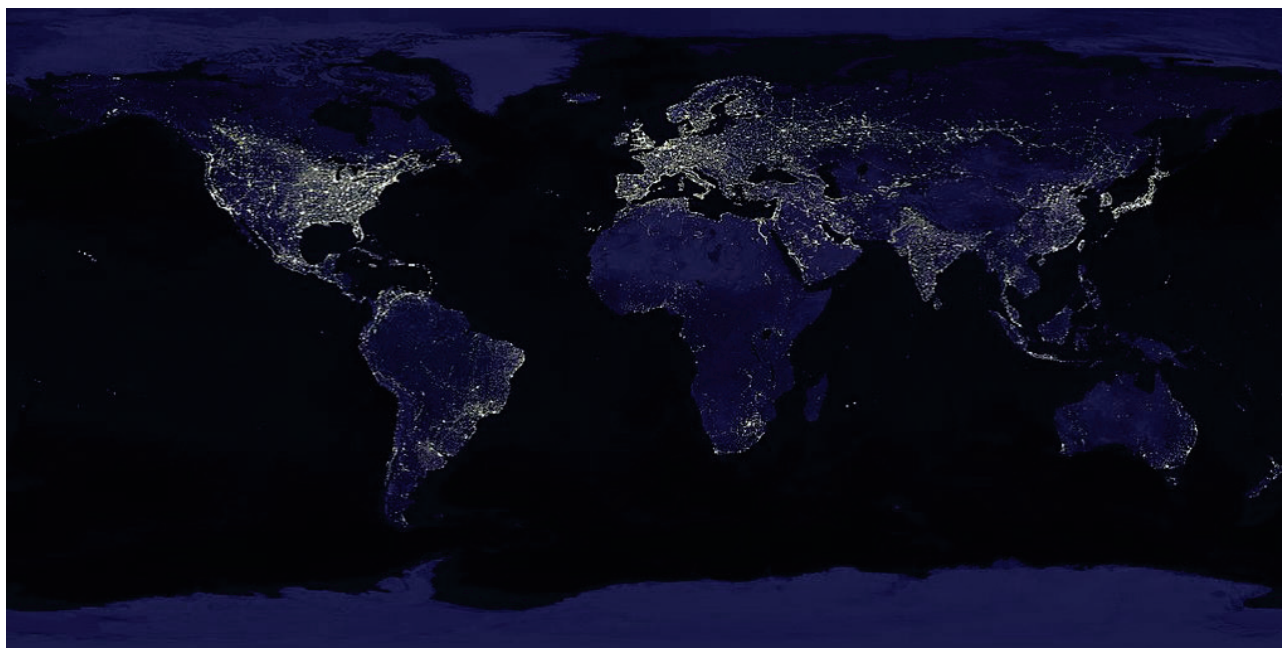


Figure 7: Global light pollution as seen from space. From Falchi et al. (2016) *New World Atlas of Artificial Night Sky Brightness*.

The above list gives some striking examples of the interference of artificial light at night on a wide variety of living organisms. The fact is that just about every species is adversely affected by artificial light at night, resulting from the desire of humans in urban or semi-urban environments for 24/7 illumination. In many cases this illumination results in increased predation, reduced reproduction or disorientation while migrating or in transit. Light at night can deter nocturnal species from foraging for food, and it can put leaf stress on many plants which lose track of photoperiodism, the alternating cycles of day and night and of the seasons.

#### ECONOMIC BENEFITS OF DARK SKIES

Global images of over-lit cities recorded from space emphasise the colossal wastage of electricity to produce so much light which is wasted by going up into outer space. This has been illustrated by the *World Atlas of Artificial Night Sky Brightness* (Cinzano et al. 2001) and the *New World Atlas of Artificial Night Sky Brightness* (Falchi et al. 2016), which showed the global spread of bright skies based on measurements of light going into space as recorded by artificial satellites. It is estimated that night sky brightness in recent decades has been increasing worldwide at about 2% per year, twice as fast as global population growth.

In 2011 the US Department of Energy estimated that in the United States 35% of light is wasted by unshielded or poorly installed outdoor lighting, including streetlights and light for commercial yards, advertising, security lighting, sports facilities and flood-lighting. This wastage amounted to about \$US3 billion of wastage energy production in the US (see the website of the International Dark-Sky

Association <https://www.darksky.org/light-pollution/energy-waste/>). This figure for waste in dollar terms has been confirmed by a recent study by Vandernoot (2020), who estimated wasted energy production for lighting in the United States in 2012 to be \$US3.4 billion. The worldwide figure is presumably an order of magnitude higher.

In many communities, street-lighting is the responsibility of local government such as city councils, and any measures to combat light pollution which also manifestly save money are generally welcomed by these authorities. However, the widespread changeover from HPS streetlights to LEDs, which is often promoted for the financial benefits of operating LEDs, needs to be viewed with caution. This is because LEDs emit much more of the harmful blue light which is almost absent from older sodium lights. What is more, the satellites monitoring global night sky brightness by upward-going illumination from cities have not been recording the blue emission at wavelengths below 500 nm.

#### ASTRONOMY AND ASTROTOURISM

In 2012, the International Dark-Sky Association (IDA) recognised a large area of Mackenzie District in the central South Island of New Zealand as the first accredited dark sky place in New Zealand or in any part of the southern hemisphere. The Aoraki Mackenzie International Dark Sky Reserve comprises 4367 sq km around Mt John Observatory at Lake Tekapo, which is a facility for astronomical research operated by the University of Canterbury.

By this time, the university already had an agreement with a local astrotourism company, Earth and Sky Ltd, for exclusive access for astrotourists to visit Mt John

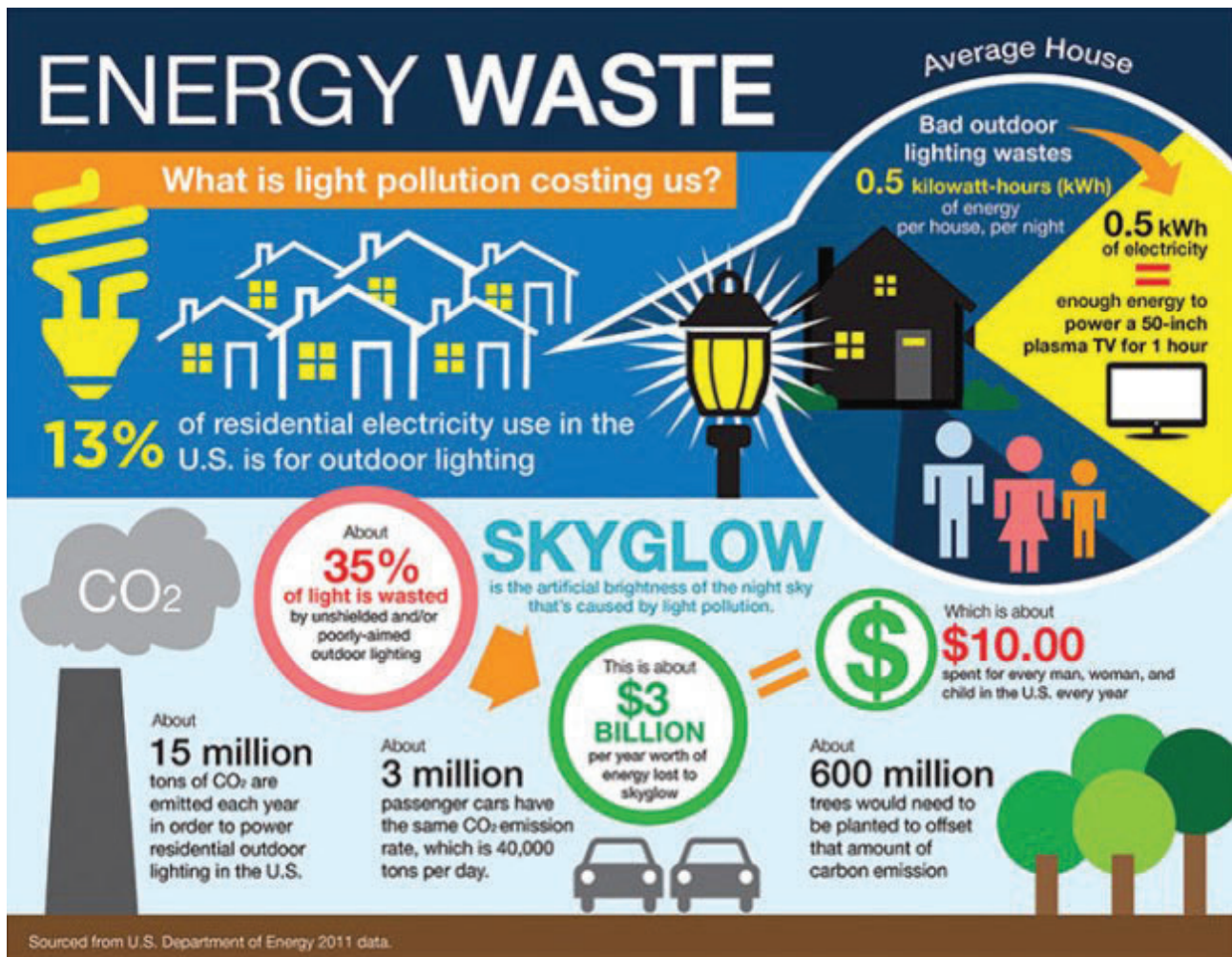


Figure 8: Energy waste from poorly shielded exterior lighting. US Department of Energy poster from 2011.

Observatory at night on a guided night-sky tour. This brand of tourism fulfils a niche in the tourism market and has been growing strongly in New Zealand, especially in the Mackenzie District, since about 2004. The result was a dramatic improvement of the local economy, with Mackenzie guest nights approaching 1 million per year by 2019. One of the benefits of astrotourism is that those booked on night-sky tours generally have to spend at least one night in local accommodation. The visitor spend in the Mackenzie District increased from about \$NZ120 million per annum during the years 2009 to 2012, to over \$300 million by 2018 and it was nearly a million dollars a day, when the Covid pandemic severely curtailed global tourism in early 2020. By this time there were nine astrotourism companies operating in the reserve. It can be concluded that dark sky protection can have a much more beneficial economic impact than just reducing electric power consumption, at least in a local area where astrotourism thrives.

Since 2012, more dark sky places have received accreditation from IDA. By early 2023 there were five dark sky places in New Zealand and about a further 15

communities in the country which had aspirations of receiving this accreditation.

New Zealand is seen as being a world leader in astrotourism as a result of very dark skies in many non-urban localities and easy tourist access to these places. Globally astrotourism is also booming, as shown by the publication of a Lonely Planet guide *Dark Skies: a practical guide to astrotourism* (Stimac 2019) and another book entitled *Astrotourism* (Marlin 2019). There are many magazine articles published in recent years promoting the virtues of this niche brand of tourism, such as one in Forbes magazine entitled *Is astrotourism the next big thing* (Altschuler 2019)?

#### THE HEALTH IMPACT OF ALAN

The adverse impact of blue light on human health has been actively researched for the last two decades. As mentioned earlier, blue light at night suppresses melatonin production and this in turn disrupts sleep patterns and our circadian rhythm. A general review article on melatonin, circadian rhythm and sleep was published by Brennan et al. (2007).

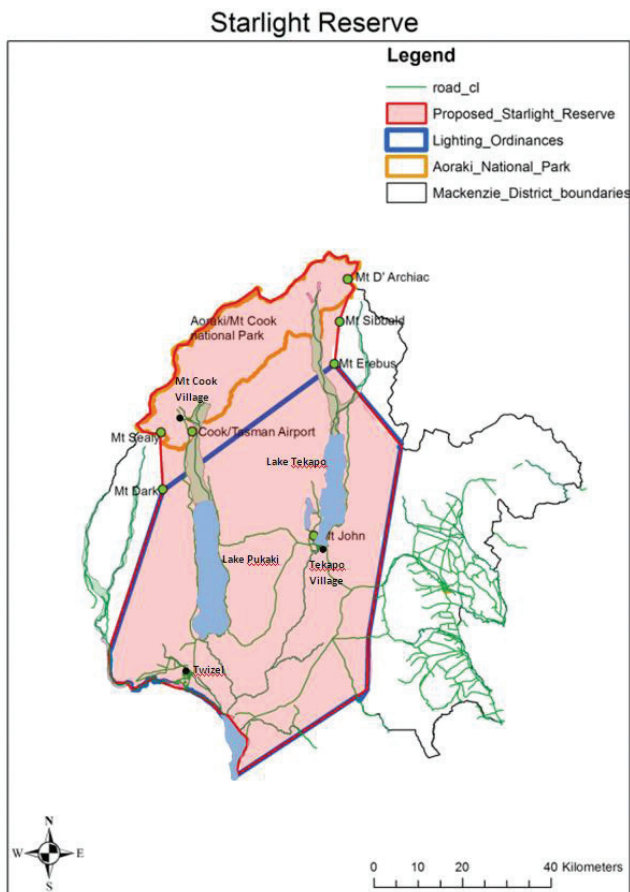


Figure 9: The Aoraki Mackenzie International Dark Sky Reserve in the central South Island of New Zealand. Mackenzie District Council map.

Hormone production in a number of glands is controlled by the day-night cycle to which the retinal ganglion cells are sensitive. Thus the pituitary, pineal (both in the brain), adrenal (on the kidneys) and thyroid (in the throat) glands are all controlled via signals from the suprachiasmatic nucleus (SCN), which acts as the body's master control clock, and a variety of different hormones are produced. Several, such as cortisol, serotonin and dopamine, are only produced in the presence of blue light between about 6 am and 10 am, when we rise at dawn after sleep. Many of these hormones are essential contributors to wellbeing and good mental health. Thus serotonin regulates mood and happiness, as well as appetite and digestion. Dopamine promotes pleasure, alertness and muscle coordination. Cortisol allows us to handle stress in our daily lives. These three hormones are all produced in the presence of blue light in the morning. Blue light is therefore essential for human wellbeing, but it should be synchronised with the natural day-night cycle and be absent at night from about 10 pm to dawn.

Several hormones are produced, like melatonin, in the absence of blue light at night. They include vasoactive intestinal peptide (VIP), which controls blood pressure, and the human growth hormone (hGH), also known as somatotropin, which stimulates growth, cell division and cell regeneration. It is thus important in human development. These six hormones are among those which are tied to a circadian cycle and controlled by blue light or its absence.

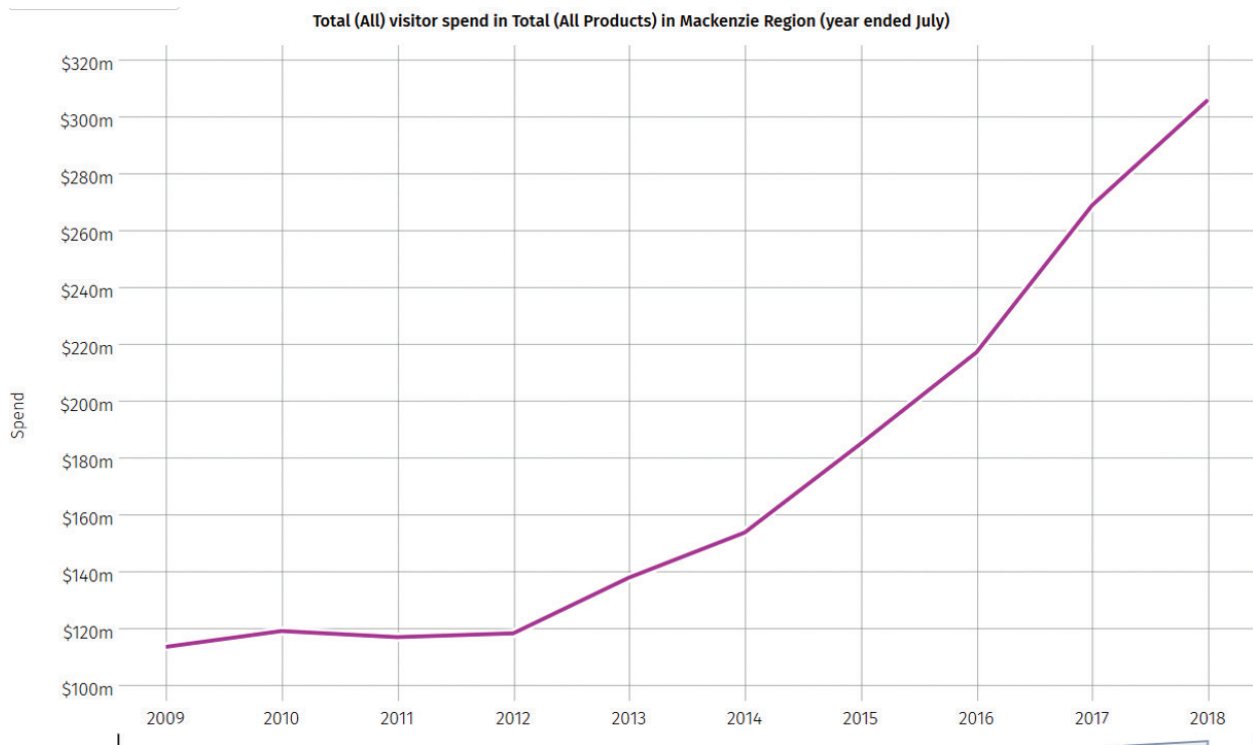


Figure 10: The visitor spend in the Mackenzie District increased rapidly after the creation of the Dark Sky Reserve in 2012. Data from the Ministry of Business, Innovation and Employment.



Figure 11: Astrotourists on a guided night sky tour at Mt John Observatory, Lake Tekapo. Photo by Fraser Gunn.

As mentioned, melatonin production at night is essential for a good night's sleep. Quite small amounts of blue light at night or about an hour before going to bed can inhibit melatonin production. Brief light levels of a few lux as produced by a computer or cell phone screen may suffice to have an adverse effect on nocturnal hormone production (Gooley et al. 2010).

The absence or disruption of melatonin secretion does not just produce a sleepless night. Symptoms similar to those associated with jetlag can be the result, and also repeated blue light exposure at night can result in the onset of mood disorders such as irritability, anxiety and depression. Obesity, diabetes and hypertension may also be the result.

Melatonin also plays a role in combating some cancers, notably breast and prostate cancer. A huge amount of research in recent years has focused on the link between blue light at night and the risk of cancer. Some of the circumstantial evidence for this link comes from the higher rates of these cancers in developed countries with more light pollution, and the increase in the cancer rates during the twentieth century as artificial light at night in large cities greatly increased. It also comes from the significantly higher incidence of breast and prostate cancer in night-shift workers, who often sleep during the day in poorly screened bedrooms and have exposure to blue daylight during times

of sleep. In 2013 the Israeli scientists Abraham Haim and Boris Portnov wrote a book with the title *Light Pollution as a new Risk Factor for Human Breast and Prostate Cancers* (Haim & Portnov 2013).

A recent study by Xia Yuan et al. (2018) analysed 61 other published studies involving women undertaking night work, with the data from over 3.9 million people in Europe, North America, Asia and Australia. The breast cancer risk for long-term night-shift workers was increased 31.6%. The risk of several other cancers was also markedly increased for these people. Whether blue light during sleep times was specifically the cause for all these cancers remains unproven, but the association is strong enough

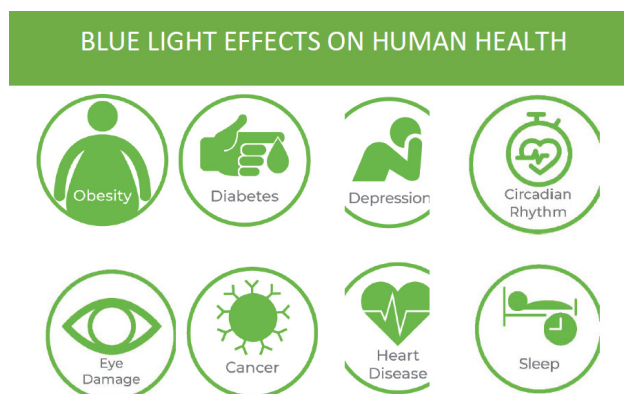


Figure 12: Blue light effects on human health.

to cause alarm. Night-time nurses in hospitals appear to be particularly at risk, and this group showed a 57.7% increased breast cancer incidence.

## CONCLUSION

The world is finally waking up to the realisation that something which is apparently as innocuous and as useful for safety and human progress as illumination at night may, in fact, be one of the major environmental challenges of the current age. A campaign started by astronomers some half a century ago, aimed simply to protect the viability of their science, has now become a challenge to the sustainability of most urban environments where the majority of the population is living. The luminous environment of cities today differs very radically from the day-night cycle that nature created for the world, and not surprisingly, such radical changes are found to be unsustainable. Paradoxically, this is one of the most difficult environmental challenges to detect and understand. We know people are often sick, obese, depressed and dying of cancer, we know many species are being driven to extinction, but until now we have been slow to recognize a major cause for these problems. Yet, of all the major environmental challenges we face today, light pollution is surely the easiest in principle to correct and overcome. Simply turn off the lights, or at least shield them, reduce the blue light emissions and ensure light only shines where and when it is needed, then the problem can largely be solved. The hope is that in the next few years, the campaigns being fought against light pollution will implement these essential steps.

In New Zealand the many communities advocating for dark skies are largely promoting the benefits of darkness at night at a local government level through lighting controls in district plans. New Zealand urgently needs a national law to promote dark skies and combat light pollution, as officials in local government are not well equipped to understand the fast-evolving technology of exterior lighting. For this reason, in January 2023 I made a petition to the New Zealand Parliament for such a national law to combat light pollution, following the examples of France and Croatia, which both introduced legislation to limit light pollution in early 2019. The book *New Zealand Dark Sky Handbook* (Hearnshaw 2021) gives more information on the dark sky movement and astrotourism in New Zealand.

## Conflict of interest

The author declares no conflict of interest.

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