The Scale and Impact of Sports Stadium Grow Lighting Systems In England

Steve Geliot[1], Jacqueline Coesfeld[2], Christopher C.M. Kyba[2,*]

[1]Citizen Scientist, UK
[2]GFZ German Research Centre for Geosciences, 14467 Potsdam, Germany

Received 30 March 2022, Accepted 20 June 2022

Abstract

Recently, many sports stadiums have begun using high power lighting systems to help the grass grow on the playing surfaces. These lights supplement winter sunlight, which is sometimes insufficient due to the low elevation of the sun and shading from the surrounding walls. In many stadiums, grow lights are operated at night, and the waste light emissions from these stadiums are extraordinary in comparison to most other areas in the cities in which they are located. Here we present space-based observations of the radiance of fourteen stadiums located in towns and cities of varying sizes and in varying geographical locations across England which each have a Premier League football stadium. We show that stadiums have dramatically brightened (typically by factors of 2-5) in recent years compared to the situation in 2012. We also show that stadiums are often responsible for an important fraction of the total light emission of the cities they are in (often 10% or more, and in one case up to 30%). In addition, the light emissions from many English towns have in fact been reducing in recent years. This means that the overall fraction of light due to the stadiums is increasing at an even faster rate than their growth in radiance. In some cases, total city emissions have actually increased due to the stadiums, undermining the environmental impact of reductions in radiance in the rest of the community. We believe that stadium grow lights are an excellent target for sustainable lighting initiatives, both because of their considerable environmental impact (especially when located near sensitive areas) and the possibility of high profile and successful waste light mitigation projects.

Keywords: Agricultural lighting, Remote sensing, Sports lighting, Supplemental lighting, VIIRS DNB

1. Introduction

During a photo shoot of the Lunar Eclipse of January 2019, we observed a significant source of skyglow [1, 2] while looking West towards Brighton from above The Long Man of Wilmington on the South Downs near Eastbourne, United Kingdom (Fig. 1). This skyglow appeared to be significantly brighter than (and separate to) the city's street lights, and it motivated us to investigate the source. We determined that the glow was coming from the American Express Community Stadium at Falmer on the outskirts of Brighton (50.8616N, 0.0837W). After further investigations, we found that this stadium is not alone: light emissions from the stadium have increased dramatically in recent years, and that similar increases have taken place at a number of UK sports stadiums. In this study, we seek to quantify the changes in light emissions from selected sports stadiums, and to compare it to the light emissions from entire communities (due to sources like street lights, security lights and illuminated advertising). After presenting results, we also discuss the environmental and social impacts of stadium lighting, and the question of how and whether such emissions should be regulated.

* Kyba C, Tel.: +49-331-288-28973.
E-mail address: kyba@gfz-potsdam.de

Fig. 1. Example photographs of the land and sky around the American Express Community Stadium near Brighton, UK. Most of the nearby area has no installed lighting. Photos by Steve Geliot.

For many decades light emissions from sports stadiums have been a familiar sight on match days, when play extends into the evenings and high mounted floodlights are operated to achieve the brightness levels required for television broadcast. To some, the sight of these floodlights is possibly seen as part of the atmosphere surrounding a great match. Waste light emissions from sporting facilities (including amateur facilities) has often been a source of conflict [3, 4], but this conflict (and the related environmental impacts) have generally been resolved when the lights are turned off after use. A more problematic recent development has been the increasing use of lighting arrays mounted on wheeled rigs which are used to promote faster growth of the grass on the actual pitches. These growing lights began to be more widely used as a result of changes to the grass pitch specifications, as well as after the Euro 2016 tournament, where some European pitches were left in a poor condition following heavy rain [5–7]. In larger stadiums, the shading effect of stadium architecture can make it difficult for grass to receive enough natural light to grow, especially during the winter months at high latitudes.

Since these supplemental lighting equipment is not fixed, it is not currently subject to any form of planning control in the UK. As a result, in the author's experience, local authorities will typically only take action on environmental health grounds in cases where artificial light from sources, such as security lighting, shines directly into people's houses. In the absence of mitigating measures such as reflective shielding, a large amount of light reflects from the ground surface, and escapes into the sky. The TLS 72 lighting rig, which to the best of our knowledge is similar to the type used at the American Express Community Stadium, uses 72 Hortilux 1000 W high pressure sodium grow lights [8]. If a stadium operates twelve TLS 72 units on a pitch at night, that works out to 864 kW of electrical power, used only for growing grass (this excludes two additional rigs for the goal areas, which often require even more intensive maintenance). If all twenty Premier League clubs were to operate lighting systems similar to this, their combined power draw during use would be nearly twenty megawatts.

Satellite imagery of the Earth at night provides an opportunity to quantitatively compare the artificial light emissions of sports stadiums among each other, to compare the emissions from stadiums to other light sources, and to track changes in light emissions over time. The following sections will demonstrate that supplemental lighting for grass in sports fields can have an extraordinary impact on a city's total light emissions, and therefore deserves special consideration in light planning and light pollution reduction efforts.

2. Methods

2.1. Satellite data

This analysis makes use of data from the Visible Infrared Imaging Radiometer Suite Day-Night Band (DNB) on board the Suomi NPP satellite. The DNB observes electromagnetic radiation in the range 500-900 nm for nearly the entire Earth's surface. The satellite overpass time is well after midnight (typically around 1:30 in the morning in standard time, 2:30 during daylight saving time), and a second overpass sometimes occurs at higher latitudes [9]. The Earth Observation Group assembles these data into monthly composite images built using only cloud- and moon-free data [10]. We further correct for background light from atmospheric airglow and the aurora near the poles, by examining areas far from human settlements and then subtracting the interpolated background radiance within the regions of interest [11, 12]. Because the instrument has little to no sensitivity to (blue) light below 500 nm, city-wide conversions from (orange) high pressure sodium to white LED that preserve total lumen output can appear as decreases in light emissions [13, 14].

The DNB has a nominal spatial resolution of 750 meters, but this is reduced in the monthly composites due to variation in the positions of the individual pixels, as well as due to scattering of light in the atmosphere [15]. As a result, small bright objects such as stadiums, greenhouses, and flares have their light distributed over several pixels in the monthly composites [16]. At some imaging angles, the view of the ground (or light emitting elements) can be blocked by buildings, and this may be the case for tall stadiums. This could result in a higher radiance being observed on the nights when the satellite views from directly above, rather than from the side [17, 18], contributing to the variance in the monthly composites [16]. The DNB observes radiance in nW/cm2sr, and we assess the contribution of regions via the common practice of summing the total radiance observed over a given area (e.g. [19–22]).

2.2. Defining regions of interest and data access

Regions of interest were selected within the Radiance Light Trends web application [23, 24], which allows users to output the values of the monthly composites for a user-defined region of interest. For each stadium investigated, a polygon was drawn which encompassed most of the brightly lit area near the stadium, covering an area from 1.1 to 2.2 km2 (Fig. 2). These limited areas do not represent the entire light emissions of the stadium (because some of the stadium light is misattributed to surrounding areas), so all results presented here should be understood as lower bounds. While a larger analysis region would collect more of the total light from the stadiums, we purposefully kept the areas of interest small, in order to minimize the extent to which other light sources contribute to the analysis (Fig. 3). We particularly tried to avoid including DNB pixels with other bright infrastructure, such as railway yards. (Future “nighttime lights” satellites with higher spatial resolution will make these types of analyses more straightforward [25–27]). After this, a second polygon was drawn encompassing the approximate city limits for the local authority area within which the stadium is located (Fig. 2). The area of each of the regions is shown in Table 1, and both sets of polygons are available in the supplementary materials. Each polygon can be uploaded into Radiance Light Trends, in order to replicate our analysis. The process for any individual polygon takes less than a minute.

Table 1. Size of the analysis areas for each stadium and city. Note that for Liverpool and Manchester, the two stadiums are combined together into a single entity for the analysis. The large city analysis area for Leeds and Sheffield is related to the large administrative boundaries, which to a large extent consists of unlit land area.

City	Stadium name	Stadium analysis area (km^2)	City analysis area (km^2)
Brighton	American Express Community Stadium	1.5 km^2	87 km^2
Burnley	Turf Moor	1.1 km^2	227 km^2
Derby	Pride Park	1.2 km^2	100 km^2
Leeds	Elland Road	1.4 km^2	410 km^2
Leicester	King Power Stadium	1.4 km^2	73 km^2
Liverpool	Anfield & Goodison Park	2.2 km^2	189 km^2
Manchester	Etihad & Man. City	1.7 km^2	216 km^2
	Old Trafford	1.2 km^2	
Norwich	Carrow Road	1.3 km^2	46 km^2
Reading	Madejski Stadium	1.1 km^2	42 km^2
Sheffield	Bramall Lane	1.4 km^2	431 km^2
Stoke	Bet 365 Stadium	1.4 km^2	90 km^2
Watford	Vicarage Road	1.1 km^2	32 km^2

A total of 14 stadiums were selected in 12 cities over a wide geographical area of England, in order to cover a range of city sizes and populations, as well as variation in the wealth of their resident football club (Fig. 4). Manchester and Liverpool each have two rival premier league clubs. In the case of Liverpool, the stadiums are close enough together that both were included in a single polygon. For Manchester, the sum of lights from the two stadiums were later summed in order to give one result for the whole city. Additionally, in Manchester the city administrative boundary falls between the two stadiums, and the city boundary was therefore extended to include them.

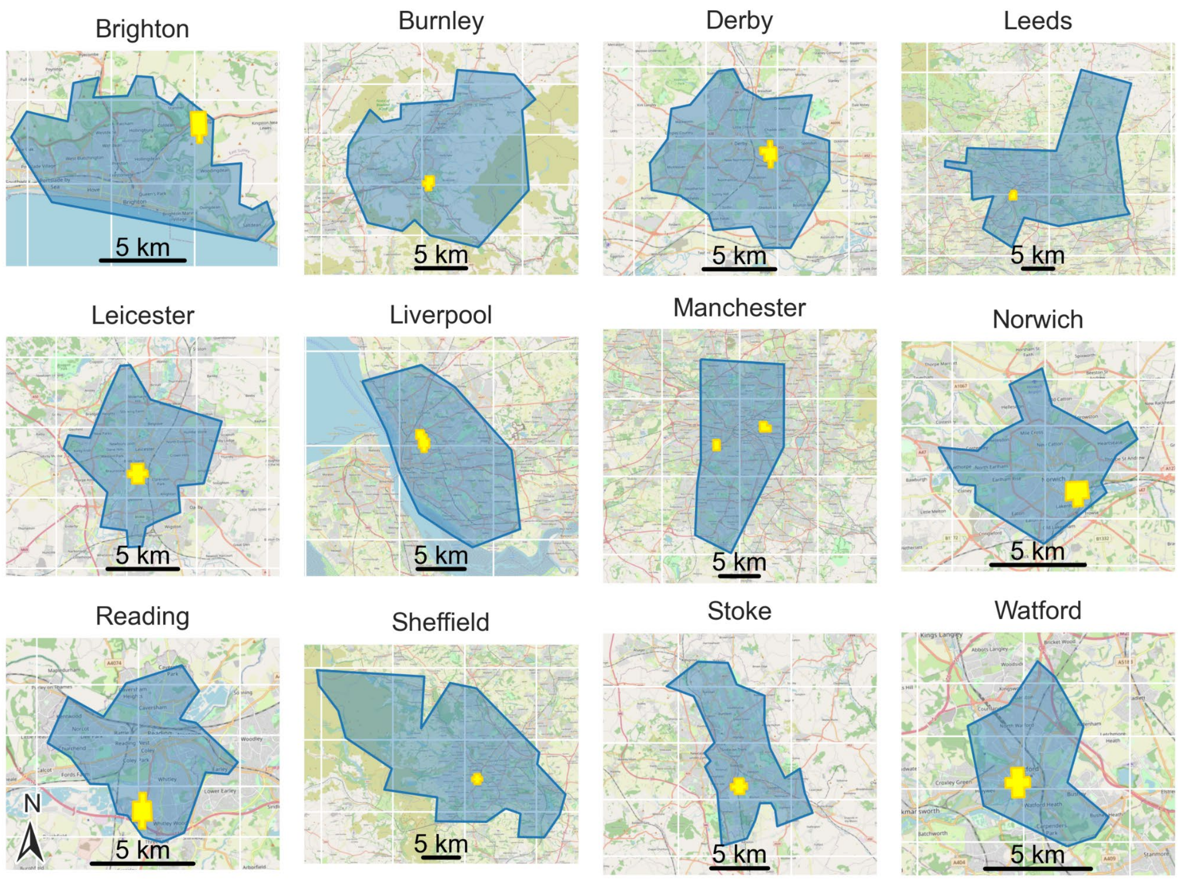

Fig. 2. Maps showing the boundaries drawn for each of the 12 communities (blue), and the analysis boundaries for the stadiums (yellow). Note that that each map has a separate distance scale.

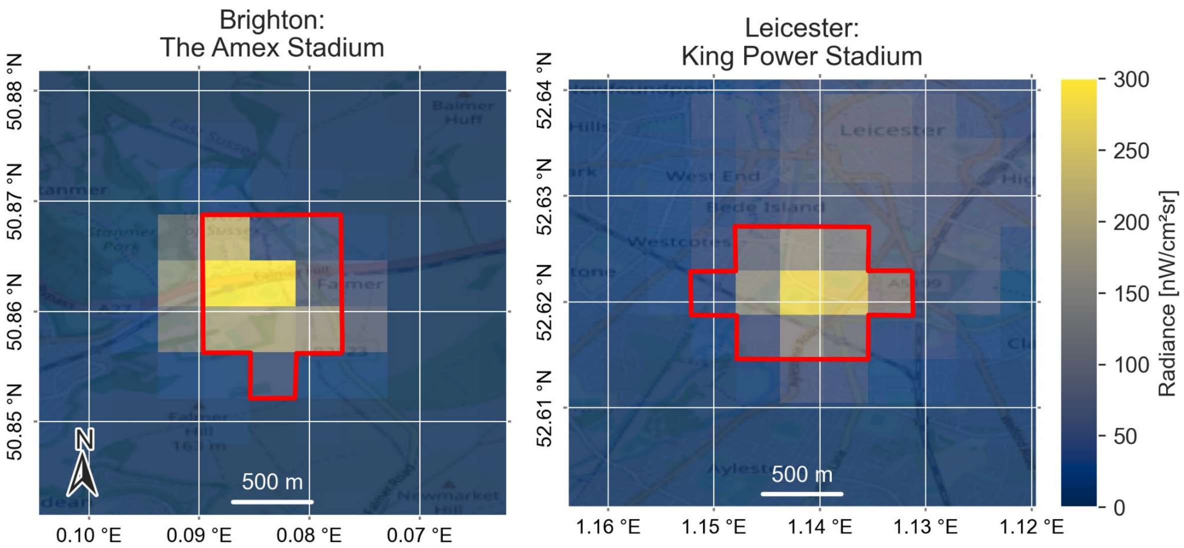

Fig. 3. Maps showing the reported radiance for the areas near two stadiums from the VIIRS DNB during February, 2019. The analysis areas are shown as a red outline. In all cases, some light from the stadium is observed as coming from outside of the boundaries, and lights from other sources are included inside the area. However, the stadiums are generally much brighter than other sources, such as the Leicester city center at top right in the right panel.

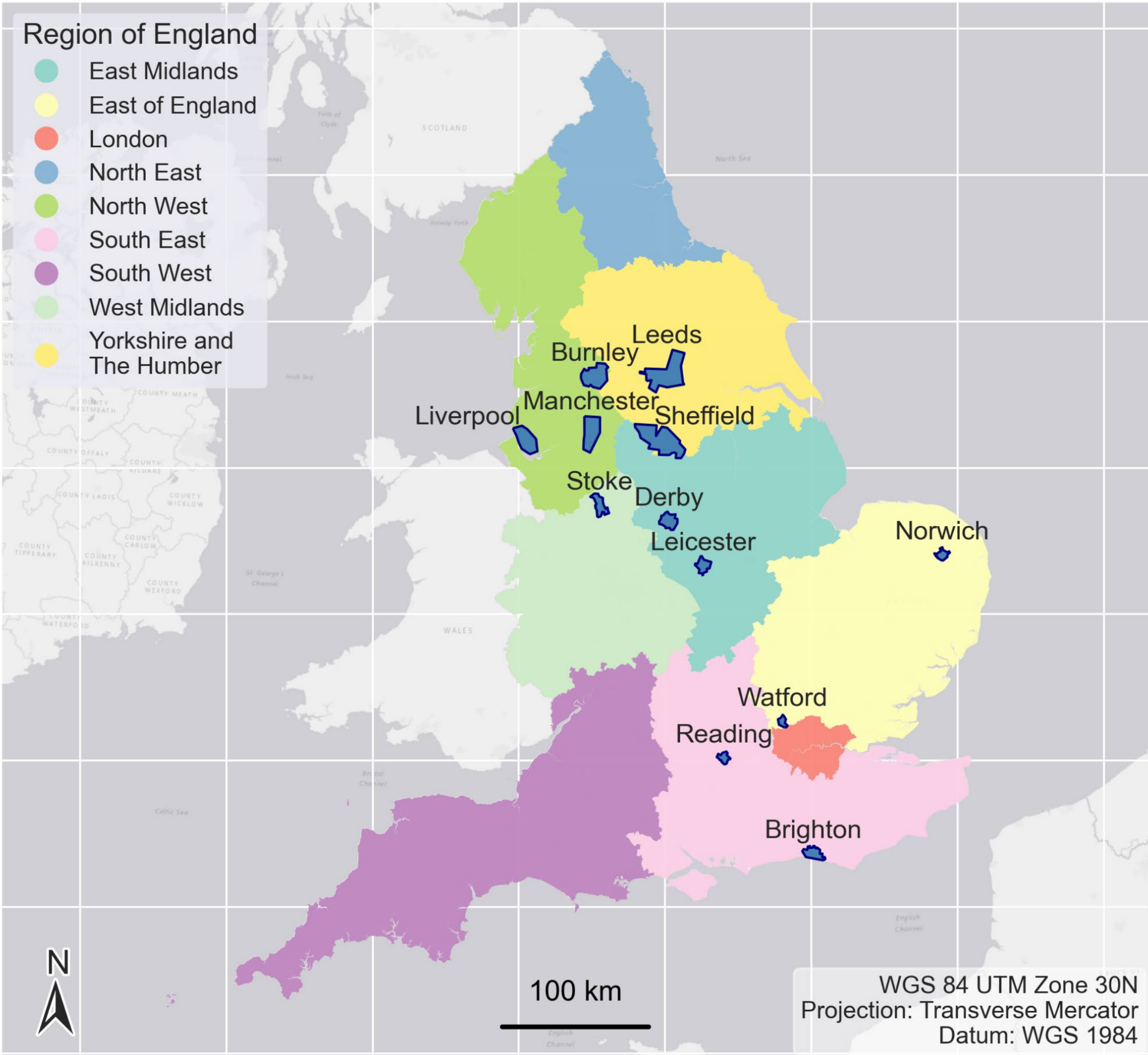

Fig. 4. Map showing the location of each of the 12 communities in the study.

Within Radiance Light Trends, we selected the "VIIRS DNB (zero point correction)" as the satellite dataset, in order to apply the airglow correction [11, 12]. Data were only available during October to March (and occasionally September), due to stray light incident on the sensor and the presence of twilight on the ground during the summer months. It is possible that the grow lights are off during the summer period, as the days are longer and the sun reaches higher elevation angles.

2.3. Analysis

We analyzed the data in two ways. First, for each monthly composite, we estimated the fraction of the total light emissions of the city light that are due to the stadium area, by dividing the sum of lights from the stadium area by the sum of light for the full city boundary (for Manchester and Liverpool, the two stadiums were summed together before doing the division). Second, we examined how the light emissions have changed over time, by dividing the sum of lights for each month by the median value observed for the stadium during the period 2012-2013.

3. Results

The light emission of all of the examined stadiums has increased considerably relative to their emissions in 2012-2013 (Fig. 5). Most of the stadiums have at least doubled in brightness, while two (Leicester and Brighton) have increased light emissions by a factor of five or more. In several stadiums, the moment of introduction of supplemental lighting is clearly visible, as there is a step change in emissions. In others (e.g. Sheffield), the increase is still dramatic, but has been seemingly more gradual (although this may be a statistical illusion due to the intrinsic variability of the satellite data, see Figs. 9 and 10 in [16]).

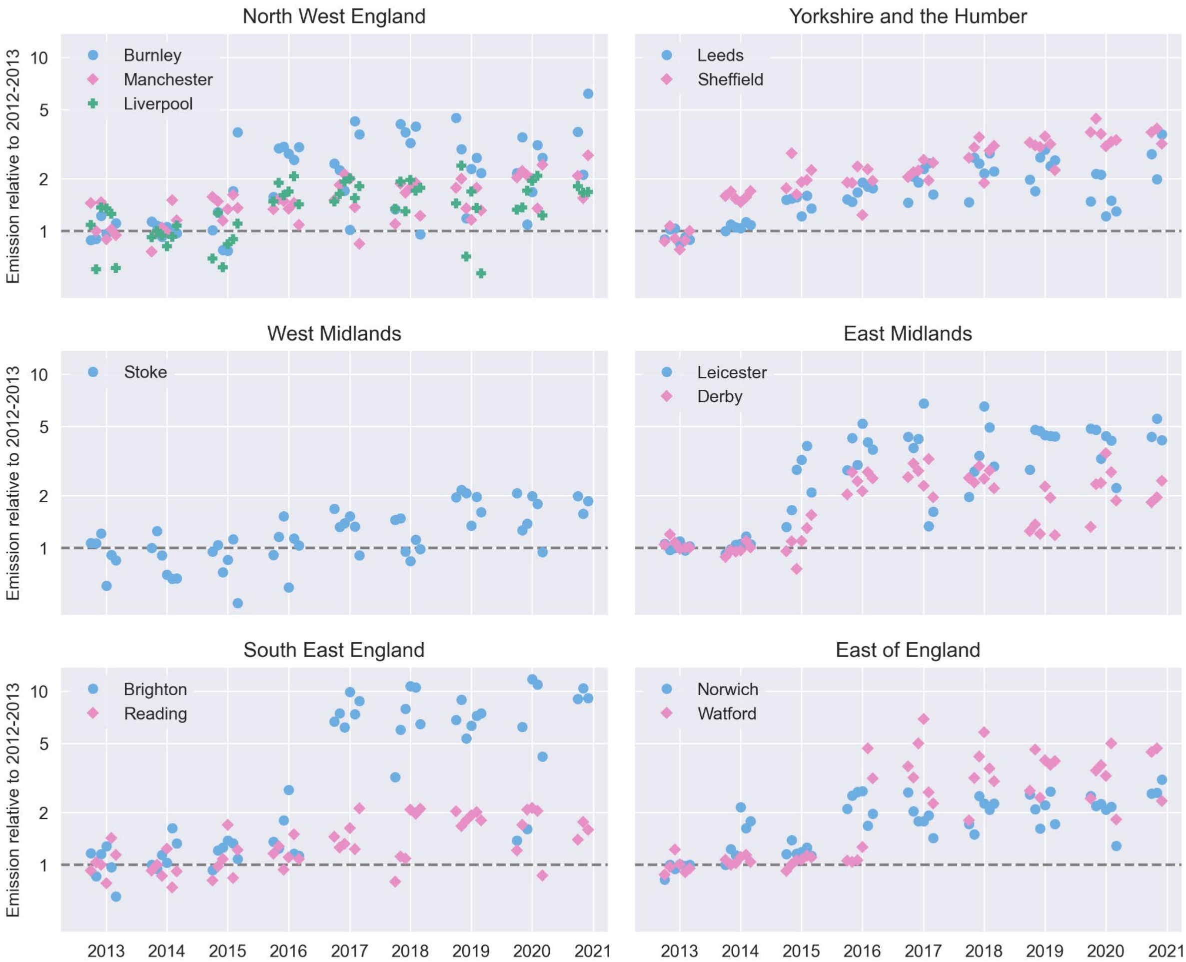

Fig. 5. Summed radiance for each stadium analysis area, relative to the median observation in 2012 and 2013. Note that the vertical axis is on a logarithmic scale.

Sports stadiums are often among the brightest objects in a city [28], and these data show that stadiums can have a substantial fractional contribution to the combined light emissions of entire cities (Fig. 6). A number of the stadiums were already responsible for more than 5% of the total light emissions of the city visible from the DNB before grow lights for turf became more widespread. Over the course of the time series, the relative fraction of its city's light emission increased for every stadium, and sometimes by dramatic factors. In Brighton and Hove, for example, (which has a population of nearly 300,000) the stadium area is now frequently responsible for about 20% of the total light emissions viewed by DNB. (To put this another way, the light output of the stadium alone is approximately equivalent to the combined light output of all of the streetlights, advertising lights, industry, aesthetic, and security lighting that are used to service around 75,000 people.) About half of the stadiums are now responsible for more than 10% of the total light emission from their communities.

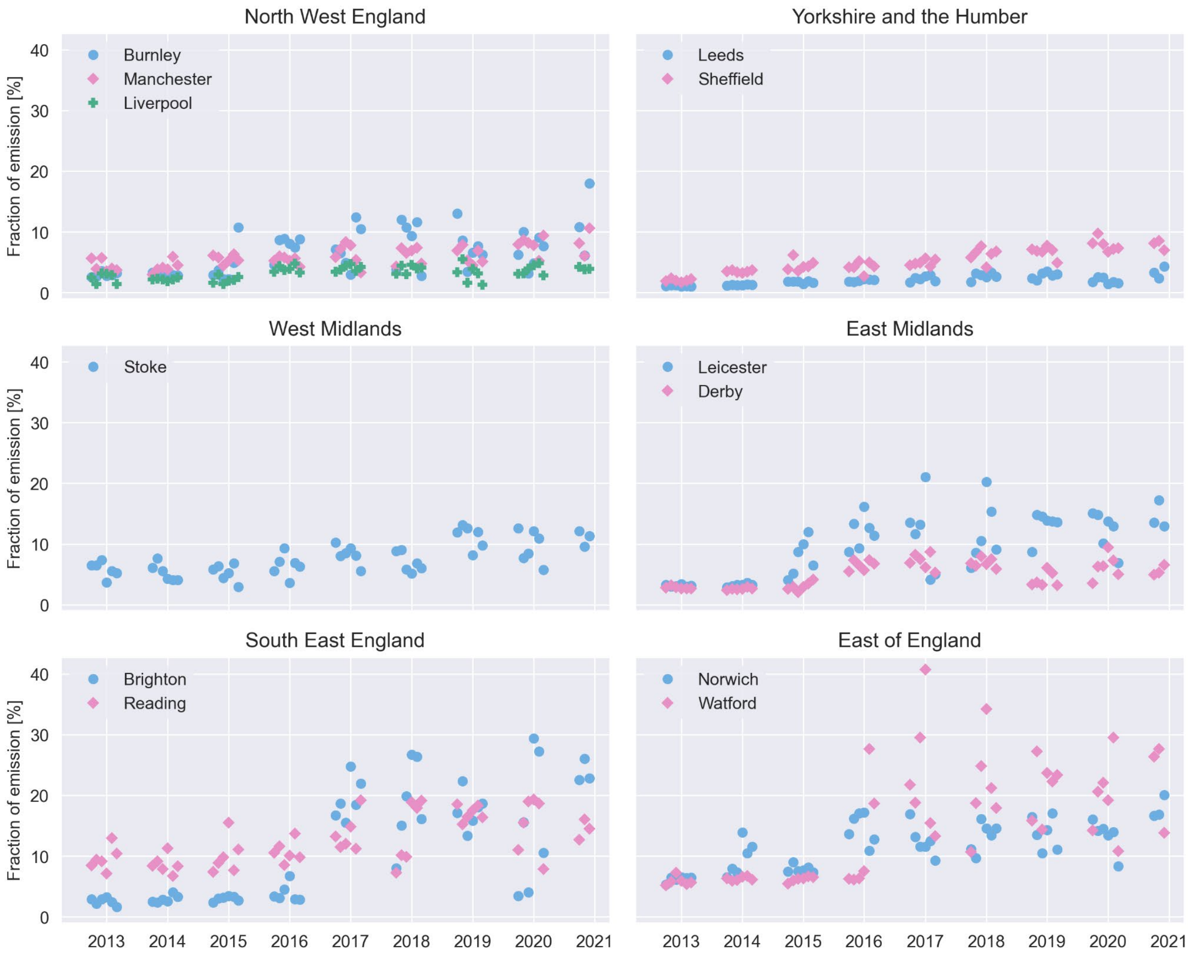

Fig. 6. Fraction of light emission of the entire city that is emitted from the stadium region over time.

The fraction of the city light emissions that come from the stadium areas (Fig. 6) has also increased in many cases for a second reason: the radiances observed by the DNB from many cities in the United Kingdom have actually decreased in recent years (Fig. 7, and see [29]). These trends towards decreasing light emissions are quite unusual compared to most countries, where emissions have been increasing consistently for decades [22, 30, 31]. It is not yet clear to what extent these decreases in the DNB correspond to real decreases in total light emissions, or to a shift in the cities spectra after citywide conversions to white LEDs. However, taking the cities and stadiums together as a whole, the increase in emissions from stadium areas means that in some cases total emissions from the city have not decreased (e.g. Brighton, Fig. 8), or have actually even increased (e.g. Watford, Fig. 8) within the 500-900 nm band observed by the DNB.

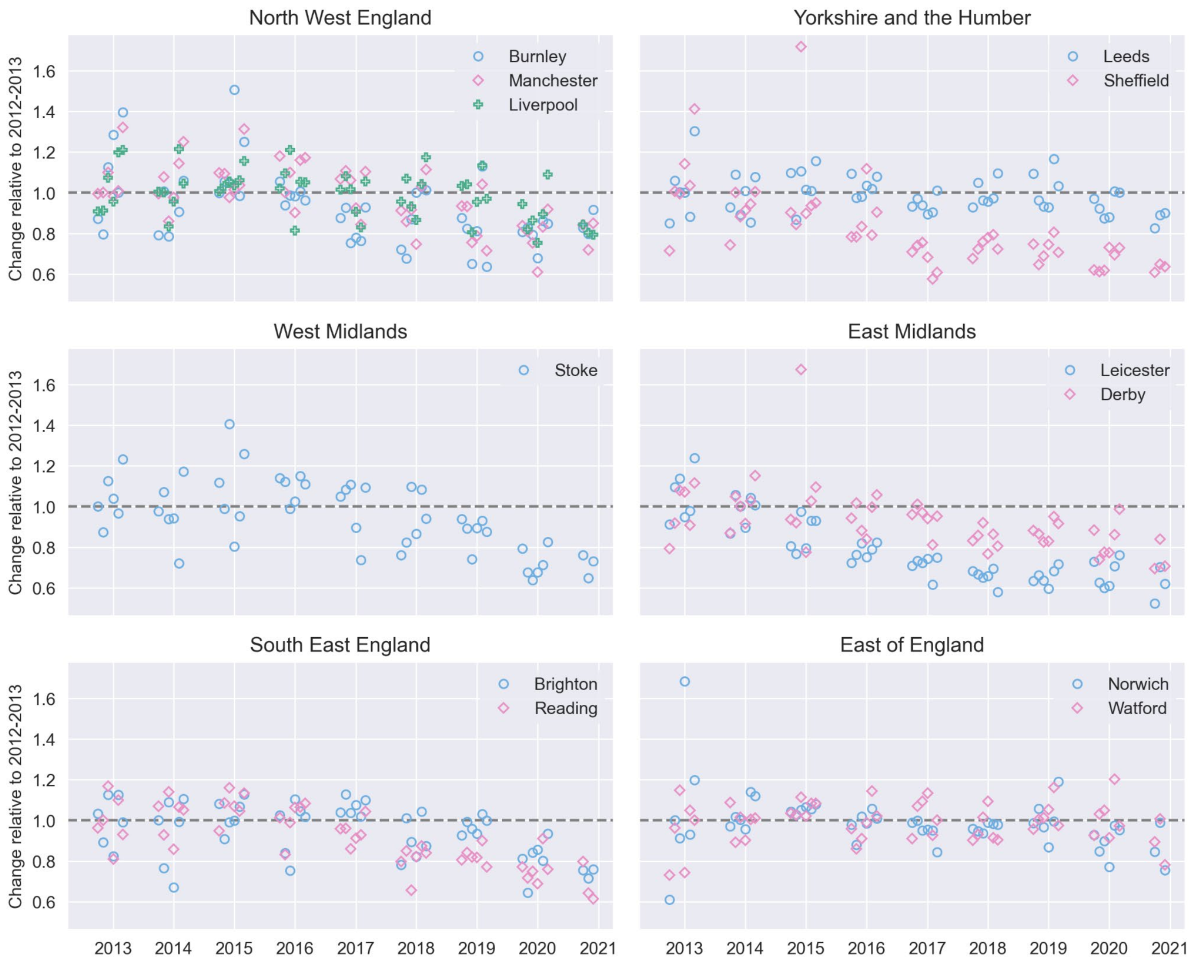

Fig. 7. Change in summed radiance for each city excluding the stadium areas, relative to the median summed radiance from 2012 and 2013. Note that two observations are not shown, as they are outside of the bounds of the graphs.

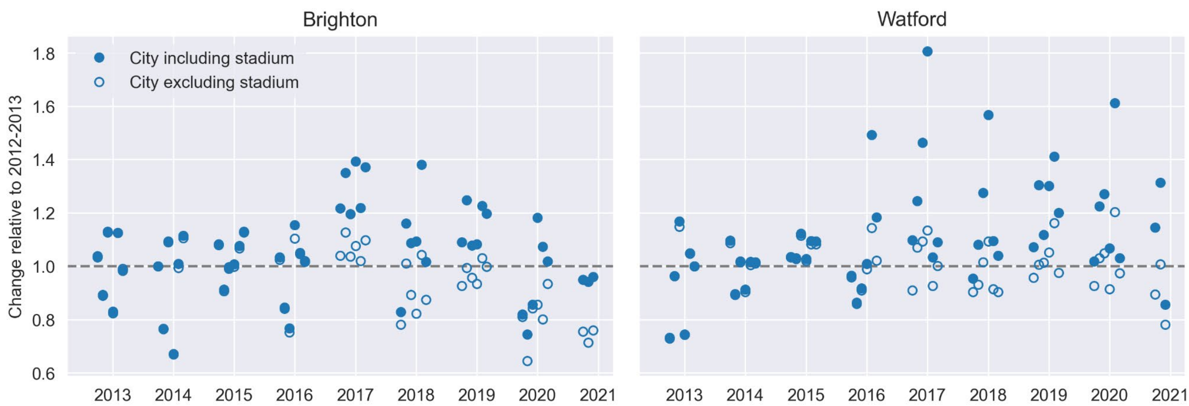

Fig. 8. Summed radiance from Brighton and Watford, relative to the median summed radiance from 2012 and 2013.The filled circles show the results for the city as a whole (including the stadium area), the empty circles show the results for the city with the stadium excluded.

The monthly composite images produced by the Earth Observation Group make it possible to infer in many cases when supplemental lighting systems were introduced at each football club, and whether they just came on all at once or if there was a test period. Although not examined here, in principle one could examine the periods of the year during which the lights are used at each stadium, as well as how bright they are relative to other stadiums. Using daily data, one could also examine whether the lights are turned on on only some days of the month, as well as if they are operated at full or reduced power.

4. Discussion

Sports stadiums have historically been extremely bright objects during game nights, but in many cases the bright light emissions of stadiums now occur late at night or through the night, due to grow lights used for the grass. Viewed from orbit, the light reflected from the pitches often outshines city centers and airports, dockyards and industrial plants [28]. In the case of the Amex Stadium in Brighton discussed here, for example, the radiance at the stadium is often near or above 400 nW/cm², while the city center of Brighton is nearer to 70 nW/cm², and even the brightest areas in the City of London are typically only about 160 nW/cm². While the traditional idea of football is a game played in the fresh air on a field of natural grass, professional football pitches have long had parallels to television studios. With the introduction of grow lights, pitches now also have parallels to intensive greenhouse agriculture. In an age and country experiencing frequent discussions of climate and other environmental catastrophes, it is surely worth reflecting on the extent to which these light emissions are justifiable and necessary.

To start this reflection, we note that usage of grow lights has changed dramatically in only the past few years. At several of the stadiums we examined, a step change in light emissions is observed, typically during 2015-2017 (Fig. 5). We presume that these changes are due to grow lights, and that these lights may have been installed in response to changing specifications for Premier League pitches (see e.g. [6]). The Brighton and Hove Albion website [32] states, for example:

"Grow lights" are used sparingly to replicate sunlight lost during winter months and to stimulate pitch growth, necessary to ensure the club discharges its duty of care to players, whilst also supporting the league's regulations regarding the quality of the stadium playing surface.

Although the growth in light emissions is apparent in all of the examined stadiums, the increase is not uniform across the UK. We do not know whether this may be related to differences in stadium architecture, or perhaps to the time periods over which the lights are active. In addition to growth in lighting, the total overall amount of light emissions is also dramatic: some of the stadiums are now responsible for over 20% of the total light output of their city late at night. Such a large output is reason for concern, and not only from the perspective of the necessary electrical consumption; these stadiums are major sources of light pollution.

Nighttime light emissions have negative environmental consequences, especially in the cases where they are very bright and concentrated. As an example, insects are frequently attracted to stadium lights, and one moth even made a famous cameo at Euro 2016 [33]. Migratory birds are likely to also be in danger of attraction, particularly on nights with poor weather [34, 35]. Brighton is known for its iconic murmurations of Starlings, Sturnus Vulgaris, over the Palace Pier each winter, and numbers of starlings gathering in UK skies has been declining in recent years [36]. While there are multiple complex causes for these declines, including the large scale loss of insects due to intensive farming methods, work on other nocturnally migrating birds suggests it is reasonable to expect that large brightly lit structures play some role [35, 37–40]. Stadium operators may therefore consider whether it could be possible to avoid the nighttime use of grow lights during peak periods of migration [39, 41], and especially on nights with poor weather and in regions like Brighton with especially large migrant populations.

Bright light emissions also impact human wellbeing, possibly from direct impacts on health [42–45], and certainly through their contribution to the degradation of the starry night sky [2, 46, 47]. This is particularly concerning when stadiums are located at the edges or outside of town, as exemplified by the impact on rural Sussex shown in Fig. 1; the nearby South Downs National Park was certified as an International Dark Sky Reserve [48] in the same year that the light emissions from the American Express Community Stadium dramatically increased (see "Brighton" in Fig. 5). Both the extraordinary brightness of stadiums and their frequent location areas that otherwise have comparatively little artificial light are similar to the problem of escape of light from greenhouses. Greenhouses with supplemental lighting are among the brightest individual objects on Earth at night [16], and waste light escaping from them has resulted in complaints from aircraft pilots [49] and the general public [50, 51]. In response, the impacts on the environment and residents have been mitigated by the installation of blackout curtains, which keep the light where it is intended. In the Netherlands, for example, some greenhouses must ensure that 95-98% of the light does not escape [50, 51]. It is therefore worth considering whether and to what extent the operators of large stadiums could minimize their impacts.

There are at least three approaches that could be directly adapted from the experience of supplemental lighting in greenhouses. First, the application of shielding to keep the light on the grass area. In addition to installing the lighting rigs above the grass, operators could perhaps install a sheet of reflective material above the rigs, in order to redirect reflected light back towards the grass surface a second time. In addition to reducing unintended emissions outside of the stadium, this should increase the efficiency of the light, potentially allowing electricity savings. Second, spectral tuning of the light sources using LEDs may allow for similar growth potential with reduced total use of electricity [52]. Third, supplemental lighting could instead be applied during daylight hours, when wasted light would have much less of an ecological impact. Leagues could also consider adjusting their schedules, in order to minimize the need for grow lights in winter. While these approaches would involve logistical or engineering challenges, it seems reasonable to expect that a multi-billion pound industry [53] should be able to find a solution for what is in the end a relatively small number of installations.

In terms of lighting conflicts, this case is a bit unusual in the degree to which it involves both a large area and a large group of people [4, 54]. We have shown that the emissions from football stadium grow lights can make up a large part of the total emissions from a large city (Fig. 6), and the skyglow generated from grow lights is visible from large distances (Fig. 1). At the same time, many people view football as a deeply cherished part of their collective culture, and these lights were deliberately installed and operated for a specific reason. Thus far no local authority or National Park Authority has taken any enforcement action against any stadium, and it is unclear (to us at least) whether the existing legal framework even provides a way to do this. We suggest that improvement in stadium grow lighting therefore presents an interesting opportunity for proponents of sustainable lighting (such as the UK's "All-Party Parliamentary Group for Dark Skies" [55]) to achieve a highly visible success.

What would such a success look like? We see three necessary requirements. First, the radiance of artificial light emissions from stadiums at night should at most be similar to that of the nearby area. (In the ideal case, the waste light would be so small as to be unnoticeable.) Second, the electrical consumption of the grow lights should be reduced to the greatest extent which is practical, both through spectral tuning of the lights and by applying the light treatment for the shortest amount of time possible. Third, the grass should meet (reasonable) league requirements. If the third of these requirements is not met, then the lighting failed its job, and if either of the first two are not met, then the lighting cannot reasonably be considered to be sustainable.

5. Conclusion

In many lighting applications, light emissions towards space are a necessary byproduct. Lighting for pedestrians, for example, requires light be scattered upwards from the walkway surface. In agricultural applications, however, light emissions to space represent wasted light that did not fulfill its intended purpose. The current practice of using grow lighting for stadium grass is not sustainable for several reasons, including wasted electricity, ecological harm, and degradation of the night sky. Addressing this should be a priority for communities where stadiums use grow lights, because stadium grow lights represent a considerable fraction of the total light emission of such cities.

6. Acknowledgement

C.C.M.K. and J.C. acknowledge funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 689443 via project GEOEssential, as well as funding from the Helmholtz Association Initiative and Networking Fund under grants ERC-RA-0031 and CS-0003.

References

[1] Rosebrugh, D W. (1935). *Sky-Glow from large cities*. Journal of the Royal Astronomical Society of Canada.
[2] Aubé, M. (2015). *Physical behavior of anthropogenic light propagation into the nocturnal environment.* Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. Département de physique, Cégep de Sherbrooke, Sherbrooke, Quebec, Canada: Royal Society. https://doi.org/10.1098/rstb.2014.0117.
[3] Morgan Taylor, M. (2006). *Light Pollution and Nuisance: The Enforcement Guidance for Light as a Statutory Nuisance.* Journal of Planning & Environmental Law.
[4] Meier, J. (2018). *Contentious Light: An Analytical Framework for Lighting Conflicts*. International Journal of Sustainable Lighting. Department of Urban and Regional Planning, Technische Universität Berlin, Germany; josiane.meier(at)tu-berlin.de: IJSL.
[5] Reuters. (2016, June 17). *State of pitches prompts concern at Uefa after bad weather in France.* The Guardian. Retrieved from https://www.theguardian.com/football/2016/jun/17/pitches-euros-concern-france-uefa.
[6] UEFA. (2017). *Pitch Perfect*. UEFA Direct, 167, 12–19.
[7] Fifa. (2010). *Manager's Guide to Natural Grass Football Pitches*.

[8] TLS. (2022, May 18). *TLS Turfpal 72 Lighting Rigs*. Retrieved May 18, 2022, from https://web.archive.org/web/20220518132527/https://ra-tls.com/rig/tls-turfpal-72-lighting-rigs/.
[9] Miller, S., Straka, W., Mills, S., Elvidge, C., Lee, T., Solbrig, J., Weiss, S. (2013). *Illuminating the Capabilities of the Suomi National Polar-Orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band*. Remote Sensing. https://doi.org/10.3390/rs5126717.
[10] Elvidge, C. D., Baugh, K. E., Zhizhin, M., & Hsu, F.-C. (2013). *Why VIIRS data are superior to DMSP for mapping nighttime lights.* Proceedings of the Asia-Pacific Advanced Network. https://doi.org/10.7125/APAN.35.7.
[11] Coesfeld, J., Kuester, T., Kuechly, H. U., & Kyba, C. C. M. (2020). *Reducing Variability and Removing Natural Light from Nighttime Satellite Imagery: A Case Study Using the VIIRS DNB.* Sensors. https://doi.org/10.3390/s20113287.
[12] Coesfeld, Jacqueline, Kuester, Theres, Kuechly, Helga U., & Kyba, Christopher C.M. (2020). *Background correction for EOG VIIRS-DNB monthly composites (data and scripts).* GFZ Data Services. https://doi.org/10.5880/GFZ.1.4.2020.003.
[13] Sánchez de Miguel, A., Kyba, C. C. M., Aubé, M., Zamorano, J., Cardiel, N., Tapia, C., Gaston, K. J. (2019). *Colour remote sensing of the impact of artificial light at night (I): The potential of the International Space Station and other DSLR-based platforms.* Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2019.01.035.
[14] Hung, L.-W., Anderson, S. J., Pipkin, A., & Fristrup, K. (2021). *Changes in night sky brightness after a countywide LED retrofit.* Journal of Environmental Management, 292, 112776. https://doi.org/10.1016/j.jenvman.2021.112776.
[15] Sanchez de Miguel, A., Kyba, C. C. M., Zamorano, J., Gallego, J., & Gaston, K. J. (2020). *The nature of the diffuse light near cities detected in nighttime satellite imagery.* Scientific Reports. https://doi.org/10.1038/s41598-020-64673-2
[16] Coesfeld, J., Anderson, S., Baugh, K., Elvidge, C., Schernthanner, H., & Kyba, C. (2018). *Variation of Individual Location Radiance in VIIRS DNB Monthly Composite Images.* Remote Sensing. https://doi.org/10.3390/rs10121964
[17] Elvidge, C. D., Hsu, F.-C., Zhizhin, M., Ghosh, T., Taneja, J., & Bazilian, M. (2020). *Indicators of Electric Power Instability from Satellite Observed Nighttime Lights.* Remote Sensing. https://doi.org/10.3390/rs12193194
[18] Tong, K. P., Kyba, C. C. M., Heygster, G., Kuechly, H. U., Notholt, J., & Kolláth, Z. (2020). *Angular distribution of upwelling artificial light in Europe as observed by Suomi–NPP satellite.* Journal of Quantitative Spectroscopy and Radiative Transfer. https://doi.org/10.1016/j.jqsrt.2020.107009
[19] Sutton, P. C., Elvidge, C. D., & Ghosh, T. (2007). *Estimation of gross domestic product at sub-national scales using nighttime satellite imagery.* International Journal of Ecological Economics & Statistics.
[20] Ghosh, T., Powell, R. L., Elvidge, C. D., Baugh, K. E., Sutton, P. C., & Anderson, S. (2010). *Shedding Light on the Global Distribution of Economic Activity.* The Open Geography Journal. https://doi.org/10.2174/1874923201003010147
[21] Townsend, A. C., & Bruce, D. A. (2010). *The use of night-time lights satellite imagery as a measure of Australia's regional electricity consumption and population distribution.* International Journal of Remote Sensing. https://doi.org/10.1080/01431160903261005
[22] Kyba, C. C. M., Kuester, T., Sánchez de Miguel, A., Baugh, K., Jechow, A., Hölker, F., Guanter, L. (2017). *Artificially lit surface of Earth at night increasing in radiance and extent. Science Advances.* GFZ German Research Centre for Geosciences, Potsdam 14473, Germany; AAAS. https://doi.org/10.1126/sciadv.1701528
[23] Stare, J. (2021, May 6). *Radiance Light Trends. Application.* Retrieved May 6, 2021, from https://lighttrends.lightpollutionmap.info
[24] Stare, J., & Kyba, C. (2019). *Radiance Light Trends (p. 5 Files).* GFZ Data Services. https://doi.org/10.5880/GFZ.1.4.2019.001
[25] Elvidge, C. D., Cinzano, P., Pettit, D. R., Arvesen, J., Sutton, P., Small, C., Ebener, S. (2007). *The Nightsat mission concept.* International Journal of Remote Sensing. https://doi.org/10.1080/01431160600981525
[26] Li, X., Li, X., Li, D., He, X., & Jendryke, M. (2019). *A preliminary investigation of Luojia-1 night-time light imagery.* Remote Sensing Letters. https://doi.org/10.1080/2150704X.2019.1577573
[27] Barentine, J. C., Walczak, K., Gyuk, G., Tarr, C., & Longcore, T. (2021). *A Case for a New Satellite Mission for Remote Sensing of Night Lights.* Remote Sensing, 13(12), 2294. https://doi.org/10.3390/rs13122294
[28] Kyba, C. C. M. ., Garz, S., Kuechly, H., de Miguel, A., Zamorano, J., Fischer, J., & Hölker, F. (2015). *High-Resolution Imagery of Earth at Night: New Sources, Opportunities and Challenges.* Remote Sensing. https://doi.org/10.3390/rs70100001
[29] Horton, H., & reporter, H. H. E. (2022, May 17). *Light pollution falling amid soaring energy prices, star survey finds.* The Guardian. Retrieved from https://www.theguardian.com/environment/2022/may/17/light-pollution-falling-amid-soaring-energy-prices-star-survey
[30] Hölker, F., Moss, T., Griefahn, B., Kloas, W., Voigt, C., & al, et. (2010*). The Dark Side of Light: A Transdisciplinary Research Agenda for Light Pollution Policy.* Ecol Soc. Retrieved from http://www.ecologyandsociety.org/vol15/iss4/art13/
[31] Sánchez de Miguel, A., Bennie, J., Rosenfeld, E., Dzurjak, S., & Gaston, K. J. (2021). *First Estimation of Global Trends in Nocturnal Power Emissions Reveals Acceleration of Light Pollution.* Remote Sensing, 13(16), 3311. https://doi.org/10.3390/rs13163311

[32] Brighton & Hove Albion Environmental Statement. (n.d.). Retrieved July 17, 2021, from https://web.archive.org/web/20210717132916/https://www.brightonandhovealbion.com/club/club/environmental-statement/
[33] de Freitas, W. (n.d.). *Moths' expert: match report on Ronaldo insect encounter at Euro 2016 final.* Retrieved July 17, 2021, from https://web.archive.org/web/20210717135331/https://theconversation.com/moths-expert-match-report-on-ronaldo-insect-encounter-at-euro-2016-final-62314
[34] Ogden, L. J. E. (1996). *Collision Course: The Hazards of Lighted Structures and Windows to Migrating Birds*. Technical report, World Wildlife Fund Canada and the Fatal Light Awareness Program, Toronto, Canada. Retrieved from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1002&context=flap
[35] Van Doren, B., Horton, K. G., Dokter, A. M., Klinck, H., Elbin, A., S. B. ,. Farnsworth, Dokter, A. M., Farnsworth, A. (2017). *High-intensity urban light installation dramatically alters nocturnal bird migration.* Publications of the National Academy of Sciences. Information Science Program, Cornell Lab of Ornithology, Ithaca, NY 14850 USA; af27@cornell.edu: PNAS. https://doi.org/10.1073/pnas.1708574114
[36] Royal Society for the Protection of Birds. (2012). *Starling population crashes across Europe*. Retrieved January 18, 2022, from http://www.rspb.org.uk/our-work/rspb-news/news/318986-starling-population-crashes-across-europe
[37] Barrington, R. M. (1911). *The Great Rush of Birds on the Night of March 29th-30th*, as Observed in Ireland. The Irish Naturalist, 20(6), 97–110.
[38] Doren, B. M. V., Willard, D. E., Hennen, M., Horton, K. G., Stuber, E. F., Sheldon, D., Winger, B. M. (2021). *Drivers of fatal bird collisions in an urban center.* Proceedings of the National Academy of Sciences, 118(24). https://doi.org/10.1073/pnas.2101666118
[39] Korner, P., von Maravic, I., & Haupt, H. (2022). *Birds and the 'Post Tower' in Bonn: a case study of light pollution.* Journal of Ornithology. https://doi.org/10.1007/s10336-022-01985-2
[40] La Sorte, F. A., Johnston, A., Rodewald, A. D., Fink, D., Farnsworth, A., Van Doren, B. M., Strimas-Mackey, M. (2022). *The role of artificial light at night and road density in predicting the seasonal occurrence of nocturnally migrating birds.* Diversity and Distributions, ddi.13499. https://doi.org/10.1111/ddi.13499
[41] Audubon Society. (2022, March 3). *Lights Out.* Retrieved March 3, 2022, from https://web.archive.org/web/20220303142422/https://www.audubon.org/lights-out-program
[42] Obayashi, K., Yamagami, Y., Kurumatani, N., & Saeki, K. (2019). *Bedroom lighting environment and incident diabetes mellitus: a longitudinal study of the HEIJO-KYO cohort.* Sleep Medicine. Department of Epidemiology, Nara Medical University School of Medicine, 840 Shijocho, Kashiharashi, Nara, 634-8521, Japan; obayashi(at)naramed-u.ac.jp: Elsevier. https://doi.org/10.1016/j.sleep.2019.07.006
[43] Paksarian, D., Rudolph, K. E., Stapp, E. K., Dunster, G. P., He, J., Mennitt, D., Merikangas, K. R. (2020). *Association of Outdoor Artificial Light at Night with Mental Disorders and Sleep Patterns among US Adolescents*. JAMA Psychiatry. Genetic Epidemiology Research Branch, Intramural Research Program, National Institute of Mental Health, Bethesda, Maryland. https://doi.org/10.1001/jamapsychiatry.2020.1935
[44] Zhong, C., Longcore, T., Benbow, J., Chung, N. T., Chau, K., Wang, S. S., Franklin, M. (2021). *Environmental influences on sleep in the California Teachers Study Cohort.* American Journal of Epidemiology, in press (kwab246). https://doi.org/10.1093/aje/kwab246
[45] Hu, K., Li, W., Zhang, Y., Chen, H., Bai, C., Yang, Z., … Yao, Y. (2022). *Association between outdoor artificial light at night and sleep duration among older adults in China: A cross-sectional study.* Environmental Research, 113343. https://doi.org/10.1016/j.envres.2022.113343
[46] Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C. C. M., Elvidge, C. D., Baugh, K., Furgoni, R. (2016). *The new world atlas of artificial night sky brightness.* Science Advances. https://doi.org/10.1126/sciadv.1600377
[47] Gallaway, T. (2010). *On Light Pollution, Passive Pleasures, and the Instrumental Value of Beauty.* Journal of Economic Issues. https://doi.org/10.2753/JEI0021-3624440104
[48] The Guardian. (2022, March 3). *South Downs recognized for quality of starry nights.* Retrieved March 3, 2022, from https://web.archive.org/web/20220303163015/https://www.theguardian.com/environment/2016/may/10/south-downs-recognised-for-quality-of-starry-nights
[49] Kalinowski, T. (2021, July 17). *Greenhouses causing "light pollution" for planes - Medicine Hat News.* Retrieved July 17, 2021, from https://web.archive.org/web/20210717142825/https://medicinehatnews.com/news/local-news/2017/01/14/greenhouses-causing-light-pollution-for-planes/
[50] Meadows, C. (2019, November 21). *Complaints gain traction regarding greenhouse lighting.* LEDs Magazine. Retrieved July 17, 2021, from https://web.archive.org/web/20210717143948mp_/https://www.ledsmagazine.com/horticultural-lighting/article/14072530/complaints-gain-traction-regarding-greenhouse-lighting
[51] Zurko, J. (2021, July 17). *The Neighbors Are Complaining.* Retrieved July 17, 2021, from https://web.archive.org/web/20210717144358/https://www.growertalks.com/Article/?articleid=23643
[52] Pattison, P. M., Tsao, J. Y., Brainard, G. C., & Bugbee, B. (2018). *LEDs for photons, physiology and food.* Nature. Utah State University, Logan, UT, USA. https://doi.org/10.1038/s41586-018-0706-x
[53] This is Premier League: Economic and social impact. (n.d.). Retrieved July 17, 2021, from https://web.archive.org/web/20210717145825/https://www.premierleague.com/news/1562726
[54] Meier, J. M. (2019). *Contentious Light: An Analytical Framework for Lighting Conflicts* (PhD Thesis). Technische Universität Berlin. Retrieved from https://depositonce.tu-berlin.de/handle/11303/9491

[55] All-Party Parliamentary Group for Dark Skies. (2022, March 4). APPG for Dark Skies. Retrieved March 4, 2022, from https://web.archive.org/web/20220304093753/https://appgdarkskies.co.uk/.