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Light Energy: Our Wasted Resource

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ABSTRACT: Artificial light at night (ALAN) is a form of visual pollution and energy waste that is often overlooked. The International Dark Sky Association estimates that 30% of all lighting is strictly for the outdoors. Furthermore, 30% of all outdoor lighting is wasted, used (1) when not needed, or (2) pointing directly upwards. In 2017, the US wasted approximately 60 billion kilowatt hours (kWh), translating to a loss of more than $6.3 billion and CO_2 emissions in excess of 23 billion pounds. ALAN has been linked to reduced production of melatonin, the body's sleep-regulating hormone, which is associated with increased risk of hormonal cancers including breast and prostate cancer. In fact, the World Health Organization (WHO) now lists shift work as a type II risk for cancer. Light at night threatens migratory birds, a majority of which fly at night presumably using constellations as their guide. Light pollution paints the sky black, pushing astronomers to ever-shrinking dark zones suitable for studying the universe. In the most severely affected cities, only a handful of stars can be seen where once thousands dazzled gazers. Society's overreliance on ALAN has resulted in energy waste, adverse health effects, and pervasive pollution contributing to climate change and concealing our starry night sky.

Keywords: ALAN, light pollution, LED, blue-light, health

AUTHOR'S NOTE: The sky used to be filled with stars. I remember spending nights looking up and counting for hours. Have you ever lost yourself in the expanse of space, realizing how small you are compared to the tiny speck one-hundred times the size of your own sun? Did you know that on nights of a new moon, it's possible to see the spiraling arms of the Milky Way Galaxy? Ironically, as the city grows ever brighter, my nights grow continually darker. The stars are disappearing behind curtains of scattered light from artificial sources. The night sky is fading out into a blank black canvas. I chose to research light pollution as part of an Energy Resources course at the University of Michigan-Dearborn because it's an economic, environmental, and societal issue. Humanity has always been inspired by the beauty in the night sky; I hope we find that beauty again.

Introduction

The 2014 Nobel Prize in Physics went to three Japanese researchers for their invention of the blue light diode (Webb, 2014). This final piece completed the trifecta needed to create the clean, white lighting now present in many modern, industrialized cities. Making white light requires wavelengths in the red, green, and blue visible light spectrum. Red and green diodes have been around since the early 1900s, only changing in efficiency and shade throughout the years. The blue light emitting diode eluded scientists for decades until the Nobel Prize winning physicists perfected it.

It is now 2020. The world is brighter than ever before. Not only are we showered by the intense rays of a star, but we have created our own sources of light. Photographs from outer space reveal bright whites and yellows splattered across an otherwise dark planet—an anthropogenic constellation that shares the locations of the most populous places on Earth (Figure 1). Light often carries positive associations as a symbol of knowledge and growth. 'Having a lightbulb moment' equates to sudden inspiration. 'Seeing the light' means coming to an important understanding on an issue. It is concerning that society's view is mostly positive when there are real, negative effects

Figure 1: NASA Earth Observatory images by Joshua Stevens, using Suomi NPP VIIRS data from Miguel Roman, NASA's Goddard Space Flight Center. Reprinted from NASA (2017).

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Table 1: Electricity market breakdown by sector for 2017. Created using data from the EIA (2018a). See Appendix for specific source information.

Sector	Number of Consumers (millions)	Consumption (average kWh/month)	Consumption total (average MWh/year)	Average rate (dollars/kWh)	2017 Total Cost (billion USD)
Residential[a]	132.58	867	10.4	0.13	$178
Commercial[b]	18.36	6,141	73.7	0.11	$144
Industrial[c]	0.84	97,610	1,170	0.07	$68
Total	151.78				$390

Table 2: Linear regression results for consumption and cost in the U.S. electricity market. Model 1 tests consumption (dependent variable) against cost/kWh (independent variable). Model 2 tests for market elasticity by taking the natural log of the variables.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.755	0.57	0.561	134.528
2	0.828	0.685	0.678	0.14377

associated with increased lighting. Ironically, the more light we have the less we may actually see. This study examines energy consumption for lighting in the US, explains the associated pollution and health effects that arise from ALAN, and describes how society can fight back to regain natural, beautiful night skies without sacrificing visibility.

Energy and Lighting in the US

In 2017, US households consumed approximately 97.7 quadrillion British Thermal Units (≈2.86 x 1013 kWh) of energy (EIA, 2018b). Of this, 38.1% went to generating electricity. Table 1 shows the 2017 market breakdown for electricity consumption in the US. The residential sector on average consumed less kWh than commercial and industrial customers but had the most consumers and higher rates. Although the commercial and industrial sectors both consumed more kWh on average per month, the sheer volume of residential customers makes this the most energy demanding sector.

An interesting pattern emerged from the data: the states consuming the most kWh also had the lowest cost/kWh. Using a simple linear regression model with SPSS, I tested the theory that consumption (dependent variable) is based on cost/kWh (independent variable) in the residential sector. The results are shown in Table 2. The regression explains about 57% of the variation centered on the mean, with every additional penny resulting in an approximate decrease of 40 kWh consumed. The weak correlation implies factors beyond price influence electricity consumption, such as length of daylight, climate, state, availability of substitutes (wood logs, geothermal energy, etc.), and others.

To further test the relationship between price and consumption, I ran a second regression by transforming the variables. By using the natural log of each variable, we can test the elasticity of the electricity market. These results are shown in Table 2. The relationship here is stronger, with 69% of the variation centered on the mean explained. According to this model, for every 10% change in price, demand (consumption) decreases by 8%. Since the change in demand is smaller in magnitude than the change in price, this is an inelastic market. Inelastic markets typically result from insufficient alternative products for consumers. The limitation on alternatives or substitute goods means a change in price will not significantly impact consumption. For example, the gasoline industry is inelastic because even if prices increase dramatically tomorrow, demand will not change much in the short run since most Americans own gas-powered vehicles. It would take time for consumers to find alternative modes of transportation like electric cars, bicycles, and public transportation. Similarly, an inelastic electricity market means there are few alternative forms of energy available to consumers in the short run. This makes increasing the price of electricity a less effective solution for targeting light pollution than policy-making or education.

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Table 3: Breakdown of lighting in the U.S. for 2017 with a focus on outdoor lighting. See appendix for sources and explanations of values

Usage	Breakdown	Ratio	Consumption (total TWh/year)[f]	2017 Total cost (billion USD)
Lighting	(17% U.S. electricity consumption)[d]	0.17	630	$66
Outdoor Lighting	(32% of overall lighting)[d]	0.32	200	$21
Estimated waste from outdoor lighting	(30% of outdoor lighting)[e]	0.30	61	$6

Table 4: Based on the percentage of each resource used to produce electricity, the estimated carbon footprint can be calculated for wasted outdoor lighting in 2017.

Resource	Percentage of electric energy produced by each resource[j]	Amount of resource used in wasted outdoor lighting	Released CO_2 (tons)
Petroleum[g]	0.564%	1.13 million ft^3	115,000
Natural Gas[h]	25.6%	51,500 million ft^3	3,000,000
Coal[i]	34.1%	3,720,000 tons	8,500,000

The Office of Energy Efficiency & Renewable Energy (2015) estimates that lighting accounts for 17% of electricity consumption in the US, with 30% of all lighting used explicitly outdoors (Office of Energy Efficiency & Renewable Energy, 2015). The International Dark Sky Association estimates that 30% of this outdoor lighting is wasted, meaning lights are installed in areas they are not needed, are left on when not in use, or are directed upwards such that light is scattered into the atmosphere. Using these ratios, we can estimate the amount of wasted outdoor lighting in the US for 2017. This is done in Table 3.

More than 60 billion kilowatt hours were wasted for a relatively unnecessary use of electricity. Lighting does not move people from point A to B. It does not power our tools. Its purpose is to let us see, and the dominating perception is more light equals more sight. Modern lightbulbs are more efficient and brighter than ever, and our persistence in installing more and more lights has nearly doubled the number of lumens cast into the night.

The financial costs alone give sufficient reason to combat wasted outdoor lighting, but the incentive increases tenfold when considering its impact on greenhouse gases. The Lawrence Livermore National Laboratory working under the U.S. Department of Energy created a flowchart breaking down US energy production. With the data from their Estimated U.S. Energy Consumption in 2017: 97.7 Quads, it is possible to calculate the estimated emissions from wasted outdoor lighting, shown in Table 4.

The volume of petroleum, natural gas, and coal used in the mix of electricity production for the wasted outdoor lighting of the entire US contributed over 23 billion pounds of CO_2 emissions into the atmosphere in 2017. This comprises 10% of emissions caused by lighting in the U.S.

Light Pollution

The International Dark-Sky Association defines light pollution as "the inappropriate or excessive use of artificial light" that "can have serious environmental consequences for humans, wildlife, and our climate" (n.d.).

Light pollution crosses property lines and trespasses freely. Images 1 & 2 illustrate how light pollution masks a star-filled night sky. Night skies like the one on the right have become increasingly rare as more light is used in cities. One-third of humanity, including 80% of North Americans, can no longer see the Milky Way. 99% of Americans and Europeans live under light-polluted skies (Falchi et. al. 2016). In the US, roughly 38% of the population is exposed to significant light pollution, more than 41 times the natural background brightness (Falchi

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Image 1 and 2: (left) Photo of a house in Canada taken during the night. (Right) Photo taken of the same house on August 14th, 2003, during a blackout. Without light pollution, residents could see bands of light from the Milky Way Galaxy with their naked eye. Photo credit: Todd Carlson. Source: Department of Physics, Florida Atlantic University (n.d.)

Image 3: The Luxor Casino in Las Vegas is the brightest location in the world due to its 39 lamps at the top, each of which reach 7,000 watts and cost $51 hourly to run (Morris, 2017). Photo Credit: Morris (2017) Source: McGraw 2017

2016). Compared with the top 20 developed countries, the US has the sixth largest proportion of population exposed to significant light pollution. Yet, 30% of the US's land area is at or only slightly above the natural background brightness (Falchi 2016), meaning there is still time for the U.S. to preserve large portions of natural sky.

As stars fade into the background and the light of the galaxy is blocked by the glow of halogen and LED lighting, we risk losing part of our identity. Astronomer Neil de Grasse Tyson said it best: "When you look at the night sky, you realize how small we are within the cosmos. It's kind of resetting of your ego. To deny yourself of that state of mind, either willingly or unwittingly, is to not live to the full extent of what it is to be human" (Department of Physics, Florida Atlantic University (n.d.)). How are we to understand ourselves if we cannot see our place in the universe?

Many of Earth's species are being tested by similar difficulties.

I. Environmental Disruptions

North America holds four of the world's largest migratory bird flight paths: the Pacific, Central, Mississippi and Atlantic Flyways (FLAP Canada, n.d.). Many migratory bird species like the Chestnut-sided Warbler fly at night using the constellations as a guide. Bright lights from cities pull them off course. Once inside city limits, the lighting, noise, and tall structures disorient the birds. Many cannot find their way out of the maze of buildings, wires, and lights. Once day breaks, reflective surfaces add to the challenge and collisions are unavoidable. Since 1993, volunteers from the Fatal Light Awareness Program (FLAP) have picked up hundreds of thousands of birds belonging to over 160 species in the Toronto region (FLAP, n.d.). Around 60% of these birds have been found dead.

Migratory birds are not the only species suffering from light at night. At least 30% of vertebrates and more than 60% of all invertebrates worldwide are nocturnal (Bogard, 2013, pp. 131). Many ecologists are concerned about sea turtles. Female sea turtles time their egg-laying so hatchlings emerge from the sand near or on the night of a full moon. Hatchlings use the moon's reflection over the water as a giant beacon or guide to reach the safety of the water. However, the full moon is no longer the brightest light in the night sky. Anthropogenic lighting along roads and houses confuse the newly hatched turtles. The natural instinct which served sea turtles so well for millions of years is no longer fool proof. Instead of heading down the beach towards the water, they now crawl towards civilization where many are crushed by automobiles and passersby, fall into cracks and sewage drains, or become dinner to the predatory species taking advantage of their confusion.

A lesser known case of these impacts occurs nightly at the Luxor Casino in Las Vegas (Image 3). The top of this pyramid-shaped structure shoots off a beam so bright, it has acquired its own ecosystem. Moths from the surrounding desert flock to the glowing point, which in turn attracts bats, which then attract owls (Morris, 2017). What ensues is a feeding frenzy; the dense concentration of food attracts the surrounding fauna, but the energy bats and owls expend flying to the casino from the surrounding desert detracts from the gains. By the time they make the journey back, they have little to no food to give to their young. The intense beams themselves are a danger. The light can disorient birds, as Ellen Meloy notes in her essay, "The Flora and Fauna of Las Vegas." Her essay describes with vivid imagery the sight of a mallard duck losing its way in the intense lighting, and colliding with a powerline.

The sight of a frying duck will no doubt linger in our minds, but it is what goes unseen that is most concerning. Hardly a second thought is given before squashing a moth beneath a roll of newspaper. Yet these organisms are credited with pollinating almost 80% of the world's flora

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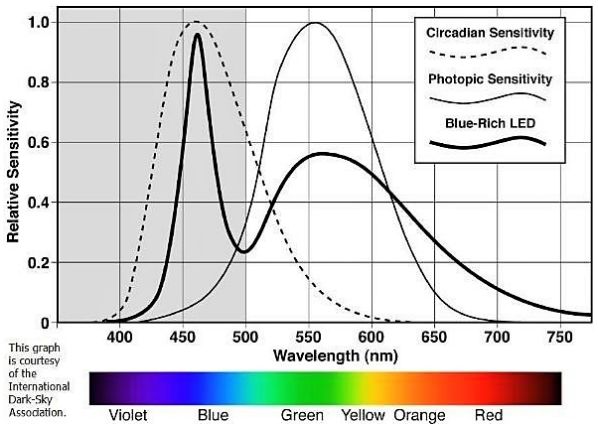

Figure 2: The peak sensitivity of these photoreceptor cells occurs in the blue light spectrum. Reprinted from the Department of Physics Florida Atlantic University (n.d.).

(Bogard, 2013, pp. 138). They emerge at night and because of their attraction to light, they suffer tremendously.

As society continues to advance, more light follows. The night sky shrinks further out of sight, and where the night retreats, its creatures vanish too.

II. Health Effects

Melatonin is an incredibly important "sleep" hormone produced by the body. The time of day regulates its release in the brain with levels rising in the evening and falling in the morning (NIH, 2015). Richard Stevens published the first article relating ALAN to cancer in 1987. His conclusion that "increasing use of electricity to light the night leads to circadian rhythm disruption which accounts for part of the breast cancer burden in the modern world and rising risk in developing countries" has had surprisingly little impact on the increasing brightness of our cities (Bogard, 2013, pp. 104). David Blask and colleagues (2005) further corroborated Stevens's claims when they ran experiments showing that human blood taken during the night prevented tumor growth in rats. When this experiment was replicated using the blood of individuals exposed to daylight and light at night, neither group's blood samples had the aforementioned tumor-fighting impact. This means that the body might respond similarly to daylight and light at night. Both scenarios cause reduced melatonin production in the body, which in turn has been linked to breast cancer.

Considering David Berson and colleagues' work from Brown University, this comes as less of a surprise. In 2002, his team published research on a newly discovered photoreceptor cell in the retina previously thought not to be light-sensitive (Bogard, 2013, pp. 105-106). These cells contribute to the external cues, or zeitgeber, that vertebrate use to reset their circadian rhythms to local times (Department of Physics, Florida Atlantic University, n.d.). Isolated in a petri dish, the cells react strongest to blue light—wavelengths approximately between 420 and 480 (Figure 2).

The ramifications of this are huge, which is in part why the WHO now lists shift work as a type II cancer risk (Bogard, 2013, pp. 108). Until recently, breathing diesel fumes and exposure to UV light were also type II risks. They have since been moved to type I, meaning they are now known and proven causes of cancer (Bogard, 2013, pp. 109).

Beyond cancer, reduced production of melatonin can also mean a harder time falling asleep. The majority of light scattered in Earth's atmosphere has a short wavelength, making the sky appear blue. Since humans evolved to be predominantly active during the day, evolution geared our photoreceptive cells to be sensitive to blue light in order to attune us to the day-night cycle. When we are exposed to blue light at night, it tricks our bodies into thinking it is still daylight. This in turn prolongs the amount of time the body needs to wind down and ready for rest. 25% of adults in the U.S. already report insufficient sleep or rest every 15 out of 30 days (American Sleep Apnea Association, 2017).

This has consequences for the economy. Tired workers are not as productive or attentive, which translates into lost revenue. Hafner et. al. (2017) analyzed 5 countries and estimates that the U.S. economy loses $411 billion annually due to sleep deprivation. Japan is second with a loss of $138 billion, Germany third with $60 billion, then the UK at $50 billion and Canada at $21.4 billion.

Sleep deprivation also takes a toll on health. The body is actively working to repair your heart and blood vessels, build new neural pathways, balance hormones, and strengthen your immune system while you are asleep (NIH 2019). This partly explains why adults managing between 6 to 7 hours of sleep each night face a 7% higher mortality risk than those who obtain 7 to 9 hours of sleep. Sleeping fewer than 6 hours per night results in a 13% higher mortality risk (Hafner et. al. 2017).

Many aspects of modern life contribute to sleep deprivation, including alcohol consumption, smoking, lack of exercise, psychosocial stress, and electronic use (Hafner et. al. 2017). Many devices are now equipped with a night-mode or blue-light filter for night-time use, though scholars like Hafner et. al. (2017) still recommend limiting screen-time before bed. Low wattage, blue-filtered lights at night can also help the eyes rest and the body prepare

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for vital sleep. The best solution is to simply leave lights off until truly needed.

Solutions

The outlook for the future is not all doom and gloom (there are too many lights for that). Educated communities around the globe are coming together to protect and bring back dark skies. Organizations like FLAP in Toronto, Canada have good reason to. Toronto lies directly in the Atlantic flyway. Hundreds of thousands of birds from over 160 different species fly near and over the city to wintering grounds in the South. This non-profit organization and roughly 100 volunteers dedicate themselves to rescue, research, protect, and educate the public on anthropogenic causes of bird collisions. Since its founding in 1993, FLAP has created guidelines for architects, engineers, and building owners, required mandatory anti-collision measures for all new buildings, and promoted the development of tinted window-films (Bogard, 2013). One measure to protect migrating species is simple: turn off extra lights at night. This is what cities like Highland Park, Michigan; Clintonville, Wisconsin; and Rockford, Illinois have done (NPR, 2011). While perhaps not entirely motivated out of concern for the environment, these cities have successfully cut back on energy consumption by turning off and even removing some of their streetlights. Rockford, home to 150,000 residents, removed 2,300 streetlights––about 15% of their total stock––saving between $250,000 and $500,000 annually (NPR, 2011).

Since shutting off lights is the best way to cut down on light pollution, it is necessary to address societal concerns surrounding light at night. The most significant is unsurprising: safety. With lighting comes a sense of security. However, the link between lighting and crime is weak to non-existent. Dr. Barry Clark from the Astronomical Society of Victoria in Australia conducted a massive review of literature on the relationship between crime and lighting. In 1977, the National Institute of Law Enforcement and Criminal Justice reviewed 60 street lighting projects and presented their findings to Congress (Clark, 2002). They admitted to "no statistically significant evidence that street lighting impacts the level of crime, especially if crime displacement is taken into account" (Clark 2002), yet in the same paragraph they mentioned how increased lighting may decrease the fear of crime. It does not change the level of crime, but it does misguide people into feeling safer about it.

Twenty years later, the same department did a more in-depth review. "Conclusions for Open Urban Places" by Eck (1997) [31] determined that lighting works in some places, has no impact in others, and proves

Figure 3: Examples of good (shielded) and bad (unshielded) forms of lighting. Many roadsides and crosswalks are being retrofitted with small LED diodes installed on the underside of the light fixtures. While this eliminates upward misdirection of light, these designs allow light to travel great distances horizontally. The exposed glare invades surrounding areas and can be blinding due to the way light scatters across the eye. Illustration by Bob Crelin. Used with permission.

counterproductive in still other circumstances. There is very little confidence that improved lighting will prevent crime since it has not been proven that offenders don't benefit from increased lighting as well (Clark, 2002). Paul Bogard, author of *The End of Night*, cites a joke he heard while researching the topic in London: "Criminals actually prefer to work in well-lit areas because they, too, feel safer" (Bogard, 2013, pp. 76). He then cites a study asking criminals what deterred them from targeting a house. The top answers were "belief that house is occupied," "presence of alarms or CCTV/camera outside the property," and, to a lesser extent, the "apparent strength of doors/window locks" (Bogard, 2013, pp. 76). While lighting inside the home may lead criminals into believing someone is home, it does not explicitly deter criminal activity on its own.

Thus, extra lighting provides the illumination a criminal needs to the point that David Crawford, founder of the International Dark-Sky Association, terms this criminal-friendly lighting (Bogard, 2013, pp. 76). Bob Mizon, coordinator for the Campaign for Dark Skies in

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the United Kingdom, stresses how people forget lighting goes both ways:

> The people who claim benefits from lighting, they never put themselves in the mind of the criminal––what does he or she possibly need? What does a burglar need, what does a rapist or mugger need? They need to assess the victim; they need to see what they're doing. I mean, who benefits most from a big security light at three o'clock in the morning? (Bogard, 2013, pp. 76).

The Chicago Alley Lighting Project is one such case where criminals seemed to benefit most. In 2000, the city installed higher-watt lighting to foster feelings of safety and decrease crime rates (Morrow and Hutton, 2000, pp. i). Instead, they experienced a 21% increase in criminal activity (Morrow and Hutton, 2000, pp. iii). In 2008, California required the Pacific Gas and Electric Company to review more current research on the topic. The company found lighting had a mix of positive and negative effects on crime, the majority of which were not statistically significant. This suggests either no link between lighting and crime or a link so subtle or complex it didn't appear in the data due to the limited study size (Bogard, 2013, pp. 79).

This does not mean lighting is unnecessary, but we can reduce the number of lumens without significant impact to society. In walking areas or traffic zones, a lower-watt light bulb not only reduces energy costs and pollution, but counters visual glares affecting passersby. Parisian lighting designer Roger Narboni hopes that people will become more comfortable with shadows and darkness:

> In North Africa, shadows are more important than light—the way that you play with the contrasts of shadows and light... We hide ourselves because the sun is so powerful. So for me in my everyday work this play between shadows and light is very important (Bogard, 2013, pp. 232).

Narboni's outlook is that lighting can be both functional and beautiful, and that darkness is a powerful medium. A new policy in Paris seeks to renew all urban lighting while reducing energy consumption by 30% by 2020 (Bogard, 2013, pp. 232), giving Narboni a chance to put his beliefs into practice.

However, not every city or household can afford a master light technician. In this case, there is a guide produced by the International Dark-Sky Association on acceptable light fixtures that minimize glare and light trespass. These forms of lighting are shown in Figure 3. Other policies that cities can take to minimize light trespass are requiring fully-shielded light fixtures, reducing wattage of lights, and including a shut-off or dimming time for low volume parking lots and roads.

Conclusion

"One of the penalties of an ecological education," said Leopold,

> is that one lives alone in a world of wounds. Much of the damage inflicted on land is quite invisible to laymen. An ecologist must either harden his shell and make believe the consequences of science are none of his business, or he must be the doctor who sees the marks of death in a community that believes itself well and does not want to be told otherwise (Bogard, 2013, pp. 178).

If we want to put an end to light pollution, wasted energy costs, biological impacts, negative health effects, and children growing up thinking a starless black sky is normal, then the public needs to be educated on the harms of artificial light at night. The data supports that ALAN causes more harm than good. The problem is our current perception of light. In order to bring about effective change, educators and policy-makers must work together. Once people learn what they are seeing (and what they are not) it will become increasingly apparent what light pollution is stealing from us. If there is anything at all positive to say about light pollution, it is that it can be solved with the flip of a switch.

References

American Sleep Apnea Association. (2017). "The State of SleepHealth in America – SleepHealth."

Audubon. (n.d.). Chestnut-sided Warbler Setophaga pensylvanica. National Audubon Society.

Retrieved from https://www.audubon.org/field-guide/bird/chestnut-sided-warbler#

Blask, D., and Coauthors. (2005). Melatonin-depleted blood from premenopausal women exposed to light at night stimulates growth of human breast cancer xenografts in nude rats. Cancer Research, 65, 23, pp. 11174-84. Retrieved from

https://doi.org/10.1158/0008-5472.CAN-05-1945

Bogard, P. (2013). The End of Night: Searching for Natural Darkness in an Age of Artificial Light, Little Brown and Company: New York.

Clark, B. (2002). OUTDOOR LIGHTING AND CRIME, PART 1: LITTLE OR NO BENEFIT.

Astronomical Society of Victoria, Inc., Australia Retrieved from http://asv.org.au/downloads/Outdoor%20Lighting%20and%20Crime,%20Part%201.pdf

DOI: 10.7916/consilience.vi22.6731
Consilience J. Sus. Dev. 2020, 22, 65-72

Cornell Lab of Ornithology. (2017). Chestnut-sided Warbler. Cornell University.

Department of Physics, Florida Atlantic University. (n.d.). Light Pollution Hurts the Night Sky for Astronomy.

EIA. (2018a). Electric Sales, Revenue, and Average Price. U.S. Energy Information

Administration.

EIA. (2018b). The United States uses a mix of energy sources. U.S. Energy Information Administration.

EIA. (2018c). Today in Energy. U.S. Energy and Information Administration. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=36953

Engineering ToolBox. (2004). Illuminance - Recommended Light Level.

Falchi, F. (2016). The World Atlas of Light Pollution. CreateSpace.

Falchi, F., Inzano, P., Duriscoe, D., Kyba, C. C. M., Elvidge, C. D., Baugh, K. Portnov, B. A., Rybnikova, N. A., and Furgoni, R. (2016). The new world atlas of artificial night sky brightness. Science Advances, vol. 2(6). DOI: 10.1126/sciadv.1600377

FLAP Canada. (n.d.). WHY WE CARE. Retrieved from https://www.flap.org/who-we- are.php.

Kogler, L., Müller, V. I., Chang, A., Eickhoff, S. B., Fox, P. T., Gur, R. C., & Derntl, B. (2015). Psychosocial versus physiological stress - Meta-analyses on deactivations and activations of the neural correlates of stress reactions. NeuroImage, 119, 235–251.

doi:10.1016/j.neuroimage.2015.06.059

Hafner, M., Stepanek, M., Taylor, J., Troxel, W. M., & van Stolk, C. (2017). Why Sleep Matters- The Economic Costs of Insufficient Sleep: A Cross-Country Comparative Analysis. Rand health quarterly, 6(4), 11.

International Dark Sky Association. (n.d.) Light Pollution. Retrieved from https://www.darksky.org/light-pollution/.

Lawrence Livermore National Laboratory. (2017). Estimated U.S. Energy Consumption in 2017: 97.7 Quads, National Nuclear Security Administration, Department of Energy.

Morris, H. (2017). The casino light beam that's so bright it has its own ecosystem (and pilots use it to navigate). The Telegraph. Retrieved from https://www.telegraph.co.uk/travel/traveltruths/famous-waypoints-aviation-luxor-sky-beam/

Morrow, E. and Hutton, S. (2000). The Chicago Alley Light Project: Final Evaluation Report. Illinois Criminal Justice Information Authority. Retrieved from http://fliphtml5.com/hawx/bsuo

NASA. (2017). How Can You Help Curb Light Pollution.

NPR. (2011). Rockford, Ill., Shuts Off Streetlights To Save Money. Retrieved from https://www.npr.org/2011/11/08/142145523/rockford-ill-shuts-off-streetlights-to-savemoney

NIH. (2015). Melatonin: In Depth. U.S. Department of Health & Human Services, National

Institutes of Health. Retrieved from https://nccih.nih.gov/health/melatonin#hed2

NIH. (2019). Sleep Deprivation and Inefficiency. U.S. Department of Health & Human Services,

National Institutes of Health. Retrieved from https://www.nhlbi.nih.gov/healthtopics/sleep-deprivation-and-deficiency

Office of Energy Efficiency & Renewable Energy. (2015). 2015 U.S. Lighting Market Characterization, accessed 17 March, 2019, https://www.energy.gov/eere/ssl/2015-uslighting-market-characterization

Steinbach, R., Perkins, C., Tompson, L., Johnson, S., Armstrong, B., Green, J., Grundy, C., Wilkinson, P., Edwards, P. (2015). The effect of reduced street lighting on road casualties and crime in England and Wales: controlled interrupted time series analysis. J Epidemiol Community Health, vol. 69:1118-1124. Retrieved from https://jech.bmj.com/content/69/11/1118.

Webb, J., (2014). Invention of blue LEDs wins physics Nobel, BBC News. Retrieved from https://www.bbc.com/news/science-environment-29518521.

Appendix

a Values calculated using information from table T5.a from EIA's 2017 Average Monthly Bill- Residential

b Values calculated using information from table T5.b from 2017 Average Monthly Bill- Commercial

c Values calculated using information from table T5.c from 2017 Average Monthly Bill- Industrial

d Provided from 2015 U.S. Lighting Market Characterization.

e Estimate taken from the International Dark-Sky Association in Tucson, Arizona. Defined as lights on where not needed, when not in use, or direct up lighting. Does not include costs for maintenance and lamps ("Light Pollution").

f Calculated by taking average residential, commercial, and industrial monthly kWh usage multiplied by number of customers in each sector, then multiplied by 12 months for yearly average kWh consumption.

g Conversions for petroleum: CO_2 emissions for petroleum calculated by taking the average CO_2 emissions of petroleum coke, residual heating fuel, and home heating and diesel fuel (distillate). Averages to approximately 27 lbs. CO_2 per gallon. Estimates from 2017 average 138,324 Btu per gallon of petroleum.

h Conversions for natural gas: 117.10 lbs. of CO_2 are released per 1000ft 3 of natural gas. EIA 2017 estimates an average of 1,034 Btu per ft3.

i Conversions for coal: 4,631.5 lbs. of CO_2 are released per 1 short ton (2000 lbs.) [2016 estimates]. Estimates from 2017 average 9,544 Btu per lb. of coal.

j Taken from U.S. Energy Flow chart by Lawrence Livermore National Laboratory (2017).

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