Investigating the Sources of Artificial Light Pollution by Utilizing Citizen Science

Abstract:

Nighttime light pollution is a growing ecological threat that threatens human health, wildlife, energy, and the environment at large. This project worked with the German Research Centre for Geosciences (GFZ) to address this issue by bridging a gap between researchers, scientists, and citizens in order to better utilize the concept of citizen science to fight light pollution. The team researched many aspects of the effects of light pollution, defined potential sources, and identified the potential for citizen science to revolutionize data collection within the light pollution research community. Two main issues for citizen scientists were identified as areas to improve: 1.) The motivations and incentives for citizen science participation and 2.) the training and ability for citizen scientists to collect accurate and useful data. In order to better prepare citizen scientists for consistent data collection, the team designed a training material guideline outlining the different light fixtures to note, shielding specifications, and window counting guidelines. The team investigated the motivations and barriers to citizen science, using this data to make recommendations for more effective recruiting. A lighting inventory was created and analyzed for multiple areas in Massachusetts and New Hampshire. The information from this experience was then applied to the context of helping other citizen scientists collect similar data. Our project provided useful data and effective training materials to the sponsor organization, preparing them to further grow their research operations in regions across the globe.

Night • Time • Light

WPI • 2020 • IQP

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WPI

Light Pollution: Known effects Unknown Causes.

Artificial Light at Night (ALAN), or light pollution, is a major global problem pervasive in industrialized societies worldwide. ALAN refers to excessive light that pollutes the atmosphere, adversely affecting many areas of human and ecosystem health, professional training, and scientific development. It is harmful to the health of human beings, affecting the sleep patterns of millions if not billions of people. Also, it negatively affects the ecosystem, harming wildlife and disrupting natural processes. Skyglow, which is the excessive brightness of the night sky due to light pollution, can be seen masking the visibility of stars in Fig. 1.

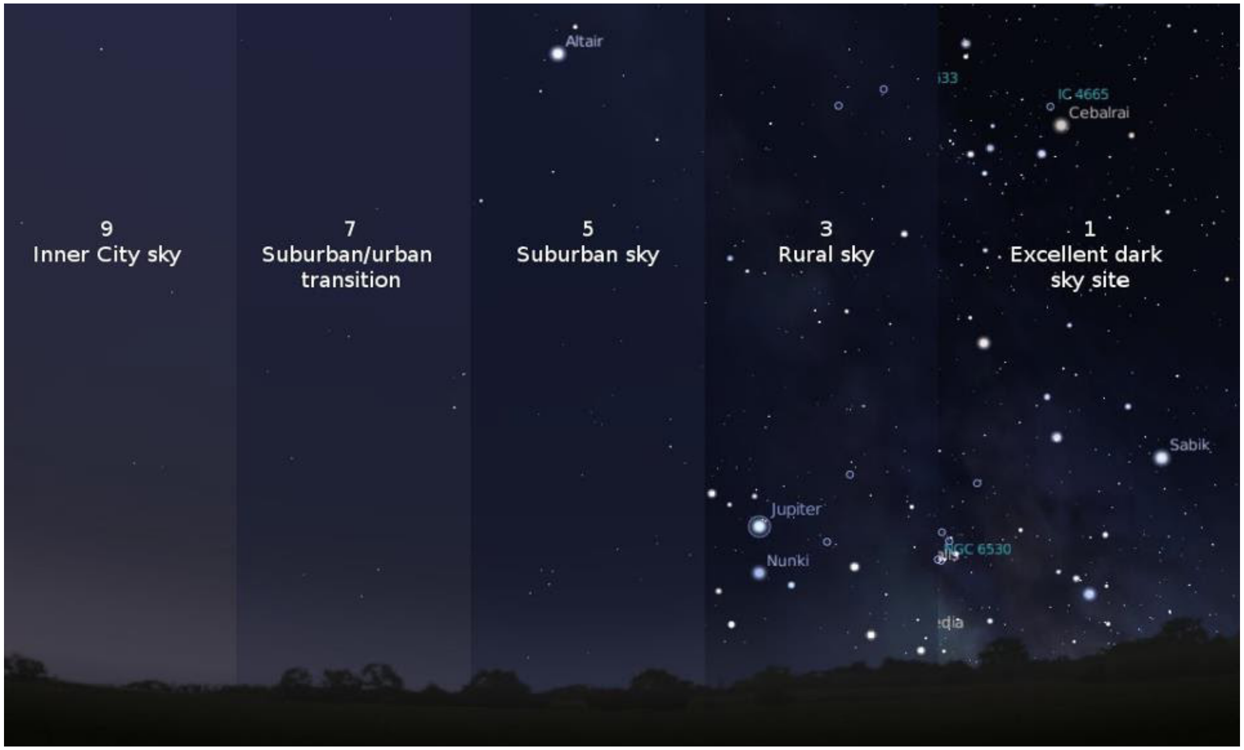


Fig. 1: Ability for humans to perceive the stars, illustrating the various levels of light pollution.

While skyglow is a global problem, the US stands out as one of the major contributors, especially in urban areas. It is estimated that approximately one third of the global population has never seen the Milky Way, whereas 80% of Americans cannot see it from their place of residence (Falchi F. et al, 2011). Despite this startling statistic, the global light pollution trend continues to rise, with global artificial light pollution increasing by two percent annually since 2012 (Kyba et al, 2017). What makes this an even more difficult problem to tackle is the fact that we do not know the specific details of where this ALAN is coming from. We lack the data needed to fully understand the problem, making it near impossible for us to take action against it.

Historically, researchers around the world have used satellite imagery to observe global luminance levels. This allows researchers to locate specific areas where light pollution occurs in excess. Unfortunately, satellite imagery lacks the precision needed to see finer details such as the exact location and types of light sources that are causing pollution (Luginbuhl, 2009). Previously, researchers have had to perform the time-consuming task of collecting data by hand in order to make up for the low resolution of the satellites. A small number of researchers could never hope to collect enough data in a timely manner to be able to analyze it properly. This is where citizen science becomes a vital resource.

Citizen science, which is a way of utilizing the general public to collect or analyze data, has been used in many other fields, but what if we were able to utilize this tool for collecting data on light pollution? Citizen Scientists now have come forward to collect data on light sources and types of light used within each area of their own neighborhood, spreading the vast workload over a large populace.

The utilization of citizen science can also aid the world in another problem relating to light pollution. Even though many people currently experience the negative effects of light pollution, it is still a mainly unrecognized issue in the public eye. With a large percentage of the human population affected by light pollution, the general public has become accustomed to the inability to observe the dark sky. Many do not realize there is any alternative. Just like other issues that are normally “out of sight, out of mind”, light pollution has lost any relevance outside of the scientific community. Due to this, few consider a dark sky to be an important factor in their life. Only a small amount of the world’s population actively takes steps to reduce their light pollution footprint, which only serves to worsen the problem. Using the general public as a means for data collection would not only further our understanding of the issue, it would also help to inform the public about the issue and why they should care about light pollution. This is why Citizen Science plays a key role in tackling both the problem of the population’s general unawareness of ALAN and the lack of data on the core issue itself.

Our goal was to find the sources of night-time light emissions in our local towns and cities of Fitchburg, MA, Arlington, MA, Bridgewater, NH, and Tijuana, MX. The team tested a paper version of the app developed by the GFZ, which was our main avenue of data collection. We have combined all of our data and created a location database of visible lighting infrastructure across all our locations. This “lighting inventory” as we call it can be compared with satellite data in order to determine specific causes of light pollution in our specific areas.

Once the app is developed by the GFZ, the larger dataset it produces can be used to find the main sources of light pollution across the globe. This knowledge could finally help decrease light pollution and give people a chance to see the night sky as it should be seen; not as a dim navy-blue monochromatic expanse with one or two specks of light, but as a sea of swirling blues with an uncountable number of stars.

What We Know About Light Pollution

Shedding Light on the Broader Issue:

Light Pollution has many negative effects on human life, wildlife, the general environment, all while being a waste of electricity in general. How we collect data on light pollution is crucial to understanding where it comes from, and what produces it. By learning about the background behind each of these topics, we can truly appreciate the scope of the larger problem at hand. This background section also covers the topic of citizen science, and how it’s use makes for the perfect data collection tool for the light pollution problem, collecting large amounts of data while raising awareness among a largely unaware populace.

Defining Night Time Light Pollution:

Night-time light pollution is broadly defined as excess artificial lighting which can have harmful effects on the surrounding environment. ALAN can be broken up into four main categories: glare, light trespass, skyglow, and clutter. These types of light pollution are illustrated in Fig. 2. Glare is the uncomfortable brightness that can blind drivers or pilots, light trespass is excessive lighting that brightens areas that were not intended to be lit, skyglow is the pink or orange haze commonly observed above urban areas, and light clutter is a grouping of lighting fixtures that may be

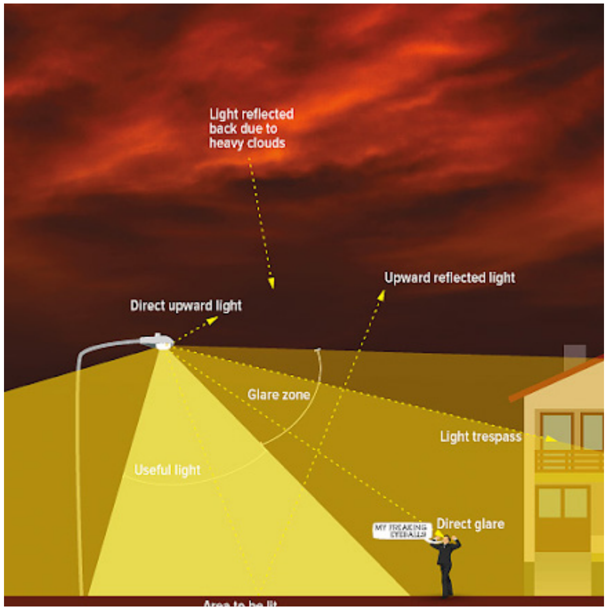


Fig. 2: Different Types of Light Pollution (Light Pollution, n.d.)

confusing or distracting.

Light pollution is produced from a variety of sources, including but not limited to street lights, electronic billboards, lighting on the interior and exteriors of offices, factories, and residences, and any source of ALAN that is not properly shielded or excessive for its desired purpose (Light Pollution, n.d.). As an example, in the city of Berlin, Germany the most common source of light pollution is streetlights, contributing to 31.6% of the skyglow emissions within the city (Kuechly et al., 2012). In Hong Kong, a city plagued with light pollution problems, the brightest parts of the city were in the commercial and business districts, where excessive urban lighting was the densest (Pun, So, Leung, and Wong, 2014). In addition, buildings with skylights or other lighting fixtures that are unshielded, such as floodlights, are other sources of light pollution.

Effects of Light Pollution On Humans:

ALAN and light pollution have multiple negative effects on human health and social behavior. The main harmful effect light pollution has on humans is its negative impact on sleep patterns. ALAN exposure has been linked to a decrease in melatonin production within humans (Falchi, Cinzano, Elvidge, Keith, & Haim, 2011). Melatonin is one of the main sleep hormones, regulating the sleep-wake cycle known as the circadian rhythm; this relationship is represented in Fig. 3.

While natural daylight positively affects circadian rhythms, ALAN exposure effectively delays the body's circadian clock, making it harder for people to fall asleep and reduces the quality of their sleep (Khalsa, Jewett, Cajochen, & Czeisler, 2003). Disruption of the circadian rhythm can lead to many problems relating to alertness, sleep habits, and even metabolic issues which may lead to increased rates of obesity (Falchi, Cinzano, Elvidge, Keith, & Haim, 2011). This disruption is usually caused by monochromatic light with wavelengths of 460nm, which is a bluish hue common within LED lighting (Falchi, Cinzano, Elvidge, Keith, Haim, 2011). Thus, as lighting technology has evolved and welcomed the use of LEDs, the harmful effects of light pollution have evolved with it, creating serious hazards for human health. These effects are not uniquely offensive to the human species however, as all wildlife in one way or another is affected by excessive light pollution.

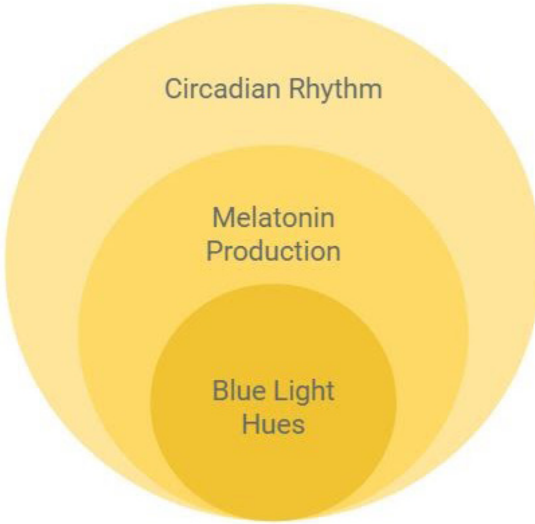


Fig. 3: Relationship Between Melatonin Production and Circadian Rhythm

ALAN and its Disruptions to Wildlife:

ALAN is also disruptive to most, if not all forms of wildlife. Studies within the last couple of decades have shown various species being affected in areas such as mating, migration and sleeping patterns. One of the major issues with ALAN exposure is its effect on mating patterns, making one of the greatest potential victims nocturnal insects. Species such as fireflies depend on flashing patterns to communicate their sex and participate in courtship (Owens & Lewis, 2018). Field experiments involving fireflies showed that ALAN (specifically 'white' LED lights) greatly reduced the amount of flashing during courtship as seen in Fig. 4 (Firebaugh & Haynes, 2019).

For animals that depend on a circannual cycle of mating, species with a lifespan of approximately one year, day-length is crucial to determine their reproductive season (Bradshaw and Holzapfel, 2010). For example, female sea turtles strongly prefer a dark beach for their nesting site and the increase in artificial light reduces their ability to find such a space (Mazor et al., 2013). There is a clear correlation between light pollution and the disruption of nesting and reproductive cycles in various species. Thus, light pollution threatens the very existence of certain species.

Environmental Damages caused by ALAN:

Not only is light pollution harmful

to humans and their animal counterparts, light pollution negatively affects the earth's ecology. According to research conducted by International Dark-Sky, at least 30% of all outdoor lighting in the U.S. is wasted mainly by unshielded lights. All this light is responsible for the impacts explained earlier and is a negligent waste of electricity. This amount of wasted lights adds up to an equivalent of 21 million tons of carbon dioxide released into the atmosphere every year. Of these 21 million tons, about 15 million tons of carbon dioxide is the result of light emitted from residential outdoor lighting such as porch lights being on throughout an entire night (International Dark Sky Wastes and Energy, n.d.).

Within the environment, ALAN affects growth and development of trees and plants, it depends on light's quality, intensity, and duration of the light-dark period in the 24-hour cycle. There are two photobiological processes in trees for development and normal growth which are photosynthesis and photoperiodism. Researchers have proven that the developmental process in plants and trees is controlled by the "duration of uninterrupted darkness during a 24-hour cycle" (Light Pollution Harms, n.d.). Even a slight ray of light in the dark period can trigger the plant to have a short night, long day cycle. The length of day can be increased by the emission of artificial lighting which will promote the continued growth of trees, leaving them in danger of the harsh winter. In order to prepare for the winter storm, trees have protective dormancy which controls leaves to shed before being damaged by the winter season (Light Pollution Harms, n.d.). For example, the ice and snow build up on the tree branches can cause the branch to break and damage the tree if the trees do not shed its leaves on time. Unlike older mature trees, young trees tend to naturally grow for a longer period which leaves them to be at a higher risk of damage. With continuous night lights, these younger trees are placed in more danger during the winter.

Light pollution is a waste of energy:

In addition to helping preserve wildlife ecosystems and the environment, reducing light pollution has economic benefits as well. According to the National Optical Astronomy Observatory (NOAO) inefficient outdoor lighting costs the world up to $3.3 Billion dollars per year. This includes public and private outdoor lighting and equates to roughly $10 wasted dollars for every man, woman, and child per year (Light Pollution Wastes Energy and Money, n.d.). This might not seem like much, but when it is all added up, the amount of money flushed down the drain is staggering. The International Dark Sky Association (IDA) states that 13% of residential electricity use in the USA is for outdoor lighting. Of that

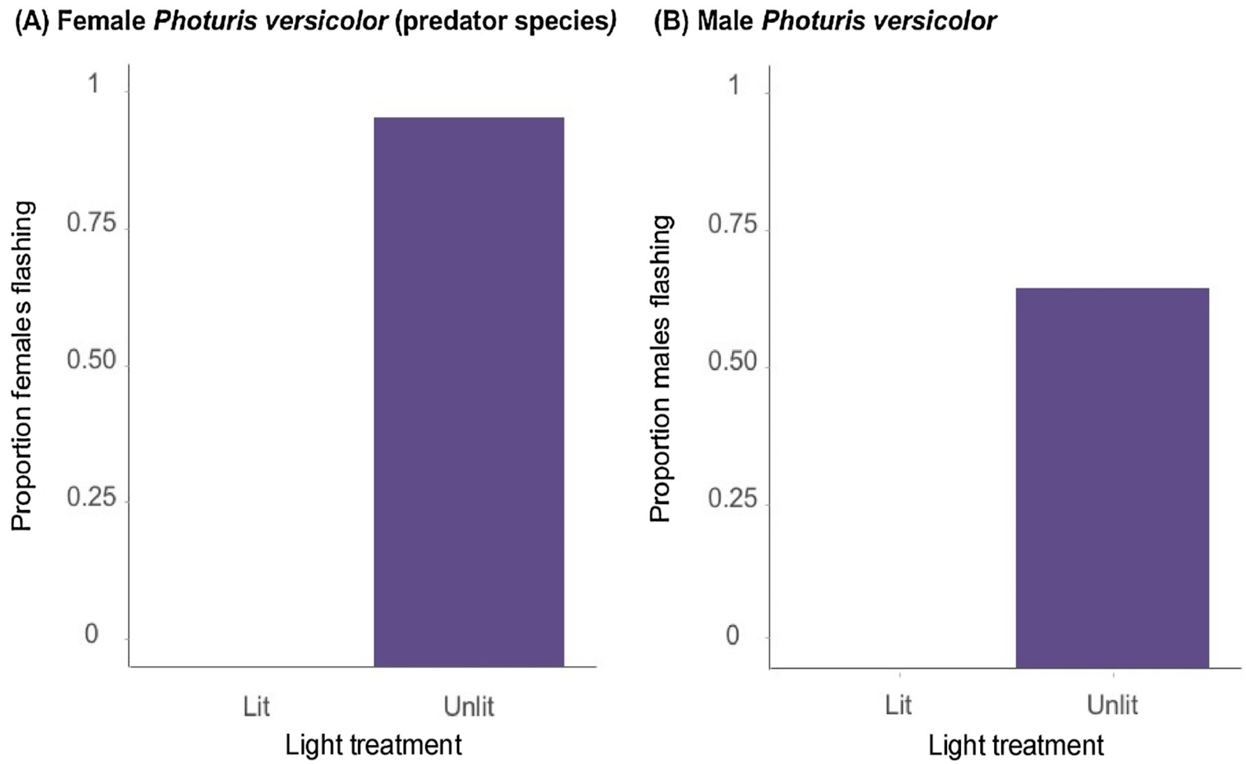


Figure 4: Flashing patterns of the Photuris versicolor in both unlit and lit areas (Firebaugh & Haynes, 2019)

13% of outdoor lighting, 35% is wasted due to unshielded or poorly aimed outdoor lighting (Light Pollution Wastes Energy and Money, n.d.).

What all of these numbers are basically saying is that excess light causes excess costs for private homes as well as corporate buildings. In order to make people care about light pollution and make actual changes, they need some sort of motivation. On public roads, streetlights are useful but are largely unused in the early morning. The government could save money if they switched to active lighting or use warm light LEDs. Regular fluorescent lighting in office buildings is inefficient and almost painfully bright. If large companies switched over to more efficient forms of lighting or started turning unused lights off, they could save money as well as the environment. Average citizens could also benefit from minimizing light trespass. Poorly designed outdoor lighting can waste up to 0.5kWh per night. The amounts of wasted energy can be seen in Fig. 5.

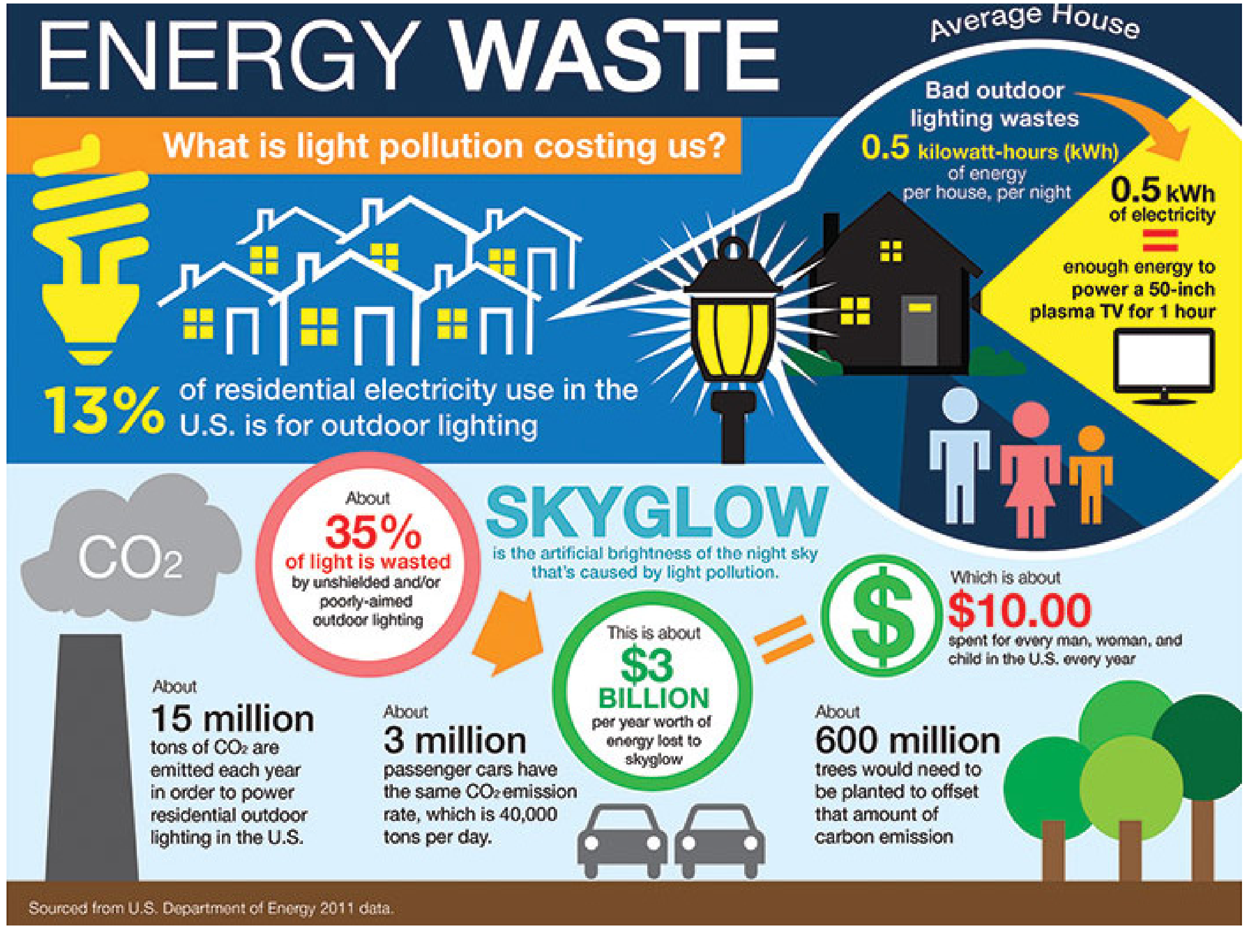


Figure 5: (Light Pollution Wastes Energy And Money, n.d.)

Measuring Light Pollution:

Light pollution and specifically ALAN are harmful byproducts of industrialized societies. In order to understand and address those harmful consequences, scientists have developed multiple methods to measure light pollution and analyze the resulting data. One of the common ways of observing and measuring light pollution is using orbiting satellites. These allow the capturing of luminance levels, providing valuable data of light pollution throughout the world. A recently explored method of surveying light pollution in cities is with the use of aircrafts. In a recent study, a team of researchers in Germany flew a small propeller plane in a sweeping fashion over all of the Berlin area, collecting high-resolution data for analysis (Kyba, 2012). While this method of data collection gave more accurate images of light luminance, it was not able to give precise sources of light. Thus, another method of light pollution measurement is by taking ground measurements.

While having greater accuracy, taking ground measurements is much more labor-intensive as each area must be individually surveyed first, then entered into a master datasheet. This method is time consuming and the scientists are not able to collect data from all parts of the world. Having people around the world collect data and sending it to the scientists will make this method more achievable. The benefit of many data-collectors allows for more precise data to be gathered by multiple people spreading out throughout an area. This method permits citizen scientists who are motivated to help improve the planet to also be involved in the research by collecting mappable data within their specific locations by following the standard process to collect data.

Citizen science is a powerful tool for data collection:

Collecting a broad and diverse set of data presents a challenge that a small group of researchers realistically cannot achieve by themselves. As stated beforehand, data collection is a major, but tedious aspect of many scientific research projects. Fortunately, there is a tool used by researchers around the globe to harness the data collection power of laypeople: citizen science. This consists of volunteers, otherwise known as citizen scientists, participating in the collection or analysis of data. The recruitment and mobilization of such volunteers.

These groups of people all follow the same protocol when collecting data and analyzing so that it can be combined into one cohesive set (SciStarter). In order to collect data within the same range, citizen scientists need to follow a specific set of guidelines which will lead them to gather more accurate data. A set of light pollution specific guidelines could offer clear explanations on different types of wasted lights, light fixtures on a building and the intensity of luminance. It is necessary to have citizen scientists follow a set of guidelines so that all the data is calibrated within the same range so that the data they collect can be comparable to other data collected by other citizen scientists.

Citizen Science in general has many real world advantages. One advantage to using Citizen Science is that it is volunteer based, which makes the cost to research institutions significantly lower compared to hiring paid researchers. One potential drawback to using citizen scientists is a potential large variance within data they collect, as every person can have a unique perspective when collecting data or performing tasks. Depending on the scenario, especially if results need to be compared with other scientific data, this can muddle data and make conclusions harder to arrive at. Which is why the guidelines mentioned previously are so important. Another drawback could be finding a population of citizen scientists who are motivated to perform the work needed within the project. With all things considered, Citizen Science presents a valuable option to research teams across the globe.

Citizen Science may be better understood when looking at examples of already existing research. One of the most widely known projects is iNaturalist, an initiative by the National Geographic Society and the California Academy of Sciences (iNaturalist). They are available via a desktop or mobile platform, where citizen scientists can easily create an account. The research consists of users documenting flora and fauna around them through observations, and this data gets shared with scientists who can identify these findings (iNaturalist). The simplicity and high public interest have caused this initiative to be a popular one. As of April 2020, they have had over 1.25 million users, which have recorded around 35 million observations (iNaturalist). Looking through successful initiatives like these, it is important to understand what qualities helped their growth. With this information, we could be able to replicate successful projects that are aided by citizen science.

Methods:

As light pollution increases each year with little to no signs of stopping, the negative impact on various groups is getting worse. Our project serves to combat the issue of light pollution on multiple fronts. We set out to help reduce nighttime light throughout the world by finding the underlying sources in different types of locations. Conducting this inventory not only generated valuable data, but also prepared us to educate citizen scientists on how to do the same. In parallel with this, we researched the reasons that would motivate people to volunteer to collect and analyze data.

Our main project goal is to encourage and educate citizen scientists in order to collect mappable data and monitor the light pollution. To accomplish the goal, we completed the following primary objectives while working remotely with our sponsors:

1. Complete a lighting inventory and map out our own luminance measurements.
2. Create a standard process for citizen scientists to use to collect data using a mobile app.
3. Investigate the motivations of citizen scientists taking part in our data collection.

Sponsor and Study Area:

Within this methods section, our team outlines a data collection plan, how that data

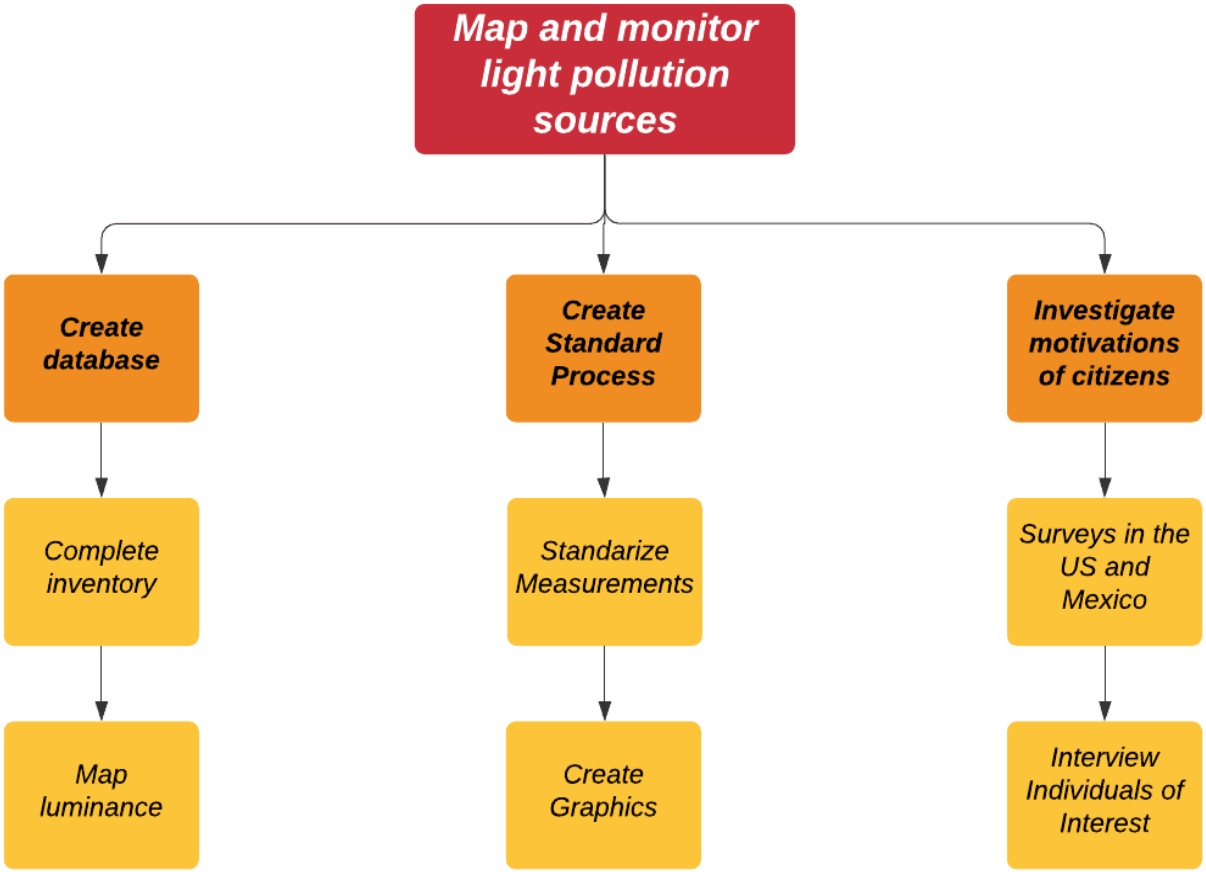


Fig. 6: Methodology overview

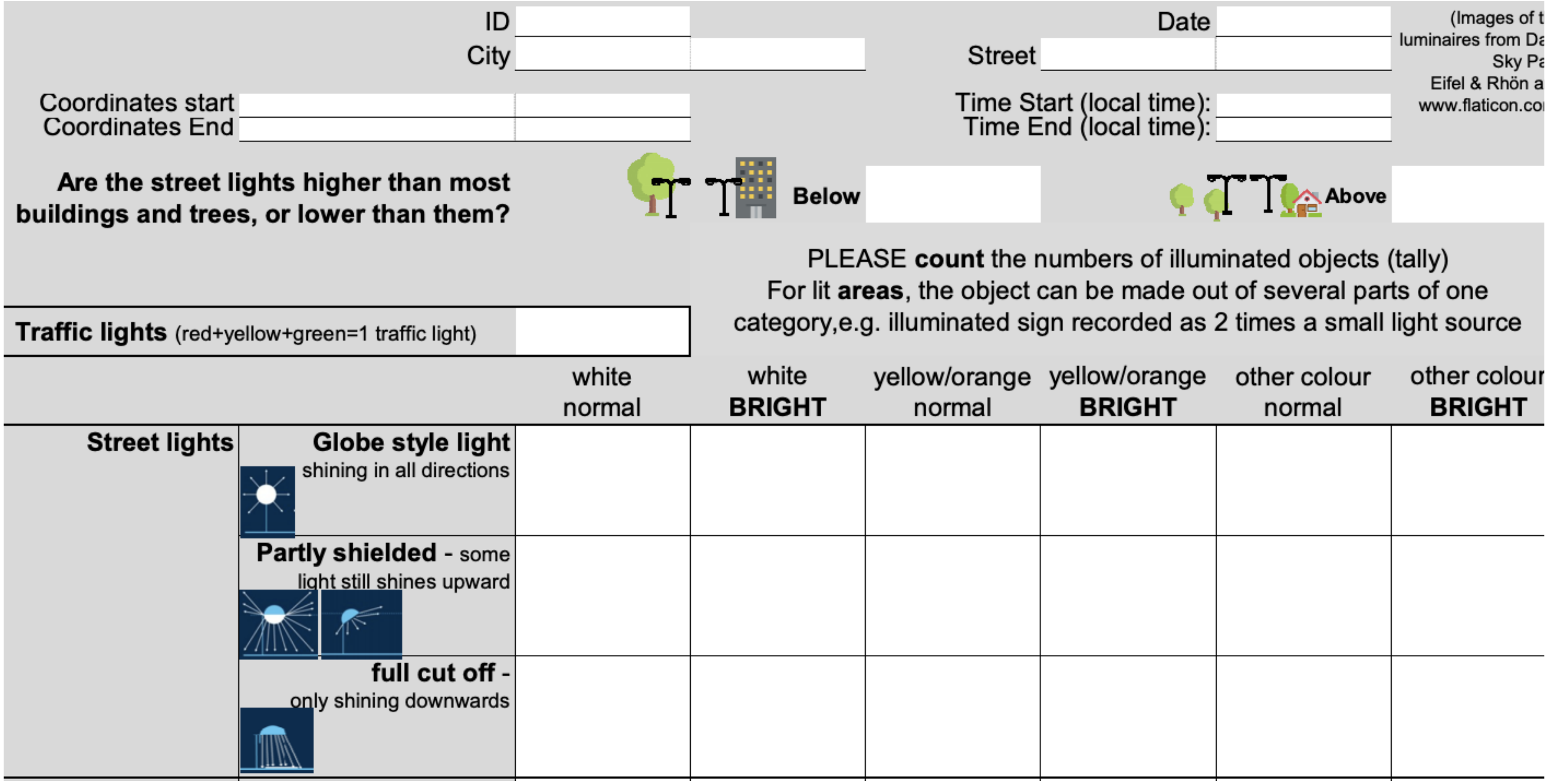
will be used to produce a protocol/guideline for reducing light pollution, and an exploratory study on the inner motivations of citizen scientists who will be using our protocol (Figure 6).

Our sponsor organization, the German Research Centre for Geosciences, or GFZ for short, is in Potsdam, Germany is a federally funded science-based organization which is on the cutting edge of Earth Science research in Germany. The organization is divided into multiple different departments, which together cover the wide field of earth science, and our project falls under their remote sensing and geoinformatics division. The researchers sponsoring our project, Dr. Christopher Kyba and Helga Kuechly, have led the field of light pollution analysis and are experts on the subject matter. In addition to this quick description, we have written a more thorough analysis of the GFZ in Appendix (A). The GFZ organization is facing a unique challenge in addressing light pollution; the GFZ and the general scientific community has a lack of data on the specific intricacies of how light pollution is produced. Our project revolves around filling this gap in data.

Objective 1: Complete a lighting inventory and map out our own luminance measurements

To find the major sources of night-time light pollution, GFZ is developing an app for citizen scientists to report light sources. We tested the paper version, Fig. 7, which is designed to start testing data collection for the future electronic application. Instructions for data collection written by Helga Kuechly and Christopher Kyba have been published on the Loss of the Night blog, these were followed accordingly to ensure accurate data (Kyba, 2019).

This preliminary form is used to gather data on all kinds of light fixtures that are encountered at night. It includes details on the light fixture’s height, light brightness and color, light source and type of shielding (or lack thereof) (Kyba, 2019). Pictures and short descriptions of each section makes it possible for both researchers and citizen scientists to understand the data collected and leaves a small space for misunderstandings. To provide further detail, both the coordinate points of the locations observed and the time of recording must be recorded at the beginning and end of each data collection session. All light sources will be recorded according to the form’s categories, and later recorded in GFZ’s database of their choice. After recording the data, it will be analyzed to assess what are the



ID
Date
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Time Start (local time):
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luminaires from Da
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Are the street lights higher than most buildings and trees, or lower than them?
Below
Above

PLEASE **count** the numbers of illuminated objects (tally)
For lit **areas**, the object can be made out of several parts of one category,e.g. illuminated sign recorded as 2 times a small light source

Traffic lights (red+yellow+green=1 traffic light)

		white normal	white **BRIGHT**	yellow/orange normal	yellow/orange **BRIGHT**	other colour normal	other colour **BRIGHT**
Street lights	**Globe style light** shining in all directions						
	Partly shielded - some light still shines upward						
	full cut off - only shining downwards						

Figure 7: Paper Form of Light Pollution Data Collection

major contributors of night-time light pollution. Following this, recommendations will be made to improve this situation.

Due to the unprecedented restrictions on travel due to the spread of COVID-19, we could not complete this project in Potsdam, Germany and have shifted the focus of the project to be based in the U.S. and Mexico based. As we remotely work on our project, we will individually collect data in four locations respective to our town of residence which are two suburban towns in Massachusetts, Arlington and Fitchburg, a small town in New Hampshire named Bristol, and a city in Mexico named Tijuana. Bristol has the least population of about 3,000 while Tijuana, Mexico has the highest population of about 2 million. These four locations vary in size of the area and population density, giving us unique datasets to analyze.

As light pollution increases each year with little to no signs of stopping, the negative impact on various groups is getting worse. This objective of our project was meant to help reduce night time light throughout the world by finding the underlying sources in different types of locations. As we conducted this lighting inventory, we wanted more people to be aware of this issue and help collect data. Asides from creating awareness, we also considered the technical aspects of properly training citizen-scientists through a standardized process.

Objective 2: Create a standard process for citizen scientists to use to collect data.

Collecting data firsthand is important for the purpose of understanding the data collection and analysis process, but the main goal of this project is to enable citizen scientists to collect consistent data wherever they reside. Being in the data collection side has enabled us to properly understand where citizens scientists might interpret measurements differently, and aid in tackling these potential misunderstandings. The problem with using a large population of people to collect data is the inconsistency within the data that they collect. Everyone sees things differently, and like types of lighting fixtures and counts of windows. To do this, we have created training material in the form of a .pdf file which helps calibrate citizen scientists before they begin collecting data. This training document serves to standardize measurements and will act as a short tutorial for participants to read before collecting data. It will include information on the different types of light fixtures people will encounter, including the difference between common streetlights and outdoor lighting, as well as guidance on how to count residential windows and commercial windows. Citizen-scientists have access to this training material on the GFZ website as well as Dr. Kyba's blog which also includes instructions on how to collect data. This guidance document will hopefully eliminate most variance within the data collected by citizen scientists, making it easier to interpret by analysts.

Objective 3: Investigate the motivations of citizen scientists taking part in our data collection

The purpose of citizen science in our project is to be able to collect a large amount of data from a wide variety of locations while simultaneously increasing public awareness of light pollution. Our goal was to find out why citizen scientists participate and contribute in their respective fields. We aimed to understand the motivations of these citizen scientists so that in the future, we can have a more effective marketing campaign and a broader active outreach.

One of the main challenges with utilizing citizen scientists is understanding why they would volunteer to help our research. In short, we investigated their motivations through a survey. Knowing that survey takers value their time, we aimed towards mostly multiple-choice questions, with the minimum amount of open-ended questions. We divided a total of 17 questions into four different categories:

- Experience with the night sky
- Knowledge about light pollution
- Experiences with light pollution
- Opinions on Citizen Science (motivations and barriers)

The purpose of the survey was to determine the level of motivation people have in helping to solve this issue based on how they are affected by the amount of light pollution they are exposed to. With these questions set to go within our survey, we needed to find an outlet for promotion. We posted our survey link along with a short description on WPI's Facebook groups, and other groups that the individuals in our team belong to. Additionally, we promoted the option to enter a raffle for a gift card at the end of the survey. After the promotion, we left the survey open for six days, constantly checking the response rate and the amount of individuals who volunteered for an interview at the end of the survey.Through this survey, we have screened people to gauge interest for interviews. Participants included everyone from the non-motivated or the disinterested, to highly motivated citizen scientists. From our investigations, we collected data that will help the GFZ tailor their data collection app towards a larger group of citizen scientists. If we can encourage and recruit for more participation, then our data set will become larger and more accurate. People will be able to learn more about the issue of ALAN and the GFZ will have access to a more expansive data set that will push them further towards their goal of reducing ALAN.

Results:

Objective 1: Data Analysis

The first objective of this project involved the collection of light fixture data in our respective locations, so that we could better understand the process behind data collection. In addition, we analyzed our data in order to make comparisons between Germany and the US, different locations within the US, and different locations within the same city. Data collection started with a trial of the collection sheet in Worcester, MA. Since then, we have collected data in Arlington, MA and Fitchburg, MA, as well as in Bridgewater, NH. We also have access to data collected previously in and around Berlin, Germany. In total we have recorded 1406 lights in the US and have access to previously collected data consisting of 2731 recorded lights. We collected field data to correlate with pixels from satellite imagery of the same locations. This approach enabled us to directly compare our lighting inventory with the luminance measurements of the Visible and Infrared Scanner (VIRS) satellite.

We analyzed our data by creating a python program, which efficiently compares data from various sources and visualizes different comparisons. These comparisons are useful because they allow us to see which areas are taking steps to reduce light pollution (i.e. more shielding, lower density of lights, etc.) and see where other areas are lagging behind. They also allow us to compare how different geographic areas (i.e. urban or rural) affect the makeup of lighting fixtures. These analyses can then be

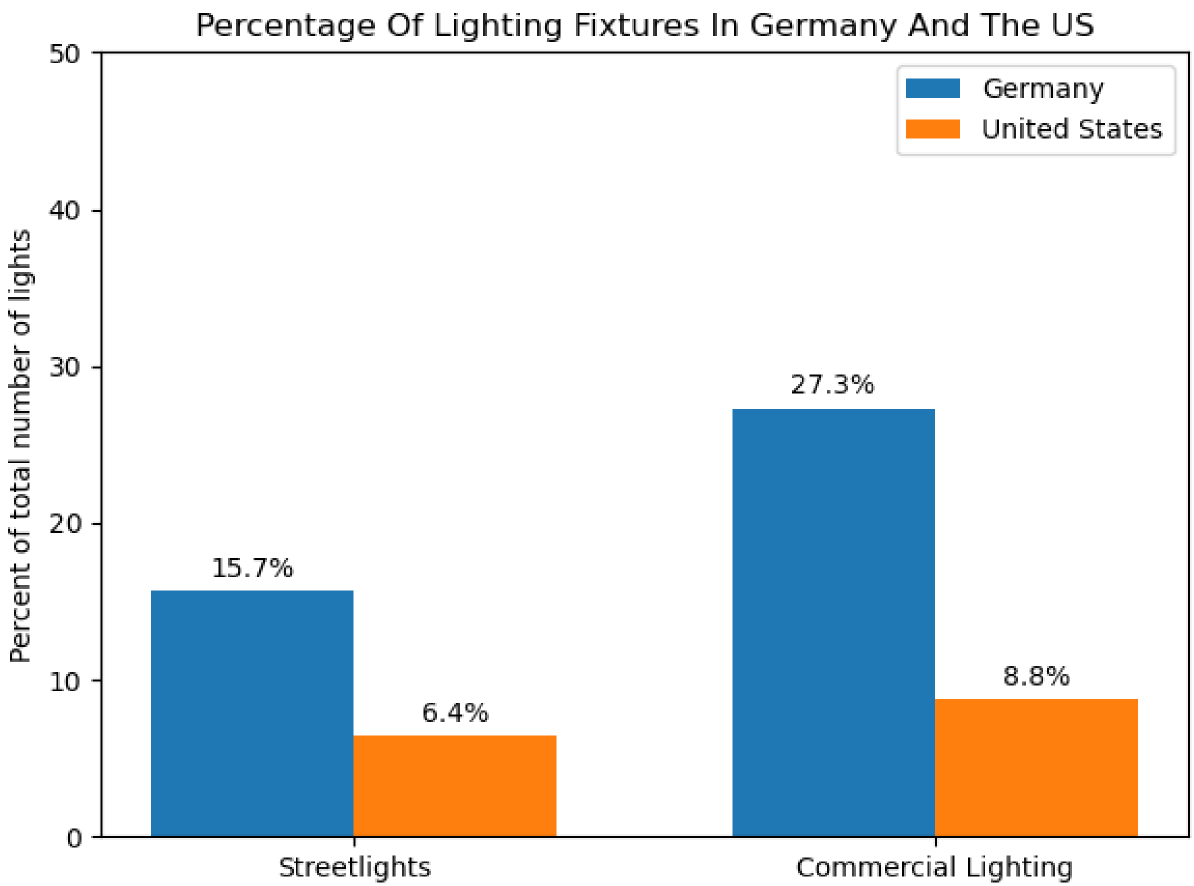

Figure 8: Percentages of types of lighting fixtures in the US and Germany

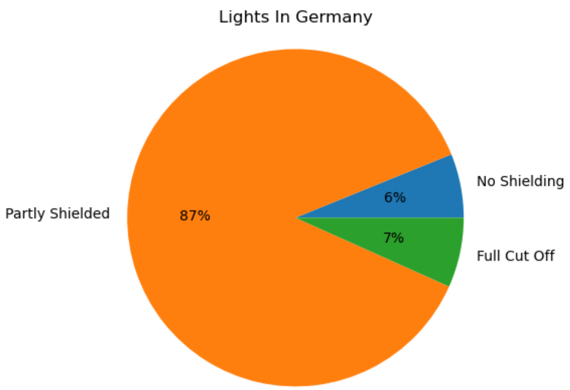

Figure 9 : Shielding in lighting fixtures within Germany

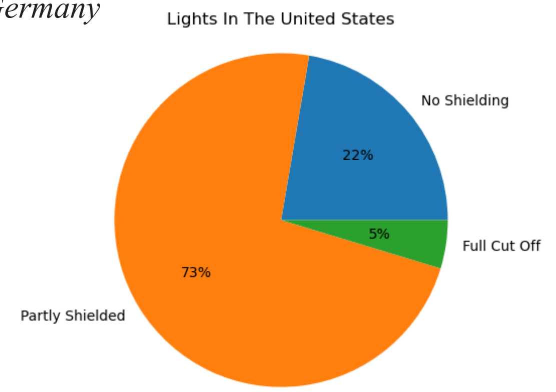

Figure 10: Shielding in lighting fixtures within the United States

used to make informed decisions on how to reduce local light pollution within the areas surveyed.

Comparisons Between the US and Germany:

When we started comparing data sets, we wanted to start out on a large scale by examining the light fixtures and radiance in Germany and the US. The data was based on previously completed sampling from 21 locations in Germany and new data from eight locations in the United States. The data included street lamps and commercial lighting. We found that residential lighting fixtures makeup over 50% of the total lighting fixtures recorded in both the German and US datasets. However, as seen in Figure 8, Germany's non-residential lighting fixtures make up 48.4% of lighting fixtures, while in the US these make up only 25.2% of these lighting fixtures. While this could be attributed to cultural or policy reasons, our area of research only expands to the comparison of data throughout different areas.

We also compared the number of shielded, partially shielded, and unshielded lights in both locations (see Figures 9 and 10).

While a clear conclusion cannot be made from a small dataset, it can start leading towards different trends in a more general sense. This data in particular shows that within the areas we observed in the US there is a distinct lack of shielding. In Germany, shielding is more common, even with a higher percentage of streetlights and commercial lighting when compared to the areas in the US.

Figure 12: Arlington, MA: very urban area close to Boston, large variety of different lighting fixtures present

Figure 10: Worcester, MA: highest density of lights and buildings of all places we surveyed

Figure 9 : Downtown Fitchburg, MA: (note the globe style lighting and bright night sky)

Figure 11: Bristol, NH -- lack of lighting in general, rural area

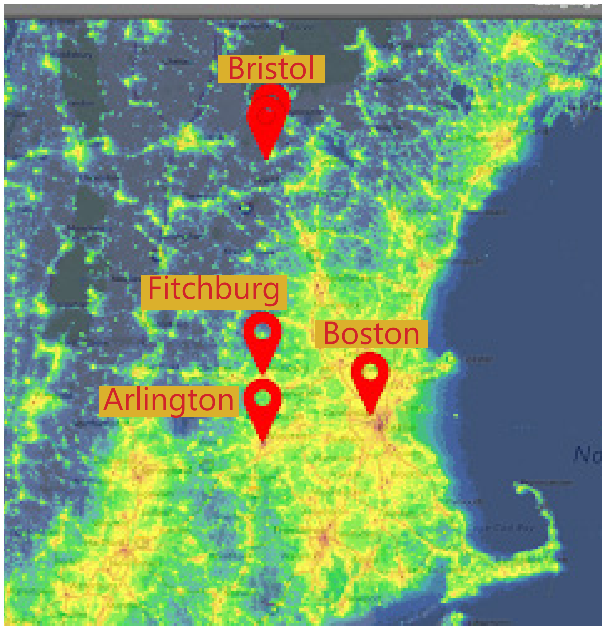

Figure 13: Locations surveyed within the US

When we look at this data in conjunction with the radiance levels of both countries, the data leads us to believe that shielding affects ALAN levels more than the number of lights outright. Whether this is due to our small dataset or not is unclear, however the data does point in this direction. By exploring these data conclusions, we can set up expectations for further research as the participation from citizen scientists increases, and allow them to either reinforce or counteract this evidence.

Comparisons Among US Cities:

After comparing international data sets, we consider lighting and radiance data across four US towns/cities with different population sizes. The population in Bristol is roughly 3,000 whereas the two suburban towns in Massachusetts (Fitchburg and Arlington)

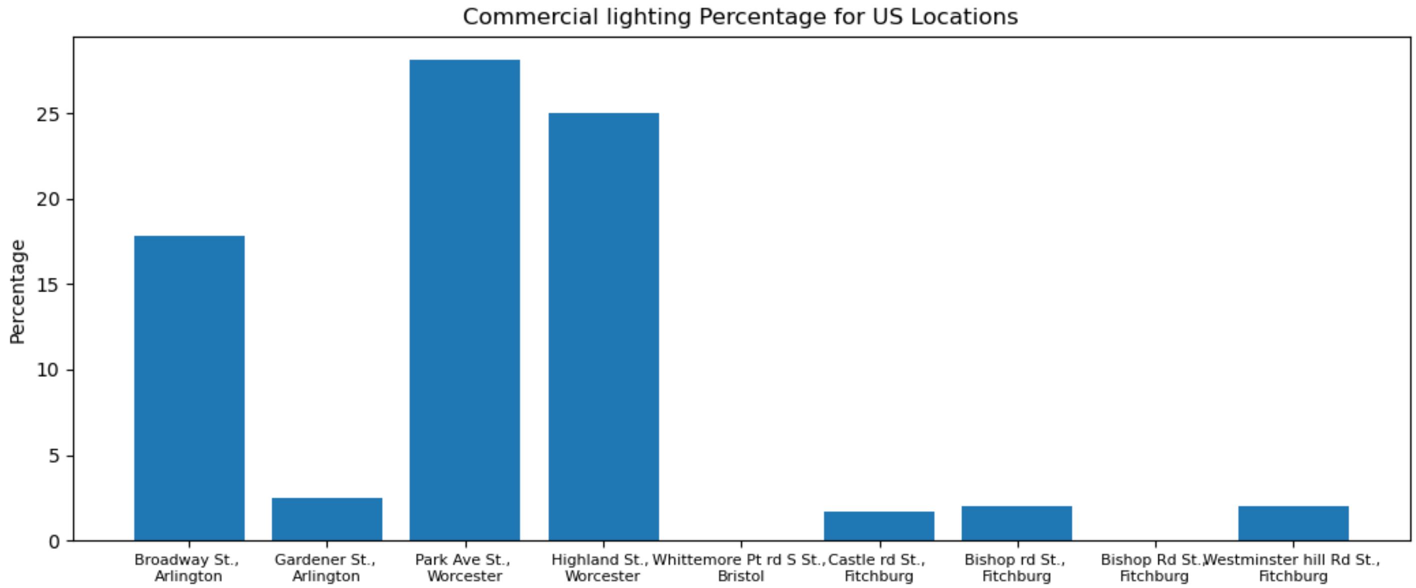

Figure 14: Percentage of lighting that is commercially operated in the locations where we recorded data

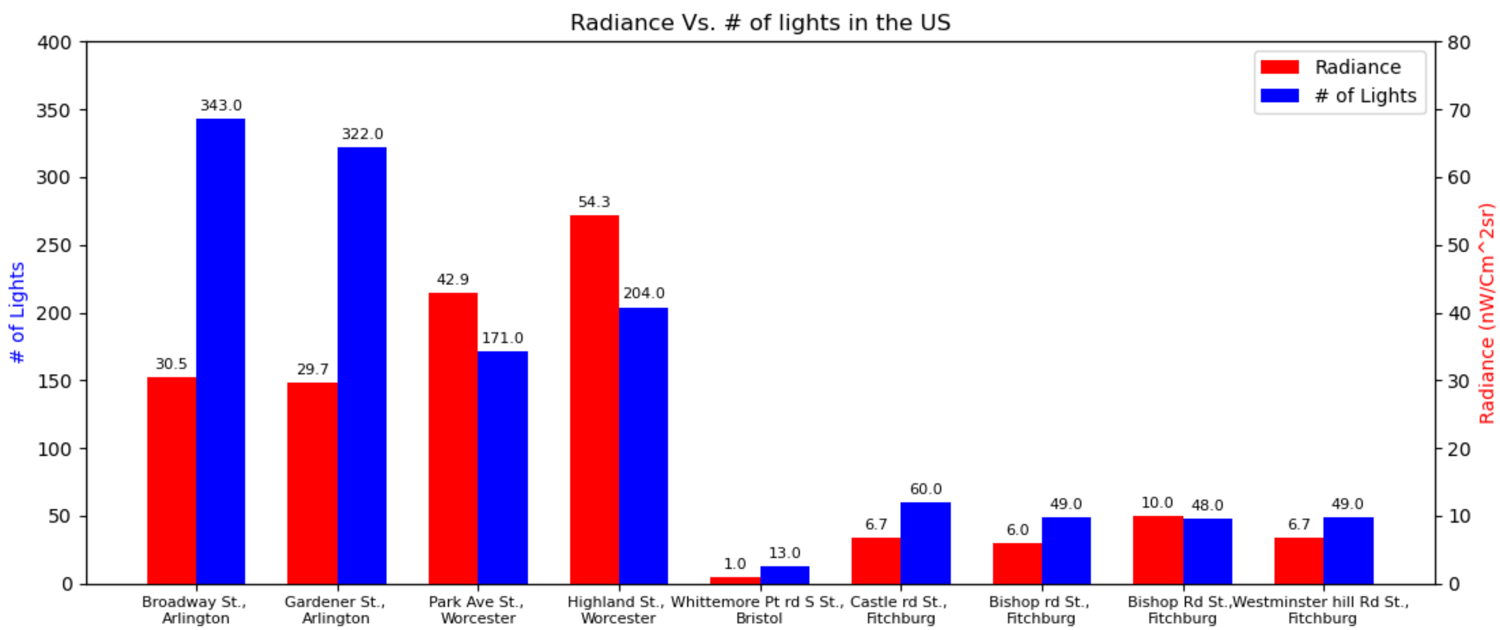

Figure 15: Radiance Vs. total light count for the locations at which we collected data

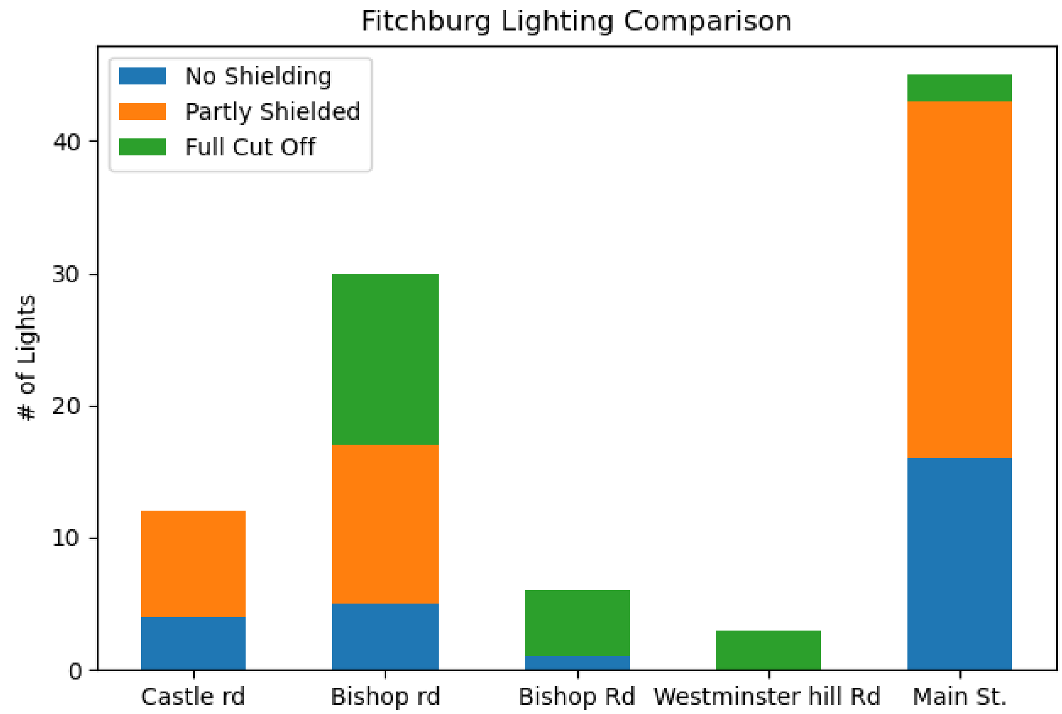

Figure 16: Comparing Light Shielding in different areas of Fitchburg, MA. note: Main St. is substantially more urban than the other 4 locations.

each have a population of about 41,000. On the far end of the scale, the Worcester city in Massachusetts has about 185,800 population.

Unlike the three locations in Massachusetts (Arlington, Fitchburg, and Worcester), Bristol, New Hampshire was comparatively more rural and contributed significantly less light pollution. The density of light varies similarly among the four locations, with New Hampshire having significantly fewer lights per pixel than the other three locations.

While collecting the data at night, we observed that Bristol was completely dark, and a flashlight was needed to observe the surrounding environment while walking through the neighborhood. Contrastingly, Fitchburg and Arlington were fairly lit in some areas where a flashlight was needed only to record the data on paper, but there were street lights to guide the path. Nightlife in Worcester was quite different, as bright lights were lit up everywhere, negating the need for flashlights. The brightness level was similar to daytime due to high amounts of commercial lighting and street lights which is graphically shown by Figure 14.

Among the four locations, Worcester has the highest radiance levels, as seen in figure 15. This is a logical conclusion given that light pollution and density of population are directly proportional. Although Worcester has more radiance, it possesses a fewer number of lights. This trend stands in contrast to the other three locations where the number of lights is much greater than the amount of radiance. The primary distinction between Worcester and the other locations is that Worcester primarily features unshielded street lights and LEDs, whereas the other locations have partly shielded sodium lights and less overall lighting density. Thus we conclude that the type of light fixture is a major factor in determining the severity of light pollution. This data is important because it shows that LEDs produce a measurable effect on light pollution, at least within the areas that were surveyed.

Comparisons Between Urban and Suburban Areas:

Next we assess differences in lighting and radiance within a single city by focusing on Fitchburg, MA. Two areas within the city were differing in population density, with one area being a suburban neighborhood on the outskirts of the city, and another being in the center of the city. Both areas varied, with each one differing in the level of shielding present, LED usage, and density of light fixtures in general. As far as satellite data goes, the suburban pixel examined had a luminance of around 6.65 nW/cm2, while the more urban part of the city had a luminance of around 37 nW/cm2.

In the suburban area, unshielded lights were less common than in the urban area, with 45% of streetlights being shielded. The minority of lights were white in hue, which suggests less use of LEDs and more use of high-pressure sodium lights. In general, lights were not very dense, with only 8.9 streetlights per kilometer.

In the urban area of Fitchburg, lights were much denser with there being 50.2 street lights per kilometer on average. Lights had similar rates of shielding as the suburban area of the city, with 47% of lights having some sort of shielding. Most lights (94%) were white in hue, suggesting the widespread adoption of LEDs within the downtown area. Figure 16 illustrates a graph comparing shielding of lights in the different areas where data was collected.

While it is important to analyze the global trends and country wide comparisons, this data on the specific town of Fitchburg is important because these ground level observations are needed to make actual change on the town level. For example, there are many unshielded lights within the downtown area of Fitchburg, which produces a lot of unnecessary light pollution. A simple solution would be to replace the globe-style streetlights with partly-shielded or full-cutoff lights. This level of data analysis can be performed at any of the individual locations surveyed, providing ways for city governments to make informed decisions on how to reduce within that specific area.

Objective 2: Training Sheet

Currently the data collected by the citizen scientists lack consistency. Volunteers do not have much knowledge about data collection and how to interpret the different categories of night-light pollution. Inconsistencies in volunteered data limits their utility. We addressed these inconsistencies by designing a training handout intended to prepare citizen scientists before collecting data. This training file may be printed

Figure 17: Data Collection Training Material

out, or viewed on a smartphone together with the data collection app. The training document is needed to calibrate the general public on how to correctly count lights. This makes the data less scattered and more accurate.

The training material focuses on three main sections of artificial light data collection. The first section educates the reader about the different types of light fixtures they could encounter, and what they each would look like. This helps them quickly know what to look for while in the field. The second section provides a visual of what different levels of light shielding is, and how to figure out what level of shielding is on the fixture they are looking at. It can sometimes be difficult to discern between partly-shielded and full cutoff lights, so the large diagrams help clear up any confusion. The final section is dedicated to the observation of windows, as this is the biggest point of confusion and variance within data collection, as noted by our sponsors. Depending on the location and the architecture of the building, the design of windows varies in sizes and shapes especially when comparing residential and commercial buildings. This section guides how to count different sizes of windows in respect to standardizing window size units.

In addition to the first sheet of information, we also included a supplementary sheet which goes more into depth on certain topics, i.e. facade lighting versus exterior lighting, how to count multiple dim windows, etc. citizen scientists might need this sheet if they live in an area where there is a lot of facade lighting or lots of windows. Its main purpose is to go more in depth on the more obscure lighting fixtures. It will help citizen scientists gain more knowledge about obscure sources of light pollution. This training document will be accessible on the GFZ blog page of Dr. Kyba which can be printed out or downloaded on mobile. Once the app has been developed, it will also be available within the app for citizen scientists to view while collecting data.

Objective 3: Perceptions Of Factors Contributing To Light Pollution

In order to better understand the motivations of citizen scientists, we conducted a survey designed to reveal the background and motivations of individuals. Our team theorized that individuals are generally aware of the basics of light pollution and ALAN, which was confirmed by our results. According to the survey, about 80% of the survey takers stated that they know what light pollution is and had knowledge of the different factors of light pollution. As seen in Figure 18, population density and urbanization are the biggest contributors to increased levels of light pollution according to the survey takers. This indicates that while many others are not aware of other factors such as “Type of Light” and “Outdoor Advertisement” as a key role of ALAN. Only 4.8% of people in each of these two categories are aware of this factor. Thus, although people are aware of the general causes, they are not able to pinpoint the main sources of light pollution.

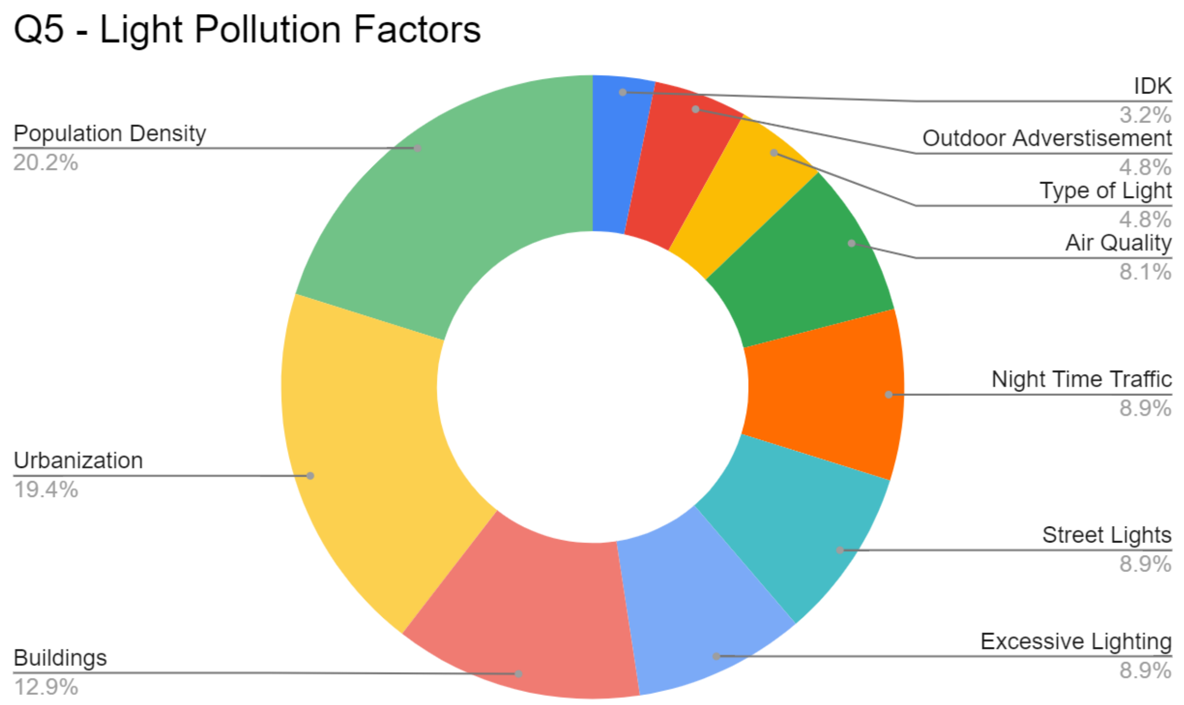

Figure 18: Light Pollution contributing factors, as answered on the survey

However, technical knowledge in light pollution is not the only factor that could affect the level of interest in citizen science. One could be ignorant about a problem but want to address it as a larger social or environmental problem. Therefore, relating light pollution to other topics could encourage individuals to become involved in the movement, not for light pollution per se, but toward a common goal of addressing other social or environmental topics. When asked how concerning light pollution is to other environmental issues, most survey participants only consider it "moderately concerning" as seen in Figure 19. Thus the public appears to conclude that pollution simply is not very relevant to other pressing environmental issues. This disconnect, combined with the fact that the vast majority of Americans are accustomed to light pollution, creates a barrier to the effort of raising awareness about light pollution.

Even fewer survey respondents associate light pollution with direct impacts on their health. When asked whether they think light pollution has had any effects on their health, only 19% of individuals said they think light pollution has had effects on their health. This leaves the remaining 81% evenly split between not thinking light pollution has had any effects on their health and being unsure about it (Figure 20). This was confirmed through our interviews: multiple research participants noted that the motivation to become a citizen scientist is based on an awareness about the effects of light pollution, as well as how much it impacts people on a daily basis.

Interestingly, 80.3% of our survey takers

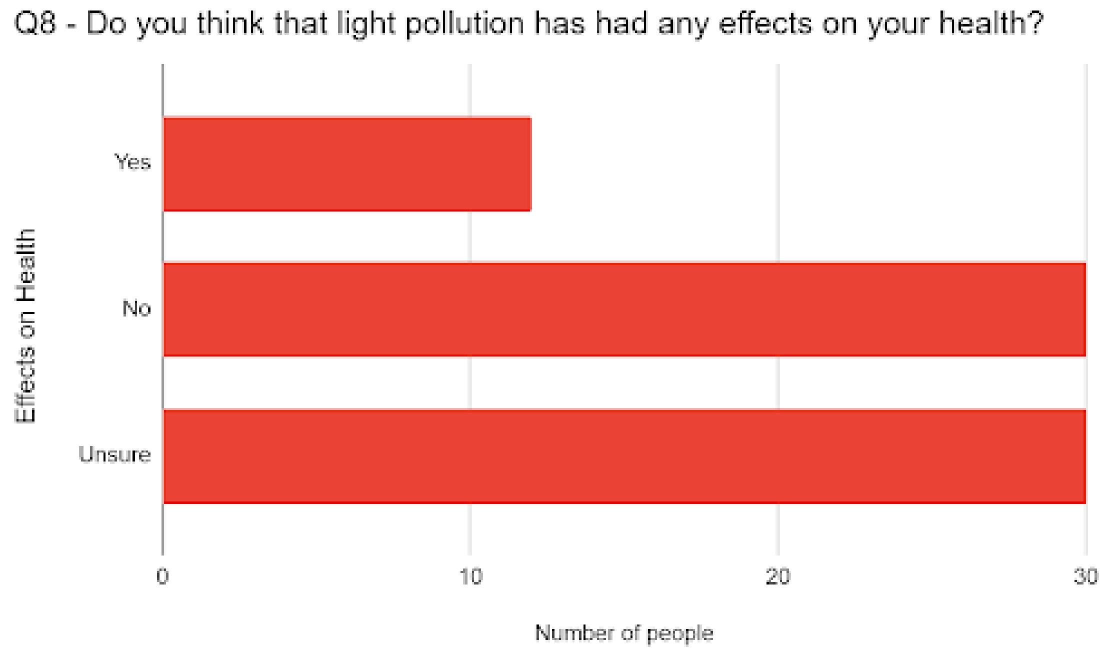

Figure 19: Level of concern compared to other environmental issues

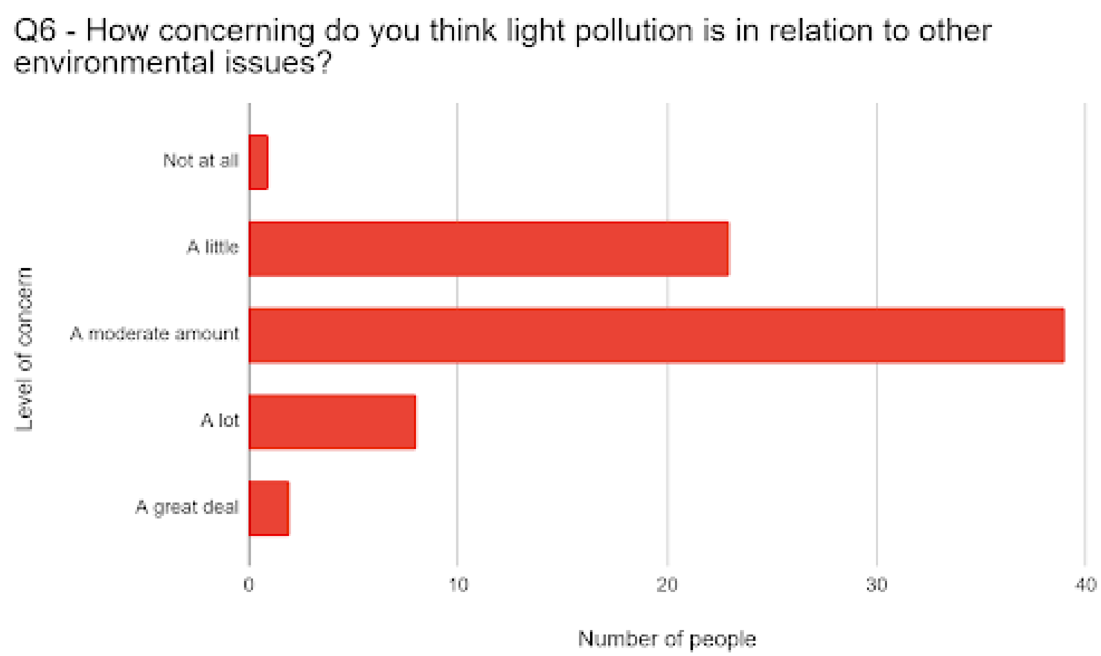

Figure 20: Awareness of effects on health

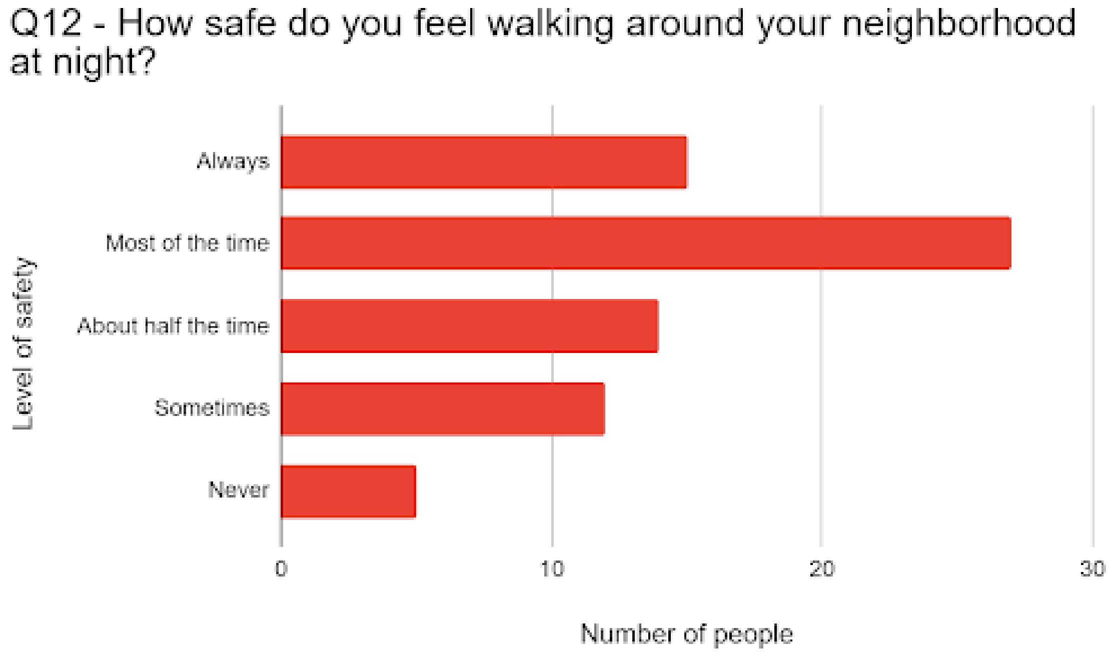

Figure 21: Safety at night in the neighborhood

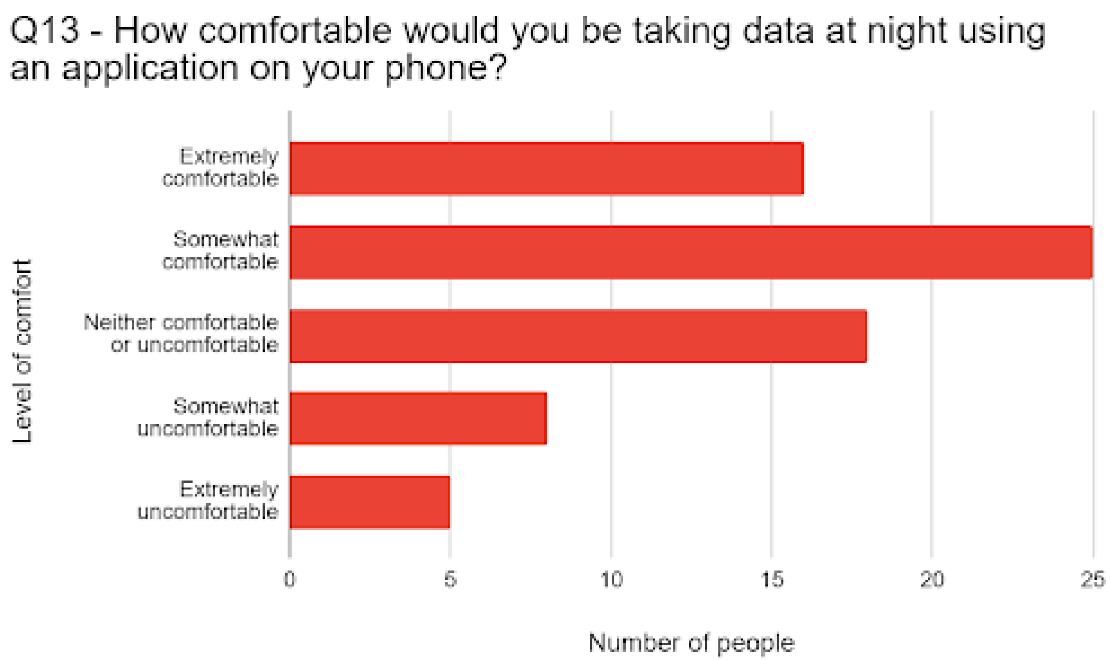

Figure 22: Usage of phone in public at night

were unaware of what citizen science is. Despite this lack of awareness about light pollution and ways to help, there is a silver lining in these results: 83.1% of individuals said they would consider participating in citizen science once they were presented with the definition and an example. With this information we could start confirming our assumption that individuals don't have to be extremely knowledgeable in a topic to be driven to participate.

Because of the previous assumption, we continued keeping knowledge in light pollution, and interest in citizen science separately to better pinpoint motivations of citizen scientists. On our questions of motivations and barriers, safety seems to be a factor as to how willing individuals would be to participate in this specific project. We asked them whether they feel safe walking around their neighborhood at night (Figure 21), and how comfortable they would be taking data at night using an application on their phone (Figure 22). When comparing both results, the level of safety seems to be proportional with how comfortable they would be taking data at night.

Most people who responded to the survey are on the "feeling more safe" side of the spectrum, as were our interviewees. However, these results contrast with the perspective of an individual in Tijuana, México, where gender violence and violence in general has been a major issue for over a decade. Our interviewee stated that while this was an interesting project, as a woman, going out at night while looking at her phone would put her at a very high risk of a violent attack. And while this is only one interviewee's experience, the same could be said by many individuals in other countries where violence is an underlying issue. With this being a definitive factor for many in whether to participate, it can cause a major fault in having diversity in citizen science.

Even when an individual's safety is not a relevant factor, this is not the only factor. For the general public, a monetary reward is the most popular response when asked what would incentivize them into participating in citizen science (Figure 23). The popularity of this response, however, could be related to our sample, since a monetary incentive in the form of a gift card raffle was offered by answering the survey. Despite this possibility, this has been counted as valid data, due to the monetary incentive being effective in producing a high rate response.

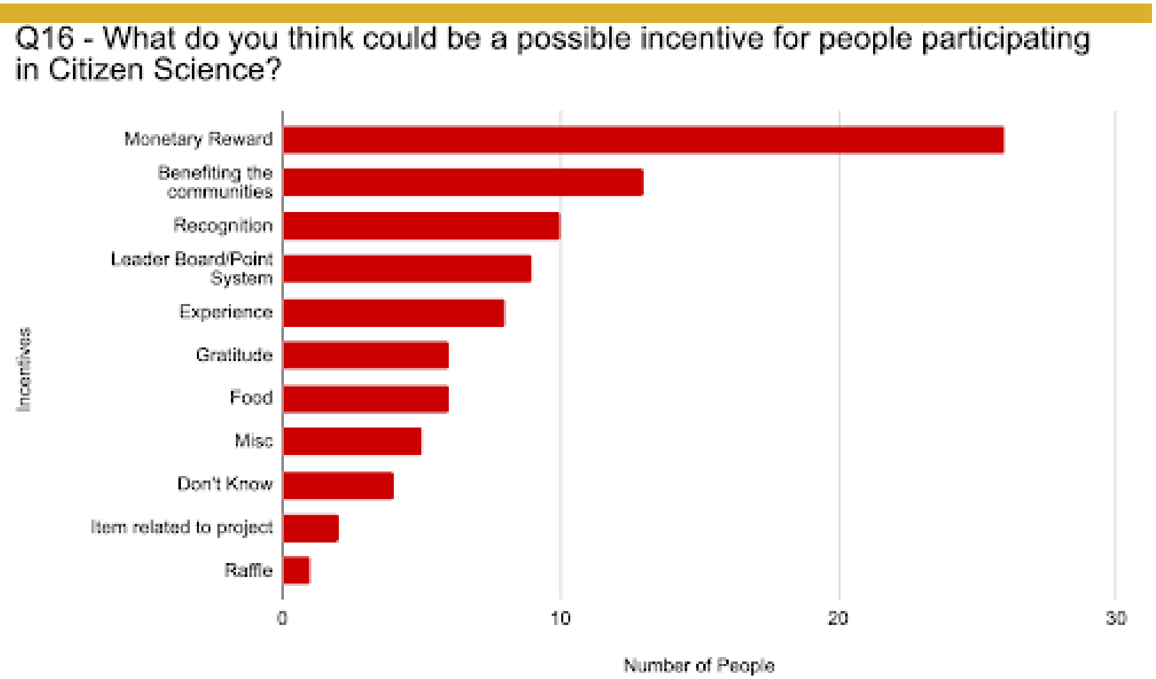

Figure 23: Motivations of citizen scientists

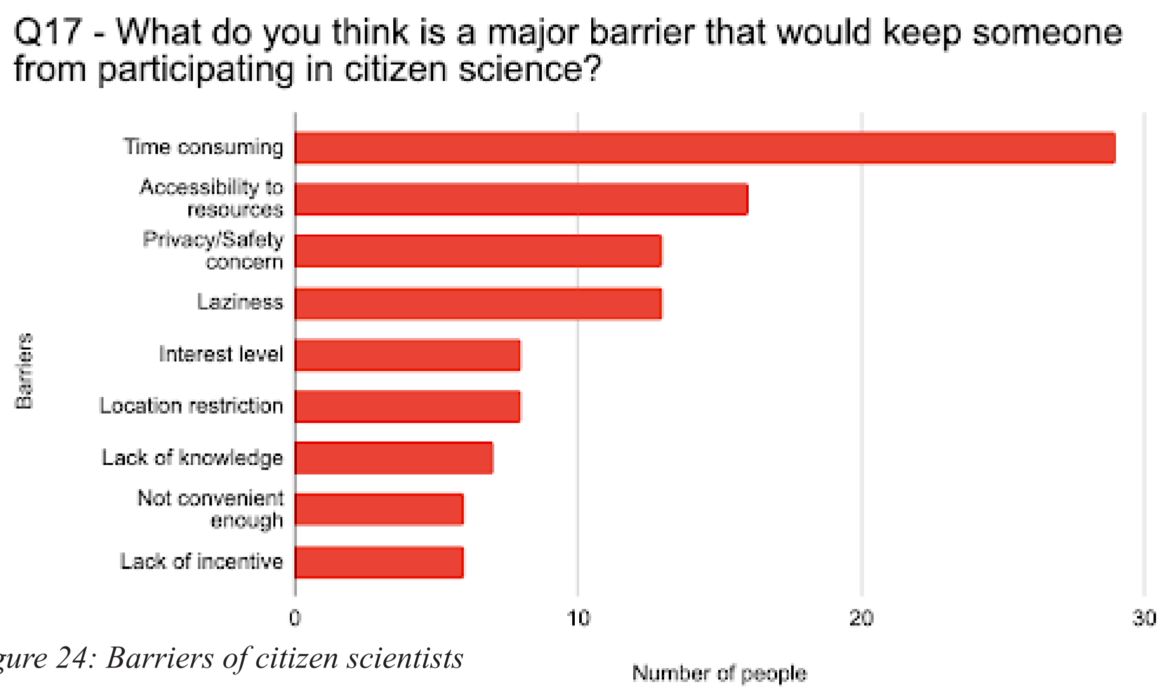

Figure 24: Barriers of citizen scientists

Despite the most popular response focusing on individual's own worth, the second most popular response completely shifts to benefiting the communities. When further investigating the popularity of this response, most individuals expressed that not only do they want to positively impact the communities, but also being able to see the positive impact following their efforts. Individuals not only like to see their impact, but also receive recognition and gratitude from the program and/or researchers themselves. Within the interviews, positive impact and recognition was much more popular than the monetary reward, since the former has more of a lasting impact in individuals. More specifically, interviewees stated that they get motivated to collect data and send it to scientists only if they can see changes being made to the environment. They do not want to participate in data collection if their contributions are not considered to make a greater change because then it would feel like their work and efforts are going to waste. In addition to understanding their impact, individuals want to be recognized for their efforts as well.

While the previous incentives are relevant, the barriers are equally important in order to figure out the motivations of citizen scientists. When asked what would keep someone from participating in citizen science efforts, the most popular response is that they consider it time consuming (Figure 24). However, it should be noted that 80.3% were unaware of citizen science prior to taking the survey. Therefore, stemming from the definition they were given, the majority assumed that most, if not all forms of citizen science are time consuming. Some of the interviewees also stated most people are busy with their jobs, academics and responsibilities at home and that they would not want to spend a lot of time collecting data. According to them, being a citizen scientist is a volunteering opportunity that they would do occasionally, but it is not their main priority.

The second most common barrier to participating in citizen science efforts was accessibility to resources. Some respondents explained that the lack of internet, cellphones, or technology in general could be a major impairment. This is an important point that must not be overlooked, since this can cause an even greater gap in the diversity of citizen science within developing countries or underprivileged areas. As the third most important barrier, respondents identified privacy and/or safety concerns, both in regards to their information being stolen and physical safety. Digital safety is an interesting and important aspect that our team had not previously considered. Considering many who are well-versed in technological topics are more likely to participate through applications, this public could also have good knowledge of data privacy and be wary of it. Therefore, when promoting the future digital application, users should have a clear layout of how their data will be used, especially with an app that relies on the recording of coordinate locations

Finally, we have another two sets of relatively popular responses that could go hand-in-hand: laziness or a lack of interest. Since individuals outside of the scientific community wouldn't consider this as an important task, it could cause a notion that others that "truly care" will participate. Additionally, when some individuals' comfort with a scientific study that has no benefit for them, comfort will outweigh the "few" benefits that participating offers. When looking at this result, and comparing it to the conversations that occurred within our interviews, simply recognizing one's effort and informing individuals of their impact could go a long way in participation rates within citizen science.

Recommendations & Conclusions:

Based on our results, there are multiple conclusions we can draw from our project. These include insights on clarification on types of lighting, the need for training, and the role of citizen scientists. Drawing from these conclusions, we propose the following recommendations on how to effectively utilize citizen scientists to collect data on light pollution. Our recommendations revolve around three core points which are increasing a sense of involvement by citizen scientists, increasing the accessibility of engagement modes and materials to be more inclusive, and increasing information. For those interested in further developing the project, we recommend some specific areas to conduct in depth research. With these recommendations taken into consideration, the data collected from citizen scientists will motivate more people to participate and are more likely to be accurate.

Updates and acknowledgements for the community of Citizen Scientists:

Our first recommendation is for light pollution programs to offer consistent updates as to how the participation of citizen scientists has helped their community, as well as acknowledgements for their efforts and others throughout the globe. As mentioned in many of the interviews and survey results, the citizen scientists would be more motivated to collect data if they were able to see how their contributions are benefiting the community. Weekly or monthly data results should be shared with the citizen scientists so that they are aware of the severity of light pollution in different areas of the world. Based on this suggestion, the app should have a personalized account section where users can keep track of the amount of data they have collected as well as be able to see contributions from other citizen scientists. It could have a leaderboard page where it shows rankings of each of the users based on the amount of data they have collected. With privacy protection in mind, only minimal personal information should be viewed by others. This method creates a small competition with the reward of pride and accomplishment that might encourage the individuals to collect more data and recruit their friends and families to participate.

Adaptation of training guidelines to increase diversity:

Second, we recommend adapting the training guidelines according to citizen scientists' feedback, language, and architectural differences throughout various countries. Our team, along with feedback from our sponsors, developed a set of training guidelines, to better prepare citizen scientists to collect data. However, this was created with German and American citizens in mind, both first-world countries with major technological developments. This training guideline could be currently most useful to first world nations, however developing countries and other areas could have a vastly different set of lights and windows. To offer more comprehensive appropriate training guidelines, we would suggest working with researchers or volunteers of different countries to offer their input and translation on the already existing training guideline. This could be a short and easy task that could vastly improve the experience of citizen scientists around the world.

Additional input from users to increase engagement:

Our third recommendation is to add more opportunities for citizen scientists to provide feedback and more information to the research team. During our data collection, we found that there were some interesting findings that we would have liked to explore, but were beyond the time and parameters of our project. For example, a house had multiple lights facing upward from the ground towards the house and served no purpose other than highlighting its architecture. We are curious about the motivations for this type of lighting. This could arguably be a light arrangement exclusive of American culture, however there is no way of knowing this by simply looking at the luminance data collected. While the end of the form had a space for additional comments, setting up the question for interesting input could bring information just as the type stated in the previous example. Possibly replacing the "Comments:" statement with "Were there any interesting findings?" or "Did you consider any set of lights unnecessary or wasteful?" could get the user to think about their experience, and note details that they did not think about beforehand.

Clarification on types of light:

Our final recommendation is to clarify the types of lights in the application through the use of additional images and a textual explanation. Throughout our time experimenting with the paper form, we noted any difficulties and kept them as pointers that could aid in the development of the digital app. One of the main issues that we had was not knowing what certain types of lights were, especially with two non-native English speakers on our team. While this problem was easily fixed with an online search, it would be more than ideal for the user to have that information readily available within the app. To do this, the main recommendation is the addition of pictures to each type of light, along with a written description. This can be achieved through simple menu options, or as an "?" button right next to each type, to not clutter the screen with information that could already be given knowledge to some individuals.

Future Research:

Some future research topics should be on constructing policies based on cultural awareness and alternative data collection methods for unsafe countries. As stated previously, culture influences people's mindset on the amount of night light that is appropriate to use. Thus, some countries tend to be more illuminated than the others. One area for future research could examine the cultural dimensions of night-time light. Governmental policies should be placed that revolves around cultural awareness. Another area for future investigation relates to the advocacy strategies that may bring a change in regulations on types and durations of light usage. This can be achieved by showing the data collections as evidence and gathering a group of citizen scientists to speak about their experience and changes they would like to see in their communities as well as the world. A final area of future research focus should be on finding alternative methods to collect data from unsafe countries where people's lives are at stake if they leave the house at night. Due to political and gang violence, night life is nonexistent even in urban areas of many nations.

We acknowledge that this project is in its starting stages, and the following recommendation might not be a priority now, however we were interested in bringing this as an addition for the future. Currently, users are prompted to indicate a light's brightness and color, which is ideal to start getting a broad set of data. In the future, when more specific data is needed to pinpoint more specific problems, citizen scientists could (if possible) be trained to identify LED lights from other types of lights. Overall, there is a need for future research in order to regulate light pollution in different areas of the world.

Conclusions:

In conclusion, there are various factors that lead to differences in light pollution around the world. The biggest factor we observed contributing to light pollution is the type of shielding on lights. This is seen in the comparison between Germany and the U.S. where Germany had greater amounts of lights but less radiance within the satellite imagery, because of higher levels of shielding within the areas surveyed. Similar results are seen between urban and suburban regions of Massachusetts, corroborating this conclusion further. Future data collections by citizen scientists can be more comparable if they use a set of data collection guidelines, as it helps them differentiate between types of light fixtures, levels of shielding and informs them on how to count windows based on various size units. Through the collection of comparable data, more conclusions can be drawn, and more actions can be taken to reduce global light pollution. In order to diversify the total dataset, more citizen scientists must be involved from different parts of the world. Looking into the types of incentives preferred and acknowledgement of their contributions will successfully help recruit more citizen scientists for this project since those are the two leading components of their motivation to participate. Citizen scientists could help to illuminate the mysteries of light pollution and could be the key to saving the night.

Acknowledgements:

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• Our Sponsors, Christopher Kyba, Helga Kuechly

• The group of German Citizen Scientists for providing us with valuable data and feedback.

•All of the people who were willing to be interviewed and take the survey form for our investigation on the motivations of citizen scientists

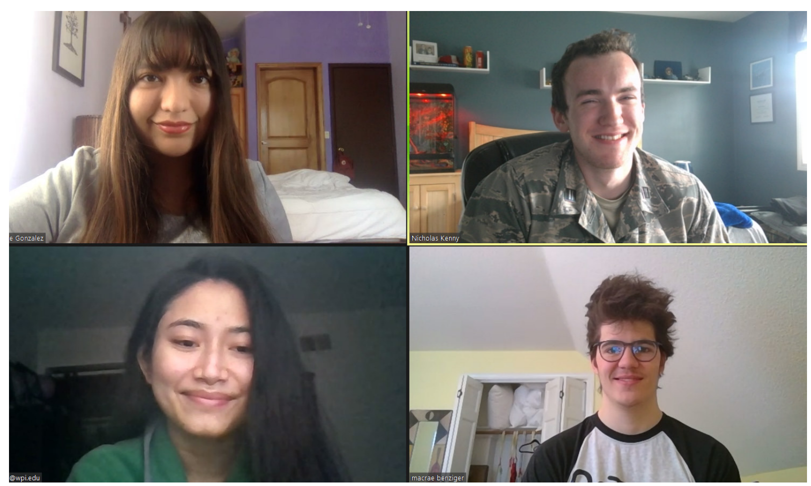

Figure 25: The Night-Time-Light team with the drip

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