

## Environmental impact (light pollution and energy wastage) of artificial grow lighting to replenish grass pitches in sports stadiums

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### Abstract

Artificial Grow Lighting has come to stay in the world of sports. It is becoming popular in the world of sport as a means of providing healthy and aesthetically looking turfs. The need to use this technology arises from several factors that contributes to the deterioration of the grasses on the playing surfaces. These factors include, shadowing caused by shading because of the design of the stadium, thereby not allowing the grass get enough sunlight for the growth of the grass, bad weather conditions: in the winter months when there is little to no sunlight the grasses suffer and ultimately wither away because of lack of sunlight to help them grow healthily.

Despite the many benefits of this technology, like prolonging the playability of sports all year round, the technology has its drawbacks and disadvantages. The technology has very significant impacts on the environment. Many of the sports stadium uses high-intensity-discharge (HID) lamps to grow the turfs, these lamps are very bright and energy intensive. This in-turn causes environmental issues like light pollution, energy wastage and carbon emission.

The light pollution from the use of artificial grow lighting can cause various degrees of health challenges for humans, and it can disrupt the natural balance in the ecosystem of the locality where the technology is in operation.

Furthermore, not only does the technology causes light pollution, it also causes energy wastage as the lamps involved in this technology are energy intensive. It requires a large amount of energy to operate, energy needed in other essential sectors of the economy like agriculture and health sector.

Additionally, the technology has other environmental challenges like carbon emission, because the energy used in operating the artificial grow lighting is from non-renewable sources.

This study seeks to find out the relationship between artificial grow light and its environmental impacts, putting a focus on light pollution and energy wastage. The research also looks at light pollution laws and energy saving laws to prevent energy wastage, proffering recommendations to reduce and ultimately put an end to the environmental impacts of artificial grow lighting in sports stadiums.

**Keyword:** Artificial Grow Lighting System; High Intensity Discharge; High Pressure Sodium; Photosynthetically Active Radiation; Photosynthetic Photon Flux Density

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## 1. Introduction

The quest for human comfort from the elements and unfavorable weather conditions has brought about the construction of semi or fully covered stadiums, this in turn causes the shading of turf pitches in sports stadiums (1). The reduction of light becomes a problem for the grass to grow, leading to the reduction in grass quality and the tolerance of wear on the pitch surfaces.

Most football season and some other sporting activities begins in the winter season when there is little or no sunlight. Light is very important in the growth and overall health of turfs, this is almost impossible to achieve because of the height of the stands and covering in the stadium, these provides comfort and shading for humans, but is detrimental to the health of the turf as the shading prevent Light from reaching the turf.

The problem of shading can be solved using artificial lighting to improve the quality of the turf (2). One of the most important factors in photosynthesis is Light, so as is water, nitrogen, carbon dioxide and temperature (3). Photosynthesis is necessary for the growth and quality of the turf and without light, photosynthesis cannot occur. Artificial grow light is introduced, to mimic the naturally occurring phenomenon of sunlight. This is done to trigger photosynthesis to promote the growth and quality of the grass turf in sport stadiums.

Sports stadiums now use artificial grow light to help the grass on their playing surfaces grow. These artificial grow light helps supplement the insufficient sunlight in winter, the winter sunlight can be insufficient because of the low elevation of the sun and shading because of the covering of the stadium and the height of the stands where spectators sit (4).

The use of Artificial grow lighting to replenish grass turf is increasingly becoming popular in sports stadiums as a means of maintaining healthy and attractive grass pitches all year round. The introduction of artificial grow lights to sport, has sent pitches of sport stadiums on its way to becoming parallel with intensive greenhouse gas production in agriculture (4). Carbon emissions produced at the 2016 Rio Olympics was estimated to be 3.6 million tons and at the 2018 Russia world cup at 2.16 million tons (5), this numbers are little compared to carbon emissions from Agriculture (12,000 mega tonnes) (6). But carbon emissions from sports is well on its way, to rivaling carbon emissions in agriculture.

However, in an age where climate change and associated disasters are frequently being discussed, it is undoubtedly worthwhile to consider the magnitude of the amount of light emissions emanating from sports stadiums. While this technology has certainly improved the aesthetics and playability of sports fields, there are concerns about the environmental impacts of artificial grow lighting. Two of the main concerns are light pollution and energy wastage.

Light pollution is a growing environmental concern that is caused by the use of artificial lighting at night, especially in urban areas. The international Energy Agency (IEA) has estimated that lighting alone accounts for around 5% of global CO<sub>2</sub> emissions, making it a significant contributor of greenhouse gas emissions (7).

This has led some to question whether the benefits of artificial grow lighting systems in sports stadiums are worth more than its environmental cost.

The second major environmental concern about artificial grow lighting is energy wastage, as the technology requires high energy usage to power it. The bright artificial lights used in artificial grow lighting systems requires significant amount of energy to operate, raising questions about their carbon footprint and potential contribution to climate change. More specifically, if the energy required to power artificial grow lighting system comes from fossil fuel sources, it can contribute to greenhouse gas emissions and climate change (8).

However, even if the energy comes from renewable sources, energy wastage can still be a problem. For example, energy efficient grow lighting systems like LEDs can still produce heat, which requires additional energy to cool the space where the system operates.

Furthermore, the disposal of outdated or malfunctioning lamps used in the artificial grow lighting system, may pose a serious hazard to local ecosystems. Many of these lamps contain mercury and lead which is very toxic and can contaminate soil and water if not well disposed or recycled.

The owners of sports stadiums sought after good quality playing surfaces not only to reduce the injury to players because of the rough playing surfaces, but also because of the aesthetics of televising the sports (9).

According to the United Kingdom's Ministry of housing, communities and local government, even-though artificial lighting is good for sporting and recreational activities, it is not always important as it has the potential to cause "Light pollution" or "Obstructive light". This is because if used in an urban area where people live, it can become irritating because the artificial light can shine into the night sky and cause sleep deprivation for people living in that locality, it is also harmful to wildlife and dark landscapes (10).

The United Nations Environmental Programme states that a study has shown that artificial light use is increasing yearly by at least two (2) percent worldwide. It states that artificial light not only affect wildlife, it affects the whole ecosystem (11).

The use of artificial light to grow turf in sports stadiums contravenes the United Nations sustainable development goals number 7(Ensure access to affordable, reliable, sustainable and modern energy for all), 9(Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation), 11(make cities and human settlement inclusive, safe, resilient and sustainable), 13(take urgent action to combat climate change and its impacts), 15(protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss) (12).

The use of artificial light to grow turf in sports stadiums also causes energy wastage, as the use of the Artificial Grow Lighting System (AGLS) is very energy intensive. Most commonly used is the High Pressure Sodium (HPS) technology, this is a really energy intensive technology and it is not sustainable. More stadiums are opting for Light emitting diode (LED) technology as it is less energy intensive (1).

Weighing the environmental costs and the benefits of the technology has made many to call for the careful consideration of the drawbacks of the technology, despite its undeniable benefits.

Therefore, there is a growing importance for an in-depth study that carefully evaluate the environmental impacts of artificial grow lighting and consider potential solutions and alternatives to mitigate these impacts.

This study will examine the environmental impacts of artificial grow lighting on grass pitches in different sports stadiums, focusing on the issues of light pollution and energy wastage and ways to mitigate these impacts.

### **1.1. Problem Statement**

For maximum comfort and protection from the elements and adverse weather conditions, humans erected buildings around playing surfaces, these playing surfaces makes use of grasses. This in turn becomes a problem for the turf's survival, because the grass is shaded from light, and light is a very essential element in the health of the grass (1).

Furthermore, because most sporting events like football season starts in the winter when there is little or no sunlight, artificial grow lighting system is used to supplement the winter sunlight to help the turf grow. It should be noted that not all light is the same and light required for human eye sensitivity is different from the light required to make a plant grow (13).

To make a plant grow, photosynthesis is required and for photosynthesis to occur light and other factors are necessary. The amount of light that is needed for the growth of the turf is measured in Photosynthetic photon flux density (PPFD), this measures the Photosynthetically active radiation (PAR) range across a base area per second (the unit is  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) (1).

In a winter season the minimum PPFD required for turf to grow is at least 40 to 150  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ , and around 200 to 300  $\mu\text{mol m}^{-2} \text{sec}^{-1}$  is required for warm season (9).

The type of artificial grow light used in these sports stadiums are the HPS and LED technology. The HPS uses High intensity discharges (HID) form of technology whereby electrical currents passes through an arc tube that is filled with gas. While LED technology makes use of light emitting diodes and they can produce almost the same amount of yield as the HPS, but with less energy (14).

Several Environmental concerns can arise while using artificial grow lighting, these concerns are light pollution and energy wastage. Running an artificial grow light is very energy intensive. To find the monthly energy cost of running a grow light, this formula was used: Total kilowatts x kWh x hours per day x 30 (days).

Therefore, consider a 1200W indoor grow light in a 4ft by 4ft area that is operated for 12hours a day if the electricity rate is £0.34/kWh. It will cost around £146.88 to operate the LED grow light for 12 hours!

Artificial light cost 85 times more than regular light (regular bulb). Grow lighting need a lot of energy consuming devices for the optimal yield of the grass (15).

Using the football pitch as a case study, the English football association states that for a football pitch for senior age players the measurement must be 116 in length and 76 in width (yards) (16).

If it costs £146.88 to operate an LED grow light in a 4ft by 4ft area, for 12 hours. It will cost a staggering amount to run the same LED grow light on a football pitch of 116 by 76 area.

The use of supplemental light in growing grass in sport stadiums is not regulated by the government, this is because the equipment used to replenish the grass is not fixed and it does not have any form of regulation or planning law in the United Kingdom. The government will only intervene if the artificial light directly beams into people's homes (4).

The light pollution caused by these artificial grow lighting is so much that it can be observed from space and stadiums are responsible for the light emissions from the cities they're situated in (the emission percentage is 10% and in an isolated case up to 30%) (4).



**Figure 1** A view of the sky and city surrounding the Amex stadium in Brighton United Kingdom. The area has no installed lighting. The brightness observed in the photo is solely from the stadium. Source: (Geliot, Coesfeld and Kyba, 2022)

Using the Amex stadium as example as seen in fig.1 without significant protective measures in place like enclosed lighting to shield the light, a large proportion of light reflects from the ground and beams into the sky (4), disrupting wildlife, air traffic and disturbs human sleep as the light brightens the surrounding area.

TLS 72 lighting system which is identical to the one used by the Amex stadium, is powered by 72 Hortilux 1000 W HPS (high pressure sodium) grow lights. Using twelve 72 of HPS on a turf at night equals 864 kW of power consumed, for only growing sports turf (not counting two more rigs positioned at the goal post areas, these two rigs consumes even more energy) (4).

If the twenty teams in the English premier league uses the same artificial lighting system as the Amex stadium, the total number of the power used in growing their turfs will be approximately 20 megawatts (4).

#### *Aims and Objectives of the Research*

The aims of this research include the following

- To evaluate the prognosis for and alternatives to artificial grow lighting for sports.
- To propose methods of mitigating the impacts of artificial grow lighting on the environment.

The objectives of this research includes...

- Investigate use in different sports.
- Investigate light pollution and its effects.

- Investigate the financial costs.
- Investigate alternatives.
- Investigate technologies used in artificial grow lighting in sports.

### 1.2. Research Questions

This research will provide answers to the questions listed below:

- What are the ethical and sustainability problems of artificial grow lighting in sports stadiums?
- What is the connection between artificial grow lighting and environmental pollution?
- Who stands to gain more in the use of artificial grow lighting in sports stadiums?

### 1.3. Structure of the Study

The study is structured into chapters and contains six chapters in total. The first chapter introduces the thesis, problem statement, aims and objects of the research, and research questions. Chapter two of the study is the literature review, gaps in literature, a look at laws on light pollution and energy wastage, and Failure modes and effects analysis on artificial grow lighting in sports stadiums. The third chapter is the methodology, it focuses on the methodology used in obtaining, analyzing and presenting the data used in the study. Limitations encountered during the course of the study were also listed in this chapter.

Chapter four centers on the results achieved by carrying out the research and discussions on the result outcomes. The fifth chapter is about the recommendations prescribed by the study and paths to follow for future research. The final chapter (six) concludes the study, summarizing the research.

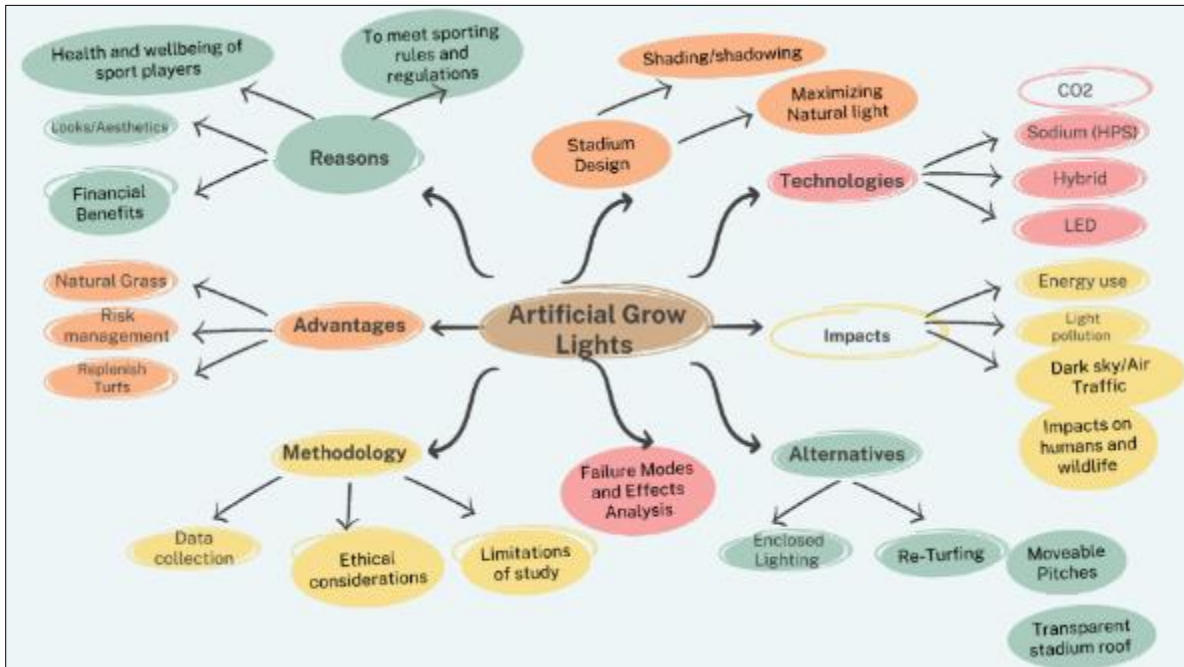


Figure 2 Mind map of the research

## 2. Background and literature review

### 2.1. Artificial Grow Lighting

#### 2.1.1. Concept of Artificial Grow Lighting

Artificial grow lighting is fast becoming an increasingly popular method for replenishing grass pitches in sport stadiums. It involves the use of artificial lights to supplement natural light, this is done to provide plants with sufficient energy for photosynthesis, by providing plants with specific wavelengths of light.

This technology has gained immense popularity in the world of sports, allowing for all year-round grass growth and maintenance, regardless of the season of the year either in summer or winter when there is little to no sunlight. The use of artificial grow lighting in sports stadiums offers several benefits, such as extended growing seasons, reduced maintenance costs, improved plant health and growth, and enhanced visual appeal for the spectators.

#### 2.1.2. Historical Background of Artificial Grow Lighting

Artificial grow lighting has been used in sports stadiums for several decades, with its history dating back to the mid-20<sup>th</sup> century. In the 1950's, fluorescent lamps were first used to grow plants indoors (Bula et al., 1991). The development of this technology paved way for the use of artificial grow lighting in sports stadiums. In the 1970's and 1980's, sports stadiums began to experiment with the use of artificial grow lighting to improve the quality of grass pitches (17). This was particularly useful in areas with limited sunlight or unfavorable weather conditions.

In the 1990's metal halide lamps became the most commonly used artificial grow lighting technology in sports stadiums (18). Metal halide were preferred for their high lighting power output and spectral properties that were well suited for plant growth. In recent years, Light Emitting Diodes (LEDs) grow lights have emerged as a promising alternative to metal halide lamps in sports stadiums. LED grow lights are more energy efficient, have a longer lifespan, and can be tuned to deliver certain wavelengths that are good for plant development.

#### 2.1.3. Current Level of Application of Artificial Grow Light in Sport Stadiums

Artificial grow lighting is increasingly being used in sport stadiums worldwide. In the United States, the use of artificial grows lighting in sports stadiums has been steadily increasing over the past two decades. According to a report by the Sports Turf Managers Association, the use of artificial grow lighting increased 27% between 2005 and 2015 (19). In Europe, the use of artificial grows lighting in sport stadiums is also on the rise. For example, in the United Kingdom, many Premier League football clubs have installed artificial grow lighting system to maintain high quality grass pitches throughout the year.

In Asia, the use of artificial grow lighting in sport stadiums is also becoming more common. For example, in Japan several baseball stadiums have installed LED grow lights to maintain grass pitches during the winter months (20). In Australia, artificial grow lighting has been used in sports stadiums for several decades, with many stadiums relying on the system to maintain high quality playing surfaces in hot, arid environments.

One notable example of the use of artificial grow lighting in sports stadium is the Mercedes-Benz Stadium in Atlanta, Georgia. The stadium features an advanced LED lighting system that creates variety of lighting effects, including dynamic colour changing sequences and dimming capabilities. According to a case study by the American Society of Horticultural Sciences, the LED grow lighting system in the stadium playing surfaces provides an ideal light spectrum for grass growth and development, resulting in healthier and more vibrant grass.

The system allows for precise control over lighting intensity, duration, and spectral composition, which can be adjusted to meet the specific needs of different plant species and growth stages.

Another example of the use of artificial grow lighting in sport stadiums is the T-Mobile Arena in Las Vegas, Nevada. The arena uses a specialized lighting system that mimics natural sunlight to enhance the growth and health of its turf. The system includes a network of LED lights that can be adjusted for intensity and spectral composition, allowing for optimal grass growth in any season.

There are also several stadiums in the United Kingdom where artificial lights are being used. Some of these stadiums are Tottenham Hotspur Stadium which has retractable pitch that slides out of the stadium to receive natural light and air, and when required it slides back into the stadium, where artificial light is used to maintain the turf (21); Manchester

City's Etihad Stadium which uses an innovative pitch lighting system known as the "SunGrow", which combines natural and artificial light to maintain its turf all year round; Brentford Community Stadium which uses a state-of-the-art pitch system that incorporates LED grow lights, which provides the grass with the necessary light and energy required for photosynthesis; and Derby County's Pride Park Stadium: the stadium uses an artificial turf growth lighting system that enables the grass have enough growth all year round.

## **2.2. Environmental Impacts of Artificial Grow Lighting**

The use of artificial grow lighting in sport stadiums is becoming more widespread globally as the technology improves and the benefits are becoming widely recognized. However, this practice can have negative environmental impacts, especially in the aspect of light pollution and energy wastage.

### *2.2.1. Light Pollution*

Light pollution is a major concern associated with the use of artificial grow lighting in sports stadiums. According to (22), light pollution refers to the excessive and inappropriate use of artificial lighting, which results in the disruption of natural light patterns. The effects of light pollution on the environment are numerous and varied.

Light pollution from sporting facilities have frequently been a cause of contention over the years, but this contention, as well as the environmental problems, has largely been always settled when the lighting is switched off after use. A more disturbing significant advances has been the increased usage of lighting arrays installed on wheeled rigs to stimulate quicker growing grass on actual fields. Because of revisions to grass pitch regulations, as well as during Euro 2016 competition, where several European stadiums were left in bad condition due to severe rain, these grow lights became more extensively employed (23).

The shadowing effects (also known as shading) of stadium design in larger sporting facilities can pose challenges for grass to absorb enough natural sunlight to thrive, particularly in winter periods (4). Since additional lighting for grass in sports facilities may have a significant influence on a city's overall light pollution, it merits special consideration in light management and light pollution control initiatives.

This form of light pollution can be a particular concern due to the proximity of many stadiums to residential areas. Several studies have investigated the effects of artificial grow lighting used in sport stadiums on nearby residential areas and humans in general. One of the key concerns is the potential impact of artificial lighting on sleep-wake cycle of nearby residents. According to a study by (22), exposure to bright light at night can disrupt the body's natural circadian rhythm, leading to sleep disturbances and other health problems. This can have significant implications for children, whose sleep patterns and development maybe negatively impacted. Artificial lighting can affect the human behavioural and emotional patterns, especially in children, as it affects their growth and development (24).

According to Kloog et al., artificial light can cause several health problems for residents close to the proximity where artificial light is in operation, these medical problems includes obesity, cardiovascular diseases and other health problems (25). The International Dark-Sky Association (IDA), states that artificial lighting from sport stadiums can contribute to the degradation of dark skies, which have negative impact on human health.

Besides being a menace to humans, artificial grows lighting can also cause significant level on light pollution, which can negatively impact wildlife and ecological system. Artificial light can negatively impact the health and behavior of urban wildlife, including birds and insects. For example, it can affect the behavior of nocturnal animals, making the animals easy visible prey to other predatory animals. It can also disrupt the natural rhythm of plants and animals, including their breeding and migration pattern.

### *2.2.2. Energy Wastage*

In addition to the effects on humans and the environment, artificial grow lighting can also have serious economic implications. The use of artificial grow lighting can significantly increase energy consumption and associated costs. According to the US Energy Information Administration (7), lighting accounts for approximately 10% of the total energy consumption in commercial buildings, including sport stadiums. The use of artificial grow lighting in sports stadiums can therefore contribute significant increase in energy consumption and greenhouse gas emission. Artificial grow lighting used in horticulture and agriculture accounts for significant portion of greenhouse gas emissions, with high-intensity discharge lamps being particularly energy intensive.



One of the major reasons for energy wastage in artificial grow lighting systems is the use of inefficient lighting technologies. High-intensity discharge (HID) lamps are commonly used in sports stadiums, but they are known for their low energy efficiency and short lifespan. A study by the American Council for an Energy-Efficient Economy (ACEEE) found that HID lamps have an average energy efficiency of 25 – 30 lumens per watt, while LED lamps can achieve 100 lumens per watt (26). Thus, the use of more energy efficient lighting technologies such as LED lamps has been known to significantly reduce energy consumption in sports stadiums and ultimately reduce greenhouse gas emissions (27).

However, while it is true that LED lamps are more energy efficient than traditional lighting technologies such as HID lamps, it is important to note that the adoption of LED lamps alone may not necessarily result in a significant reduction in greenhouse gas emissions. This is because the environmental impact of lighting systems goes beyond just its energy consumption.

For instance, the production, transportation, and disposal of LED lamps also have environmental implications. The manufacturing process of LED lamps requires the use of rare earth metals, which have negative environmental impacts if it is not sourced and disposed of properly (28). Furthermore, the disposal of LED lamps at the end of their lifespan is also a concern, because they contain electronic components that can be harmful to the environment.

The time, duration, and frequency of lighting also contributes to energy wastage. It is noted that many of the sport stadiums operates their artificial grow lighting systems late in the night. A study by this research into why these stadiums uses the AGLS at night shows that, it is done to cut their energy bill because energy is cheaper at night. Many energy providers operate an on-peak and off-peak model of energy billing, where energy tariff is high during the on-peak (8am-10pm) and off-peak (10pm-8am) when energy tariffs are low.

Since the sports stadiums incurs very high energy bills because of their use of energy intensive grow lighting system, they operate the artificial grow lighting system late at night during the off-peak period when the energy tariff is low.

Although, many of these sports stadiums operates their artificial grow lighting system at night, a visit by the research student to Manchester United's Old Trafford Stadium shows that some of them operate the artificial grow lighting system during the day. The system was in operation between 1pm and 2pm when the researcher left the pitch side.



**Figure 3** An image of the Artificial Grow Lighting System in operation during the day at Manchester United's Old Trafford stadium. Bright orange glow can be observed underneath the AGLS. Source: Picture taken by the research student

A study by (Pellegrini et al., 2019) investigated the energy consumption of a football stadium with a hybrid lighting system (natural and artificial lighting) (29). They found that the energy consumption of the stadium increased significantly during the winter months when artificial lighting was used more frequently. One potential strategy that has been recommended is to optimize the use of natural light. However, the design and layout of the stadium also play an important role and dictates the possibility of maximizing natural light.



The impact and orientation of sports stadiums on energy consumption, depends on the stadium's design. When a stadium's pitch is covered, either partially or fully covered by the roof, the turf receives little to no natural light at all. This affects the quality of the turf, such turfs require the use of artificial grow lighting system, which requires more energy consumption.

Also monitoring and managing lighting schedules of the artificial grow lighting system has been identified as means to reduce energy wastage. However, while it is true that monitoring and managing the artificial grow lighting schedules can help reduce energy wastage in stadiums using artificial grow lighting, it is important to note that this is only one aspect of a comprehensive energy management strategy. Monitoring and managing lighting schedules alone may not be enough to achieve significant energy savings in sports stadiums.

To effectively reduce energy wastage, it is necessary to implement a range of energy saving measures that address the entire lighting system. For instance, using Solar Photovoltaics (PV) as a source of storing energy and making sure the system draws its energy from the solar PV. This will not only save the stadium from paying high energy bills, it will also make sure that the system uses energy from a clean renewable source.

Furthermore, human behavior also contributes to energy wastage from using artificial grow lighting system, due to negligence and incompetency staffs can leave the AGLS running beyond the required time and duration it needed to operate for, thereby contributing to energy wastage.

### *2.2.3. Gaps in Literature*

While there is a growing body of literature on the environmental impact of artificial grow lighting in sports stadiums, there is still some gaps in the research.

The potential health impacts of light pollution from artificial grow lighting on nearby communities has not been extensively studied. While some studies have examined the effects of artificial light on wildlife and plant communities, more research needs to be done to understand more potential health implications relating to light pollution caused by the use of artificial grow lighting.

Similarly, the effectiveness of alternative management strategies, such as natural light for reducing the environmental impact of artificial grow lighting is not well established. While some studies have compared the energy consumption and environmental impact of different types of artificial grow lighting systems, more research is needed to be done to understand how alternative management strategies may reduce energy consumption and greenhouse gas emissions in sport stadiums.

Also, the economic viability of alternative management strategies with the use of natural light for reducing the environmental impact of artificial grow lighting is also unclear. While some studies have examined the cost-effectiveness of different types of artificial grow lighting systems, more research is needed to understand the economic implications of alternative management strategies, particularly in the context of different types of sport stadiums and playing surfaces.

## **2.3. Reasons for the Use of Artificial Grow Lighting in Sport Stadiums**

### *2.3.1. Financial Benefits*

Sports stadium owners are in sport business primarily to make profit. The global sports market is valued at over £403 Billion as at the year 2020 and it is projected to surpass £565 Billion by the year 2026 (30).

The budget to host the recently concluded Qatar 2022 FIFA world cup stands at £173 Billion, this amount is for the construction of stadiums and other projects relating to the world cup. This astronomic amount is comparable to the 2021/22 budget of the Department of Health and social care of England which totals about £185 Billion (30).

Another reason artificial grow lighting is used in replenishing turfs is cost cutting. According the stadium manager of Newcastle united stadium Eddie Rutherford, it cost the club £120,000 to re-turf the pitch mid-season and with the introduction of artificial grow lighting system, it costs the club just around £64,000 to run the grow lights all season.

The stadium and club owners wants to cut cost and increase profit is one of the reasons for using grow lighting systems in their stadiums.

### *2.3.2. Looks and Aesthetics*

Most sporting activities are televised, the quest for clean motion pictures and the perfect video of the stadium will bring in more viewers. Having an aesthetically looking stadium will generate more television “rights” and bring in more profits for the sport stadium owners.

In the United Kingdom, pitch management is serious business as enormous amount of funding is pumped into keeping the grass green. According to the William Ralston who writes for the Guardian Newspaper “the pitches used to look like marshlands, deserts, ice rink depending on the time of the year”. But has the world of sports begin to generate mega financial profits, immaculate looking pitches became a vital part of sports image and the people entrusted with keeping the pitches green became sporting stars.

The cost of living and food prices in the UK increased to an all-time high by 16.7% in 12 months till January 2023, first of its kind in 45 years. Making the costs of essentials increased to an unaffordable high rates (31).

Millions of people in the UK struggle to get access to food, making UK rank among the highest in countries with food poverty in Europe, it is estimated that 4.2 million people (about 6% of the population) were affected by food poverty. The figure includes 9% of all children. The figure increased in 2022, as a total of 9.7 million Adults were affected by food insecurity as at September 2022 (31).

The EU’s subsidy for farmers also known as Common Agricultural policy (CAP) plans to grants UK farmers £3 Billion a year worth of subsidy. Not all farmers will have access to the funding and not all farmers will get involved (32), while the UK sports grounds-management alone is worth well over £1 Billion and increasing, and they give employment to over 27,000 people who are specialists in every area of grass science. They study everything from how grass affects the game of sport, how to breed grasses that is not affected by shading, chemicals that makes grass greener etc. (33).

More money is being invested in growing grass for sporting activities and research into making this grass greener, while farmers lack funding for growing food that will benefit the general populace and curb the increasing level of food poverty.

### *2.3.3. Health and Wellbeing of Sports Players*

The health and wellbeing of the athletes and players in sports is another reason why stadium owners and management employ the use of Artificial grow lighting system. In the past sports activities occurs on hard playing surfaces and it is noted that players sustain various degrees of injuries, from mild to severe injuries.

Sports club owners spends a lot of money in buying these players to represent the club in sports competitions, and an injured player costs the owners a lot of money. The owners lose money if the injured player/players is not competing, as some spectators only come to watch their favourite player compete.

The sports club owners also lose money in catering for the healthcare recuperation of the player, as they have to pay doctors and other healthcare workers to look after the health and wellbeing of the player.

Safety is paramount in sporting activities because it has been discovered that many mild injuries such as skin cuts and abrasion and severe injuries such as anterior cruciate ligament (ACL) occurs as a result of not properly maintaining sport pitches. They’re classified as non-contact injury as it is commonplace for a player’s foot to be stuck in grass when tackled, thereby leading to serious injury (34).



**Figure 4** A picture collage of bad pitches from different sports. The first image from the left is from a cricket match, the top image from the right is from a rugby match and the bottom picture is from a football match. Source: (35)DailyMail.co.uk (football’s golden years), TheGuardian.com (Sport: Bad pitches), Riveronline.co.uk (Kingston rugby overcome awful conditions to ease past Reading)

Fig.4. Shows the various states of bad sports pitches, the first image from the left shows a bare cricket pitch. Bare surface causes injuries to the cricket players, cricket players are known for sliding, and crawling to catch the cricket ball, knee abrasion is a common injury sustained by the players. To put a stop to the constant injuries by players, stadium owners opted to invest in AGLS for growing the grass on the pitch and keeping the grass healthy.

The top picture shows a rugby pitch and the bottom picture is a football pitch, the condition of the pitches is not favourable to the health and wellbeing of the players as they’ll be prone to injuries because of the condition of the pitch.

#### 2.3.4. To Meet Sporting Rules and Regulatory Standards

Every registered sporting activity has a regulatory body that effects rules and policies that affects the members of such bodies. They determine the amount of players a sporting team can own, the number of competitions a player can compete in etc.

According to the English Football Association, every football team in England must meet what it calls Performance Quality Standards (PQS), this provides a minimum criterion for the quality, performance and usability of a natural turf surface. It is the minimum acceptable benchmark e.g. turf hardness, colour, height, ground cover, evenness etc. for different competitions of the sport e.g. international club competition, FIFA competitions, local leagues etc.

Other sports associations have similar rules that protects the interests of the association, as it relates to turfs.

**Table 1** The English Football Association Performance Quality Standards of a football Natural Turf. Source: thefa.com

Element	Limits	Method of use
Sward Height mm	20-60 PS 20-75 SM	BS 7370 : P3A3
Hardness in g	35-200	STR method of test using a 0.5kg Clegg impact Hammer from a height Of 0.55m
Water infiltrate mm/hr	5	BS 7370:P3 A8
Evenness – 2 meter straight edge	< 20mm	BS 7370:P3 A4
Slop – direction of play	< 1.25%	BS 7370:P3 A5

Ground cover %	> 70 for SH 25.30 > 80 for SH 30.35	BS 7370:P3 A6
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## 2.4. Impacts of Artificial Grow Lighting System

### 2.4.1. Light Pollution

Light pollution can be defined as any light that shines directly or indirectly into an unwanted/unintended spot. This can be directly into the sky or downwards around the source of light.

Artificial light is the major cause of light pollution. Since the invention of artificial light in the 19<sup>th</sup> century, artificial light has been a source of light to prolong human night-time activities and brighten the darkness during night time for the benefit of the society. It is used for safety purposes as light helps with human movements from point A to B at night, prolonging the night-time productivity for the economy, creating more time for recreational activities that involves the use of light, artificial light is also used in agriculture for growing plants, etc.

However, when artificial light becomes a source of annoyance, nuisance, harmful to both humans and animals, affects the night sky, it is said to be Light Pollution.

About 80% of the world's population are living under light polluted skies (36). According to BBC, 99% of the population of Europe and America lives under skies that are 10% brighter than necessary (37).

### 2.4.2. Impacts of Light Pollution

- Impacts on wildlife:** It is estimated that about 100 billion nocturnal insects dies every summer because of Artificial light. This is because the insects usually rely on the moon for its orientation and direction, the insects become distracted by the bright light from the artificial light and they become disoriented and fly around the light all night.

They become exhausted and are too frail to reproduce and eventually dies (36).

The New York City Audubon Society said that every year about 10,000 migratory birds are either killed or injured from crashing into high-rise buildings and skyscrapers as a result of brightened night sky and close to 98 million to a billion birds dies from collision in North America every year (38).
- Impact on night sky and dark landscapes:** Light pollution obstruct the beautiful Night sky. Stars are usually visible at night, it is difficult and almost impossible to see the stars because of light pollution. This affects astronomers from studying and advancing the science of astronomy. And it also prevents people from enjoying the night sky and the beauty of dark landscapes.
- Impacts on airplanes:** Several impacts arise from the crash of an airplane. Not only does humans suffer casualties, wild lives are also displaced and the leakage from the plane also contaminates the soil. Light pollution can affect the visibility of pilot and cause an airplane to crash. Light pollution caused by yard-laser light can pose a big flight risk. According to the Federal Aviation Administration over 8,000 strikes from yard laser light was reported in November 2021, a significant rise from 6,000 cases reported in 2020 (39).
- Impact on human health:** Artificial grow light affect the circadian rhythms in human. The human body follows what is known as the circadian clock, where the human body adapts to a 24-hour day/night cycle. Artificial grow light disrupts the sleeping pattern of humans thereby causing serious medical problems like sleeping disorder, depression etc. Artificial light also disrupts the human's ability to produce melatonin, which is produced in the human body at night.
- Impact on animal communication:** Some animals use light as a means of communication, example of such animal is the female glow-worm. They attract males from 45m away using their bioluminescent light, artificial light can affect the communication between the animals. Other animals that uses light as a means of communication includes the fireflies, coyote, wolves etc. The wolves and coyotes howl the loudest during new moon, this is done by the animals to reduce trespassing, or to gather the packs together for hunting purpose. Artificial light can impede the communications in these animals.

### 2.4.3. Light Pollution in the Eye of the Law

In the United Kingdom, the Department for Environmental, Food and Rural Affairs (DEFRA) are responsible for legislations relating to statutory nuisance, to prevent cases where there is unreasonable interference of personal comfort or amenities of people nearby (40).

Section 79(1) (fb) of the Environmental Protection Act 1990 states that local authorities must take appropriate steps to investigate complaints of Artificial light emanating from a particular establishment(s) that is harmful to health or constituting general nuisance. If the authorities are satisfied that a statutory nuisance is occurring, about to occur or reoccurring, the local authority must issue an abatement notice which is in-line with section 80 of the Act, which requires that the nuisance be abated or restricted from occurring.

The local authorities take into full account of several things when evaluating Artificial light nuisance complaints. They take into account the time of the day when it occurred, for how long it occurred, how frequently it occurs, what best practice was adopted by the perpetrator, how reasonable the activity being carried out is etc.

Another law that tackles the issue of light pollution is the Clean Neighbourhood and Environment Act 2005, Section 102 of the Act makes Artificial light that is prejudicial to health or causes a Nuisance a criminal offence.

The person responsible for the light pollution can be advised to abate the nuisance, or be fined possible up to £5,000.

#### *2.4.4. Artificial Grow Lighting System as A Source of Light Pollution*

To meet up with sports governing bodies regulations and other reasons stated in previous Chapter 2.4.4, stadium owners employs the use of AGLS to replenish the grass on their pitch.

However, study has shown that this system is a major source of light pollution. The system is operated late at night or throughout the night, thereby causing an orange glow blanket covering its immediate locality, causing harm to humans and wildlife.

Stadiums are a part of the total light emissions of the city they're situated in, contributing 10% or sometimes 30% of the total light emissions from that city (4).

Since the AGLS is operated at night, it can be viewed as far as the orbit space. A study using the Amex stadium in Brighton shows that the radiance from the pitch of the stadium most times outshine the light emitting from the dockyards, airports, city centers, and even industrial plants. The radiance of light from the pitch of the Amex stadium while using AGLS, is above 400 nW/cm<sup>2</sup>, compared to just 70 nW/cm<sup>2</sup> from Brighton City Centre, and London bright areas with only 160 nW/cm<sup>2</sup> (4).



**Figure 5** Orange glow blanketing Falmer Village in South Downs, picture taken at 9pm when the AGLS from the Amex stadium was in operation. Source: theguardian.com Brighton stadium put the light out plea

The people of Falmer village complains of lack of sleep and the impact of the AGLS from Amex stadium on the ecosystem of the local area. There has been calls to take action and petitions signed by the people of the village to put an end or look for an alternative to the AGLS (41).

## 2.5. Energy wastage and the Law

In the United States alone commercial buildings accounts for 20% of the U.S. energy consumption, and its projected to increase to 36% by 2030 (42). Sports stadiums are classified as commercial buildings as it generates revenue from the sporting activities and shows.

The energy use intensity and energy wastage from commercial buildings necessitated mandatory laws to meet carbon emission reduction goals by the government. Laws like the Energy Saving Opportunity Scheme (ESOS) was created to make sure commercial buildings reduce its energy use intensity.

ESOS is a law that was created in July 2014, it requires businesses considered not to be small/medium scale (businesses with 250 employees and above with an annual turnover exceeding €50 million) to conduct a mandatory energy efficiency audit (ESOS Assessment) every four years. The Assessment will carry out calculations on the business energy usage, make findings on how to identify methods of saving energy and how to manage energy. The assessment's findings will then be submitted to Environment Agency (EA).

## 2.6. Alternatives to Artificial Grow Lighting System

There are a few alternatives to the use of artificial grow lighting system in sports stadiums. These alternatives are needed to curb the continuous environmental, biological and ecological nuisance of the technology.

The use of enclosed lighting, re-turfing, moveable turfs/pitches, and transparent stadium roof will go a long way in controlling and ultimately eliminating this nuisance.

- **Enclosed lighting:** The main reason why light emission from the AGLS blankets the nearby locality whenever it is in operation, is because of the lack of covering. The light emission from the system causes environmental and ecological problems as stated in the problem statement in chapter 1.  
The use of a covering or operating the AGLS in an enclosed space will stop the emission of the light into the atmosphere. A few sport stadiums have introduced this system of lighting, but many sports stadiums still operate their AGLS in open spaces thereby creating untold hardship on the people and wildlife in the locality where the stadium is located.
- **Re-turfing:** Stadiums are very expensive to build and stadium owners build these stadiums to make profit, therefore stadiums with high spectator capacity are built for financial benefits. This in turn causes problem for the turfs to grow properly because of shading problem (turfs needs sunlight to grow), as the spectators sitting area blocks the sun from shining on the turfs and air circulation is also blocked thereby causing the turf to get enough air to grow healthily.  
Because stadiums are built for financial reasons, the owners allow several arrays of sporting and recreational activities in the stadium. For example, one stadium can host rugby, football, cricket, music concert and even car racing activities.  
These activities put wear and tear on the grass. Instead of using AGLS to replenish the grass, the turf can be replaced with a new healthy turf.  
Returfing is the process of replacing an old turf by laying a new one. When this is done instead of the AGLS, it will curb energy waste and stop environmental impacts of AGLS.
- **Moveable pitches:** Instead of using AGLS, stadiums can introduce the use of moveable pitches whereby the pitch can be moved outside the stadium, so that the turf can get better sunlight and air circulation. This system is already in use at the Millennium stadium in Wales.
- **Transparent stadium roof:** The use of transparent stadium roof, will help curb the issue of shading in sport stadium, as the issue of shading causes the turf not to get enough sunlight to grow properly. The transparent roof will allow ample sunlight to shine directly on the pitch, to help replenish the grass.

## 2.7. Technologies Involved in Artificial Grow Lighting System

- **CARBON DIOXIDE (CO<sub>2</sub>):** Because carbon dioxide is an essential part of photosynthesis which makes the grass grow, carbon dioxide artificial grow lighting system is used by hanging burners over the grass and it is ignited to create artificial heat which in turn creates carbon dioxide CO<sub>2</sub>. The process will help replenish the grass.
- **HIGH PRESSURE SODIUM (HPS):** This type of technology uses high intensity discharge lights (HID). When they are in operation, they emit light when electrical current passes through a tube containing noble gas and a gas that is a mixture of sodium and mercury vapour. As a result of this, a bright orange/red light spectrum is achieved at a temperature of about 2200K. The HPS system provides several light colour spectrums ranging

from yellow 570-590(nm), orange 590-630(nm), and red 630-750(nm). These light spectrums can vary depending on the type of bulb used and the choice of manufacturer used.

- **LIGHT EMITTING DIODE (LED):** This type of system makes use of light emitting diodes placed on printed circuit board, thereby making the LEDs to act like computer chips. The LEDs are semi-conductors, so when they're turned on and off the result is instant.  
LEDs are more energy efficient, because they consume less energy and they generate low carbon emission and the general operating cost for running LED system is low (43).
- **HYBRID:** Most users of HPS system are slowly moving towards the use of LED system, but they are doing this by slowly infusing LED to HPS thereby creating a hybrid system. The system will achieve improvement in light efficiency, and a decrease in carbon emission.

## 2.8. Advantages of Artificial Grow Lighting System

### 2.8.1. Natural Grass

One of the advantages of AGLS is because it encourages the use of natural grass, as studies have shown that synthetic/artificial grass is bad for the environment. Synthetic turfs have a limited lifespan and disposing of it during its end of life can be a huge challenge.

Disposing of synthetic turf can bring up hassles such as removal, transportation etc. The Synthetic Turf Council states that an average sport field measures about 80,000 square feet, comprising about 400,000 pounds of infills and 40,000 pounds of turf. Recycling of synthetic turfs is challenging because the turf is made up of several chemical properties and polymer therefore it needs special technologies to recycle. And the use of natural turfs helps meet several sporting regulations that requires the use of natural turfs. This has been discussed in chapter 2.4.4.

### 2.8.2. Risk Management

Risk management is a process of structurally identifying, evaluating, and prioritizing risk and making sure that every factor that can negatively affect a system is put into consideration before putting the system to use. The risk management process identifies and monitors the risk, and finds a systemic approach to minimize the risk.

Risk management also deals with identifying uncertainty and the likelihood of something outside the objectives of the system happening to the system. It also deals with the impact of such uncertainty on the system.

However, while looking at the likelihood of risk happening to the artificial grow lighting system, it is imperative we also take a look at the probability of the system failing.

A failure mode and effects analysis was carried out on the artificial grow lighting system to determine the possibility of the system failure relating to the impact of the system on the environment, thereby creating light pollution, unreasonable energy consumption and its contribution to greenhouse gas emission.

#### Failure Mode and Effects Analysis

- **Failure mode and effect analysis (FMEA):** Can be defined as a comprehensive analysis of the probability or likelihood of failure, this is intended to prevent failures. It is a preventative method of making sure that failure does not occur before setting up a system. FMEA is done to prevent or reduce the likelihood of disastrous failure that can lead to severe injuries or have calamitous effects on the environment.

The FMEA done on the artificial grow lighting system is done to know the failure modes and the effects of the system on the environment and its impact on the health of the general public, wildlife and the impact on energy wastage and carbon emission.



**Artificial Grow Lighting System (AGLS) Failure Modes and Effects Analysis (FMEA)**

FMEA prepared on 22/04/2023

Process or Product Name:	Artificial Grow Lighting System (AGLS)					Prepared by: Moses Sodiq Sobajo	Page <u>1</u> of <u>1</u>									
Responsible:	Research Student (Moses Sodiq Sobajo)					FMEA Date (Orig) <u>22/04/2023</u> (Rev) _____					NOTE: This FMEA is carried out to know the impact of Artificial Grow Lighting System on the Environment (Light Pollution and Energy Wastage in sports stadiums. Recommendations has been made for the management of sports stadiums to take.					
Process Step/Input	Key Process Input	Potential Failure Mode	Potential Failure Effects	How Severe (Severity Rating)	Potential Causes of Failure/s	Frequency of Error (Occurrence Rating)	Current Controls	Current Ability to Detect Error (Detection Rating)	R P N	Actions Recommended	Resp.	Actions Taken	How Severe	Frequency of Error	Current Ability to Detect Error	R P N

<p>Artificial Growth Lighting System (AGLS)</p>	<p>Operating the Artificial Growth Lighting System (AGLS)</p>	<p>Light Pollution to the health of the general population of the people living in the locality, where the AGLS is in operation. The effect on health can be severe conditions like obesity, sleep deprivation and stunted growth in children. And it also affects flora and fauna. it is a known factor in the high mortality rate of wildlife.</p>	<p>Detriments to the health of the general population of the people living in the locality, where the AGLS is in operation. The effect on health can be severe conditions like obesity, sleep deprivation and stunted growth in children. And it also affects flora and fauna. it is a known factor in the high mortality rate of wildlife.</p>	<p>Rating= 9 This is considered to be very severe as it affects the health of the public.</p>	<p>&gt;Lack of covering provided for the AGLS while it is in operation. The light from the AGLS is really bright, if it is operated within an enclosed space, the light can be refracted from the ground (most AGLS light are facing the ground) into the atmosphere, blanketing the nearby area with bright light.</p>	<p>Rating =7 Depending on the scheduled rule of the sport season, the condition of the grass and the purpose of use of the turf by the stadium owner. It can occur every day or couple of days weekly.</p>	<p>As at when preparing there isn't strict control process to prevent or detect the failure.</p>	<p>Rating=2 There isn't enough process to detect the failure.</p>	<p>RP N= Sx Ox D= 12 6</p>	<p>&gt;Enclosed Lighting can be adopted, where the AGLS is operated within an enclosure, so that light particles cannot escape into the atmosphere thereby creating light pollution.  &gt;The AGLS can be operated only during the day so that the light emanating from the AGLS does not disturb the dark sky at night.</p>	<p>&gt;The sports stadium managed. The grounds management in-charge of nurturing the grass.</p>	<p>Research into the AGLS.</p>					<p>0</p>
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		Energy Wastage (Intense Energy Use)/Carbon Emission	>The AGLS is a very energy intensive system, it requires a lot of energy to operate, and because it is being operated for several hours, sometimes up to 12 - 18 hours. It wastes energy needed by other important sectors of the economy. >It contributes to carbon emission and greenhouse gas emission, because the energy used in the operation of the AGLS is usually from nonrenewable sources.	Rating=8 It is considered to be very severe as it is energy intensive and a contributor of carbon emission.	>Lack of monitoring systems to put the amount of energy usage in check. >Not using energy from renewable sources to operate the AGLS.	Rating=5 Depending of the use of the AGLS and some sports stadiums now use LED grow lights which are energy efficient.	Some sports stadiums now adopt the use of LED AGLS, and the energy efficiency of the LED is widely known.	Rating=4 Enough is not done to detect the energy wastage and energy usage because as the time of preparing this FMEA, some big stadiums in the world consumes about 25,000kWh of energy per match. This amount of power is the same as the amount used by 10 house in a 12 months period.	160	>Installing systems that can monitor the energy usage of the AGLS to curb the energy wastage. >Using energy from renewable sources to curb carbon emission. >Using LED lighting technology which are better in energy efficiency than the commonly used High Pressure Sodium(HPS) artificial grow lighting system.	>The sports stadium management is responsible for carrying out the recommendations.	Research into the AGLS.															0
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		Recycling and Disposal Failure at End-of-life	>The lamps used in AGLS contains toxic chemical materials that are harmful to both humans and wildlife. If the system is not properly recycled at end of life and the toxic materials spills into the earth, it can contaminate water and the soil. >The metals used in the system can become scraps at the end of life of the system and become heaps at landfills and illegal dumps, creating public health and safety hazards.	Rating = 7	>Not properly recycling and disposing the materials used in the AGLS will lead to public health and safety hazards.	Rating=3	There are several recycling plants and land dumps being used in the recycling and disposal of materials used in AGLS at end of life.	Rating= 5	105	>instead of mining for metals used in the construction of the AGLS, proper recycling can be done to create new metals from the scrap metals created at the end of life of AGLS. This will not only cut cost of buying or mining for new metals, it will also save the environment from toxic contaminants found in metals and lamps used in AGLS.	>Sports Stadium management	Research into the AGLS.							0
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**Figure 6** Failure Mode and Effect Analysis of Artificial Grow Lighting System. Source: Prepared by the Research Student

Parameters for preparing the FMEA: Each failure modes were identified and all of the consequences relating to the system. The potential effects of failure, its severity, potential causes of the failure, the frequency of the failure occurrence, the current control process, the level of detection of the failure and the risk priority number was determined.

To find out how serious the effects is, the severity rating denoted with S is rated from 1 to 10, 1 is rated as being insignificant and 10 being catastrophic level. The occurrence rating denoted with O, determines the probability of failure occurring and it is rated on a scale of 1 to 10 with 1 being unlikely and 10 being unavoidable. To determine the detection rating denoted with D, it is rated on a scale of 1 to 10, with 1 being that the detection level is highly likely to detect the failure and 10 being not certain of detecting failure.

To determine the Risk priority number  $RPN=S \times O \times D$

Where

S = Severity

O = Occurrence

D = Detection

The failure mode when calculated indicted a critical characteristics of Y and a severity rating of 9 because the artificial grow lighting system poses a health hazard to the people and wildlife close to the proximity of the sport stadiums.

Recommendations for actions to be taken was given and maybe the sports stadiums management will take these actions to put an end to light pollution occurring during the operation of the AGLS.

### *2.8.3. Replenishing Turfs*

Several factors cause turf quality to reduce and eventually die. Environmental factors such as lack of sunlight because of the winter season, shading because of lack sunlight as a result of spectator sitting arrangement and not getting enough air circulation causes the quality of turf to reduce.

AGLS helps to replenish the grass and assist with photosynthesis, which is needed for the grass to achieve a healthy growth.

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## **3. Methodology**

This chapter provides a comprehensive account of the methods used to collect, analyze and discuss the information and data that formed the basis of this study. It also includes important details about the case study stadiums and the nature of the data collected. Furthermore, the limitations associated with the procedures employed in this study are thoroughly addressed.

### **3.1. Research Method**

Research is typically conducted using a specific methodological framework, which is determined by the nature of the study. Quantitative research is used when numerical data are involved and Qualitative research is used for studies that involve non-numerical data. Some studies may use a combination of both Quantitative and Qualitative methods if the nature of the study requires the use of both methods. The choice of the research methodology also influences the outcome and conclusion of the study.

This study is made of qualitative and semi-quantitative data, a comprehensive failure mode and effects analysis (FMEA), together with bibliometric analysis where the study draws some of its data from written scientific books, articles and research publications. Primary data were also gathered by the research study from a visit to Old Trafford stadium in Manchester.

The data utilized in a research study can be generated from two sources namely, primary and secondary. Primary data is a data generated directly by the researcher, while secondary data involves the use of data and information collected by others. Secondary data can be gathered from various sources. This study's approach is based on primary and secondary data.

### **3.2. Research Approach**

For this study the methodology can either be inductive or deductive in nature. Inductive approach involves the close examination of patterns and observations derived from synthesized data, using that to develop a hypothesis or theory on the subject matter (44). While deductive approach is the process of testing a pre-existing theory or hypothesis based on the result acquired from the analysis of synthesized data (45). This study employed the use of inductive approach because of the need of gathering data and information to investigate a known phenomenon and pattern, which in this case is to understand and assess the environmental impacts of artificial grow lighting used to replenish grass pitches in sports stadiums, and further develop explanations in the form of hypotheses based on the observed pattern and phenomenon.

It is important to point out the concept of research strategy, which refers to the approach a researcher adopted during the process of conducting their study. It refers to the preferred method or approach utilized in the research process (44). For example, a research study may involve conducting experiment (experimental research), examining a specific area or case based on existing knowledge of a phenomenon (case study research), conducting interviews with selected participants (interview research), conducting field surveys (survey research), or undertaking a systematic review of existing literature (literature review). In this study, both literature review and case study research approach will be adopted.

### **3.3. Research Philosophy**

The underlying set of beliefs that guides how data relevant to a study are obtained, synthesized, and interpreted is called a research philosophy (2). There are four commonly recognized types of research philosophies.

Pragmatism postulates that gaining a holistic and strategic understanding of an object of interest requires multiple perspectives and approaches, rather than relying solely on a single picture (44). While Positivism involves the measurement and observation of a phenomenon from an objective standpoint in order to develop hypotheses (46).

Realism which is a form of positivism, focuses on the analysis of collected data to generate knowledge (44). Interpretivism, centers on unraveling the complexities of human roles in the social environment (44).

Considering these factors, the inductive approach identified in chapter 3.2 and other methodology stated, this study can be characterized as utilizing an interpretive research approach.

### **3.4. Data Collection**

Initially the method of collecting data was centered on the information provided by the sports stadiums management and collection of the primary data by the researcher through witnessing the artificial grow lighting system in operation. Emails were sent out to the different sports clubs to give insight into their artificial grow lighting use, the sports clubs refuse to respond to the mails.

Following the sports clubs ignoring the mails sent out to them, the research study subsequently adopted a different data collection format. The research study then adopted a descriptive research design, making use of primary data and information collected by the researcher from a visit to Manchester United's Old Trafford stadium, where the researcher witnessed the artificial grow lighting system in operation and observed the results relating to the operation of the artificial grow lighting system and utilizing secondary data collected from existing sources to gain insights into the environmental impacts of artificial grow lighting. This approach allowed for a comprehensive assessment of the topic using available data.

Since information and data directly from the sports club and sports stadium management was not available, the study relied on peer-reviewed scientific literature, technical reports, and relevant regulations and guidelines a primary and secondary sources. A systematic approach was adopted to ensure the reliability and validity of the findings.

Comprehensive data collection was carried out from various sources on light pollution, energy consumption, parameters for growing grass, and relationship between light pollution, human health and keeping wildlife safe.

The information and data were collected using a systemic and rigorous methods described below:

#### *3.4.1. Literature Review*

An in-depth review of existing literatures was conducted to identify relevant studies that provided information and data on the environmental impacts of artificial grow lighting in sports stadiums. Electronic databases, such as Google Scholar, Research Gate, SAGE journals, Science Direct etc. were searched using keywords connected with artificial grow lighting, energy wastage from using artificial grow lighting, artificial grow lighting in sports stadiums, environmental impacts of artificial grow lighting. Relevant peer-reviewed journals were specially selected for extraction of data.

#### *3.4.2. Technical Reports*

Technical reports from relevant bodies and organizations such as Environmental agencies, government agencies, sports governing bodies, lighting technology manufacturers etc. were reviewed to collect data on lighting energy consumption, current technologies available etc. The data collected from these reports provided enormous information on the current practices and available technologies used in sports stadiums for artificial grow lighting, with detailed associated environmental impacts.

#### *3.4.3. Regulations and Guidelines*

Chapter 2.5.3 detailed some of the regulations and guidelines relating to the use of artificial grow lighting system. Environmental laws and guidelines by relevant regulatory bodies relating to the protection of environment and human health safety and regulatory guidelines by sporting agencies were reviewed to provide data on current standard and available recommendations for sports stadium management practices as it relates to light pollution, grass quality, laws and policies as it relates to light pollution etc.

The data from these sources provided a standard criterion for assessing the environmental impacts of artificial grow lighting in sports stadiums.

#### *3.4.4. A Visit to a Football Stadium and Formulating a Failure mode and Effects Analysis*

Data was collected by witnessing the artificial grow lighting system in operation. Observing its operation and the time of the day when it is in operation. A failure mode and effect analysis was prepared, to know the magnitude of catastrophe that is bound to happen if the artificial grow lighting system fails.

#### *3.4.5. Mind map*

Mind map was generated to create a visual understanding of the overall dissertation. This was done for the readers to better grasp the direction the researcher chose, to highlight the environmental impacts of artificial grow lighting in sports stadiums.

### **3.5. Analyzing the Data**

The data collected for this study were analyzed by comparing statistical and analytical methods to draw conclusion and gain insights into the environmental impacts of artificial grow lighting in sports stadiums. The data analysis was performed using the following steps:

#### *3.5.1. Literature Synthesis*

Common themes and patterns relating to the environmental impacts of artificial grow lighting in sports stadiums was drawn from the literature review. These data were synthesized to know the relationship between artificial grow lighting and its environmental impacts. The findings from various studies were compared and contrasted to gain a better understanding of the topic.

#### *3.5.2. Comparative Analysis*

The data collected from various sources, such as data from regulatory guidelines, technical reports and journals, were compared to find out the trends and variations in the use of artificial grow lighting in sports stadiums. Comparison between different artificial grow lighting technologies, energy consumption, and other relevant factors were used to assess the environmental impacts related with different trends and practices.



### *3.5.3. Assessment of Environmental Impacts*

The data were analyzed to assess the environmental impacts of artificial grow lighting in sports stadiums, focusing on light pollution and energy wastage. The findings were compared with relevant environmental standards and guidelines set by various governmental bodies and organizations with the aim of protecting the environment.

### *3.5.4. Recommendations for Sustainable Sports Stadium Management Practices*

Based on the findings from analyzing the data, recommendations were made for sustainable sports stadium management practices, especially grounds management in charge of looking after the turf pitches to prioritize environmental protection, focusing on the impact of artificial grow light on light pollution and energy wastage. The recommendations are discussed in subsequent chapters.

## **3.6. Data Presentation**

For this study, the data collected was presented using different methods to ensure the comprehensibility and clarity of the study. The data was presented using illustrative images and figures and table for the better understanding of the reader/s. The data was presented using the following methods:

### *3.6.1. Illustrative images and figures*

The images and figure were used to visually present the data to show current practices and various states of the playing surfaces without the aid of artificial grow lighting system. The images were adopted to give a clear and visual understanding of the topic. Appropriate labelling was added to the images for better interpretation.

### *3.6.2. Tables*

Table of the guidelines by sport governing body was presented to get the idea, of why sports stadiums introduced artificial grow lighting system to their turf management. A table of the Failure mode and effects analysis was presented to get a better view on the failure probability of the artificial grow lighting system and the effects that comes with it.

### *3.6.3. Descriptive text*

Descriptive texting style was employed to provide a narrative summary of the key findings from analyzing the data. This text gave a concise overview of the results, highlighting the findings as it relates to light pollution, energy wastage, and sustainable sports stadium management practices. It was used to interpret the findings and drawing conclusions, making sure relevant literatures and guidelines were adequately referenced to support the findings.

## **3.7. Limitations of the study**

Several limitations were encountered during the course of this study. The following limitations were encountered:

### *3.7.1. Availability and Quality of Data*

The quality and availability of the secondary data for this study varies, leading to the accuracy and reliability of the findings. Since the data used in this study is collected from various sources, their accuracy and comprehensiveness are dependent on the original data collection methods and reporting standards of those sources.

### *3.7.2. Scope of the Data*

The scope of the available data may have limitation as regards to the variable and parameters that can be assessed. In this study, the main focus is on light pollution and energy wastage of artificial grow lighting in sports stadiums. However, there are other relevant factors that contributes to the environmental impacts of artificial grow lighting in general, such as carbon emission, recycling and other factors which are beyond the scope of the study.

### *3.7.3. Generalizability*

The findings of this study is specific to selected case stadiums and may not be generalized to other sports stadiums or geographical locations. This is because, the environmental impacts of artificial grow lighting can vary depending on several factors such as geographical location, weather conditions, and the size of the sport stadium, as well as difference in lighting technologies and stadium managements.

Therefore, it is imperative to exercise caution when applying the findings of this study to other contexts.

#### *3.7.4. Lack of Control Group*

The study is based on semi-primary and secondary data base. The investigations carried out by the study doesn't involve a control group, this is because when mail was sent out to selected sports clubs, they refuse to respond to the mail. Without a carefully selected control group, it may be challenging to establish a cause-and-effect relationship between the use of artificial grow lighting and its environmental impacts. Other factors such as the design of the stadium, turf management practices and weather condition can also influence the outcomes, making it a serious challenge to isolate the effects of artificial grow lighting alone. Without verifiable data supplied by the stadium management, like stadium design blueprint, the current turf management procedures of the stadium, and other relevant data it is challenging to get the entire environmental impacts of artificial grow light.

#### *3.7.5. Time Constraints*

The investigations of this study is limited by the timeframe of available data. Because of advancements in lighting technologies, changes in turf management practices, and evolving environmental regulations, the environmental impacts of artificial grow lighting may change over time.

The data employed in this study may not fully capture these temporal changes, and the findings may not reflect the current state of the issue.

#### *3.7.6. Inherent Bias*

There may be inherent bias in this study, this may arise from the data used in the investigations of the study. This is because the data sources may have their own bias, such as reporting bias, sampling bias etc. these can affect the reliability and accuracy of the study's findings. Some of the data of this study were extracted from the literature reviews of some environmental and climate change campaigners, and their reporting on the environmental impacts of artificial grow light may be from a standpoint of bias and personal beliefs.

For this study, the researcher's own beliefs and biases were eliminated at every stage of conducting this research.

#### *3.7.7. Ethical Issues*

Since the study draws some of its findings from secondary data, ethical considerations relating to data privacy, confidentiality, and consent may arise. Therefore, this study made use of appropriate referencing and acknowledging ideas picked up from the sources of the secondary data. Every other ethical regulations and guidelines were adhered.

#### *3.7.8. Interpretation of Results*

This study's interpretation of result is based on available data and analytical techniques. Perspective interpretation was also adopted. Different researchers may interpret results differently, so it is important to admit this limitation.

Despite the limitation of interpretation of results, the study seeks to provide valuable insights on the environmental impacts of artificial grow lighting in sports stadiums, focusing on light pollution and energy wastage. The findings of this study can contribute greatly to the existing literature on the topic and awareness on prioritizing environmental protection in sports management practices.

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## **4. Results**

After a careful review of existing literatures on the topic, witnessing the artificial grow lighting system in operation at a sport stadium and creating a failure mode and effects analysis of the system. The findings show that even though the AGLS is very vital in the health and aesthetic look, and usability of the grass turf in any weather condition, its continuous use can cause various degrees of health challenges to the people living close to the sport stadium where the AGLS is in operation.

This is because of the light pollution associated with the use of the AGLS. Sports stadium managements employs different types of AGLS technologies in the cultivation of the grass turf. The technologies include high pressure sodium, LEDs, Carbon Dioxide etc. All of these technologies makes use of lamps that produces several bright spectrums of lights required for keeping the turf green. The brightness from these lamps can be very intense, thereby creating a blanket of bright glowing light covering the locality where the stadium is situated.

This can be noticed in Fig.5 of this study, showing an image of Falmer Village in South Downs, where the light pollution emanating from the Amex stadium in Brighton (because of the AGLS in operation), covers the whole of the village. This light pollution has caused untold hardship for the people of the village. The people are complaining of sleep deprivation and other health challenges.

Artificial grow lights do not only cause sleep deprivation, it also causes several other health challenges like stunted growth in kids, and obesity. The light pollution from the AGLS not only affect humans, wildlife is also not spared from the menace of light pollution from the use of artificial lights in sport stadiums.

The light pollution from AGLS causes disruption to the migration patterns of many animals, it also affects their feeding patterns, and also disrupts the natural balance of the ecosystem.

Nature lovers are also not left out, in the continuous environmental impacts of light pollution caused by artificial grow lighting in sports stadiums. The International Dark Sky Association (IDA), said that the increasing effects of the use of artificial light has made it impossible to enjoy the beautiful view of the starry dark night sky.

A Case study of the Amex stadium in Brighton, shows that the brightness of the stadium is in the region of  $400 \text{ nW/cm}^2$ , this is higher than the light intensity generated by Brighton's city center, and other bright areas in the city (4). The light brightness can be view from space, showing how bright the artificial grow lighting system can get.

To find out the cost implications of running an artificial grow lighting and its energy wastage. A scenario was created to get an idea of how much it will cost to run the AGLS, as there is no available data on the financial cost from the sports clubs. In the scenario, to operate the AGLS in a space of 4ft by 4ft, using 1200W of grow light, running the AGLS for 12 hours, and using the Office of Gas and Electricity Markets (OFGEM) average electricity tariff of £0.34/kWh to calculate the cost.

The formula used is Total kilowatts x kWh x hours per day x 30 days.

$$\text{Total number of kilowatts} = 1200\text{W} (1200 \div 1000) = 1.2$$

$$\text{kWh} = 0.34$$

$$\text{Hours per day} = 12$$

$$\text{Days} = 30$$

Total Amount to run the AGLS in a month will be  $(1.2 \times 0.34 \times 12 \times 30) = \text{£}146.88$ .

This amount is for running the AGLS in a small space of 4ft by 4ft, in a sports stadium the pitch covers a larger area, and in other sports like golf where the playing surface covers acres of lands, it will cost an astronomic amount to keep the grass green. The lamps used in the technology are energy intensive, and running the artificial grow light for long period of time can lead to energy wastage, this is because of several factors ranging from lack of monitoring system to switch off the system after a specific duration of time, to human attitude towards energy wastage.

A failure mode and effects analysis for the AGLS was created in Fig.6. It shows the failure probability of the system, how severe the failure is, the frequency rate of the occurrence, how likely it is for the failure to be detected, the possible causes of the failure. Recommendations were made to prevent the failure of the system and the catastrophic environmental implications the failure will bring.

A look at different laws that guides light pollution and energy wastages, shows that even though there are laws that prevent light pollution, the laws are not strict enough, as some laws are as simple as just telling the premises causing the nuisance to switch the light off. And a meagre sum of £5,000 be paid as fine. The fine is a paltry sum for sports stadiums, which are known for generating millions of pounds in revenue yearly.

And energy wastage law like Energy Saving Opportunity Scheme (ESOS), which requires the commercial companies to submit energy assessments every four years. This law is too lax, because energy wastage can continue everyday by the commercial premises, this energy is needed in other essential part of the economy such as the health care sector.

## 5. Discussion

Sports turf in the past used to be barren surfaces where athletes compete for sport's honour and glory. The introduction of grass turfs to cushion the effects of sliding, falling and other impacts that causes injury to the athletes has made sports not just playable for the athletes, it also brought aesthetic visual appeal to the spectators.

Other reasons why the grass turf was introduced to sport includes, sport's governing bodies regulatory specifications and guidelines directed at sport clubs, financial reasons on the part of the sport stadium owners. Sport stadium owners makes sure to make their playing surfaces greener to gain financial benefits from television "rights". When the sporting activity is televised, the aesthetic appeal of the turf on the fans watching from the comfort of their home makes them pay more to watch the sport.

Because of factors such as shading and harsh weather conditions, has made it impossible for the turf to be green all year round. Shading is caused by the design of the stadium, where the height of the spectator covering or stadium roof covers the grass from receiving enough sunlight that promotes photosynthesis in the grass. The lack of sunlight deprives the grass vital nourishments to survive and the in-turn wither away slowly creating patches of barren lands on the stadium's playing surface.

Bad weather such as continuous snowing and rain, results in lack of sunlight for the grass turf to grow healthily. To circumvent these challenges, artificial grow lighting was introduced to supplement the amount of sunlight the grass receives.

This study found out that, most sports stadiums operates their artificial grow lighting system at night. This action by the sport stadium causes, light pollution because of the reflection of light from the stadium into the atmosphere, disrupting the ecological system of the area and adversely affecting humans living in the area where the stadium is located.

A further research was done to better understand why the stadiums operate their AGLS at night, shows that many energy providers lowers their energy tariffs at night, making energy cheap at night. The sports stadium management utilizes this low tariffs to cut their energy cost, not minding the light pollution that comes with operating the artificial grow light at night.

Although, a visit to Manchester United's stadium shows that not all sport stadium operates their AGLS at night, research shows that a lot of the stadiums operate the system at night.

Even though light pollution is becoming a frequent occurrence in many urban cities, research has shown that sports stadiums now contribute over 20% to the overall light pollution of the city they're situated in late into the night (4).

It is important to note that, the environmental impacts of artificial grow lighting are not limited to light pollution. Energy wastage is also a concern as the lamps used in the AGLS technology is energy intensive.

The intensive use of energy for cultivating grass for sporting purpose, which doesn't contribute to any key area in the survival of humanity, has raised ethical concerns if the environmental and sustainable impacts of artificial grow lighting in sport stadiums is worth it. Funds needed by farmers, medical scientists and the likes are being funneled into the science of sports turf technology. Energy used in running the AGLS, may also be from nonrenewable sources creating concerns for the sustainability of the system, as the system can be a producer of carbon if the energy used in operating it is not from renewable source.

Who stands to gain more by the use of the AGLS in sports stadiums? The stadium owners and management stands to benefit more financially, because not every human enjoys or is involved in sport. A larger part of the population can do without the AGLS in sport and would prefer the technology be put to use in other important sector of the economy like Agriculture. To help with cultivating food crops to put an end to food poverty.

## 6. Recommendations

After a thorough perusal of the topic (environmental impacts of artificial grow lighting to replenish grass in sports stadiums), focusing on light pollution and energy wastage. This study has established the relationship between artificial grow lighting in sports stadiums and its environmental impacts (light pollution and energy wastage), taking a further step by looking at the technology's carbon emission. The following recommendations were generated by the study:

- Presently most stadiums still make use of high-intensity-discharge grow lighting technology in their turf management. Energy efficient grow lighting technology like LEDs should be used, as studies has shown that LEDs are more energy efficient and are known to have a longer lifespan.
- Monitoring systems and timers should be added to the AGLS, so it can monitor the duration and amount of time needed for the AGLS to be in operation so as to prevent energy wastage. Monitoring system that monitors the intensity of light should be added to the AGLS to cut-off or shutdown the AGLS if the intensity of light reaches or surpasses a set amount of intensity.
- Enclosed lighting: The AGLS should only be operated in a confined enclosing, so that light from the system does not reflect into the atmosphere thereby causing light pollution.
- Staffs need to be educated on the need for reducing energy wastage and the effects of light pollution on humans and wildlife. The stadium's ground management staffs operate this machines, the staffs need to be aware of the impacts of the continuous use of the machine even when not needed, as it can cause energy wastage.
- Transparent roofing technology and other alternative spectator sitting arrangements can be employed, during the planning and design stage of the stadium. This will allow the turf get better sunlight and air circulation and cancel out the problem of shading.
- Renewable energy sources like solar can be used to power the AGLS. Solar panels can be fitted into the stadium's design to get enough sunlight during the day, to ensure the sustainability of the AGLS.
- Stringent policies and laws needs to be put in place by the Government and relevant stakeholders, to make sure that sports stadium managements adhere to the environmental impacts artificial grow lighting.

### 6.1. Paths to Follow for Future Research

Although, this study has provided recommendations to reduce and ultimately end the environmental impacts (light pollution and energy wastage) of artificial grow light in sports stadium, further research investigations need to be carried out to better understand the topic.

The following research investigations need to be carried out:

- Further investigations into the financial costs of operating the AGLS is needed, as sports stadium managements are frugal with the financial figures used in operating the AGLS.
- Future research should investigate other environmental impacts of artificial grow light in replenishing grass in sports stadiums. This need to be done as this study is limited to only light pollution and energy wastage.
- Research needs to be done on finding better sustainable and energy efficient technology, as the most energy efficient technology obtainable as at the time of completing this study is the LED. Even though LED is energy efficient and last longer than other traditional AGLS technology, questions about its sustainability abounds. This is because LED technology produces large amount of heat when it is in operation, and it requires cooling which also draws more energy thereby causing energy wastage and burnt LED lamps when not properly disposed or recycled can add to carbon emission.
- Research into the health implications of light pollution and its relationship with artificial grow light in sports stadium need to be established. As at the time of conducting this study, several medical studies have implicated the exposure to light pollution in the prevalent cases of cancer in the society. This assertion needs to be confirmed

### List of Acronyms and Abbreviations

Abbreviation	Definition
LEDs	Light emitting diode/s
AGLS	Artificial Grow Lighting System
HID	High Intensity Discharge

HPS	High Pressure Sodium
PAR	Photosynthetically Active Radiation
PPFD	Photosynthetic Photon Flux Density

## 7. Conclusion

The birth of artificial grows lighting in sport stadiums has brought many benefits to turf management, stadium owners and sports lovers. But, it brings with it several environmental implications. A few of those Implications include light pollution and energy wastage.

This study has shown the effects of light pollution, emanation from the use of artificial grow lighting in growing grass turfs in sport stadium. The effects of the light pollution include health challenges like sleep disorder, obesity and stunted growth (in children) in people living in the locality where the AGLS is operated. Light pollution also affects wildlife, disrupting the natural balance in their ecosystem.

The study also shed light on the energy wastage of the AGLS, as a result of the intense energy demand of the system. Recommendations were made to combat the growing environmental menace of artificial grow lighting in sport stadiums.

Immediate attention needs to be drawn to the environmental impacts of artificial grow light in sports stadium, by relevant stakeholders and governmental bodies if we're going to have a sustainable and carbon free future not only for ourselves, but for future generations.

## Compliance with ethical standards

### *Acknowledgments*

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## Appendices

Email was sent to the following sports clubs to see their artificial grow lighting system in operation and get their data on turf management practices. No response from the clubs as at the time of completing this research.

- Leicester football club (Football)
- Leicester City Tigers (Rugby)
- Derbyshire CCC (Cricket)

ENGT5304 Dissertation log – project development and engagement

Name: Moses SODIQ SOBAJO

P-number: 2701184

Week	Progress/development notes	Supervision engagement
	<p><i>Provide a brief description of the progress you have made (e.g. how you have refined the aim &amp; objectives, how you have identified relevant data sources, which analysis steps you have completed)</i></p> <p><i>How this builds on previous steps or notes?</i></p> <p><i>how you have taken supervisor comments or suggestions into account</i></p>	<p><i>Include date and format of the discussion that took place via e.g. email exchange, online meeting etc.</i></p>
1	The supervisor gave advice on the general outline and structural look of the research. The advice helped me develop the research work. I was able to know the direction to follow in the research study.	23/02/2023 Physical meeting
2	My progress was discussed with the supervisor, and he gave guidance on other aspects of light pollution and energy wastage that research can be done on. The help me link other areas that I hadn't thought of. After creating aims and objectives, the supervisor's guidance helped me create a detailed literature review.	23/03/2023 Physical meeting
3	The supervisor advised I look into the risks associated with the AGLS and relate its effects. A research into this helped me create a Failure modes and Effects Analysis (FMEA), to determine the probabilities of failure of the system, how severe, its frequency of occurrence and recommendations was suggested by me on actions to take. The FMEA was generated and added to the study.	27/04/2023 Email exchange
4	The supervisor suggested, I look into other health challenges associated with light pollution. And other Environmental effects of artificial grow lighting in sports stadiums.	02/05/2023 Email Exchange
5	The supervisor suggested other areas to improve on in the entire study, and advised I go through the entire work and give proper citations and references appropriately.	02/05/2023 Telephone Conversation.
... add rows as needed		