Psychological and Behavioural Science

Tackling Light Pollution

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Table of Contents

Background

Throughout history, mankind's ideas and innovations have helped humanity to take significant leaps forward towards improved quality of life, increased life expectancy, and complex systems of economic and social order (Limburg et al., 2002). However, Homo sapiens' technological advances have also had an unparalleled effect on the ecological balance of the planet, leading to severe negative effects on ecosystems at air, earth and sea levels (Worm & Paine, 2016). One of these consequences is pollution, which can be defined as the introduction of damaging materials into the environment (National Geographic, 2011), and, in this regard, studies, research and interventions around the world have focused on certain forms of pollution including air, water, and noise. However, as urbanisation increases, so has the presence of artificial light (Eisenbeis & Hänel, 2009). Accordingly, the present essay aims to focus on tackling light pollution, an issue which has gained relevance and acknowledgement in environmental discussions but has not yet penetrated the awareness of most of society.

Light pollution is defined as the obstructive use of artificial light and. It has been shown to have serious consequences across various domains including human health, biodiversity and climate change (Gallaway et al., 2009; Lyytimäki et al., 2012).

Firstly, light pollution is harmful to human physical and mental well-being as it contributes to the suppression of melatonin, preventing our biological clock from working normally and affecting the circadian rhythm. The circadian rhythm is a 24-hour day/night cycle which influences physiological processes, including brain wave patterns, hormone production and cell regulation in almost all organisms (Chepesiuk, 2009, Stare, n.d.). Thus, disruption to the circadian rhythm by light pollution has been linked to a variety of mental and physical problems in humans, including depression, insomnia, cardiovascular disease, and cancer: Davis et al. (2001) suggested that women with lower levels of melatonin production due to light pollution had increased risk of breast cancer.

Secondly, with increasing levels of artificial light, biodiversity is put at risk. Mammals, birds, sea turtles, insects and reptiles are dangerously affected by light pollution because their feeding, sleeping, mating,

and migration cycles are constantly disturbed (Bermudez, n.d.). Additionally, Rich and Longcore (2006) concluded that "unless we consider the protection of the night, our best-laid conservation plans will be inadequate". Biodiversity is one of the key elements for human life on earth. Without diversity in nature, the existence of humanity is in danger. We need biodiversity to protect the planet and its already changing climate (Shah, 2014).

Finally, poor lighting design leads to excessive use of light. This contributes to carbon emissions, as well as creating light pollution. For example, wasted artificial light at night is accountable for the release of approximately more than 12 million tons of carbon dioxide into the atmosphere (Bermudez, n.d). Going further, in 2005, the California Energy Commission reported that in the USA, approximately 6% of the 4.054-million-megawatt-hours (MWh) of electricity produced is used for outdoor lighting, of which roughly 30% is excessive or wasted, i.e. light pollution (IDA, n.d.). This is 72.9 million MWh of electricity being generated at a cost of approximately $6.9 billion per year. This is 66 million metric tons of CO_2 (Ristinen & Krausharr, 2006), which is needlessly emitted every year. As an example, eliminating light pollution in the USA would be equivalent to removing over 9.5 million cars from the road (Gallaway et al., 2009) and we, therefore, need to understand how and where it is caused.

Light pollution is created by many different sectors of society as all artificial lighting emitted above the horizontal line is likely to cause light pollution. "Streetlights, advertising signs, skyscrapers, factories and illuminated sporting venues" are the most significant contributors to the problem (Kelley, 2010). However, given this broad range of sources, our ambition in this essay is to dive deep into one of them and focus solely on light pollution produced by advertising and for marketing purposes, specifically in London.

Since the beginning of the 20th century, we have become increasingly used to bright shop windows and neon signs as they shape our night-time image of a big city (Guardian, 2014). Arguably, the lighting and the extended time of day it provides, has made cities even more popular to visitors and provides an enhanced shopping and tourist experience, enabling them to explore urban spaces after dark (Guo et al., 2011). Furthermore, given the fact that humans are naturally drawn to light and become more perceptible to changes in the environment after dark, businesses, shop owners and marketers are

rewarded with increased shopping and brand awareness opportunities (Taylor & Sucov, 1974). In this regard, it is not surprising that studies have found that, especially in cities, decorative lighting and advertisements contribute heavily to light pollution both in residential and commercial areas. Despite there being regulations in several countries such as the Commission Internationale de l'Éclairage (CIE) in France or the International Dark-Sky Association (IDA) in the United States, most of them have largely focused on restrictions towards the street and urban lighting in general. However, artificial light stemming from advertising has hardly seen strict regulations and has therefore been more difficult to enforce in both legal and societal terms. As a result, our main stakeholders including business owners, advertisers, regulators and bystanders such as neighbours or pedestrians continue to be unaware of the issues and therefore do not report the violations even though maximum levels of luminance are generally surpassed (Ngarambe & Kim, 2018).

All in all, if organisations persist in doing business, as usual, governments continue to disregard the rising problem at the public health level, and citizens remain watching from the sidelines, we will continue to be blinded by the light. Our essay aims to provide a way to integrate all actors and eventually offer alternative solutions towards tackling light pollution.

Introduction

First, we present the two theoretical frameworks chosen to analyse light pollution as a problem and develop solutions: Installation Theory (IT) (Lahlou, 2018) and COM-B (Michie et al., 2011). As a group, our understanding and consciousness around light pollution has led us to view the world around us differently and has led us to action by raising complaints to local councils and getting matters solved practically and effectively (see Appendix A). We believe that using appropriate psychological interventions, we can effectively tackle light pollution.

Theoretical Frameworks

Installation Theory

IT is an analytical framework that incorporates individual and social perspectives in its explanation of behaviour. The units of analysis are 'installations': a "specific, local, societal setting, where humans are expected to behave in a predictable way" (Lahlou, 2016). An installation guides behaviour in a specific direction. According to IT, the different determinants of behaviour are: "affordances in the material environment", i.e., physical objects, "embodied competences in the subject", i.e., innate or learned human abilities, and "social regulations", i.e., social norms, which themselves are set and governed. Each determinant works separately and in conjunction with the others to make the individual feel "naturally driven to do what is appropriate" (Lahlou, 2018), and perform the desired behaviour.

IT is a useful tool for analysing how installations are guiding behaviour in everyday life to produce light pollution behaviours because it helps to divide up the installation into its fundamental parts. This allows the analyst to devise appropriate solutions to produce large-scale behaviour change.

The COM-B Model and the Behaviour Change Wheel

COM-B stands for Capability, Opportunity, Motivation, and Behaviour. People must have the capability, opportunity, and motivation to perform a behaviour (Michie et al., 2011). '**Capability'** comprises both psychological capability, which is an individual's knowledge and mental strength and stamina, and physical capability, which is an individual's physical strength and stamina. '**Opportunity'** comprises physical and social opportunity. Physical opportunity requires having the time, location and resources to perform a behaviour, and social opportunities are the cultural norms and social cues in place for the individual. '**Motivation'** refers to the mental processes which guide our decision making. Reflective motivation is the ability to make plans and to evaluate the successes and failures of previous events. Automatic motivation is individuals' desires, impulses, and inhibitions.

The Behaviour Change Wheel (BCW) is a structured approach for designing and evaluating behaviour change interventions with COM-B underpinning the performance of a behaviour (Michie et al., 2011). By synthesising nineteen different frameworks, it uses behaviour change theory to promote a

comprehensive analysis of the available options as well as to ensure that the constituent parts of intervention are acting synergistically. Interventions appear on two levels with **intervention functions** on the first level, (associated with capability, opportunity, and motivation) and **policy categories** on the second (see Figure 1.). Using the BCW facilitates the easy selection of policy-based interventions which exploit the three determinants of behaviour.

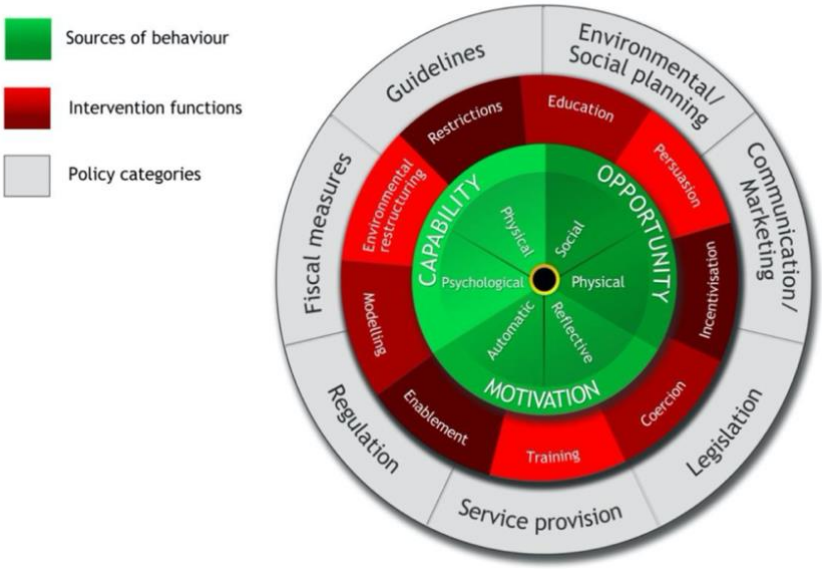

Figure 1. The Behaviour Change Wheel (Michie et al., 2011)

The activities in the BCW process for designing an intervention strategy are a) behavioural target specification b) behavioural diagnosis using COM-B c) select intervention strategy (red) e) select implementation strategy (grey) and finally f) evaluate impact using APEASE criteria (acceptability, practicability, (cost-)effectiveness, affordability, safety, equity). These activities will be applied to all three installations of light pollution outlined below (design, implementation, public evaluation).

Using IT and BCW together

IT's main strength is in the analysis of the current situation concerning the production of light pollution. The theory provides a framework whereby different and interacting influences on behaviour can be analysed to find areas where physical affordances, social regulation, or embodied competences are guiding people into light-polluting behaviours. When areas for improvement have been identified,

COM-B model and the BCW are excellent tools for devising policy interventions which are likely to be effective, because they target the three determinants of behaviour. Since light pollution is not generally recognised as a (pressing) issue by the public, altering installations alone to make humans feel "naturally driven" to do what is appropriate (Lahlou, 2018), may lack the potential to address this lack of consideration.

Problem Analysis

The 3 Stages of light pollution

The occurrence of light pollution can be divided into different stages involving diverse stakeholders. Most studies have examined behavioural installations of energy consumption, focusing mainly on household or office energy consumption (Staddon et al., 2016). There is limited research on light trespass or the installation in which it occurs. However, according to Karol and colleagues (2010), "business advertising is one of the biggest causes of excessive lighting". Spotlights, and advertisement signs are often intensely lit and angled improperly or inefficiently, causing light pollution (Karol et al., 2010).

We will approach light pollution through three installations, in which we have identified a gap for intervention: Design, Implementation and Public Evaluation. We will analyse each stage using IT, considering the relevant stakeholders and their central activities. The 'Design' stage describes the process of planning and designing advertisements, both in shop windows and billboards. This installation occurs in the Marketing Department/Office, with the business being the main stakeholder. The 'Implementation' stage comprises regulation of light and light pollution in advertising. The government is the main stakeholder. Finally, the 'Public Evaluation' stage is peoples experiences of light pollution and the call for awareness in the community. The context of the installation is neighbourhoods and local communities, and the main stakeholders are bystanders, such as residents and pedestrians.

Stage	Relevant Stakeholder	Central Activity	Installation
Design	Business	Plan and design the advertisement.	Marketing Department
Implementation	Government	Regulate light trespass and pollution.	Local authorities/Shop windows/ Billboards
Public Evaluation	Bystanders	Regulate and raise awareness through community groups.	Local Environment/Community/ Shop windows/Billboards

Table 1. The Stages of Light Pollution

Stage 1: Design

We recognize that there are several installations in which the design and planning stage of advertising takes place. The space in which the Marketing Department operates will be the main installation we analyse at this stage of light pollution. Advertising design takes into account different factors such as costs, affordances and current trends.

Lighting has three purposes in advertising: attracting customers, facilitating the evaluation of merchandise, and creating awareness and ambience, as well as facilitating the completion of the sale (Park & Farr, 2007). Lighting serves as a valuable tool for most marketers, enabling them to draw attention to their brand and products while creating a welcoming and positive environment for their customers using 'emotional design' (Quartier et al., 2009).

1.1 Embodied competences

Light pollution has only recently been given noticeable attention and is still considered an unfamiliar issue, compared to other forms of pollution (Hölker et al., 2010). Overuse of lighting for advertising purposes is because people are naturally drawn to light (Taylor & Sucov, 1974) and it can have a significant impact on our subconscious and purchasing behaviour (Horská & Berčík, 2014). This means that using light in advertising can be very valuable. However, even when the shops are closed, shop windows, marketing billboards and signs stay lit up, causing inefficient use of light and result in light pollution. This is due to people being unaware of the unwanted consequences and the wish to maximise

the utility of their displays. Currently, there are also no existing regulations globally, that ensure that design processes are executed with potential light pollution in mind (ASA, 2020).

Furthermore, especially after dark, when shops are closed, lighting serves little to no purpose for business performance and is often only kept on due to inertia. The design process and the individuals responsible for the planning process are likely to be under the influence of the present bias, focusing on gains that are made in the present and disregarding and underestimating however the negative externalities for the future and implementation (O'Donoghue & Rabin, 1999).

1.2 Physical Affordances

For decades marketers have used bright lights to gain customers' attention and to drive sales. The infrastructure of campaign/advertising design is therefore often very standardised and is rarely revised. Subsequently, most marketing agencies and businesses have billboard spaces and properties with standardised lighting which they do not have the power to control. There is also a factor of competition between businesses for advertising, who are competing for the attention of the customers through the brightest lights and biggest signs. Businesses have limited capabilities to measure the effectiveness of using shop lighting in relation to sales, compared to the ease of measuring the performance of online advertisements.

1.3 Social Regulation

Social norms are important factors in the design and planning process of advertising. It is a social norm to have cities brightly lit and therefore businesses follow suit using billboards and shop windows (Bramley, 2014). Being part of a retail environment creates competition for customers between different businesses. This incentivises businesses to remain open later into the night, and to use excessive lighting to attract more customers. Research suggests that we naturally associate light with something positive and welcoming (Fleischer et al., 2001), feelings that marketers use to sell and attract customers. Seasonal lighting around Christmas is equally used to create an atmosphere and to re-enchant the night.

Stage 2: Implementation

During implementation, relevant stakeholders are either local or national government. They oversee that businesses comply with guidelines regarding the use of artificial light. Consequently, the main installations where these activities take place are government offices and their respective local or national websites. Although there certainly is limited awareness around the impact of light pollution within governmental institutions, examples around the world will show us progress in this respect.

2.1 Embodied competences

Regulation depends upon the knowledge of policymakers. The UK government stipulates core competencies for effective regulation (UK Gov., 2016) however these are insufficient when applied to light pollution. Firstly, as the obstructive use of artificial light is a novel issue, general knowledge and experience around the problem is lacking and therefore leads regulators to operate under an availability heuristic (Tversky & Kahneman, 1974). In other words, when presented with several pressing matters regarding pollution, regulators would tend to address those they are more familiar with such as noise or air pollution, as opposed to light. Secondly, officials must be able to understand who they are regulating and communicate appropriately with the businesses and their owners. Businesses seldom know of the faults they are committing through their advertising practices. Perspective-taking (Farr, 1997), framing and simplifying information (Tversky & Kahneman, 1981) is imperative in engaging with businesses in an informative, yet constructive manner. The embodied competence of critical evaluation becomes increasingly difficult when not supported by the necessary physical affordances (Lahlou, 2018), which we will discuss in the following section.

2.2 Physical affordances

Once an advertisement has been implemented, the material components that contribute to the regulation of light usually come in the form of technologies that measure, monitor, and evaluate it. Currently, mapping technology provides information at the district level for varying degrees of light pollution, stating, for example, that 19 out of the 20 brightest areas are London boroughs (CPRE, 2015). Nonetheless, we do not have technology to measure and monitor light in specific areas at the street

level, similarly to the monitoring of air pollution such as the London Air Quality Network (LAQN, 2020).

Apart from tracking tools, other action-oriented material layers (Lahlou, 2018) at this stage are local and national government websites. Presently, most local council websites do not have a complaint directory related to light nuisance and therefore most complaints would have to go under the "Other" option, creating friction between people wanting to report light pollution, and their being able to report the problem (Thaler, 2018). This friction will reduce the reporting of light pollution.

2.3 Social Regulation

Government regulation provides legal guidelines for light pollution levels in London. There are guidelines and permission controls for new lighting installations and monitoring under the Clean Neighbourhoods and Environment Act 2005 (UK Government, 2021). London can take inspiration from countries who have previously implemented novel light pollution measures as pioneering examples.

Singapore has the world's most light-polluted skies, followed by Kuwait, Qatar, and the United Arab Emirates – all densely populated countries (Robert, 2016). Some of the highly affected countries in the world have already implemented measurements to tackle light pollution. In recent years, Singapore and Hong Kong's government have been working on policies for businesses and governmental projects, like Environmental Zones to control light pollution (Ling, 2010; Robert, 2016).

Despite these efforts, light pollution has continued to increase. We target the UK government to regulate and control light pollution as it has been done with air pollution (LAQN, 2020).

Stage 3: Public Evaluation

The setting of the public evaluation installation is local neighbourhoods and communities. The main stakeholders are bystanders such as neighbours and pedestrians, who are most affected and hold partial responsibility in the reporting and reduction of light pollution.

In addition, environmental activists are playing a crucial role in public opinion management and influence when it comes to sustainability problems and public response. Charities and social activists

can form interventions in current behaviour. In terms of light pollution, the public, once aware of the issue, could function as a form of pressure on government and businesses to take the problem more seriously and implement solutions. Social movements are proven to be an effective tool to accomplish social change and governmental action. Social movements are collectives with a common goal, which they try to reach by the mobilisation of citizens (Braccini et al., 2019).

3.1 Embodied competences

The embodied competence regarding the installation of public evaluation consists of two parts: First, people perceive light as something safe and positive and are not aware to what extent it's efficient and when it gets 'too much' or harmful (Banerjee et al., 2012; van Rijswijk & Haans, 2018). However, people are sensitive to blue light emitted by digital screens. Blue light is proven to be harmful to your sleep pattern, hormones, and your eyesight (Harvard Health, 2020). In recent years people have started to protect their eyes from the danger of blue light screens by using blue light filters in glasses (Oehler, 2021). As individuals are increasingly becoming aware of the dangers of certain types of light to their health, this perception could be translated into the context of light pollution.

Second, most people in London are not aware of the danger of light pollution. Even though light pollution is an emerging environmental problem, it is not very well-acknowledged in society. Deliberate ignorance of the issue is the reason for the lack of attention this topic has received (Lyytimäki et al., 2012). The availability heuristic is immensely powerful in this regard (Tversky & Kahneman, 1974). Conclusively, the necessary awareness is a missing embodied competence.

3.2 Physical affordances

Presently, 90% of the UK population owns a smartphone (Deloitte, 2019) and so mobile applications are a convenient tool to raise awareness and monitor issues such as real-time air quality levels (Air Quality News, 2019). Other technologies have taken even further steps by integrating gamification and social media techniques into their apps, encouraging users to participate, share and collaborate to tackle significant problems like noise pollution (Martí et al., 2012). With regards to light pollution, progress has been made through interactive maps that show how light pollution affects different geographical

areas across the UK (CPRE, 2015). However, there still is ample space for future technology-based developments, whose aim could be to measure the type and amount of light emanating from a specific advertisement and classify it accordingly. Furthermore, digital technology such as social media platforms help overcome geographic barriers, enabling people to come together to form social movements more efficiently (Braccini et al., 2019), and pressure decision-makers (Earl et al., 2014) towards structural changes. Consequently, when developing modern technologies towards tackling light pollution, the social regulation layer must also be considered.

3.3 Social Regulation

Societal expectations around the use of light, especially in advertising, have not yet gained the necessary relevance since social regulation is still practically non-existent (Lyytimäkip et al., 2012). In this respect, social sanctions and reminders could be useful tools to change the social norms around light in advertising (Lahlou, 2018). A trending norm could be the negative framing of light pollution as studies show individuals are more likely to adhere to them (Mortensen et al., 2019).

London is home to many environmental organisations and activist groups (Meetup, 2021) and a substantial number of people participate in them (Vidal, 2013). Light pollution could conveniently be added to the list of environmental problems these groups tackle as they naturally share the same interest: protecting nature and animals as well as fighting global warming.

Solutions: Behaviour Change Wheel

Having looked at the motives and goals of each installation as well as the potential activities/areas that can be altered in favour of reducing light pollution, the following sections will lay out our potential solutions. Using the Behaviour Change Wheel, we will first outline the desired **behavioural outcomes** and **determinants** within each installation followed by relevant **interventions** and evaluation.

Describing the Behaviour Change Wheel

1. Intervention: Design

As well as being the main stakeholders of this stage, businesses and their marketing departments are also in possession of the most executive power. Therefore, the suggested interventions will be focusing on targeting employees specifically in marketing. Table 2. summarises the behavioural target and diagnosis in the design stage of light pollution.

1.1 Behavioural target & Diagnosis

The desired behavioural outcome is to have light pollution taken into account when designing advertisements for shop windows and billboards. This would mean not only thinking about light in terms of energy- and cost-efficiency, but also in terms of the environmental impact of light pollution and how light could be used more sparingly while maintaining the quality of the advertising.

Having previously outlined the way installations drive light polluting behaviours in Problem Analysis, Table 2. presents this analysis in terms of behavioural determinants using Capability, Opportunity and Motivation.

Behavioural target					
Prioritize designing with appropriate, energy efficient lights, environmental impact, light thresholds and regulations in mind, use lights smarter not more.					
Behavioural diagnosis					
Capability		Opportunity		Motivation	
Physical	Psychological	Physical	Psychological	Reflective	Automatic
Not targeting non-visual senses in advertising enough	Lack of understanding of the impact of different types of lights used	Rented billboards use lights in a standardised way	Lack of light-usage feedback on sales	Lack of business responsibility taken for light pollution	Wanting to stand out among competitors with brightness

Table 2. Summary of behavioural targets and diagnosis for the design stage

1.2 Intervention functions & Policy categories

Following the BCW, the intervention functions education, enablement, modelling, and environmental restructure and restriction could be used to tackle light pollution stemming from the advertisement design process. **Education** is knowledge transformation. This is different from training, which is skill acquisition. Helping employees becoming aware of light pollution, its causes, and its effects on the environment may help to decrease their use of excessive lighting. **Enablement** is the provision of tools and skills to allow advertising designers to reduce their reliance on light in their advertising, and therefore to reduce their production of light pollution. For example, providing precise information on the luminous efficiency and skyglow impact of different types of lights (such as in Figure 2.), can help designers to incorporate responsible light usage into their work. **Modelling** is the provision of an example from which efficiency or creativity in light usage could be emulated. An example of this is the billboard presented in Figure 3. It uses the lack of light to its advantage, creating a memorable and effective advertisement. Presenting examples such as this could encourage designers to think outside of the box and achieve more by using less light. The physical and social context can be changed using **environmental restructuring**. The enablers discussed above (luminance measures, dimmers, smart lights) could help monitor and reduce light trespassing after businesses close. Marketing departments could decide to work with different business partners to rent or purchase advertising billboards, so that they could have more control over the amount and way light is used. This would also allow for businesses to test the efficiency of their displays. Finally, **restrictions** by the businesses can prevent the marketing department from using certain lighting design.

Type of light source	Colour	Luminous efficiency (in lumens per watt)	Sky glow impact (relative to LPS)
LED streetlight (white)	Warm-white to cool-white	120	4-8
Low pressure Sodium (LPS/SOX)	Yellow/amber	110	1.0
High pressure Sodium (HPS/SON)	Pink/amber-white	90	2.4
Metal Halide	Warm-white to cool-white	70	4-8
Incandescent	Yellow/white	8-25	1.1
PCA-LED	Amber		2.4

Figure 2. Example of the information table that could be provided within enablement. Extracted from Wikipedia based on the research done by Aubé et al. (2013) and Luginbuhl (2014).

Figure 3. Example of modelling, effective and creative advertising style from South African electricity company, Eskom

Environmental/social planning, guidelines, and legislation are policy categories from the BCW which will be useful to create behavioural change in the design process. Environmental/social planning ensures that the design of stores and billboards are specifically targeted by interventions to reduce the overuse of light. Using **guidelines**, good light practices can be mandated with the expectation of punishment/cost by **legislation**.

1.3 Evaluation

Using the APEASE criteria (Mitchie et al., 2011), we have evaluated each suggested intervention function to determine its practicality. APEASE stands for acceptability, practicability, effectiveness, affordability, safety, and equity. **Acceptability** refers to the extent to which relevant stakeholders judge the presented intervention to be appropriate. This can be different for different stakeholders. **Practicability** is the extent to which the design can be delivered to the target population. This increases if highly trained staff or extensive resources are available. **(Cost-)effectiveness** refers to the effect size of the intervention in context as well as the appropriateness of choosing a more economical solution

over a less economical one. An intervention is considered **affordable** if it can be delivered within an acceptable budget. **Safety** refers to the understanding of the possible side-effects that may occur and that should be considered before proceeding. Finally, **equity** is defined as the extent to which the suggested intervention can increase or decrease general wellbeing and living standards across society.

	Acceptability	Practicability	(Cost)-effectiveness	Affordability	Safety	Equity
Education	✓	✓	✓	✓	✓	✓
Enablement	✓	✓	✓	✓	✓	✓
Modelling	✓	✓	✓	✓	✓	✓
Environmental Restructuring	✓	✗	✓	✗	✓	✓
Restrictions	✗	✓	✓	✓	✓	✓

Table 3. Evaluating the interventions suggested for Design Stage using APEASE criteria.

As Table 3. shows, **environmental restructuring** and **restrictions** were evaluated as the least practical for businesses in this stage. Environmental restructuring in the form of installing monitoring technologies and changing business partners has the most potential for large-scale change but will also be more difficult to implement due to budget and pre-existing business relationships.

2. Intervention: Implementation

In the implementation stage, our main stakeholder and executive force is the government. This section will outline possible interventions focusing on government offices. Table 3. summarises the target for behavioural intervention and solutions to light pollution in this stage.

2.1 Behavioural target & diagnosis

The desired behavioural outcome is for government offices and relevant employees to treat and regulate the problem of light pollution with the same degree of urgency as with noise or air pollution. Table 4. presents the problem analysis in terms of behavioural determinants. Nevertheless, as the stakeholders

in this stage recognise light pollution as a problem to some degree, this diagnosis highlights possible behavioural improvements rather than pointing out shortcomings.

Behavioural target					
Regulate light and light pollution similarly to noise or air pollution, ensure businesses' compliance with light pollution guidelines.					
Behavioural diagnosis					
Capability		Opportunity		Motivation	
Physical	Psychological	Physical	Psychological	Reflective	Automatic
Already existing management and inspection of streetlights	Imposing feedback loop for compliance via regulations	Enable technology to measure, monitor & report non-compliance	Intent to have an objective evaluation of light and its impacts	Initiate effective communication and relationship with businesses	Weaken the availability heuristics that is in favour of noise- and air pollutions

Table 4. Summary of behavioural targets and diagnosis for the implementation stage

2.2 Intervention functions and Policy Categories

Pre-existing guidelines facilitate government intervention in the regulation of business' light use. **Enablement** and **training** could be suitable interventions at this stage. Technologies which allow for the measuring and monitoring as well as the reporting of non-compliance during routine inspections would aid government officials' objective evaluations. Similarly, by setting up a proper complaint directory on the government website, citizens and businesses alike would be partners in detecting and reporting light usage malpractice. Using **modelling** to present countries that are successfully implementing light pollution restrictions (e.g. light temperature and curfew) could help remove government officials' availability heuristics and make the problem of light pollution a higher priority for them as well as give them ideas of strategies they might adapt to suit London. Presenting hugely popular cities such as Hong Kong, France and Singapore as pioneering example would help officials overcome their preconceptions of tourists' preferences for cities with many lights, and the lights driving tourism numbers. **Incentivisation**, the process of creating an expectation of reward is employed in Hong Kong to award light licences to businesses complying with luminance thresholds. This could be used

both on behavioural level rewarding successful employees as well as installation level rewarding businesses.

Along with the already existing guidelines, **regulations** and **fiscal measures** could also be introduced. For example, the employment of a tax system or other financial methods could help to tackle light-polluting behaviour by increasing or reducing financial cost. This would discourage non-compliance to the guidelines. Departments across the Civil Service may be involved since the reinforcement of these changes require clear **communication** on the part of the government. Here, the government's communication strategy could set an example for smart and effective light usage.

2.3. Evaluation

	Acceptability	Practicability	(Cost)-Effectiveness	Affordability	Safety	Equity
Enablement	✓	✓	✓	✓	✓	✓
Training	✓	✓	✓	✓	✓	✓
Modelling	✓	✗	✓	✓	✓	✓
Incentivisation	✓	✓	✗	✗	✓	✓

Table 5. Evaluating the interventions suggested for the Implementation Stage using APEASE criteria.

The evaluation suggests that at this stage the use of **modelling** and **incentivisation** is less appropriate than other interventions. Modelling a strategy from other countries may help in the creation of alternative methods for imposing regulation, however, due to the differences in government, there may be many unforeseen obstacles present in delivering these to the public. Using incentivisation, governments may risk increasing both budget as well as individual's intent to care for the matter, as once the promise of reward is taken away, the desired behaviour may not continue.

3. Intervention: Public Evaluation

In this final stage of light pollution, the stakeholders are those experiencing the negative externalities of light trespass: the general public. The following paragraphs will detail interventions specifically

targeted at bystanders in the local community. Notably, these interventions are not targeting individuals' light usage and contribution to light pollution but aim to create awareness and a feedback loop within the community, so that the design of advertising, government regulation, and public pressure will work together to reduce light-polluting behaviour. Table 4. Summarises the behavioural targets and diagnosis for this stage.

3.1 Behavioural target & diagnosis

The desired behavioural outcome is to have the general public express and voice concern over issues regarding light pollution thereby pressuring businesses and governments to reduce light pollution. Table 6. presents possible behavioural improvements based on the problem analysis for Public Evaluation.

Behavioural target					
General public expressing concern and frustration over light pollution caused by advertising (and streetlights), increasing social pressure on businesses.					
Behavioural diagnosis:					
Capability		Opportunity		Motivation	
Physical	Psychological	Physical	Psychological	Reflective	Automatic
Lack of monitoring and feedback technology	Recognizing the current use of harmful lights	Pressuring businesses and government through activism and boycott	Giving public/collective opinion a platform by mobilizing social network	Light pollution is not yet regarded as a sustainability issue	Wanting to stay unaffected by light pollution, build on frequency illusion bias

Table 6. Summary of behavioural targets and diagnosis for public evaluation stage

3.2 Intervention functions & Policy Categories

Business practices which can be seen by the public are dictated by public evaluation: if the public do not approve of a business, their sales may drop. Having an audience who are conscious of light pollution will pressure business leaders into reducing light pollution behaviours. Understandably, **education** as an intervention is a crucial part of this process. Education could help people to recognise harmful light usage and understand potential long-term impacts. This could give rise to the frequency illusion bias (Tversky & Kahneman, 1974), a form of selection bias which describes the tendency to notice something more often after having noticed it for the first time, enlarging its frequency. For example,

harmful lights (e.g. blue light) are increasingly being recognised as a problem with night modes and blue-light filtering glasses gaining popularity (Oehler, 2021). Thus, the frequency illusion bias, enacted by education, can therefore act as a form of **persuasion,** changing behaviour by inducing positive or negative emotions. This bias can be used to the advantage of reducing light pollution, using social networks for spreading information as well as encouraging digital activism. Similarly, **coercion** can also be used as a general intervention on the public. Coercion creates the expectation of something bad occurring if a certain behaviour is not happening. Framing light pollution as a sustainability issue can increase the efficacy of coercion as other polluting activities are already regarded as having a negative impact in the future. Associating light pollution with something as urgent as the climate crisis can result in the general public pressuring businesses and governments into taking action.

In terms of policy categories, **communication/marketing,** which are ironically responsible for the light pollution problems raised in this paper can be used to reinforce behaviour changes. **Service provision** can also aid in empowering the public with the tools to recognise and monitor luminance thresholds allowing them to raise concerns grounded in observations.

3.3 Evaluation

	Acceptability	Practicability	(Cost)-Effectiveness	Affordability	Safety	Equity
Education	✓	✓	✓	✓	✓	✓
Persuasion	✓	✓	✓	✓	✓	✓
Coercion	✓	✗	✓	✓	✗	✓

Table 7. Evaluating the interventions suggested for Public Evaluation Stage using APEASE criteria.

In this stage, **coercion** may be less practical than the other types of interventions simply because creating the expectation of the occurrence of negative events does not automatically pressure individuals into action, and is certainly not easy to achieve without a central strategy.

Discussion and Limitations

Throughout this essay, we have provided a theory-based approach towards analysing and solving light pollution in London. We divided the process of light pollution into the three distinct stages of design, implementation and public evaluation. Through the lens of IT, we identified how each layer of the corresponding installation shaped the behaviour of our main stakeholders according to their central activity and were able to detect gaps of opportunity. Moreover, we complemented IT with COM-B and the BCW to deepen our comprehension of the problem and develop behavioural targets which are: awareness and education, environmental restructuring in terms of technological tools which for example enable the monitoring of luminance, as well as problem recognition. Effective prevention of light pollution requires the simultaneous engagement of all three layers and stakeholders, complementing and building upon their efforts.

Finally, we are aware that our proposals are not sufficient to tackle light pollution as a whole and certain limitations must be laid out. Firstly, our work is focused on interventions that could potentially be applied in London. However, cultural differences and foreign regulations should be considered as they may not be fully replicable in other countries. Secondly, there is a clear lack of experimental and behavioural studies of light pollution around the world and, although general awareness is increasing, we are still at a very early stage and our interventions respond to that reality. Thirdly, we recognise that we have proposed interventions that include costly technologies but have not considered the cost impact on individual businesses. Lastly, our main limitation may be the fact that the innate human affinity for light will be difficult to overcome, and further research will be crucial to understanding how we can change the human relationship to light, and how we can start to embrace the positive aspects of darkness.

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Appendices

A. Complaint to Islington Council resulted in the instalment of a shield, preventing the light from trespassing into the household unnecessarily.