

Article

Energy Efficiency in Public Lighting Systems Friendly to the Environment and Protected Areas

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Abstract: Solid-state lighting technology, such as LED devices, is critical to improving energy efficiency in street lighting systems. In Ecuador, government policies have established the obligation to exclusively use LED systems starting in 2023, except in special projects. Ecuador, known for its vast biodiversity, protects its national parks, which are rich in flora, fauna and natural resources, through international institutions and agreements such as UNESCO, CBD and CITES. Although reducing electrical consumption usually measures energy efficiency, this article goes further. It considers aspects such as the correlated color temperature in the lighting design of protected areas, light pollution and the decrease in energy quality due to harmonic distortion. Measurements of the electromagnetic spectrum of the light sources were made in an area in the Galápagos National Park of Ecuador, revealing highly correlated color temperatures that can affect ecosystem cycles. In addition, the investigation detected levels of light pollution increasing the night sky brightness and a notable presence of harmonic distortion in the electrical grid. Using simulations to predict the behavior of these variables offers an efficient option to help preserve protected environments and the quality of energy supply while promoting energy savings.

Keywords: energy efficiency; lighting design; light pollution; LED; environment



Citation: Velásquez, C.; Espín, F.; Castro, M.Á.; Rodríguez, F. Energy Efficiency in Public Lighting Systems Friendly to the Environment and Protected Areas. *Sustainability* **2024**, *16*, 5113. <https://doi.org/10.3390/su16125113>

Academic Editor: Vincenzo Costanzo

Received: 9 May 2024

Revised: 7 June 2024

Accepted: 13 June 2024

Published: 16 June 2024



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1. Introduction

The implementation of artificial lighting has allowed humans to carry out greater activities at night, increasing their productivity. However, it also produces consequences that are often not considered during the construction of lighting systems, such as critical effects on protected areas or sensitive ecosystems.

Some factors to consider in implementing a lighting system within protected areas are the light source technology, light pollution [1], power quality and color temperature with its associated spectral emission [2]. This work reviews these factors, emphasizing the efficient use of energy, which is particularly important in a protected area because of the resources used for its electrical generation.

The concept of energy efficiency in outdoor lighting systems has become increasingly significant in recent years due to users' growing demands [3] and governments' necessity to allocate energy resources appropriately [4]. The commitment to environmental stewardship, greenhouse gas reduction, waste minimization and proper disposal has led to an evolution in the lighting system components [5].

Numerous studies have been undertaken to examine the efficiency of lighting systems from diverse perspectives, including emerging solid-state lighting technologies [6], public lighting [7], and management policies [8]. It impacts aspects of power quality criteria, methodologies for replacing HPS technology with LED [9] and energy savings due to its change [6]. Solid-state lighting (SSL) represents an important alternative for the search

for alternative lighting sources for applications in illumination [10], energy efficiency [11] and the performance of light-emitting diodes (LED) [12]. LED technology is presented as an alternative for all types of lighting, covering ultra-low power levels [13] and even presenting itself as an efficient alternative in greenhouse lighting [14] and a better investment in road lighting [15]. Various studies have investigated the technical efficiency of this type of technology, discussing parameters in the phosphor of chip LED such as color temperature [16], efficiency for lighting design considering the stability of luminous flux and installation parameters [17]. The efficiency of this technology includes the LED driver [18], and all the elements of this technology influence the system's efficiency. These parameters influence the color appearance of the light source, and studies show that this, in turn, influences the execution of visual tasks [19]. The improved efficiency of LEDs has led to the wide adoption of this technology in the commercial and residential sectors [20]. Their widespread installation has significantly reduced energy consumption compared to traditional lighting sources, with 32% less nominal installed power compared to Metal Halide [9].

Recent research explores successful SSL implementation in outdoor lighting systems [21]. LED technology shows positive results [20], not only from the point of view of energy efficiency but also in terms of the improvement in the quality of illumination [4], which can be shown in parameters such as the uniformity of the illuminated surfaces [22].

Materials science and research into improving the construction of SSL chips have shown new insights into the efficiency of light sources [23]. Advanced semiconductors [24], light propagation structures and material robustness [25] for lifetime extension have been development goals that still have a way to go. Here, challenges appear to be solved, such as the thermal management of a luminaire [26], which directly influences its properties, the stability of its color properties over time [27] and the reduction in costs [28].

In lighting systems, it is essential to analyze the spectral emission of the source and its correlated color temperature [29]. Correlated color temperature (CCT) in lighting is a parameter related to visual perception and comfort [30] and the energy efficiency of lighting systems. The CCT determines the chromatic appearance of the light emitted by a lighting source [31]. Additionally, the Color Rendering Index (CRI) and the performance of different colors from the users' perspective are also influenced by the CCT [32].

LED lamps and luminaires have garnered significant user acceptance due to their versatility in offering sources with different CCTs [33] and a relatively high CRI compared to other lighting technologies [34]. This not only underscores the superiority of LED lamps over traditional sources in terms of their efficiency at different CCTs but also emphasizes the crucial role of the audience in the design process. By understanding the audience's needs and preferences, the design process becomes more user-centric, enhancing the overall experience and making the audience feel empowered and involved. Visual and psychological comforts are also crucial aspects [35], so system design is not limited to CCT and an energy analysis [36]. The study of Trop et al. [37] delves into the intricate relationship between visual comfort, CCT and an integrated system design from the planning stage and simulations to the implementation of the required systems. The perception of the space, productivity and well-being of system users has also been a critical focus [38], highlighting the need for a holistic approach to implementing light systems.

The relationship between CCT and work productivity is also an area of research that demonstrates the importance of CCT as a lighting source. The study developed by Cheng et al. [39] shows how different color temperatures influence the mood or work performance of workers and their satisfaction with the workplace. All these characteristics of LEDs lead to a massive migration towards this technology and its installation in practically all spaces to be illuminated, often without considering the impacts it causes on flora and fauna.

Furthermore, light pollution is an increasing problem in lighting systems and the conservation of protected areas. The pollution of the night skies can be defined as the amount of artificial lighting directed towards the sky and dispersed in the atmosphere, interfering with the natural vision of the night sky [1]. Light pollution concerns the parameters of

lighting designs [40]. Urbanization and the increase in light points have had an impact on light pollution and the opacity of the skies from an astronomical perspective [41] but also from human health [2] and environmental care perspectives [40].

The study developed by Barentine et al. [41] has provided quantitative measurements of light pollution in different sectors of the planet and its correlation with the visibility of bodies in the sky. The quality of the night sky has direct applications for observational astronomy. Even with telescopes, the visibility of stars and other celestial bodies is significantly affected. Areas such as Hawaii or La Serena [42] have restrictive measures since they are places where astronomical research is carried out.

In some cases, lighting fixtures are installed improperly, resulting in high levels of reflected light that can harm human life and contribute to light pollution. When the reflected light levels go beyond a specific range, they can disrupt the body's natural circadian rhythm, leading to sleep disorders, mental health issues and hormonal imbalances [35].

The quantification and characterization of the quality of the night sky can be carried out through several methodologies [43]. The study developed by Ges et al. [44] proposes night sky quality indices based on spectral measurements, and the study developed by Kolláth et al. [45] does so through radiance measurements. However, they all allow for generating concepts and precise tools for evaluating light pollution. The International Commission on Illumination (CIE) has also generated guidelines for minimizing sky glow [46].

Technological progress alone does not necessarily lead to decreased consumption in a particular city or country. Effective state policies and government regulations are essential in enforcing certain technologies while prohibiting the usage of outdated ones [8]. The research conducted by Pothukuchi [47] indicates that implementing specific regulations to encourage the adoption of efficient technologies can lead to significant savings for citizens and promote the shift towards sustainable lighting systems. The economic viability of investing in new technologies has resulted in pollution reduction and significant long-term savings for various case studies, making it an essential consideration for control bodies' decision-making [48].

Regulatory bodies are responsible for identifying lighting requirements depending on the areas intended to be illuminated. Regulations play a crucial role in ensuring the preservation of areas home to diverse and important plant and animal species. Various articles have presented metrics on the effectiveness of management measures aimed at reducing light intensities [49], limiting correlated color temperature [50] and implementing shutdown schedules to preserve ecosystems [2].

The CIE has also generated standards for quantifying CCT based on its electromagnetic spectrum, the color rendering index and its different methodologies to establish the energy efficiency of a given lighting source [51]. The Illuminating Engineering Society (IES) has also developed standards for measuring and characterizing SSL light sources [52].

An important issue arises when efficient lighting systems must be used in protected areas or sensitive ecosystems [53]. The economic benefits of reducing energy consumption are apparent [15]. However, the impact of certain properties of the new technology on specific ecosystems must be considered. Accumulating evidence suggests that artificial lighting has significant effects on biodiversity. The study developed by Coleman et al. [54] demonstrates that the exposure of certain species to LED light can alter reproduction and behavioral patterns [55].

Artificial lighting can disrupt many species' natural rhythms and biological cycles [56], and Bolliger et al. [57] find impacts on insects and bats about the color of LED light. The study developed by Bolliger et al. [58] shows that the electromagnetic spectrum overloaded at wavelengths below 400 nm can trigger changes in migration, reproduction and even animal feeding habits, generating ecosystem imbalances [55]. Furthermore, light pollution can hurt the ability of various animal species to see clearly at night. The study developed by Falcón et al. [59] presents a correlation between excessive nocturnal luminosity and the disorientation of nocturnal animals, complicating the activities of the species' life cycle,

such as hunting and mobilization. The study of Bolliger et al. [57] has also shown that lights of a specific wavelength can minimize adverse effects on nocturnal fauna.

Insects such as bees or butterflies fulfill their role as pollinators for the reproduction of various plant species. The study developed by Briolat et al. [60] demonstrates that nighttime lighting from some types of LEDs can interfere with pollination activity, threatening crop production and plant biodiversity; additionally, there may be losses in movement and migration patterns.

Aquatic ecosystems are a critical point at which the consequences of artificial lighting based on LED extend. Visible radiation from lighting sources affects different aquatic organisms, including fish, crustaceans and algae [61]. Changes in feeding, reproduction and migration patterns have been observed in their river and marine environments [62].

Many outdoor lighting sources are visible to flying species. Migratory birds also feel the effect of artificial lighting with the electromagnetic spectrum of LED sources [63]. The study developed by McLaren et al. [64] demonstrates that certain types of large-scale lighting sources can disorient birds during migration, causing risks of collision and a loss of direction and also affecting the health of bird populations.

Likewise, energy efficiency must be considered. An “energy-efficient” system aims to reduce consumption while ensuring minimum lighting values on surfaces that users need. Lighting designs are as important as the technology used [65].

An efficient lighting system requires good power quality. Power quality refers to the minimum parameters that electrical energy must have when delivered to the user. Compliance with these parameters guarantees that the equipment has an adequate voltage supply. The resources used in protected areas must be used optimally due to their scarcity, safeguarding the means necessary to produce them. At the user level, two parameters directly affect the losses in the distribution lines and, consequently, an inefficient use of energy: the power factor and the total harmonic distortion. The power factor is the relationship between active power (watt) and apparent power (voltamperes). A power factor of one or close to one means that reactive power is not present and, consequently, active power is equal to apparent power. The implementation of inductive loads directly affects the power factor. The greater the influence of inductive loads, the more the power factor will decrease. The adequate management of electrical energy consumption by users implicitly entails a power factor close to one. This indicates that all the energy consumed in protected areas is effectively used.

The total distortions produced by the harmonics of the voltage and current waves (THD) are a critical component that directly impacts the quality of the energy supply [66]. THDs have a direct consequence on energy efficiency [67]; for example, as shown in [68], harmonics can cause the loss of electrical equipment and devices, reducing the system’s overall efficiency. Another effect of THDs outside the recommended limits causes the measuring equipment to be inaccurate, causing an inadequate reading. Because the equipment would be working outside the technical specifications, it is complex to establish control over its metrological drift [69].

When dimmed, the LED luminaires’ driver introduces new harmonics into the system’s power quality, similar to other devices connected to the electrical network [70]. This implies that other devices connected to the same electrical network may suffer some type of additional stress since they receive a lower quality of energy.

In protected areas, a comprehensive approach to the LED lighting source’s life cycle is essential. The study developed by Albu et al. [71] highlights the significance of the final decomposition phase, which requires appropriate waste management for sustainability and environment friendliness. A thorough grasp of luminaire design and materials [72] can unlock the potential for efficient equipment and a decrease in end-of-life waste, offering a promising path forward.

2. Materials and Methods

The present analysis was conducted in the Galápagos Islands, Ecuador. In this country, as of 2024, purchases for public outdoor lighting must be with LED technology. Ecuador has 11 protected natural reserves (national parks), with the Galápagos National Park being the most representative. Famous for its biodiversity in flora and fauna, it has national and international protection agreements such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Convention on Biological Diversity (CBD) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), among others.

The parameters of interest were analyzed through measurements in the Galápagos National Park of Ecuador. The brightness of the night sky was monitored using a Sky Quality Meter SQM-LU-DL (Unihedron, Ontario, Canada) at two points: one with installed lighting systems in the “El Progreso” location (Zone 1) and the second as a control group with a measurement in an area away from the lighting systems (Zone 2) in the “San Joaquin” hill (Figure 1).

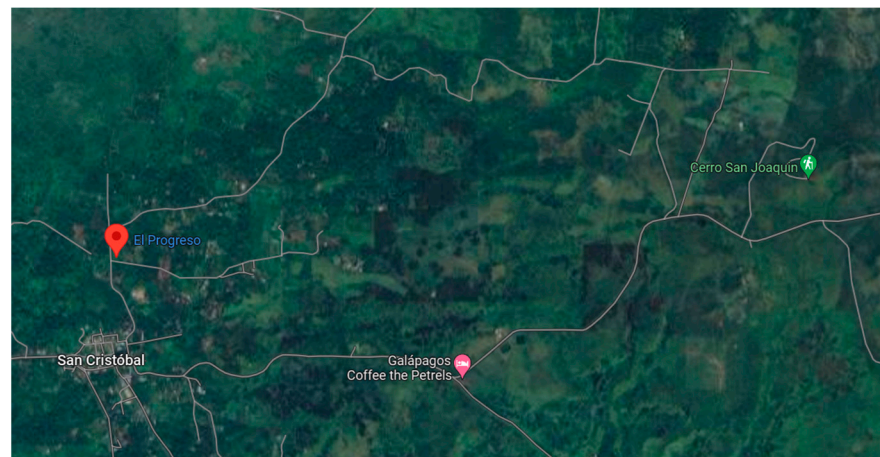


Figure 1. Location of measurements.

The electromagnetic spectrum of the luminaires installed in these lighting systems was analyzed with a StellarNet (Tampa, Florida) UVIR spectrometer. Subsequently, using a mathematical model, the correlated color temperature (CCT) was calculated.

The total harmonic distortion for the analysis of energy quality was measured using a METREL (Horjul, Slovenia) 2892 power analyzer. In this case, an installed luminaire was isolated in the laboratory and powered by an LISUN (Shanghai, China) LSP-15kVA adjustable source with a constant temperature. The results were compared with the luminaire’s total harmonic distortion (THD) dimmed to 60% of its nominal luminous flux value.

Finally, a photometric behavior analysis of the installation was conducted through a Dialux Evo 12.1 simulation. A new installation was proposed to solve the problems of the parameters of interest while maintaining the lighting service at the required levels.

3. Results and Discussion

The results found are presented below.

3.1. Night Sky Quality

Values of night sky brightness S_b measured in $\frac{\text{mag}}{\text{arcsec}^2}$ were obtained for 13 days and nights (Figure 2).

Night sky brightness values in zones of light pollution detection

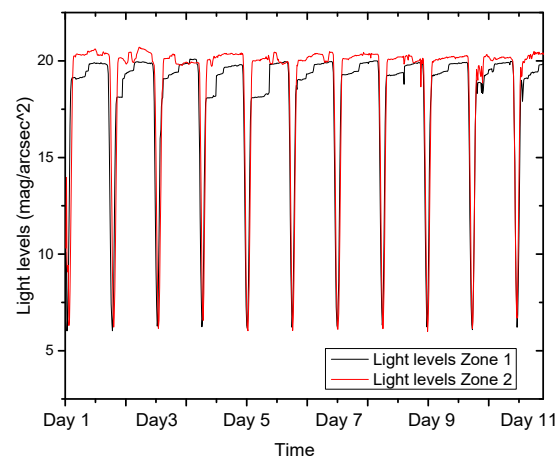


Figure 2. Measured night sky brightness values.

Temperatures vary from 28 °C during the day to 16 °C at night (Figure 3). The measuring equipment is not affected by the environment in this temperature range.

Ambient temperature in zones of light pollution detection

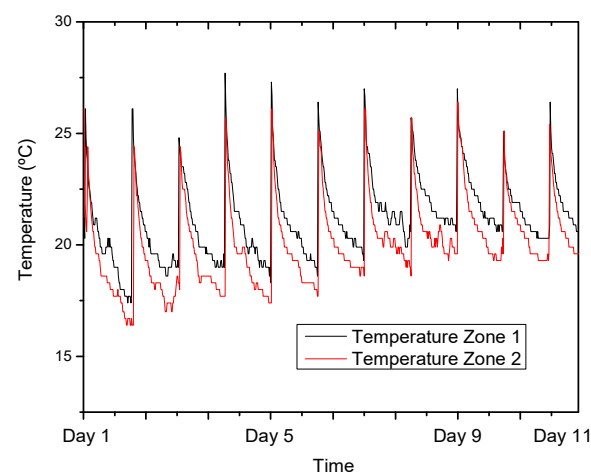


Figure 3. Behavior of the temperature in the measurement zones.

Figure 2 shows that the same levels of sky darkness are reached every night. It is found that at the darkest point of the nights monitored in the two sampling areas, the highest value of S_b in Zone 1 is $20.7 \frac{\text{mag}}{\text{arcsec}^2}$, which implies a value of 4.5 on the Bortle scale or a visibility of the Milky Way with a lack of details. The reference measurement in Zone 2 was carried out in a sector of the national park without close lighting in a radius of 3 km, and an S_b value of $21.5 \frac{\text{mag}}{\text{arcsec}^2}$ was observed, corresponding to a scale of 2 on the Bortle scale, which is a visibility of the Milky Way rich in detail.

Light pollution produced by uncontrolled lighting is affecting the sharpness of the night sky in this protected national park on two levels of the Bortle scale. One factor that can affect these measurements is the inclination of the luminaires in the system. At the moment, they have an angle of inclination of 15°. This angle is usually useful for meeting street lighting levels in luminance values and uniformities. However, it allows a certain amount of luminous flux to exit towards the sky, which can cause the measured behavior.

3.2. Electromagnetic Spectrum and Correlated Color Temperature

The electromagnetic spectrum of 11 installed luminaires was obtained (Figure 4). It was found that the spectra of the set of luminaires were qualitatively similar.

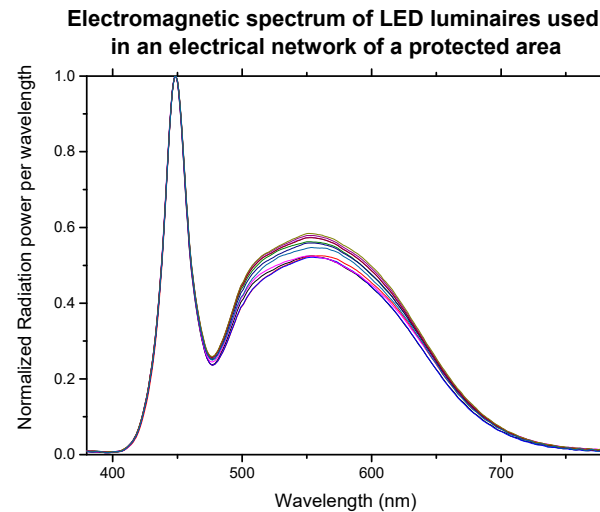


Figure 4. Electromagnetic spectrum of the installed LED luminaires; each color is a different luminaire tested.

To quantify the similarity obtained, the CCT was calculated. For this, given an electromagnetic spectrum $\Phi_\lambda(\lambda)$, where λ is wavelength, the parameters X , Y and Z must be found according to Equations (1)–(3).

$$X = k \sum_{\lambda} \Phi_{\lambda}(\lambda) \bar{x}(\lambda) \Delta\lambda, \quad (1)$$

$$Y = k \sum_{\lambda} \Phi_{\lambda}(\lambda) \bar{y}(\lambda) \Delta\lambda, \quad (2)$$

$$Z = k \sum_{\lambda} \Phi_{\lambda}(\lambda) \bar{z}(\lambda) \Delta\lambda, \quad (3)$$

where $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are numerically defined in CIE 15 [31], and k is defined in Equation (4).

$$k = \frac{100}{\sum_{\lambda} \Phi_{\lambda}(\lambda) \bar{y}(\lambda) \Delta\lambda}. \quad (4)$$

Then, calculate parameters x and y using Equations (5) and (6).

$$x = \frac{X}{X + Y + Z}, \quad (5)$$

$$y = \frac{Y}{X + Y + Z}. \quad (6)$$

Finally, using Equation (7), calculate the CCT.

$$\text{CCT} = a \left(\frac{x - x_e}{y - y_e} \right)^3 + b \left(\frac{x - x_e}{y - y_e} \right)^2 + c \left(\frac{x - x_e}{y - y_e} \right) + d, \quad (7)$$

where $x_e = 0.3320$, $y_e = 0.1858$, $a = -437$, $b = 3601$, $c = -6861$ and $d = 5514.31$. These values are suggested by McCamy in his previous work [73].

It was obtained that the average CCT of the luminaires in nominal operation is 6051 K, and when they are dimmed to 60%, the CCT is 6218 K. According to NOM-031 [74], there are CCT intervals where the user can consider that the color is the same. In this case, 6532 ± 510 K is accepted. Therefore, there is no perceptible variation by the user in color temperature when the system has been dimmed up to 60%.

Although this color temperature does not have much influence on human users, since it is a transit street, ecosystems are seriously affected. The blue radiation of LED luminaires can affect several species of invertebrates, bats and turtles. Figure 4 clearly shows an important load of blues represented in CCTs greater than 6000 K. This can significantly affect the natural functioning of ecosystems on national parks.

Cold CCTs (over 4000 K) are commonly chosen for installations because their efficiency values are usually reported in 150–160 lm/W. Cold CCTs improve the CRI, improving image perception [75], and correlate with greater comfort [76] for human users. However, in ecosystems, they have a transcendental impact due to their electromagnetic spectrum influencing the behavior of flora and fauna. The precise charge of radiation above 400 nm (blue) impacts biological cycles.

The result obtained in the previous section on radiation emitted towards the sky as light pollution, together with the result obtained on the CCT, can aggravate the effects on the flying fauna, which is abundant and diverse in the national park. The study proposed by McLaren et al. [64] agrees with the possibility of this behavior. Although photometry is not adequate for evaluating its effects on biodiversity, since all photometric magnitudes are corrected by the human eye sensitivity curve $V(\lambda)$, radiometric measurements such as the electromagnetic spectrum can provide a metric in this sense. The CCT is a parameter that, for now, is used for this characterization.

3.3. Power Quality in Dimming

Power quality is one of the main problems when using LED technology. LED luminaires need to convert AC voltage to DC. The driver is the element in charge of this conversion, but it introduces harmonics in the network. One way of quantizing is Total Voltage Distortion (THDv), and the other is Total Current Distortion (THDi). In the dimming process, the light emitted by the luminaire is reduced, and its power is also reduced. The dimming can alter the energy quality in the electrical network.

The measurements obtained show that, at reduced power, the amplitude and order of harmonics increase. Figure 5 shows the difference in THDv between nominal and attenuated operations.

Comparison of voltage distortion between nominal and dimmed operation.

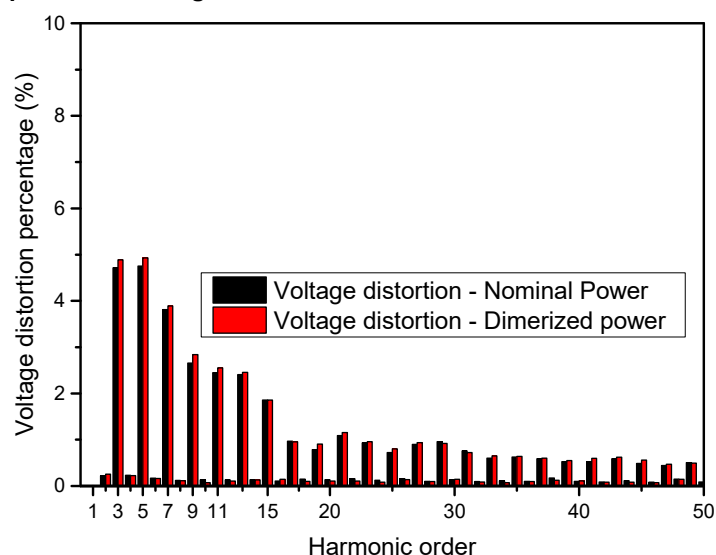


Figure 5. Voltage harmonic spectrum for the comparison between the nominal operation and dimmed operation of the luminaire.

Harmonic one is not represented since it is equivalent to 100%. The highest harmonic values are found in the orders three and five, with values close to 4.7%. It can be observed

that these values do not generate a representative difference between the nominal and attenuated operation. The presence of these harmonics could cause stress on the insulation in the loads that are fed to the system. According to IEC 61000-2-2 [77], the established limit is 5% and 6% for harmonics three and five, respectively. Although the luminaire presents relatively large values, it complies with the standard's requirements [77].

The THDi of nominal operation is 46.5%, and it is 99.2% for reduced operation. The luminaire at nominal power presents high levels of current harmonics (Figure 6), especially the third harmonic, which can influence an oversizing of the neutral conductor, heating in the distribution transformers, the inadequate operation of electrical protections and adverse influences on measurement equipment. In sensitive ecosystems, these adverse effects must be minimized for the efficient use of energy, and considering that the distribution transformer in this network has a star-delta connection, the third harmonic and its multiples must be monitored because they are additive in the neutral due to the 120° displacement that exists between them. However, when its operation is reduced, the value of the third harmonic increases by around two-fold, causing a more significant distortion of its current (Figure 6). It is known that the main effect of the third harmonic is to increase the current in the neutral line, which results in a higher current and losses in the distribution network, which are aggravated when the luminaire is dimmed. According to IEC 61000-3-2 [78], the required limits for the distortion of harmonic currents are 27% for the third harmonic and 10% for the fifth harmonic, which causes the luminaire to not comply with its nominal and reduced operation.

Comparison of current distortion between nominal and dimmed operation.

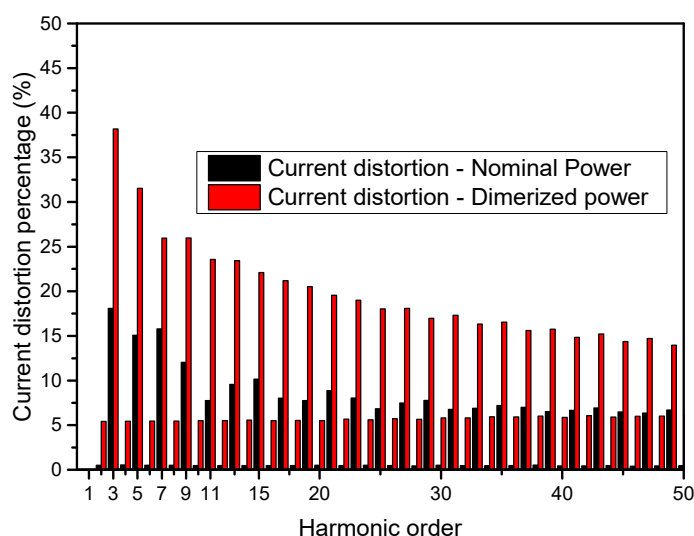


Figure 6. Current harmonic spectrum for the comparison between the nominal operation and dimmed operation of the luminaire.

Organizations managing lighting systems must know the number of luminaires installed per circuit to comply with regulations, especially with dimmed or reduced power. The proposal to control these levels is that luminaires entering sensitive ecosystems must be tested in a laboratory before installation. Efficiency plans may include remote management and a path to becoming smart cities [79]. However, the performance of the installed luminaires must be considered before implementing a lighting plan. The measured luminaire was part of a pilot plan to achieve “energy efficiency with dimming” with a non-mass production luminaire. Using this recommendation, the luminaires are replaced with the luminaires tested in Figures 7 and 8.

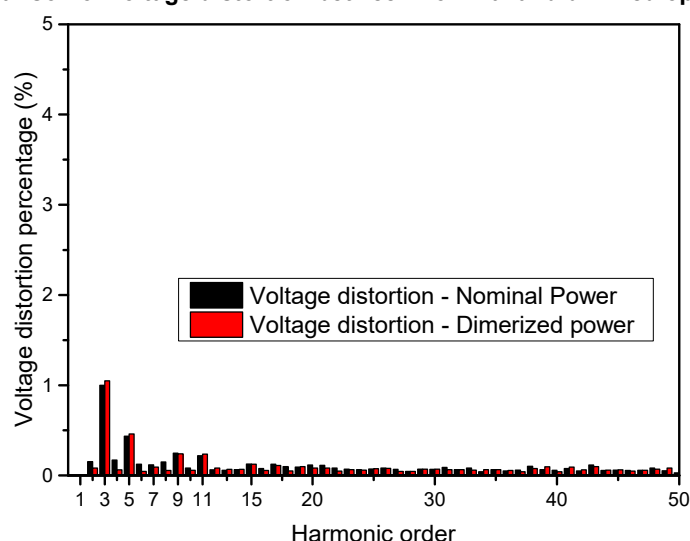
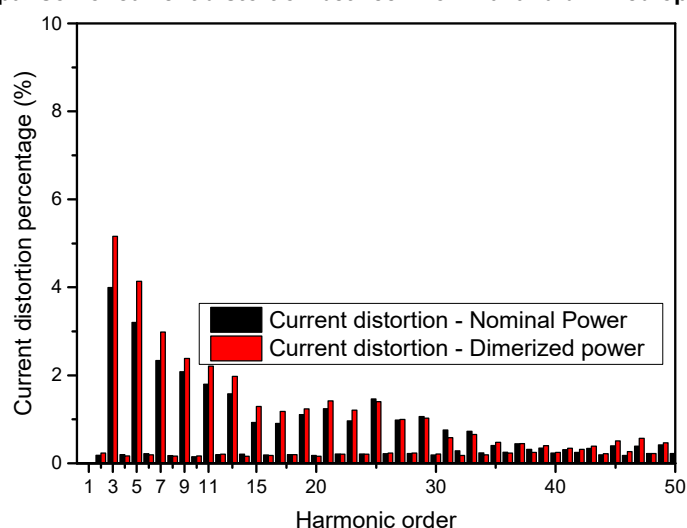
Comparison of voltage distortion between nominal and dimmed operation.**Figure 7.** Voltage harmonic spectrum for the comparison between the nominal operation and dimmed operation of the luminaire for replacement.**Comparison of current distortion between nominal and dimmed operation.****Figure 8.** Current harmonic spectrum for the comparison between the nominal operation and dimmed operation of the luminaire for replacement.

Figure 7 shows relatively low harmonic levels, generating a THD_v of 1.3%, with its third harmonic close to 1% for nominal and reduced operations. These levels comply with the IEC 61000-3-2 standard [78] and maintain the supply quality in the distribution network.

The THD_i is 7.3% for nominal operation and 9.0% for reduced operation. It can be observed that, as in the previous case, there is an increase at the dimming time; however, for the replacement luminaire, the increase is slight, adding only 1.7% of additional total distortion when operating nominally. Even with this increase, it can be observed that harmonics three and five and the other odd harmonics comply with the IEC 61000-3-2 [78] standard for both modes of operation. This implies that the distribution network currents will maintain an adequate quality according to the standard. Controlling harmonic levels through laboratory evaluation is a proposal that generates the maintenance of energy quality and contributes to the sought-after energy efficiency.

3.4. Lighting Design Proposal

The street lighting class is M6, according to the criteria contained in the CIE 15 [31]. A roadway R3 is considered with a coefficient reflectance of $q_0 = 0.07$, with two lanes of 7 m each. According to Table 1, the two installations, the current one and the proposed one, comply with the requirements demanded in CIE for class M6. However, the proposed installation presents better efficiency in the LED luminaires. The existing infrastructure can lower the luminous flux with the proposed luminaires and, at the same time, meet the lighting quality criteria.

Table 1. Installation arrangement and lighting performance for each stage.

Stage	CCT [K]	Street Arrangement							Lighting Performance			
		Luminous Flux (Luminaire) [lm]	Luminaire Wattage [W]	Efficiency [lm/W]	Height [m]	Overhang [m]	Boom Angle [°]	Boom Length [m]	Lav [cd/m ²]	U0	U1	TI [%]
									≥0.30	≥0.35	≥0.40	≤15
Actual	6051	4672	44.0	106.2	8.250	−0.650	15.0	0.5	0.38	0.37	0.4	8
Proposed	2960	2960	23.9	123.8	7.482	−0.650	0.0	0.5	0.3	0.47	0.43	10

Overall uniformity values of 0.47 were achieved compared to the current 0.37, and longitudinal uniformity values of 0.43 were achieved compared to the current 0.4. Although both types of luminaires exceed the minimum required (Table 1), the proposal generates better uniformity values.

The proposed installation has several advantages compared to the current installation (Figure 9); it reduces the installed power by 54% and maintains the same lighting levels required by regulations. Despite presenting lower energy consumption, the general and longitudinal uniformity presents improvements concerning the current installation. This can be achieved thanks to the selected photometry of the luminaire proposed for replacement. The proposal aims to replace only the luminaires with their arm, instead of replacing the columns, due to the impact and difficulty that it would present in a sensitive area. When replacing the lighting system, the inclination of the luminaire arm is limited. In the actual installation, the arms are installed with a 15° inclination; this contributes to a part of the luminaire's emission being directed toward the sky. Moreover, on the other hand, by replacing the lighting system with the proposals presented, the inclination of the luminaire is 0°, which prevents the direct emission of luminous flux towards the sky.

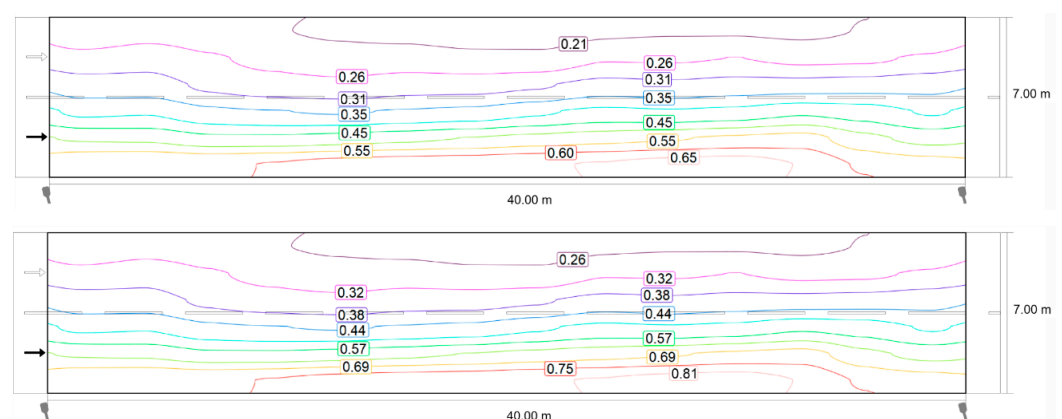


Figure 9. Lighting levels: proposed (above), actual (below).

Another aspect that is considered in the replacement of the road system installation is the correlated color temperature. While in the actual installation, the CCT is 6051 K, the proposal considers installing luminaires with a CCT of 2960 K. Installing CCT warmers in protected areas is recommended, but their efficacy must be considered when selecting a

luminaire. This paper selected a luminaire model that currently allows for an efficacy of 123.8 lm/W with 2960 K.

Thanks to the advancements in LED technology, it is possible that higher efficiencies can soon be achieved in warmer color temperatures. This could lead to the installation of LED lights with a CCT close to 3000 K, impacting protected areas and their fauna to a lesser extent. In the proposed lighting system, several factors are combined to provide lighting levels that meet the regulations' requirements and simultaneously reduce the impact on sensitive areas.

4. Conclusions

The results and analysis indicate that the facility's critical parameters significantly affect the natural park ecosystem and energy quality. The night sky brightness due to the installation of artificial lighting is two levels above the reference on the Bortle scale, obtaining readings of $20.7 \frac{\text{mag}}{\text{arcsec}^2}$ for the place with the installation and $21.5 \frac{\text{mag}}{\text{arcsec}^2}$ for the control group. This implies an essential lever of sky pollution for a UNESCO-protected national park.

The distribution of the electromagnetic spectrum of the installed LED luminaires and the location of their placement affect the biological cycles of some species in this ecosystem due to its CCT of 6051 K for nominal operation and 6218 K for dimming operation. According to NOM-031, both CCTs are in the same range, and humans cannot perceive the difference. However, in the natural reserve, there is a high diversity of birds and flying insects that can be affected by this CCT, along with the amounts of light that escape directly into the sky.

The attenuation process compromises the quality of the energy coming from the electrical grid due to the growth of THDi from 46.5% to 99.2%. This can be explained by the fact that the measured luminaires were designed within the framework of a pilot project for "energy saving" by dimming. However, they nevertheless deliver high distortion values to the grid. An industrial LED luminaire for a replacement was measured, delivering THDi values of 7.3% in nominal operation and 9.0% in dimmed operation. These values comply with the IEC 61000-3-2 regulation, and by generating public policy for their control in the laboratory, it is possible to maintain a required level for the electrical power supply.

The proposal suggests adjusting the CCT to values lower than 3000 K, which is a CCT with a low impact on flora and fauna according to references, and by changing the installation angle of the luminaires from 15° to 0°, it is possible to reduce the sky pollution. A general uniformity value of 0.47 and a longitudinal uniformity value of 0.43 were achieved. Furthermore, controlling the total harmonic distortion (THD) during light intensity regulation with a public policy of control to install LED luminaires in the national park could prevent pollution in the power grid. After conducting the simulation with luminaires with these characteristics, it was found that the lighting levels on the street are achieved by luminance and uniformity.

Author Contributions: Conceptualization, C.V. and F.E.; methodology, C.V. and F.E.; writing—original draft preparation, C.V.; writing—review and editing, all authors; supervision, M.Á.C. and F.R.; funding acquisition, M.Á.C. and F.R. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by University of Alicante Research Groups Grants (VIGROB23-162).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data obtained in this research are original and are available from the authors under request.

Acknowledgments: The authors thank TRANSELECTRIC EP for allowing for the use of its facilities in the IIGE Lighting Laboratory.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study, in the collection, analyses or interpretation of the data, in the writing of the manuscript or in the decision to publish the results.

References

- Peña-García, A.; Sędziwy, A. Optimizing lighting of rural roads and protected areas with white light: A compromise among light pollution, energy savings, and visibility. *Leukos* **2019**, *16*, 147–156. [\[CrossRef\]](#)
- Falchi, F.; Cinzano, P.; Elvidge, C.D.; Keith, D.M.; Haim, A. Limiting the impact of light pollution on human health, environment and stellar visibility. *J. Environ. Manag.* **2011**, *92*, 2714–2722. [\[CrossRef\]](#) [\[PubMed\]](#)
- Kayumov, D.; Bulatbaev, F.; Kayumova, I.; Breido, J.; Bulatbayeva, Y. An engineering approach for the qualitative assessment of the luminous flux of led lamps. *Int. J. Energy A Clean Environ.* **2023**, *24*, 31–43. [\[CrossRef\]](#)
- Yoomak, S.; Jettanasen, C.; Ngaopitakkul, A.; Bunjongjit, S.; Leelajindakraierk, M. Comparative study of lighting quality and power quality for LED and HPS luminaires in a roadway lighting system. *Energy Build.* **2018**, *159*, 542–557. [\[CrossRef\]](#)
- Baig, M.S. Carbon Footprint and Economic Assessment of LED Bulbs Recycling. In *Environmental Assessment of Recycled Waste; Environmental Footprints and Eco-Design of Products and Processes*; Springer: Singapore, 2023; pp. 29–41.
- Djuretic, A.; Kostic, M. Actual energy savings when replacing high-pressure sodium with LED luminaires in street lighting. *Energy* **2018**, *157*, 367–378. [\[CrossRef\]](#)
- Yoomak, S.; Ngaopitakkul, A. Optimisation of lighting quality and energy efficiency of LED luminaires in roadway lighting systems on different road surfaces. *Sustain. Cities Soc.* **2018**, *38*, 333–347. [\[CrossRef\]](#)
- Cao, M.; Xu, M.; Yin, M. Understanding light pollution: Recent advances on its health threats and regulations. *J. Environ. Sci.* **2023**, *127*, 589–602. [\[CrossRef\]](#) [\[PubMed\]](#)
- Hermoso-Orzáez, M.J.; Rojas-Sola, J.I.; Gago-Calderón, A. Electrical consequences of large-scale replacement of metal halide by LED luminaires. *Light. Res. Technol.* **2018**, *50*, 282–293. [\[CrossRef\]](#)
- Khanna, V.K. *Fundamentals of Solid-State Lighting: LEDs, OLEDs, and Their Applications in Illumination and Displays*; CRC Press: Boca Raton, FL, USA, 2014.
- Uddin, S.; Shareef, H.; Mohamed, A. Power quality performance of energy-efficient low-wattage LED lamps. *Measurement* **2013**, *46*, 3783–3795. [\[CrossRef\]](#)
- Jin, H.; Jin, S.; Chen, L.; Cen, S.; Yuan, K. Research on the lighting performance of LED street lights with different color temperatures. *IEEE Photonics* **2015**, *7*, 1–9. [\[CrossRef\]](#)
- Fontoynt, M. LED lighting, ultra-low-power lighting schemes for new lighting applications. *Comptes Rendus Phys.* **2018**, *19*, 159–168. [\[CrossRef\]](#)
- Nelson, J.A.; Bugbee, B. Economic analysis of greenhouse lighting: Light emitting diodes vs. high intensity discharge fixtures. *PLoS ONE* **2014**, *9*, e99010. [\[CrossRef\]](#) [\[PubMed\]](#)
- Campisi, D.; Gitto, S.; Morea, D. Economic feasibility of energy efficiency improvements in street lighting systems in Rome. *J. Clean. Prod.* **2018**, *175*, 190–198. [\[CrossRef\]](#)
- Ryu, G.-H.; Ryu, H.-Y. Analysis of the temperature dependence of phosphor conversion efficiency in white light-emitting diodes. *J. Opt. Soc. Korea* **2015**, *19*, 311–316. [\[CrossRef\]](#)
- Rabaza, O.; Gómez-Lorente, D.; Pérez-Ocón, F.; Peña-García, A. A simple and accurate model for the design of public lighting with energy efficiency functions based on regression analysis. *Energy* **2016**, *107*, 831–842. [\[CrossRef\]](#)
- Moo, C.S.; Chen, Y.J.; Yang, W.C. An efficient driver for dimmable LED lighting. *IEEE Trans. Power Electron.* **2012**, *27*, 4613–4618. [\[CrossRef\]](#)
- Lee, C.W.; Kim, J.H. Effect of LED lighting illuminance and correlated color temperature on working memory. *Int. J. Opt.* **2020**, *2020*, 3250364. [\[CrossRef\]](#)
- De, K. A review of solid state white light emitting diode and its potentials for replacing conventional lighting technologies in developing countries. *Appl. Phys. Res.* **2014**, *6*, 95.
- Khan, M.F.; Reddy, S.; Swanson, A.G. Replacement of HPS luminaires with LED luminaires for the lighting requirements of an outdoor electrical substation. In *Proceedings of the IEEE Sustainable Smart Lighting World Conference & Expo (LS18)*, Mumbai, India, 8–10 June 2023.
- Bhattacharya, S.; Majumder, S.; Roy, S. Modelling of the effects of luminaire installation geometries and other factors on road illumination system photometric parameters and energy efficiency. *World J. Eng.* **2023**, *ahead-of-print*. [\[CrossRef\]](#)
- Wu, X.; Zhao, X.; Ren, Q.; Du, L.; Pei, M.; Hai, O. Design efficient energy transfer $\text{Ca}_2\text{Al}_2\text{SiO}_7$: Bi^{3+} , Eu^{3+} phosphors by cationic substitution for full-spectrum W-LED lighting. *Ceram. Int.* **2023**, *49*, 18852–18860. [\[CrossRef\]](#)
- Hossain, N. Advances and significances of nanoparticles in semiconductor applications—A review. *Results Eng.* **2023**, *19*, 101347. [\[CrossRef\]](#)
- Kim, Y.P.; Kim, Y.S.; Ko, S.C. Thermal characteristics and fabrication of silicon sub-mount based LED package. *Microelectron. Reliab.* **2016**, *56*, 53–60. [\[CrossRef\]](#)
- Bieber, C. LED Light Emission as a Function of Thermal Conditions. In *Proceedings of the Twenty-Fourth Annual IEEE Semiconductor Thermal Measurement and Management Symposium*, San Jose, CA, USA, 16–20 March 2008.

27. Chen, H.T.; Tan, S.C.; Hui, S.Y. Color variation reduction of gan-based white light-emitting diodes via peak-wavelength stabilization. *IEEE Trans. Power Electron.* **2014**, *29*, 3709–3719. [\[CrossRef\]](#)
28. Seunarine, K.; Haymoor, Z.; Spence, M. Recent advances and perspectives in photometry in the era of LED lighting. *Meas. Sci. Technol.* **2023**, *35*, 021001.
29. Chen, Y.; Ma, T.; Ye, Z.; Li, Z. Effect of illuminance and colour temperature of LED lighting on asthenopia during reading. *Ophthalmic Physiol. Opt.* **2023**, *43*, 73–82. [\[CrossRef\]](#)
30. Avci, A.N.; Memikoğlu, İ. Effects of LED lighting on visual comfort with respect to the reading task. *Int. J. Electr. Comput. Eng.* **2017**, *11*, 974–978.
31. Commission Internationale de L'Eclairage/International Commission on Illumination/Internationale Beleuchtungskommission. *CIE 015:2018 Colorimetry*; International Commission on Illumination: Vienna, Austria, 2018.
32. Zhao, H. White light emitting devices with high color rendering index and electrically adjustable color temperature. *Appl. Phys. Lett.* **2023**, *123*, 151901. [\[CrossRef\]](#)
33. Satvaya, P.; Mazumdar, S. Performance analysis of a variable flux and CCT-based outdoor LED luminaire. *J. Opt.* **2023**, *52*, 1305–1317. [\[CrossRef\]](#)
34. Jiang, H.; Huang, M.; Yang, F.S.; Liu, Y. Evaluation of Color Rendering Index for LED and Fluorescent Light Sources. *Appl. Mech. Mater.* **2015**, *731*, 22–26. [\[CrossRef\]](#)
35. Schledermann, K.M.; Hansen, T.S.; Bjørner, T. Perceived visual comfort and usefulness of a circadian lighting system implemented at a nursing home. *Multimed. Tools Appl.* **2023**, *82*, 5253–5269. [\[CrossRef\]](#)
36. Fu, X.; Feng, D.; Jiang, X.; Wu, T. The effect of correlated color temperature and illumination level of LED lighting on visual comfort during sustained attention activities. *Sustainability* **2023**, *15*, 3826. [\[CrossRef\]](#)
37. Trop, T.; Shoshany Tavory, S.; Portnov, B.A. Factors affecting pedestrians' perceptions of safety, comfort, and pleasantness induced by public space lighting: A systematic literature review. *Environ. Behav.* **2023**, *55*, 3–46. [\[CrossRef\]](#)
38. Najjar, G.A.; Akkad, K.; Almahdaly, A.H. Classification of lighting design aspects in relation to employees' productivity in Saudi Arabia. *Sustainability* **2023**, *15*, 3614. [\[CrossRef\]](#)
39. Chen, R.; Tsai, M.C.; Tsay, Y.S. Effect of color temperature and illuminance on psychology, physiology, and productivity: An experimental study. *Energies* **2022**, *15*, 4477. [\[CrossRef\]](#)
40. Azman, M.I.; Dalimin, M.N.; Mohamed, M.; Abu Bakar, M.F. A brief overview on light pollution. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *269*, 012014. [\[CrossRef\]](#)
41. Barentine, J.C.; Wallner, S.; Kocifaj, M. Towards future challenges in the measurement and modelling of night sky brightness. *Mon. Not. R. Astron. Soc.* **2023**, *527*, 5553–5558. [\[CrossRef\]](#)
42. Angeloni, R.; Uchima-Tamayo, J.; Arancibia, M. Toward a Spectrophotometric Characterization of the Chilean Night Sky. A First Quantitative Assessment of ALAN across the Coquimbo Region. *Astron. J.* **2024**, *167*, 67. [\[CrossRef\]](#)
43. Kocifaj, M.; Wallner, S.; Barentine, J.C. Measuring and monitoring light pollution: Current approaches and challenges. *Science* **2023**, *380*, 1121–1124. [\[CrossRef\]](#)
44. Ges, X.; Bará, S.; García-Gil, M.; Zamorano, J.; Ribas, S.J.; Masana, E. Light pollution offshore: Zenithal sky glow measurements in the mediterranean coastal waters. *J. Quant. Spectrosc. Radiat. Transf.* **2018**, *210*, 91–100. [\[CrossRef\]](#)
45. Kolláth, Z.; Jechow, A. Natural variation of the colour and spectrum of the night sky observed at a potential european reference site for dark skies. *J. Quant. Spectrosc. Radiat. Transf.* **2023**, *303*, 108592. [\[CrossRef\]](#)
46. Commission Internationale de L'Eclairage/International Commission on Illumination/Internationale Beleuchtungskommission (CIE). *CIE 126-1997 Guidelines for Minimizing Sky Glow*; International Commission on Illumination: Vienna, Austria, 1997.
47. Pothukuchi, K. City Light or Star Bright: City light or star bright: A review of urban light pollution, impacts, and planning implications. *J. Plan. Lit.* **2021**, *36*, 155–169. [\[CrossRef\]](#)
48. Gaston, K.J.; Davies, T.W.; Bennie, J.; Hopkins, J. REVIEW: Reducing the ecological consequences of night-time light pollution: Options and developments. *J. Appl. Ecol.* **2012**, *49*, 1256–1266. [\[CrossRef\]](#) [\[PubMed\]](#)
49. Laforge, A.; Pauwels, J.; Faure, B.; Bas, Y.; Kerbirou, C.; Fonderflick, J.; Besnard, A. Reducing light pollution improves connectivity for bats in urban landscapes. *Landsc. Ecol.* **2019**, *34*, 793–809. [\[CrossRef\]](#)
50. Luginbuhl, C.B.; Boley, P.A.; Davis, D.R. The impact of light source spectral power distribution on sky glow. *J. Quant. Spectrosc. Radiat. Transf.* **2014**, *139*, 21–26. [\[CrossRef\]](#)
51. Commission Internationale de L'Eclairage/International Commission on Illumination/Internationale Beleuchtungskommission (CIE). *Test Method for LED Lamps, LED Luminaires and LED Modules* | CIE S025; International Commission on Illumination: Vienna, Austria, 2019.
52. Illuminating Engineering Society of North America (IES). *Approved Method: Optical and Electrical Measurements of Solid-State Lighting Products ANSI/IES LM-79-19*; Illuminating Engineering Society of North America: New York, NY, USA, 2019.
53. Shahzad, K.; Čuček, L.; Sagir, M.; Ali, N.; Rashid, M.; Nazir, R.; Nizami, A.; Al-Turaif, H.A.; Ismail, I.M.I. An ecological feasibility study for developing sustainable street lighting system. *J. Clean. Prod.* **2018**, *175*, 683–695. [\[CrossRef\]](#)
54. Coleman, J.L.; Lum, D.W.H.; Yao, X. From sodium-vapour to LEDs: How an outdoor lighting retrofit affects insects in Singapore. *J. Urban Ecol.* **2023**, *9*, juad009. [\[CrossRef\]](#)
55. Lee, K.E.M.; Lum, W.H.D.; Coleman, J.L. Ecological impacts of the LED-streetlight retrofit on insectivorous bats in Singapore. *PLoS ONE* **2021**, *16*, e0247900. [\[CrossRef\]](#)

56. Altermatt, F.; Ebert, D. Reduced flight-to-light behaviour of moth populations exposed to long-term urban light pollution. *Biol. Lett.* **2016**, *12*, 20160111. [[CrossRef](#)]
57. Bolliger, J.; Hennet, T.; Wermelinger, B.; Blum, S.; Haller, J.; Obrist, M.K. Low impact of two LED colors on nocturnal insect abundance and bat activity in a peri-urban environment. *J. Insect Conserv.* **2020**, *24*, 625–635. [[CrossRef](#)]
58. Bolliger, J.; Haller, J.; Wermelinger, B.; Blum, S.; Obrist, M.K. Contrasting effects of street light shapes and LED color temperatures on nocturnal insects and bats. *Basic Appl. Ecol.* **2022**, *64*, 1–12. [[CrossRef](#)]
59. Falcón, J.; Torriglia, A.; Attia, D.; Viénot, F.; Gronfier, C.; Behar-Cohen, F.; Martinsons, C.; Hicks, D. Exposure to Artificial Light at Night and the Consequences for Flora, Fauna, and Ecosystems. *Front. Neurosci.* **2020**, *14*, 602796. [[CrossRef](#)]
60. Briolat, E.S.; Gaston, K.J.; Bennie, J.; Rosenfeld, E.J.; Troschianko, J. Artificial nighttime lighting impacts visual ecology links between flowers, pollinators and predators. *Nat. Commun.* **2021**, *12*, 4163. [[CrossRef](#)]
61. Marangoni, L.F.B.; Davies, T.; Smyth, T.; Rodríguez, A.; Hamann, M.; Duarte, C.; Pendoley, K.; Berge, J.; Maggi, E.; Levy, O. Impacts of artificial light at night in marine ecosystems—A review. *Glob. Chang. Biol.* **2022**, *28*, 5346–5367. [[CrossRef](#)]
62. Singhal, R.K.; Chauhan, J.; Jatav, H.S.; Rajput, V.D.; Singh, G.S.; Bose, B. Artificial night light alters ecosystem services provided by biotic components. *Biol. Futur.* **2021**, *72*, 169–185. [[CrossRef](#)]
63. Burt, C.S.; Kelly, J.F.; Trankina, G.E.; Silva, C.L.; Khalighifar, A.; Jenkins-Smith, H.C.; Fox, A.S.; Fristrup, K.M.; Horton, K.G. The effects of light pollution on migratory animal behavior. *Trends Ecol. Evol.* **2023**, *38*, 355–368. [[CrossRef](#)]
64. McLaren, J.D.; Buler, J.J.; Schreckengost, T.; Smolinsky, J.A.; Boone, M.; Emiel van Loon, E.; Dawson, D.K.; Walters, E.L. Artificial light at night confounds broad-scale habitat use by migrating birds. *Ecol. Lett.* **2018**, *21*, 356–364. [[CrossRef](#)]
65. Mansfield, K.P. Architectural lighting design: A research review over 50 years. *Light. Res. Technol.* **2018**, *50*, 80–97. [[CrossRef](#)]
66. Brusil, C.; Arcos, H.; Espin, F.; Velasquez, C. Analysis of harmonic distortion of led luminaires connected to utility grid. In Proceedings of the 2020 IEEE ANDESCON, Quito, Ecuador, 13–16 October 2020.
67. Rymarczyk, T.; Korzeniewska, E.; Wantuch, A.; Olesiak, M. Effect of LED Lighting on Selected Quality Parameters of Electricity. *Sensors* **2023**, *23*, 1582. [[CrossRef](#)]
68. Swami, H.; Jain, A.K.; Azad, I.H.; Meena, N. Evaluation of input harmonic characteristics of LED lamps connected to utility grid. In Proceedings of the 2018 IEEMA Engineer Infinite Conference, New Delhi, India, 3–14 March 2018; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2018.
69. Velásquez, C.; Castro, M.A.; Rodríguez, F.; Espin, F.; Falconi, N. Optimization of the Calibration Interval of a Luminous Flux Measurement System in HID and SSL Lamps Using a Gray Model Approximation. In Proceedings of the ETCM 2021—5th Ecuador Technical Chapters Meeting, Quito, Ecuador, 12–15 October 2021.
70. Pinto, M.F.; Mendonça, T.R.F.; Duque, C.A.; Braga, H.A.C. Street lighting system for power quality monitoring and energy-efficient illumination control. In Proceedings of the IEEE International Symposium on Industrial Electronics, Santa Clara, CA, USA, 8–10 June 2016.
71. Albu, H.; Beu, D.; Rus, T.; Moldovan, R.; Domnița, F.; Vilčeková, S. Life cycle assessment of LED luminaire and impact on lighting installation—A case study. *Alex. Eng. J.* **2023**, *80*, 282–293. [[CrossRef](#)]
72. Velásquez, C.; Espin, F.; Rodríguez, F.; Castro, M.A. Heat transfer modeling in road lighting LED luminaire. In Proceedings of the 11th International Conference On Mathematical Modeling in Physical Sciences, Belgrade, Serbia, 5–8 September 2022.
73. McCamy, C.S. Correlated color temperature as an explicit function of chromaticity coordinates. *Color Res. Appl.* **1992**, *17*, 142–144. [[CrossRef](#)]
74. NOM-031-ENER-2019; Eficiencia Energética Para Luminarios con Led Para Iluminación de Vialidades y Áreas Exteriores Públicas. Especificaciones y Métodos de Prueba. Comité Consultivo Nacional de Normalización para la Preservación y Uso Racional de los Recursos Energéticos; Secretaría de Gobernación de México-Diario Oficial de la Federación: Mexico City, Mexico, 2019.
75. Valetti, L.; Floris, F.; Pellegrino, A. Renovation of Public Lighting Systems in Cultural Landscapes: Lighting and Energy Performance and Their Impact on Nightscapes. *Energies* **2021**, *14*, 509. [[CrossRef](#)]
76. Iacomussi, P.; Radis, M.; Rossi, G.; Rossi, L. Visual Comfort with LED Lighting. In Proceedings of the 6th International Building Physics Conference, Torino, Italy, 14–17 June 2015.
77. IEC 61000-2-2:2002; Electromagnetic Compatibility (EMC)—Part 2-2: Environment—Compatibility Levels for Low-Frequency Conducted Disturbances and Signalling in Public Low-Voltage Power Supply Systems. International Electrotechnical Commission: Geneva, Switzerland, 2002.
78. IEC 61000-3-2:2018; Electromagnetic Compatibility (EMC)—Part 3-2: Limits—Limits for Harmonic Current Emissions (Equipment Input Current ≤ 16 A per Phase). International Electrotechnical Commission: Geneva, Switzerland, 2018.
79. Iacomussi, P.; Valpreda, F. Lighting a smart society. In Proceedings of the XXII International Symposium on High Power Laser Systems and Applications, Frascati, Italy, 9–12 October 2018.

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