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Rethinking Sustainable Cities at Night: Paradigm Shifts in Urban Design and City Lighting

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Abstract: Since the establishment of the 17 Sustainable Development Goals (SDGs) by the United Nations General Assembly in 2015, various perspectives on sustainable cities have been developed and adopted in order to achieve a better and more sustainable future. However, background research has revealed that these goals and targets are limited because they do not take into account the growing body of lighting-related research in diverse fields on the impact of outdoor illumination on humans, flora and fauna. Recently, exterior lighting has been also linked to environmental degradation and as an indirect contributor to the current climate change emergency. Therefore, this study aims, by using online interviews with over 50 experts who work in the field of artificial light at night (ALAN), to assess whether the SDG objectives adequately reflect the latest knowledge about sustainable cities. The Elsevier 2021 SDG mapping matrix was used to find the correlation between the keywords that define each SDG and the keywords used by a group of international experts. This work suggests there are missing targets in current SDGs, especially SDG 11, connected to sustainable cities and communities. It also offers useful guidance on how to rethink the existing approach of cities that aim for sustainability, by applying eight (8) key aspects of urban lighting for healthier and environmentally responsible outdoor illumination, by means of a correct design process, along with a five-step strategic plan of action. The crucial role of multidisciplinary and interdisciplinary collaboration with experts has also been outlined, via the inclusion of new actors such as lighting professionals and researchers, who are currently absent in this important discourse.

Keywords: sustainable cities; sustainable developments goals (SDGs); SDG11; city lighting; urban lighting; outdoor illumination; nighttime outdoor lighting; ALAN; light pollution; Elsevier 2021 SDG mapping

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1. Introduction

In the last 100 years, three different paradigm shifts took place regarding the development of the urban planning approach, with each one driven by a different factor: (1) technical conditions for roads and cars; (2) road safety and visibility conditions for pedestrians and cyclists; and (3) environmental conditions and its effects on dark skies, plants, animals and people.

These approaches also influenced the way outdoor illumination in cities was designed and implemented during this time. Back in the third decade of the XX century, modernist urban planners and architects, influenced by advancements in the automobile industry, created the concept of a car city, also known as an automobile city [1], which was implemented globally after WWII (Figure 1a). Once the war was over, many cities were in ruins and needed rebuilding, which took the form of highway construction and the introduction of travel distances between work and home to accommodate the needs of the automobile industry [2]. A personal car became a status symbol of post war wealth and a

sign of economic prosperity, with technical street lighting supporting vehicular functions. However, over time, these cities were viewed as functionally disintegrated. Pedestrians were forced to play a secondary role and these places were no longer considered liveable. In addition, all the existing lighting regulations favoured vehicular safety [3]. With the mass production of cars and their consequent increase in numbers, other aspects also increased, such as constant city congestion, the lack of free parking spaces, increased air pollution, and noise etc. Therefore, in the early XXI century, with more and more people moving into cities, urban planning and urban lighting required a different approach, as urban functions now involve living, working and relaxing in the same place. This realisation called for the second paradigm shift in urban planning and design processes [4]. A human-centric shift that no longer relied on cars for connectivity for low-density urban sprawl, but focused instead on residents [5]. This meant a shift towards a more connected pedestrian and cyclist city (Figure 1b) with urban lighting that supported their needs.

(**a**) (**b**) (**c**)

Figure 1. Development of city lighting approach: (**a**) car city (after 1945); (**b**) pedestrian and cyclist city (since the first decade of the XXI century until the present day); (**c**) healthy and environmentally responsible sustainable city (since the second decade of the XXI century until the present day). Source: authors' own work.

Recently, a third paradigm shift took place in the second decade of the XXI century. The human-induced climate change crisis combined with a mounting body of research, has demanded a new approach for healthier and environmentally responsible, sustainable cities (Figure 1c) that include outdoor illumination. This environment-centred approach calls for the incorporation of environmental, human and non-human factors.

In the context of the current climate change emergency caused by greenhouse gases emitted by human activities [6] and recent natural disasters such as hurricanes, typhoons, floods, droughts or wildfires—sustainability, defined as "the quality of causing little or no damage to the environment . . . " [7], should be an important aspect addressed by sustainable cities.

Since the establishment of the 17 Sustainable Development Goals (SDGs) [8], which include 169 associated targets by the United Nations General Assembly in 2015, various perspectives on sustainable cities have been developed and adopted in order to achieve a better and more sustainable future.

However, background research has revealed that these goals are limited because they do not take into account the growing body of results on the impact of outdoor illumination from lighting-related research in diverse fields, such as environmental sciences, biology, medicine and astronomy—especially the effects of new LED light sources on humans, flora and fauna.

Although the subject of sustainable cities at night is multi-faceted, it has not been treated in a holistic manner due to a lack of understanding on these complex, interlinked aspects. Up to the present time, some researchers have provided insights into the body of knowledge involving city lighting, from the perspective of energy performance [9], smart cities [10], virtual reality [11], assessment [12] or users' satisfaction [13]; however, there is still a noticeable lack of research on sustainable cities at night and the impact of light pollution from outdoor illumination on humans, flora and fauna in context of the UN's SDGs [14–16]. Thus, more studies are required to help further our understanding of these aspects.

When the 2014 Nobel Prize for Physics was awarded for the "invention of efficient blue light emitting diodes [LEDs], which enabled bright, white, energy saving light sources" [17], the general public gained the impression that this new lighting technology would contribute to a more sustainable future for cities [18]. As municipalities around the globe quickly convert their current functional and decorative external lighting to LED in an attempt to conserve energy and save money, other key factors are overlooked.

However, the World Economic and Social Survey 2013, addresses energy efficiency as an environmental management pillar for sustainable cites [19]; nevertheless, *Our Common Future*, also known as the Brundtland Report, published in 1987, defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [20]. This extends beyond energy savings by addressing additional elements. In addition, principle 4 of *The Rio Declaration on Environment and Development* from 1992, which was seen as a guide for the future sustainable development of countries and cities, states that "in order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it" [21].

Therefore, the first purpose of this research is to assess if the SDG objectives adequately reflect the latest knowledge about sustainable cities and to find the correlation (gaps and strengths) between the keywords that define each SDG and the keywords used by a group of selected international experts in their interviews.

The second purpose is to provide a holistic overview of the key aspects of urban lighting that a sustainable city at night should fulfil, along with useful guidance on how to rethink the approach for healthier and environmentally responsible outdoor illumination. This is based on background research, the opinions of experts who were interviewed for this study, and the insights and practical knowledge of one of the authors, who is a researcher and practicing lighting professional.

Lastly, the authors have developed a strategic plan of action for illumination in sustainable cities that balances the various lighting needs of humans with the natural environment, taking into consideration forecasts of globalization and an increase in the world's population. By 2050, as much as 68% of the world's population will live in urban agglomerations [22], significantly increasing existing pollution and contributing to the continued deterioration of the global environment, as well as the reduction of green areas. This means these problems need to be addressed in the most strategic way possible, so that cities at night can better meet the needs of their inhabitants, entire urban ecosystems and the planet.

This paper is presented in two distinct parts. The first part uses experts' input in response to an open-ended question to develop an evaluation of the relevance of the SDGs with respect to nighttime outdoor lighting in cities. The second part analyses and proposes a new approach to urban design and city lighting (the introduction of new actors, iterative design process and a five-step strategic plan of action) in order to solve the current problems of goal SDG11 targeting sustainable cities and communities at night [23].

2. Methods

This section clarifies the procedure of data selection and content analysis that was followed in the study to answer the research questions. Mixed used research methods (qualitative and quantitative) were applied.

2.1. Background Research—Literature Review (Qualitative Research Method)

This inquiry involved an in-depth assessment of published information on sustainable cities at night and lighting-related research in diverse fields, such as astronomy, environmental sciences, biology and medicine, on the impact of outdoor illumination on humans, flora and fauna, including: books, scientific research papers, lighting standards, regulations and environmental reports. In addition, keywords such as "city lighting"; "urban lighting"; "outdoor illumination"; "nighttime outdoor lighting"; "ALAN"; "light pollution" were searched in all of the 17 UN SDG Goals and 167 targets to find a potential relation.

2.2. Online Interviews (Qualitative Research Method)

To understand the meaning of the term "sustainable cities at night" and to collect the necessary data, a qualitative research method [24] in the form of an online interview [25,26] was performed during December 2021, via private email correspondence and the LinkedIn platform. This method was also chosen due to COVID-19 pandemic restrictions and because the study participants were a geographically dispersed population. More than 50 carefully selected international participants with various backgrounds related to exterior illumination and outdoor lighting, were requested to answer the following question: "Sustainable cities at night, what does this statement mean to you based on your occupation?".

Moreover, further discussions with experts helped to identify the key missing aspects of urban lighting and gaps in existing design processes that are considered crucial for the creation of successful sustainable cities.

Participants

General demographic sample characteristics of the participants were arranged in the form of a self-exploratory table with four variables related to: (1) gender; (2) country of residence; (3) continent of residence; and (4) occupation (Table 1). More than 50 professionals in various fields were recruited via email to take part in the study. It should be noted that originally, the group of invited specialists included 85 people. Participation was voluntary and unpaid. These participants represented experts in their respective fields. They were selected based on distinct and objective achievements, and at least five (5) years of broad and deep understanding and competence in their particular field in terms of knowledge, skill and experience through practice and education. They were recognized and highly respected by their peers. The lighting professionals provided outdoor illumination on a large scale in urban agglomerations, in accordance with lighting standards, and many of them have managerial positions in well-known lighting design practices. Whereas the researchers had many years of research experience and their publications are listed in the Web of Science (WoS) and Scopus databases, with many citation.

Regarding gender, male experts dominated (63%), as urban lighting has been a male-dominated engineering field since its establishment. From the point of view of profession, participants were divided into five groups based on their professional experience of the topic. Lighting professionals (35.8%) and researchers (26.4%) had the largest representation.

The largest two groups were formed by European (73.5%) and North American (18.8%) experts, most probably due to the fact that professionally designed urban lighting has been applied in these regions for a longer period of time.

Table 1. Overview of demographic sample characteristics. Source: authors' own work.

Variables	Group	Category	No. of Items	(%)
Gender	NA	Male	34	63
		Female	19	37
Country of residence	NA	AU	2	3.8
		BE	1	1.9
		DE	10	18.9
		DK	1	1.9
		FI	1	1.9
		FR	2	3.8
		IN	1	1.9
		IT	3	5.7
		NE	1	1.9
		NL	2	3.8
		NZ	1	1.9
		SE	4	7.5
		UK	14	26.4
		US	10	18.9
Continent of residence	NA	Africa	0	0.0
		Asia	1	1.8
		Australia and Oceania	3	5.6
		Europe	39	73.5
		North America	10	18.8
		South America	0	0.0
Group/Occupation	Group 1:	City Representative	3	5.6
	Group 2:	Urban Planner *	1	1.8
		Architect *	3	5.6
		Landscape Architect/Designer *	1	1.8
		Lighting Professional *	19	35.8
		Light Artist *	2	3.6
	Group 3:	Luminaire Manufacturer	4	7.5
	Group 4:	Researcher	14	26.4
	Group 5:	Environmental Lawyer	2	3.9
		Medical Doctor	1	1.8
		Responsible Lighting Advocate	4	7.5

* Designer in the built environment.

2.3. Software Analysis (Quantitative Research Method)

2.3.1. Text Analysis/Input Data

The basic tool used for text analysis was MATLAB software with Text Analytics Toolbox, which allowed, among other things, the analyses of text data, its statistics, and the generation of a word cloud—a visual representation of the frequency of words that appeared in the text [27].

- Data set of keywords of all experts' answers based on interviews.

Data Table A (see Supplementary Material) is the table of experts' answers; it has one field, "Responses", and four additional fields concerning the characteristics of the respondents, "Gender", "Country of residence", "Continent of residence", "Groups/Occupation". Ultimately, the array for Table A consisted of 53 × 5 cells.

- Keyword dataset for each SDG 1 to SDG 16 with weights based on Elsevier 2021 SDG mapping.

Elsevier's data science teams worked with researchers/specialists to generate SDG search queries to help track and demonstrate progress towards the targets of the United Nations Sustainable Development Goals (SDGs) [28] by identifying terms relevant to each goal and evaluating the precision with which these terms were recovered in relevant publications.

The authors divided each keyword Tables S1–S16 into 16 SDG categories (see Supplementary Material). Each of these tables is characterized by two fields (names of included variables): "Keyword" and "Weight", due to the fact that 100 keywords were collected together with the strongest weights for a given SDG. Each of these arrays contained 100 × 2 cells.

2.3.2. Analysis of the Experts' Answers Taking into Account Their Characteristics

In order to obtain the response characteristics depending on the type of respondent groups, the MATLAB software function wordCloudCounts was used to select all the words used by the respondents, together with the number of uses/repetition. These data was stored in Table T (see Supplementary Material), which had two fields: "Word" and "Count". The next step was to search for words from Table T (see Supplementary Material) in each of the individual responses of the experts—53 cells of Table A from the "responses" field > the result of these actions was the matrix R consisting of 0 and 1 with dimensions of 53 (number of responses) × number of specified individual words in responses (the number of Table T cells for the Word field). In the case of the R matrix, when a given element R (m, n) is equal to 0, the indicated no recognized word with the number n in the given answer m. However, when such an element is equal to 1, it means that the word has been recognized. Then, analyses were made, taking into account the division into groups in terms of:

- Gender
- Country of residence
- Continent of residence
- Group/Occupation

Using the tools and functions of the MATLAB software, an automatic determination was made of the percentage of respondents from a given category, in a given group, using a specific word in their answer. The result of this analysis has been presented in four tables (see Supplementary Material):

- Table S—with 3 fields: "Word", "Male", "Female"
- Table N—with 16 fields: "Word", "AU", "BE", "DE", "DK", "FI", "FR", IN", "IT", "NE", "NL", "NZ","SE", "UK", "US"
- Table C—with 4 fields: "Word", "North America", "Europe", "Australia and Oceania", "Asia"
- Table P—with 6 fields: "Word", "Group1", "Group2", "Group3", "Group4", "Group5"

For these four tables, apart from the "Word" field, cells indicated what percentage of respondents from a given group used a given word.

On the basis of these data, further analyses were made and conclusions were drawn, which are described in Section 4—Results.

2.3.3. Text Analysis/Correlation of SDG Keywords with the Experts' Answers

In order to be able to assess the relationship between the experts' answers and the keywords for each SDG, the functions and tools of the MATLAB software were used, which automatically searched for individual keywords in the cells of Table A, concerning the experts' answers (taking into account the overall text—a total of all 53 answers/cells). The final result of the analyses was the extension of 16 Tables S1–S16 with 3 additional fields: "Number of repetitions in responses".

On the basis of these data, additional analyses were made on the assessment of the dependency of keywords of each SDG and the answers of the respondents, which are presented in Section 4—Results.

3. Scientific Questions

The following questions have been posed in order to accomplish the research goal of developing a strategic plan of action for outdoor illumination in sustainable cities that balances the various lighting needs of humans with the natural environment:

Question 1. *To what extent do SDG goals reflect the latest knowledge and research from various fields in the context of sustainable cities at night and urban lighting?*

Question 2. *Is there a correlation between SDG goals/targets and experts' responses regarding sustainable cities at night?*

Question 3. *What key aspects of urban lighting should be met by the SDG 11 for cities and communities in order for them to be sustainable after dark?*

Question 4. *What kind of urban lighting design processes, actors and effective actions should be identified so as to create healthier and environmentally responsible sustainable cities at night?*

4. Results

This section provides a precise description of the results and their interpretation.

4.1. Review of Latest Knowledge and Research on Sustainable Cities at Night Reflected in SDGs

Until recently, few people related outdoor illumination as an indirect contributor to environmental degradation and climate change, even though the latest studies and environmental reports link them together, as highlighted below. For example, burning fossil fuels, which is a main contributor to global warming, has an impact on Earth's increased temperature, and the use of fossil fuels has been used to produce electricity for outdoor illumination. One-fifth to one-sixth of the world's electricity production is consumed by electrical light sources [29]. Urban illumination (compared to rural areas with no outdoor lighting) directly impacts climate change in cities, with spring seasons commencing earlier, extending the photoperiod of illuminated trees and plants, meaning their leaves bud prematurely [30]. In addition, trees do not lose their leaves in time for winter. This causes them to become weaker and less healthy so they become more vulnerable to climate change flooding and pests. The health of trees and plants is important because they play a critical role in cities as they counteract air pollution by converting carbon dioxide into breathable air [31]; they also reduce noise, reduce the urban heat islands in cities, and create important ecosystems for various organisms such as birds, insects and mammals such as bats. The night-time outdoor illumination of streets, buildings and urban parks also attracts insects that can hasten insect decline [32]. Many of them are crucial for the pollinating process, and without their contribution, humans and ecosystems would not survive, because 80% of food production requires pollination by other living organisms [33]. Exposure during the nighttime to blue-rich white light has numerous adverse effects on the environment. For example, this can lead to problems with reproduction, the avoidance of suitable habitats, changes in seasonal migration routes and a reduction in numbers or even the extinction of certain species. Various animals, such as birds, are attracted towards artificial lighting during migration periods causing collisions with buildings and structures that can result in injury or death. Recent data indicate that around 600 species of breeding birds have been lost in European Union countries between 1980 and the present day [34]. Fish such as young salmon migrate through streams, rivers and estuaries to the ocean. These fish migrate at night, cued by illumination levels, and this timing is designed to reduce predation. However, when attracted to illuminated urban bridges, fish become an easy target to predators such as birds and other animals, and as a consequence, their chances of survival are greatly reduced [35,36]. Nocturnal animals such as urban bats can also be negatively impacted by outdoor illumination as this causes a delay or prevents the emergence from their roosts, affecting feeding behaviour, and changing commuting and foraging routes [37]. Bats are important nighttime predators (insect hunters) as they make it possible to limit the use of toxic insecticides in agriculture and forests, and their presence

indicates a strong, healthy and stable natural ecosystem [38]. Additionally, when human settlements on the coast have seaside condominiums, houses and hotels along beaches with poorly executed lighting, female sea turtles are discouraged from nesting, and young sea turtle hatchlings are attracted away from the sea, decreasing their chance of survival [39]. All of this can directly contribute to the loss of biodiversity, on which human existence and wellbeing is dependent [40,41]. *The Living Planet Report* published in 2020 by The World Wildlife Fund, revealed that in the last half century, vertebrate species have declined by an average of 70% [42]. It is also believed that new LED technology with high emissions of blue wavelengths of light might be the potential origin of certain chronic diseases in humans, including cancer [43]. Today, 83% of the human population lives under light polluted skies [44], and the blue component of outdoor lighting increases light pollution much more than older lighting technology (the scotopic/photopic ratio of 4000 K LEDs shows they increase light pollution by 170%), completely prohibiting urban astronomy [45].

Despite this existing knowledge, research in the previously mentioned fields has not yet had a significant impact on cities and communities at night that aim to be sustainable.

This review identified only seven SDGs and eight associated targets indirectly connected to the latest knowledge and research on sustainable cities at night and urban lighting (Table 2).

Table 2. SDGs and associated targets related to sustainable cities at night.

SDG Goal	Target	Detailed Target Description
SDG7	7.a	By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including **renewable energy**, **energy efficiency** and advanced and **cleaner fossil fuel technology**, and promote investment in energy infrastructure and clean energy technology
SDG9	9.4	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource use efficiency and greater adoption of **clean** and **environmentally sound technologies** and **industrial processes**, with all countries taking action in accordance with their respective capabilities
SDG11	11.6	By 2030, reduce the adverse per capita **environmental impact of cities**, including by paying special attention to air quality and municipal and other waste management
SDG12	12.8	By 2030, ensure that people everywhere have the relevant information and awareness for **sustainable development and lifestyles in harmony with nature**
SDG13	13.2	Integrate **climate change measures** into national policies, strategies and planning
SDG15	15.1	By 2020, ensure the conservation, restoration and sustainable use of **terrestrial** and **inland freshwater ecosystems** and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
	15.5	Take urgent and significant action to reduce the **degradation of natural habitats**, halt the **loss of biodiversity** and, by 2020, protect and prevent the **extinction of threatened species**
SDG17	17.7	Promote the development, transfer, dissemination and diffusion of **environmentally sound technologies** to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed

4.2. Written Answers to the Interview Question Provided by International Experts

By analysing 12,874 words in total, this method provided accurate and detailed records of answers from 53 experts (Table 3). This information reflects the latest knowledge and research from various fields in the context of sustainable cities at night and it enables readers of this paper to access the experts' answers and improve their own understanding of this subject.

Table 3. Detailed overview of the written answers to the interview question by international experts. Source: authors' data.

No.	Profession/ Field of Activity	Name	Country *	Quote
1	City representative (Chicago)	Agata Dryla-Gaca	US	"Sustainable cities at night are well designed, developed and operated with an understanding and respect for the natural rhythms of nature. The whole urban ecosystem with all its living organisms are taken into consideration. Such cities also rely on renewable sources of energy, they reduce pollution and contribute to air quality and the comfort of living—providing aesthetic and safe urban spaces."
2	City representative (City of Jyväskylä)	Elisa Hillgen	FI	"To me, it's obvious that we need to think about (and design) the urban environment also for the dark times—people and cities are active 24/7. We need to make choices that are good in the long run, not only for people, but also for nature and animals. Sustainable to me, in lighting design means control, amount, direction and quality of light (and fixtures), that works for a long time and doesn't cause any harmful side effects. We understand the meaning of beautifully illuminated facades, bridges and parks, but we need to carefully consider what kind of lighting, where and why—and also have tools and power as cities to impact on results".
3	City representative (City of Malmö)	Johan Moritz	DK	"From my side, lighting design in sustainable cities is formed by two basics: aesthetics and function. With this in mind I would keep it as simple as: light where it's needed and light when it's needed. This give enormous possibilities of interpretation but it also provides a simple guide as to what to look for when you handle the nightscape."
4	Designer in the built environment (Urban planner)	Riccardo Marini	UK	"Sustainability is a big word and much misused. In relation to cities, I have a simple view that a sustainable city is one that attracts and keeps people there because it offers a high liveability standard—social sustainability is the most important thing for me. To achieve this you actually need considerable environmental sustainability, a critical component of our ability to live on planet earth. I truly believe that we over light everything, not for one minute do I want to create dangerous urban landscapes where people are scared. Moonlight varies anywhere between 0.05 to 0.32 lux and we as a species, can operate perfectly safely with that level of illuminance. We need to understand the perception of light can be mood enhancing or it can create horrible hostile environments that are truly non sustainable. Safety, wellbeing, liveability with a dash of magic is what we are looking for to sustainably light our cities—and in this case the rules need to be rewritten—less is more."
5	Designer in the built environment (Architect)	Filippo Lodi	NE	"Cities as an urban technology concentrate on living/working/playing in one place and therefore, are a sustainable concept by virtue of optimizing resource usage. We could optimize further by adding "light where it's needed". If we talk from a climate change/ecology perspective we should have a more systemic approach, such as what effects what, and at what scale."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
6	Designer in the built environment (Architect)	Foteini Kyriakidou	SE	"Sustainable cities at night are inclusive cities. Lighting as one more element of design should provide a context in which all humans (despite sex, mental or physical difficulties, and social and economic status) can enjoy the urban nocturnal environment. Additionally, also flora and fauna should be treated with the same care and consideration."
7	Designer in the built environment (Architect)	Christine Storry	AUS	"All cities are different, so nighttime sustainability (economic, social and environmental) means different things in different urban contexts. However, as a general rule when considering the impact of artificial light at night, the positive sides of lighting (safety, illumination, visibility, legibility and place-making), and the negative (light pollution, impact on dark skies and animals) all need to be considered."
8	Designer in the built environment (Landscape Architect, Urban Designer)	Sophie Thompson	UK	"Sustainable cities at night in words—Happy, safe, welcoming, joyful, sociable, equitable and nurturing"
9	Designer in the built environment (Lighting professional)	Edward Bartholomew	US	"Sustainability should support all communities equally, including the application of quality lighting and beneficial darkness. Quality lighting balanced with beneficial darkness is sustainable."
10	Designer in the built environment (Lighting professional)	Anne Bureau	FR	"Sustainable cities at night should be decentralized to avoid thousands of people travelling from the suburbs to the city centre and back. There should be no illuminated football games at night (or other sport events) because this attracts insects, and causes sky glow above the stadiums and their parking areas."
11	Designer in the built environment (Lighting professional)	Roberto Corradini	IT	"A more sustainable city is not a goal limited to audacious city planners and engaged eco-enthusiasts, it should be a common vision shared by its citizens. For a lighting designer this means a deep reflection on the concept of sustainability itself. We are often asked to provide more energy efficient lighting schemes, or to replace old streetlights with LEDs, just to say a few. But this is only part of the issue. It is time to shift our thinking about the night. We lighting designers must always keep in mind the impact our lighting designs have on the nocturnal environment. A city's lighting impacts people's health in the long-term (and the effects are known). Energy saving is not enough, a light that shines during the night alters the biological rhythms of plants and animals. Moreover, when a luminaire reaches the end of its life, it must be recycled according to the most strict laws. An environment-centered design is the only way we have to conserve natural resources and prevent more severe damage to our planet."
12	Designer in the built environment (Lighting professional)	Enrique Garcia Carrera	US	"Sustainable cities by night means places that are welcoming and embracing to its inhabitants and visitors, while being mindful and proactive in utilising resources in a way that will ensure long term well-being for generations to come."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
13	Designer in the built environment (Lighting professional)	Carmela Dagnello	UK	"The idea of sustainable cities sometimes seems to play against the freedom acquired in recent years to living the urban context at night. We cannot demonise only the lighting for being handled without an holistic approach. As conscious lighting designers of today, we should make ethical choices and contribute now to sustainable cities of tomorrow."
14	Designer in the built environment (Lighting professional)	Amardeep M. Dugar	IN	"Sustainable cities can be defined as areas where people live and work that carefully meet present needs without compromising the needs of future generations, with night skies being one of the key needs."
15	Designer in the built environment (Lighting professional)	Brian Healy	UK	"Sustainable Cities at Night should incorporate lighting that is fit for purpose. People, Place and Planet all require a full light source assessment and mitigation."
16	Designer in the built environment (Lighting professional)	Rob Honeywill	UK	"As a lighting designer, sustainable cities at night for me means having an overarching holistic approach for everything that is light, and working to bring balance to the environmental night-time perception of our streets and buildings. Simplifying, decluttering, reducing our sky brightness, and developing our spatial ques against our socio-psychological needs."
17	Designer in the built environment (Lighting professional)	Dr Nicolas Houel	FR	"Sustainable cities at night are cities that listen, hear and adapt to the stories of their users' night-time cognitive experiences. At night, the ambiance of these cities echo individual and collective representations. This echo stimulates the permanent reshaping of their identities, multiple, moving, and durable."
18	Designer in the built environment (Lighting professional)	Allan Howard	UK	"Sustainable cities at night means that through light we create a safe environment that enables wayfinding while also creating interest that attracts people into spaces which benefits the local economy. It's not just about the effect, it involves consideration of the products we use, how we place them, their energy and carbon footprint, as well as the use of lighting controls to achieve the task of minimising our footprint on the environment—and through good practice, mitigating the impact on residents, fauna and flora, and the night time sky".
19	Designer in the built environment (Lighting professional)	Florence Lam	UK	"Lighting has the power to shape the way we perceive a place at night, making it safer, more inclusive and inviting; facilitating healthy and sustainable urban lifestyles. Sustainable cities at night means adopting a systemic place-based lighting approach, which celebrates conservation and biodiversity, encourages partnerships and community co-development, and balances the long-term health and wellbeing of people, place, and planet to deliver net positive environmental, societal and economic outcomes."
20	Designer in the built environment (Lighting professional)	Paula Longato	DE	"For me, sustainable cities at night mean they provide safety for both humans and nature. People should be able to wander at night with a sense of safety and enjoyment, and at the same time, be able to gaze at the stars (implying, of course, that there is no or little light pollution)"

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
21	Designer in the built environment (Lighting professional)	Mark Major	UK	"Sustainable cities at night to me, means carefully balancing the benefits that artificial light provides, both socially and economically, whilst ensuring we minimise any potential damage to the planet. This doesn't only mean using as little energy as possible but also avoiding over-lighting and over-specification, minimising light pollution and mitigating negative impacts on both people and local ecologies. We also need to think about how we can re-use and re-cycle the equipment we use, looking at much greater circularity of design. Given the climate emergency we need to really think very hard indeed about treating electric light as a precious commodity. We should only use exactly what we need, where we need it and when we need it!"
22	Designer in the built environment (Lighting professional)	Alexander Rotsch	DE	"The role that urban lighting plays in cities will be influenced more and more by a multitude of social, economic, environmental, technological, and political factors. A sustainable urban lighting design helps cities to master the challenge of the future to be more resilient while also being a healthy, comfortable, safe and fun place to live. It does not loudly celebrate itself or is just functional, but serves the residents, including humans, animals and flora. It is smart, interactive and inclusive. It supports creating a distinct identity which makes the city at night time more legible. It uses natural light at its best potential during daytime. It fosters well-being, promotes reasonable consumption, and applies the principles of a circular economy. And it conquers back darker skies at night for humans and wildlife to enjoy."
23	Designer in the built environment (Lighting professional)	Prof. Andreas Schulz	DE	"Artificial light is an important aspect for the cityscape during the night. It offers orientation and well-being for an individual society with different demands on living and moving within a city. This leads to the focus of sustainable lighting solutions to fulfil human and environmental standards."
24	Designer in the built environment (Lighting professional)	Dr Linnaea Tillett	US	"The sustainable city of the future will have public lighting that takes its energy from the sun and can be quickly and efficiently replaced when it is washed away, blown over, or burnt to the ground."
25	Designer in the built environment (Lighting professional)	Paul Traynor	UK	"I think that of all places where public lighting can be justified it's in our cities. Night-time economy is just one aspect of urban situations, whether that's the hospitality trade or for shift-workers. Sustainability is a greater objective than it ever was, but not to the exclusion of why our cities are interesting places to live or visit at night."
26	Designer in the built environment (Lighting professional)	Koert Vermeulen	BE	"For me a sustainable city by night means that inhabitants have to make the right decisions and keep their part liveable by keeping the environment safe, respectful and long-term sustainable, and the government also needs to ensure the city is comfortable and that it makes decisions about long-term sustainability for its inhabitants. It cannot come from one side only. It's not government has to do it for me and then I can do whatever I want."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
27	Designer in the built environment (Lighting professional)	Carla Wilkins	DE	"For cities to be sustainable at nighttime there must be a balance between vibrant urban living and the experience of sensible resource-saving lighting. As lighting designers, we have to enhance our design intelligence with an holistic approach that respects all creatures. "
28	Designer in the built environment (Light artist)	Titia Ex	NL	"Making cities more sustainable and healthy at night means we have to (re)learn our physical connection and sensitivity to both light and dark. By being aware of this, we can extinguish superfluous lights and media billboards and add quality."
29	Designer in the built environment (Light artist)	Daan Roosegaarde	NL	"Everyone is now in their own little bubble, disconnected from each other. I realised that every night, there is actually an amazing light performance hidden up high in our sky. Seeing stars brings the stars back to our own street. The stars are just one switch away."
30	Luminaire manufacturer	Urbain du Plessis	AU	"Providing the right light for the purpose, where and when it's required is fundamental to achieving good outcomes for every activity, from romantic dinners to brain surgery and carnivals. Failure to achieve the purpose, equates absolute waste, doing so with minimum impact is the bedrock of sustainably."
31	Luminaire manufacturer (iGuzzini)	Peter Ross	IT	"The topic Sustainable Cities at Night for iGuzzini means iGuzzini-life. Since the early 1980s, iGuzzini has been an activist and is active in the battle against light-pollution, providing professional lighting tools with the highest efficacy, energy saving controls solutions, and precise light-distributions. Sustainably illuminated Cities at night are liveable, safe and responsible in their use of electrical energy."
32	Luminaire manufacturer (Selux)	Dwayne Waggoner	DE	"For us at Selux, sustainability at night considers not only the sustainability of a product, but also the sustainability of the environment and living creatures. Ensuring that luminaires are insect and animal friendly is an important concern. Additionally, products that are not only sourced sustainably but also designed to last and endure over time is an important factor for us to consider as outdoor lighting manufacturers."
33	Luminaire manufacturer (Bega)	Michael Wilson	UK	"I believe it is a fundamental requirement by all, to reduce damaging impacts on the environment and to provide us all with wider benefits to the World we live in. This means zero wasted light, simple and intelligent controls, and the ability to appreciate our beautiful World without harming it."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
34	Environmental Lawyer	Dr Phil Cameron	US	"The Sky and Night Sky are a public space. The sky includes air, sound and light. These are a kind of property owned by the community and are a common good. Protection of public spaces (and the protection of rights) is one of the primary reasons the government is established, according to most constitutions. The rationale is that public spaces belong to everyone. So that everyone can enjoy the public spaces, the government takes control of these spaces, to protect these spaces so that no one person or group destroys, blocks or impedes this community property. This is the rationale for the government controlling parks in cities, large areas of wilderness, and also for the government controlling the air and skies above cities and the whole country."
35	Medical doctor	Dr Mario Motta	US	"To have sustainable cities in the future, we must have protection for human health and the local and wider environment. To that end, without sacrificing quality of life at night, it's important to favour light fixtures that emit low to zero levels of blue light, and limit glare. This will make our cities safer for humans by reducing the carcinogenic potential of high blue emissions from light sources. This approach will also protect local wildlife, even to the surrounding suburbs and the countryside—with no significant compromise of true outdoor lighting needs."
36	Researcher	Dr Salvador Bara	SE	"Sustainable cities at night are cities meant for people and the environment. They provide a comfortable lighting atmosphere that use artificial light in a sensible way: as a means and not an end, with restraint and common sense, fully aware of its immense usefulness and its well-known negative effects. Cities understand that ornamental light was meant to help appreciate the cultural values of the built heritage, and not the other way round. They also consciously meet the need of darkness (the 'besoin d'obscurité' in Samuel Challéat words) that we all have as human beings."
37	Researcher	Dr John Barentine	US	"A truly sustainable city at night carefully sets exterior lighting levels that provide comfort, amenity and safety for multiple users of outdoor spaces; responsibly manages energy use; and supports a thriving nocturnal urban ecology. Those conditions in turn enable a robust nighttime economy that helps residents improve their own lives by providing opportunities that don't simply end every day at sundown."
38	Researcher	Fabio Falchi	IT	"All the artificial lighting of cities at night, including light that is somehow useful and the light that escapes outdoor, even if produced indoor, should not impact on the environment and on human health and well-being. Nor should it compromise the often neglected but fundamental cultural aspect connected to the now denied inspiration given by contemplating the starry sky. As light propagates in the atmosphere, the impact of city lights can affect the night environment very far from the light sources, polluting the sky even at hundreds of km away."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
39	Researcher	Dr Ava Fatah gen. Schieck	UK	"Sustainable cities at night are defined through rhythms, flows and temporal rhythms. Yet, sensory rhythms such as light and sound, in particular night rhythms, seem to be overlooked. We need to take sensory rhythms into account when designing for urban life, to support, extend and even enable new activities to take place during the night."
40	Researcher	Dr Maja Grubisic	DE	"In the context of light pollution, sustainable cities at night means to me that light is used in a way that takes into consideration visual needs, safety, aesthetics, and its health and biological impacts. This means using the minimum light intensity necessary for its purpose and choosing warm light colours when possible, minimising glare, light spill and obtrusive lighting, avoiding the illumination of habitats like water or tree tops in parks, and switching architectural and commercial lights off late at night. An interdisciplinary approach is obviously needed to deliver this. Noise reduction is also important in a sustainable city, but this is another topic."
41	Researcher	Dr Kevin Houser	US	"In nighttime urban environments, too much light is far more common than not enough. This leads to glare, increases the likelihood of circadian disruption, consumes excessive energy, requires more lighting gear, wastes money, and disrupts ecosystems. Light is also employed as a surveillant technology, where the negative consequences of light at night disproportionally affect neighborhoods identified as "high crime", where such classifications are a consequence of racial profiling and systemic structural inequities. Durable and lasting progress in the sustainability of nighttime environments will be elusive until the structural inequalities that exist in cities are squarely addressed."
42	Researcher	Dr Benedikt Huggins	DE	"Lighting our cities to meet Sustainable Development Goals requires us to look beyond energy efficiency. We need new ideas on how to regulate urban and suburban areas to reduce their environmental impact while improving our public infrastructure at night."
43	Researcher	Dr Annette Krop-Benesch	DE	"Sustainable cities must be more than energy-efficient. They must protect the resource of night as a dark and quiet time period, to allow their residents the time they need to regenerate and live a healthy, well-balanced life."
44	Researcher	Dr Raul Cerveira Lima	SE	"A sustainable city (at night) considers artificial light a pollutant, and therefore, uses it sparingly to favour the balance of ecosystems and the fixation or return of wildlife, whilst avoiding discomfort to residents caused by obtrusive light or glare. In addition, the city's night landscape and public spaces should include a dark and starry sky for contemplation, which can be achieved with an effective management of public and private lighting, while also achieving a reduction in the propagation of light outside the limits of the city."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
45	Researcher	Dr Alejandro Sanchez de Miguel	SE	"Sustainable cities should follow related lighting norms/regulations, but as these are much higher than what is actually needed they should be adopted only when they are scientifically meaningful. Limits on light pollution should be agreed to in order to stop its increase, and to minimise any damage to global and local ecosystems. All existing bad lighting should be improved and environmental impact studies should be performed for new developments."
46	Researcher	Dr Sibylle Schroer	DE	"Sustainable cities at night provide a fair service to all stakeholders whilst using a minimal amount of resources. They are fair in providing illumination with the least adverse effects on nocturnal ecological systems and human well-being, they also reduce energy consumption and the use of human resources (i.e., security guards working at night, etc.) by providing a pleasant environment without glare and obtrusive lighting that intrudes into living habitats."
47	Researcher	Dr Don Slater	UK	"While the word 'sustainability' has probably been stretched beyond any clear meaning, I think we generally mean that cities at night should be able to reproduce a safe and dynamic stable nightlife (including supporting both workers and consumers), and that it should not detract from global environmental sustainability through its carbon footprint, pollution or destruction of habitats. But above all else, a sustainable city at night is one that is designed for 'social' sustainability, so it allows for the active use of city spaces and supports the urban needs of diverse and often conflicting citizens and visitors."
48	Researcher	Catherine Perez Vega	DE	"It is an opportunity to re-think the many ways that light is used by night. It's time to lead responsible lighting approaches based on scientific evidence that considers lighting for the benefit of society, while also protecting naturally dark skies, and recognising the value of the night-time for living organisms and ecosystem services, and the realms we typically forget."
49	Researcher	Ken Walczak	US	"Sustainability is only an effective concept if society as a whole is aware of and invested in its benefits. I believe our cities are overwhelmed by light at night because how it's used and why it's used, has rarely been questioned."
50	Responsible lighting advocate	Ruskin Hartley	US	"Today, cities worldwide strive to be more sustainable by reducing their carbon footprint, reclaiming water, and planting trees. To me, light pollution is the most visible indication of a city's commitment to sustainability. To be considered "sustainable", cities must also take steps to use light at night more responsibly, reducing their overall environmental impact."
51	Responsible lighting advocate	Anna Levin	UK	"Night itself is integral to true sustainability, and its importance is often underestimated, therefore, a sustainable city needs sufficient darkness to maintain the long-term health of all inhabitants—humans, plants and animals. Artificial light at night needs to be understood as pollution, used sparingly and designed carefully to minimise harm and ensure maximum accessibility."

Table 3. *Cont.*

No.	Profession/ Field of Activity	Name	Country *	Quote
52	Responsible lighting advocate	Simon Nicholas	UK	"In my view, the rapid shift to LED for outdoor lighting has been a complete disaster because of a lack of understanding of the serious drawbacks with LED and a total failure to take an holistic view of the purpose and needs of public realm illumination. Sustainability means so much more than just minimising energy use when the pursuit of such a singular goal causes so many unwanted side effects. It's hard to believe that this technological shift has taken place when it's so blatantly obvious that moving from a low-CCT, low-luminance, isotropic light source to a high-CCT, excessively high-luminance, anisotropic source has serious, multiple adverse consequences for health, equality and ecology."
53	Responsible lighting advocate	Kyra Xavia	NZ	"Sustainable cities understand darkness is a precious resource and an asset that needs to be treasured. This involves ensuring policy, planning and development respect the nighttime. It also means finding creative ways for inhabitants to experience a sense of appreciation, comfort and safety in spaces that are kept intentionally dim (nocturnal placemaking)".

* The two-letter country codes were applied based on the International Standard for country codes ISO 3166-1.

4.3. Analysis of the Experts' Answers

By analysing all 53 responses all together, 754 words were identified (Table T) using and the functions available in the Text Analytics Toolbox. The total number of their repetitions was 1951. A large proportion of these words were repeated numerous times. The most frequently used words were: *light*, repeated 97 times; *cities*, repeated 71 times; *sustainable*, repeated 69 times; and *night*, repeated 57 times. The frequency of occurrences of the most popular words is presented in the Figure 2 in the form of a bar chart.

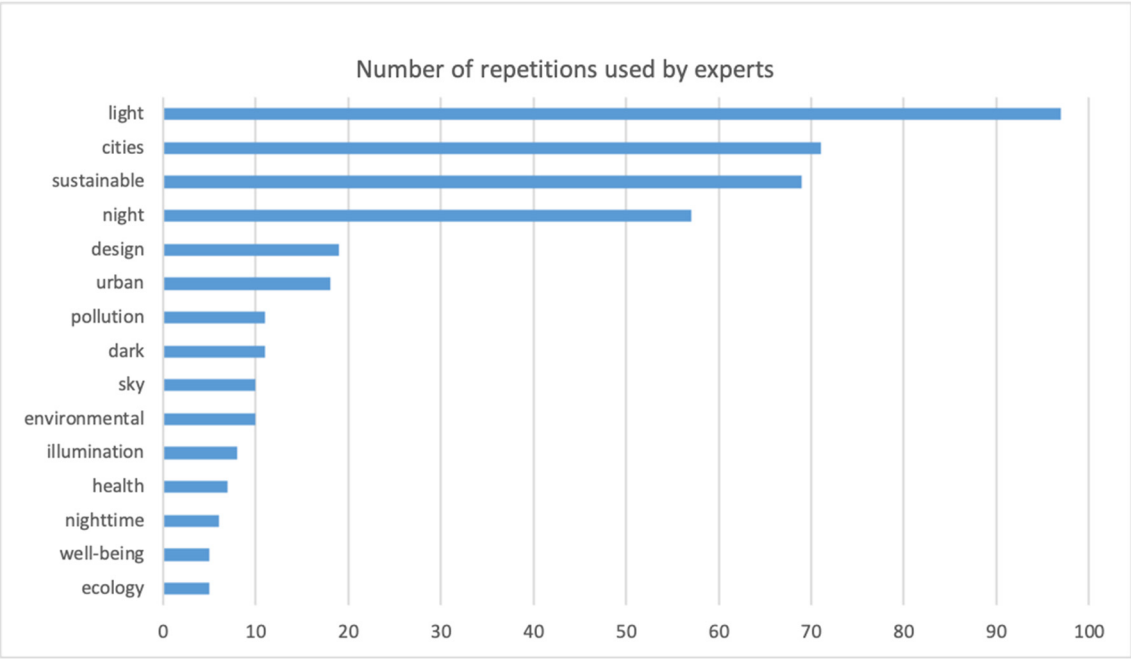

Figure 2. 15 most common keywords used by experts (interview participants) in context of sustainable cities at night presented as a composite bar chart. Source: Authors' data.

According to the performed statistical analysis, 44 words repeated in the experts' answers are included in the SDG keywords, which was only 6% of all words in total, of which, only 15 of the words were repeated 5 or more times (Figure 3). These numbers strongly indicate a lack of proper correlation between SDG keywords with the experts' answers. The latest knowledge and research from various fields in the context of sustainable cities at night has not been properly reflected in SDG goals and targets.

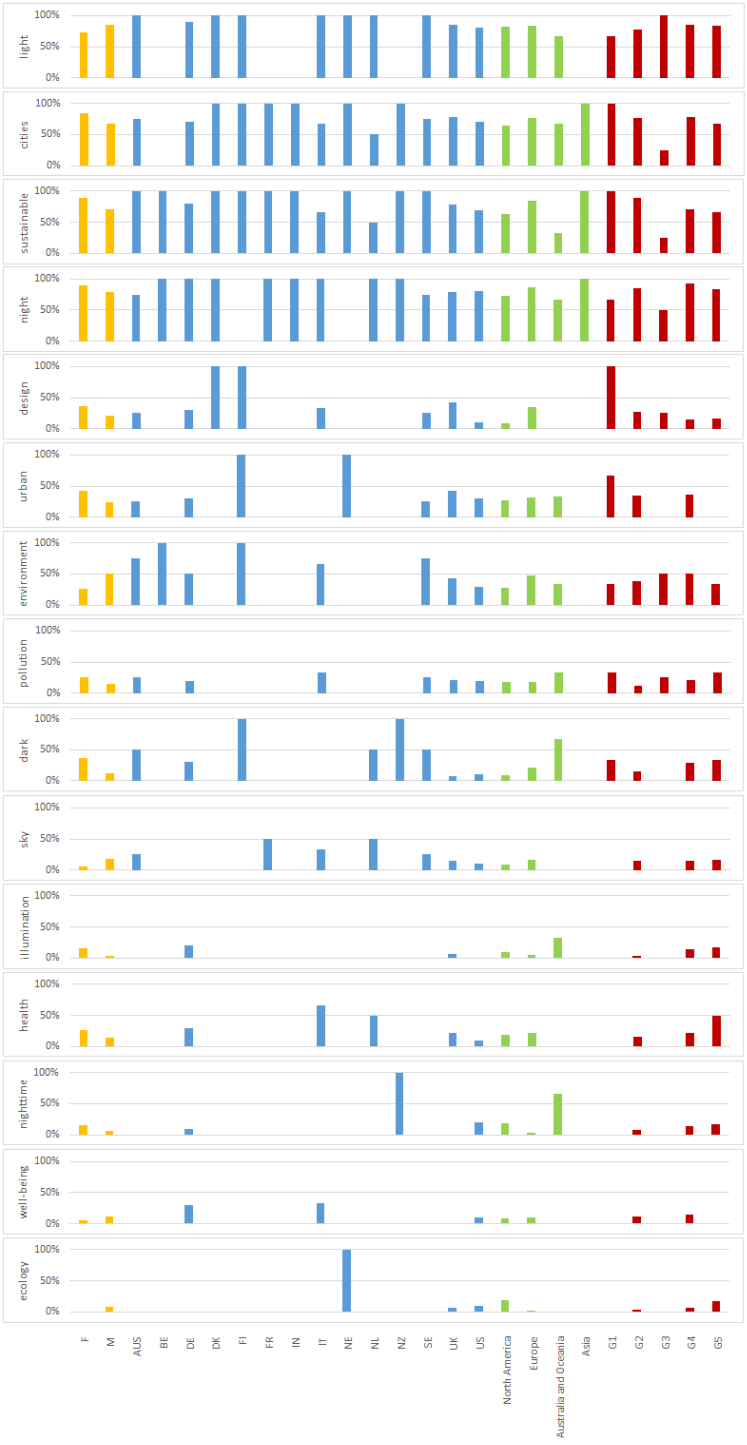

Figure 3. Fifteen of the most important and commonly recognized keywords used by experts in the context of sustainable cities at night and their percentage of use based on gender, country of residence, continent of residence and group/occupation, presented as a composite bar chart. Source: authors' data.

4.3.1. Gender

No significant differences were noticed in the opinions of experts by analysing 15 selected words, while one insignificant conclusion was found: women used the words: *dark*, *pollution* or *health* more often, while men mentioned *ecology* and the *environment* more often.

4.3.2. Country of Residents

Due to limitations such as the representation of one expert from some countries, it is difficult to assess any meaningful dependence. However, the division into continents gives a clearer picture of the differences in some words, and the division into countries gives an additional insight into the details of the statements.

4.3.3. Continent of Residents

In the case of the most frequently used words, such as: *light*, *cities, sustainable* and *night*, there are no significant differences in the statements. The only word one could pay attention to is *sustainable*, because a much smaller percentage of residents from Australia and Oceania used this word. The representation of one expert from the continent of Asia, did not mention the word *light* at all. However, due such a low representation, the analyses of this group should not be treated equally with other groups that represent continents.

In the case of less frequently used words, we can see that the words

- *dark*, *illumination*, *nighttime*—were used by a greater percentage of inhabitants of the continent of Australia and Oceania,
- *health* and *wellbeing*, *sky* and *ecology* have been used only by the people of America and Europe.

4.3.4. Groups/Occupation

The division into groups allows us to draw the most interesting conclusions—here, we can see what particular professional groups pay attention to. In the case of the most frequently used words (light, cities, sustainable, night), we noticed that group 3 (Luminaire Manufacturers) used a significantly lower percentage of the following words: cities, sustainable, night. In the case of less frequently used words, we can see the following:

- *design*—was used by 100% of group 1 (City Representatives) representatives, representatives of other groups used this word in their statements in a significantly lower percentage,
- *urban*—was used only by representatives of groups 1, 2 (Designers in the built environment, including Lighting Professionals) and 4 (Researchers),
- *environment* and *pollution*—was used by representatives of all professional groups, at a similar level, not exceeding 50%,
- *dark*—has not been used by representatives of group 4
- *sky*, *illumination*, *health*, *nighttime*, *ecology*—are the words used by three groups: 2, 4 and 5 (Environmental Lawyers, Medical Doctors, Responsible Lighting Advocates).

However, it should be noted that a significant percentage of group 5 used the word *health*, and for the remaining words the percentage was similar,

- *wellbeing*—was used only by representatives of groups 2 and 4.

4.4. Correlation of SDG Keywords with the Experts' Answers

On the basis of all tables obtained from SDG 1 to SDG 16 (for description and characteristics, see Section 2—Methods), the total number of identified SDG keywords (all words) in the experts' answers were verified. The result of 98 keywords was a total of 376 repetitions of keywords (these values take into account the lack of repetition of the keyword in several SDGs—repetitions were eliminated from this analysis). Figure 4 shows the graphical form of the individual keywords used by the experts and the frequency of their occurrence.

Figure 4. The word cloud of the individual keywords used by the experts and the frequency of their occurrence in SDGs. Source: authors' data.

In order to be able to verify the dependence of the subject matter raised in the question, the number of repetitions of keywords for each SDG were summed up separately. The results are presented in Figure 5.

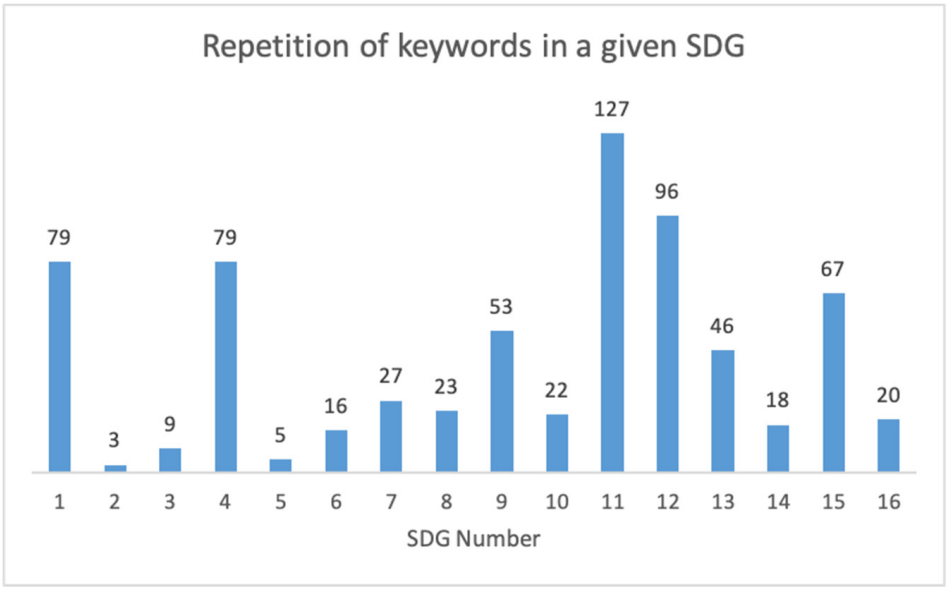

Figure 5. The arithmetic mean of the repetitions of experts' keywords per SDG 1 to SDG 16, presented as a composite bar chart. Source: authors' data.

Word clouds were generated (Figure 6) to verify in more detail the specific words used per SDG 1, 4, 9, 11, 12, 13, 15, for which the repetition values were above average (the arithmetic mean of the repetitions was 43).

Figure 6. The word cloud graphics for the keyword repetition values above average in the SDG 1, 4, 9, 11, 12, 13, 15, indicating the importance of each word with font size and colour. Source: authors' data.

Based on the word cloud graphics, the keyword *sustainable* was not identified in targets of SDG 1 (No Poverty), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). Therefore, with SDG 11 being very closely connected to the topic of this paper, the answer to Q3 on key aspects of urban lighting which should be met by for cities and communities to be sustainable after dark, seems to be relevant, as they could possibly be discussed and integrated in future targets.

4.5. Analysis of the Actors Involved in Urban Design and City Lighting

Tables 1 and 3 reveal that there are emerging professionals currently involved in the field of ALAN that exist apart from the established, traditional *actors* (urban planner, architect, landscape architect, urban designer, engineer and transport planner).

The identified new group of professional actors (lighting professionals, researchers, specialists, and artists) can contribute their skills and knowledge to help better understand the different requirements and challenges involved in creating appropriate solutions for sustainable cities at night (Figure 7). This is fundamental due to the development of new technologies, novel scientific research and the complexity of urban design and city lighting issues.

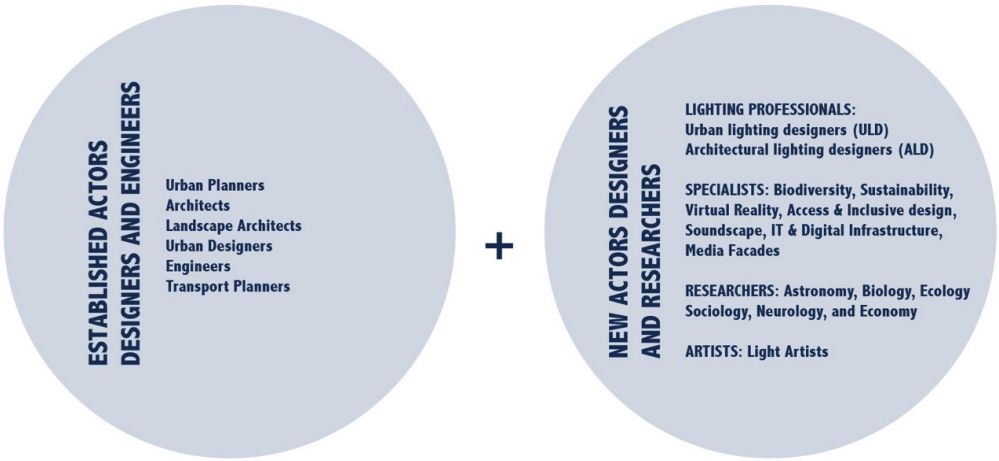

Figure 7. Established and new actors in urban design and city lighting. Source: authors' own work based on experts' opinions.

4.6. Analysis of Key Aspects of Urban Lighting in Successful Sustainable Cities, Identified from Online Interviews

The content of Table 3 indicates that each of the experts highlighted the most important key aspects based on their professional background/occupation. However, positive change can only be integrated for urban lighting in sustainable cities by connecting all these aspects together, and by establishing their hierarchy and clearly defining their aims in a holistic manner.

5. Limitations of the Study

Despite the contributions mentioned in Section 4, this study has its limitations, which can be identified in three areas below:

5.1. Experts' Interviews

5.1.1. Sample Size

The obtained data sample is limited. Interviewing more participants from various countries and continents could possibly bring different perspectives to the research.

5.1.2. Gender

The use of an equal number of interview participants (female and male) could possibly influence the results of keywords, as some research indicates that linguistic differences between genders exist [46] and females tend to use a different vocabulary to explain certain aspects/phenomena. As the field of urban lighting is relatively new and often male dominated, it was difficult to match these numbers.

5.1.3. Groups

The number of people in the group could be more homogenous, as this might impact the number of keywords and their hierarchy.

5.1.4. Language

In order to obtain an international perspective, not all the experts were native English speakers; therefore, the intended meaning may have been lost when translated into English, or they may use more simplified wording to describe certain phenomena.

5.2. Research Methodology

5.2.1. Research Question

In order not to influence the opinions and feedback of the respondents, the main interview question was open ended, and it did not include a precise description connected to urban lighting. This approach could impact the final results.

The answers from experts could have been followed up with some more targeted questions in order to more clearly target the experts' responses to the SDGs. Unfortunately, this was not possible due to scheduling constraints.

5.2.2. MATLAB Software

MATLAB chose not only the nouns and adjectives, but also the other words indirectly related to the topic, such as: just, even, common, etc. Therefore, it was necessary to verify each word and, if necessary, eliminate it. Additionally, to identify the most repeated keywords terms, this software searched and evaluated single words. Currently, to describe certain phenomenon, a combination of two words is necessary, for example: "light pollution", "carbon footprint", "environmental impact", "environmental sustainability", "dark skies", "human health", "energy savings", "artificial light", "outdoor lighting", "night-time economy", "lighting norms", etc. Hence, the results of keywords may differ from the intentions of the experts and lead to gaps in the analysis.

5.2.3. Elsevier 2021 SDG Mapping

Not all the SDGs were included in the Elsevier 2021 SDG Mapping; for example, Goal 17 (Partnership) was not taken into consideration as this research does not yet have sufficient research available to map [47].

The identified keywords by Elsevier are based on SDGs/targets wording as well as their contributors' interviews and these do not seem to include aspects connected to artificial light at night and its impact.

6. Discussion

Recent initiatives, including the international conference on Responsible Outdoor Lighting at Night (ROLAN 2022) [48] and Dark and Quiet Skies for Science and Society II. Implementing the Recommendations [49], support the argument that the impact of urban lighting in sustainable cities remains poorly understood in the context of sustainable development. Therefore, in this paper, we examined if SDGs with their goals and targets reflect the latest knowledge and research from various fields in the context of sustainable cites by night. Besides, we wanted to see if there was a link between SDGs and targets, and experts' responses about this topic. We also investigated which key aspects of urban lighting should be met by the SDG11 for cities and communities to be sustainable after dark. Lastly, we sought to understand what new design process, actors and actions should be introduced to balance the various lighting needs of humans, with their desire to coexist with the natural environment in cities without adversely impacting them, in order to create sustainable cities at night that are healthier and environmentally responsible.

6.1. The Lack of Latest Knowledge and Research on Sustainable Cities at Night Reflected in SDGs

The reviewed Sustainable Development Goals (SDGs) and their targets were shown to be limited, with very little association to sustainable cities at night and outdoor illumination, as they did not take into account the growing body of lighting-related research in diverse fields on the impact of outdoor illumination on humans, flora, fauna and the natural environment. Although, there are some references to renewable energy, energy efficiency, clean and environmentally sound technologies and industrial processes, environmental impact, sustainable development and lifestyles in harmony with nature, climate change measures, degradation of natural habitats, loss of biodiversity, and the extinction of threatened species; however, these are not directly linked to outdoor illumination (Table 2). Furthermore, none of the six article keywords described in Section 2.1 could be identified in SDG11 and other UN Goals.

6.2. Missing Targets in SDGs

Despite some limitations identified by the authors in Section 5, the analysis and statistics of the performed study revealed the topic of the impact of artificial light at night on cities has been omitted from the SDGs and targets. In Figure 8, the keywords were compared between SDG1 to SDG16 and the experts' interviews. This revealed a different focus between the expert group and the SDGs on the issue of sustainable cities at night with the SDGs missing crucial words, for example light and night. This indicates that Elsevier 2021 SDG mapping is a matrix which requires improvement, as the suggested keywords used in the SDGs have been created by people who seem to be lacking awareness about the aspects raised in this paper. This also indicates that by missing these targets in the SDGs, policy makers and the general public cannot be properly educated to protect the planet and to balance social, economic and environmental sustainability.

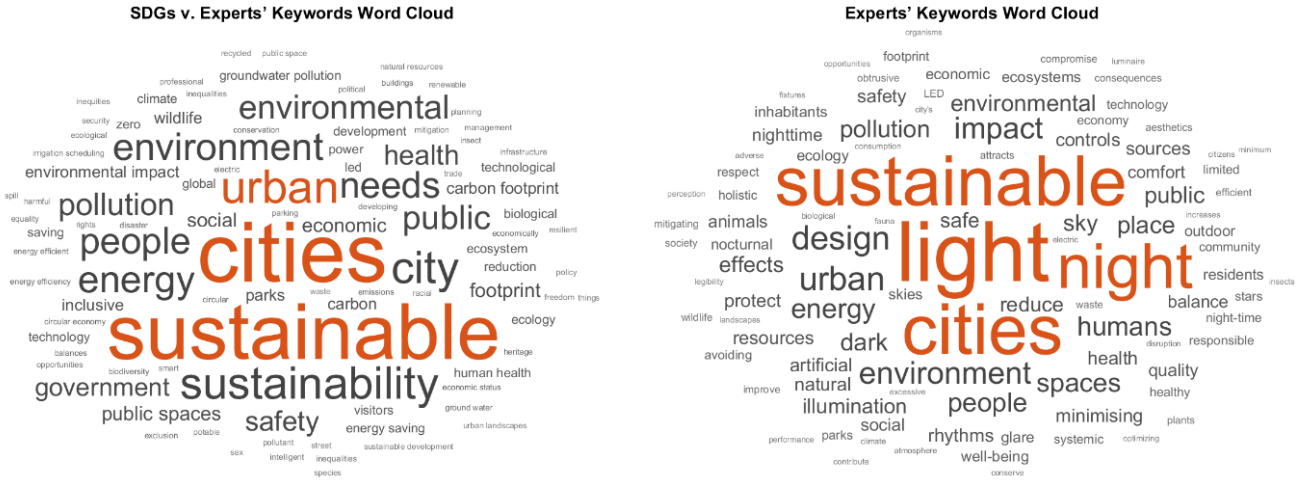

Figure 8. The word clouds of the individual keywords connected to sustainable development and sustainable cities, mentioned by (**a**) goal SDG 1 to SDG 16 and (**b**) experts' interviews. Source: authors' data.

6.3. Key Aspects of Urban Lighting in Sustainable Cities

As urban lighting is a relatively new field with emerging professionals [50], many aspects have not been addresses by sustainable cities. Currently, there seems to be an uncoordinated explosion of vividly coloured and bright outdoor illumination on building façades, in parks and in the streetscape of many cities around the world [51,52]. Many *urban planners* and *architects* appear to have discovered the design possibilities of artificial lighting as a new medium, overlooking the importance of thinking holistically about environmental

aspects [53,54]. In addition, some *lighting professionals* may be unaware of the negative impact their urban illumination can cause, if designed improperly, which necessitates a serious rethink of their design approach [55]. Unfortunately, the new knowledge of the impact of artificial lighting on humans, flora and fauna is rarely available to them and very complex [16]. The reason for this is that until recently *researchers* worked in isolation and did not share the findings of their scientific work with those who design cities and the lighting. This occurred because researchers were not considered an important partner in the overall research process [56]. However, some *luminaire manufacturers* have recognized the importance of collaborating with researchers and lighting professionals and the need to develop new tools, as well as lighting solutions to support the safety and wellbeing of humans, flora and fauna [57,58]. Yet the process to develop appropriate sustainable solutions is not immediate. In addition, although *responsible lighting advocates* (representing the end users) are informed and knowledgeable about the various challenges, they are rarely invited to be part of the design process [59]. Although some *city representatives* are aware that they need to make choices that are beneficial in the long term, not only for people, but also for nature and animals, the process to coordinate all the stakeholders involved can often be overwhelming and complex.

In order to create truly sustainable cities, not only by day but also at night, eight (8) key aspects of urban lighting were identified by the authors: (1) social; (2) safety, security and wayfinding; (3) cultural and heritage; (4) environmental; (5) regulatory and legal; (6) night-time economy; (7) public health and wellbeing; and (8) technological (Figure 9). As many of these aspects have not been taken into consideration by the UN Agenda 2030 [60], it is therefore proposed, that the *SDG 11 Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient and sustainable* [42] should be updated to address these key aspects, including the mitigation proposals for the numerous adverse impacts caused by artificial lighting at night (ALAN) on public health, wellbeing, and the environment.

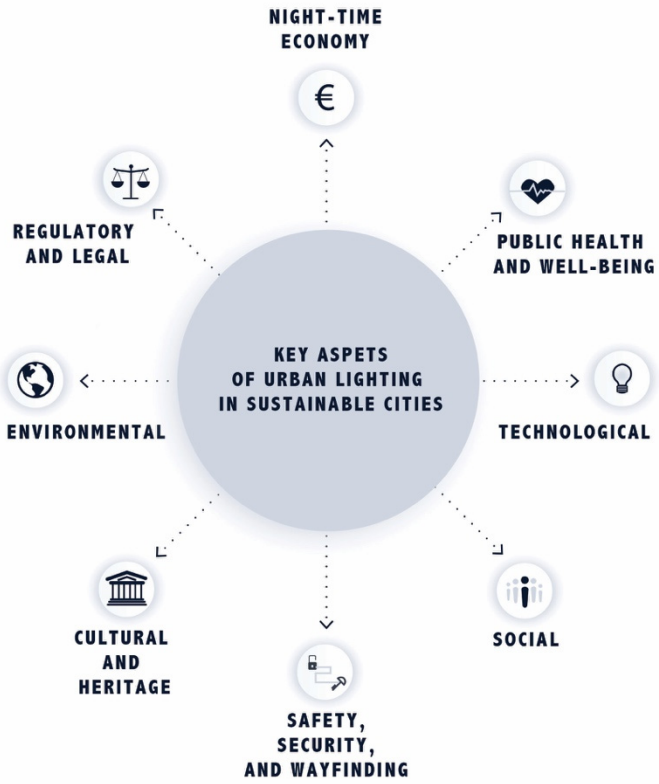

Figure 9. Eight key aspects of urban lighting in successful sustainable cities identified by online interviews. Source: authors' own work based on experts' opinions.

(1) Social

Urban lighting should support the active use of public spaces in cities by residents and visitors during the evenings and early nights, by improving its liveability and social relationships within the urban community regardless of gender, age, race or economic status [61,62].

(2) Safety, Security and Wayfinding

Urban lighting should also provide safety and visual reassurance in cities for elderly residents and visitors, supporting their orientation and wayfinding by guiding them around outdoor environments and public spaces with the help of appropriate lighting [63–67].

(3) Cultural and Heritage

Decorative urban lighting should facilitate appreciation for the cultural value of the built heritage via the sensitive illumination of buildings façades, monument, structures and artefacts to give them identities after dark [67].

(4) Environmental

Urban lighting should reduce light pollution in order to respect human needs and the natural environment, including flora and fauna. It is also crucial to question what kind of urban illumination is needed, as well as where it is needed and when. Additionally, the built environment can benefit from prioritising nocturnal placemaking (deliberately leaving some areas free of illumination so they are dark sanctuaries for ecology); preserving humanity's right to have visibility of the dark night sky and celestial bodies as an ancestral global common; and enabling continual professional and amateur night-time observations [16,37,68].

(5) Regulatory and Legal

Urban lighting should be properly regulated in the form of soft and hard laws, and it should also be monitored in order to counteract artificial light pollution and its negative impact [37,59,69].

(6) Night-time Economy

Urban lighting should support nocturnal activities including tourism, retail and hospitality [62,68].

(7) Public Health and Wellbeing

Properly designed urban lighting should take into consideration public health and wellbeing by avoiding over illumination, light trespass into the windows, balconies and gardens of residential properties, and glare, all of which can desynchronize circadian rhythms, resulting in insomnia and hormonal imbalance [43].

(8) Technological

Urban lighting should save energy by using energy efficient light sources, along with luminaires that integrate proper optical design, have an appropriate light spectrum and employ smart lighting control systems. In addition, it should include aspects such as a circular economy, and the reuse and recycling of lighting equipment. Moreover, urban lighting should apply other forms of natural and inexhaustible energy such as solar energy to power the outdoor illumination of our cities [16,70,71].

6.4. The Design Process

6.4.1. Current Urban Lighting Design Process

The current standard process for an urban lighting project revealed by experts during online interviews, typically involves four actors: *the client*, *designer in the built environment*, the *contractor* and *end user* (Figure 10).

Figure 10. The current linear design process of an urban lighting project. Source: authors' own work based on experts' opinions.

In the existing process there is improper communication between the stakeholders (the client, the designer in the built environment, and the contractor), as well as the end users (residents, responsible lighting advocates, visitors).

They interconnect in a linear manner with the following actions: briefing, documenting and execution. The top-down hierarchical approach is the way things are communicated.

The *client* describes all the possible project requirements so as to provide sufficient information for appointing a suitable *designer in the built environment*. Briefing documents describe all the crucial project requirements that need to be met with the final successful design solution. It outlines the deliverables and scope of the urban lighting design project including any products or works, as well as the timing and budget. Despite this, briefing documents can often be very confusing, particularly when members of a project team are working together for the first time or the *client* does not explain all of the project requirements.

The *designer in the built environment* prepares the concept design and the design development, as well as detailed design documents that describe the urban lighting solution to the *client*. The role of the lighting designer as the person responsible for designing the urban lighting has not yet been established. Typically, urban lighting is orchestrated, overviewed and conceptualised by urban planners or architects (building, landscape) and planned by the electrical engineer or luminaire manufacturer (who provides free design for selling the luminaires to the *client*). The necessary skills and knowledge to provide the appropriate vision and solutions for the complex task of city nighttime illumination are therefore often underprovided. There are also no established definitions of a lighting design strategy or lighting masterplan, nor are there guidelines on how to integrate urban lighting into overall urban development policies and processes.

The project is executed by the general *contractor* based on the documentation issued and prepared by a traditional *designer in the built environment*, who can also assist the *contractor* by reviewing their drawings and preparing operation and maintenance documents. The general *contractor*, usually appointed by the client, is responsible for the execution of the overall project, including the provision of all materials, labour, equipment and services necessary for project completion. The *contractor* employs specialised subcontractors to execute the various tasks explained in the detailed documentation. This is often a unidirectional process.

The *end users* are often involved too late in the design process to influence any design change or the direction in which the project is going. To complicate this, the *end users* have no tools to allow for the possibility of measuring and communicating their feedback and social satisfaction.

6.4.2. Proposed Iterative Urban Lighting Design Process

To cover the latest research facts, knowledge and technologies, the collaborative process among established and new actors is essential for the success of urban lighting at night. The proposed iterative design process involves repetitive rounds of analysis and feedback; the objective is to arrive at the desired decisions and results with each repetition (iteration). This iterative process breaks down the many issues of large and complex urban lighting into smaller chunks. With each iteration, additional features can be designed, developed and tested until a fully functional final lighting design solution is arrived at, ready to be

deployed. The *client*, *designer in the built environment* (incl. researchers and specialists) and *contractor,* together with the *end users*, should all work together towards a common goal—a successful urban lighting solution that supports a sustainable city (Figure 11). This iterative process provides an equal role to all the participants, allowing a platform for communication, decision-making and the implementation of appropriate solutions.

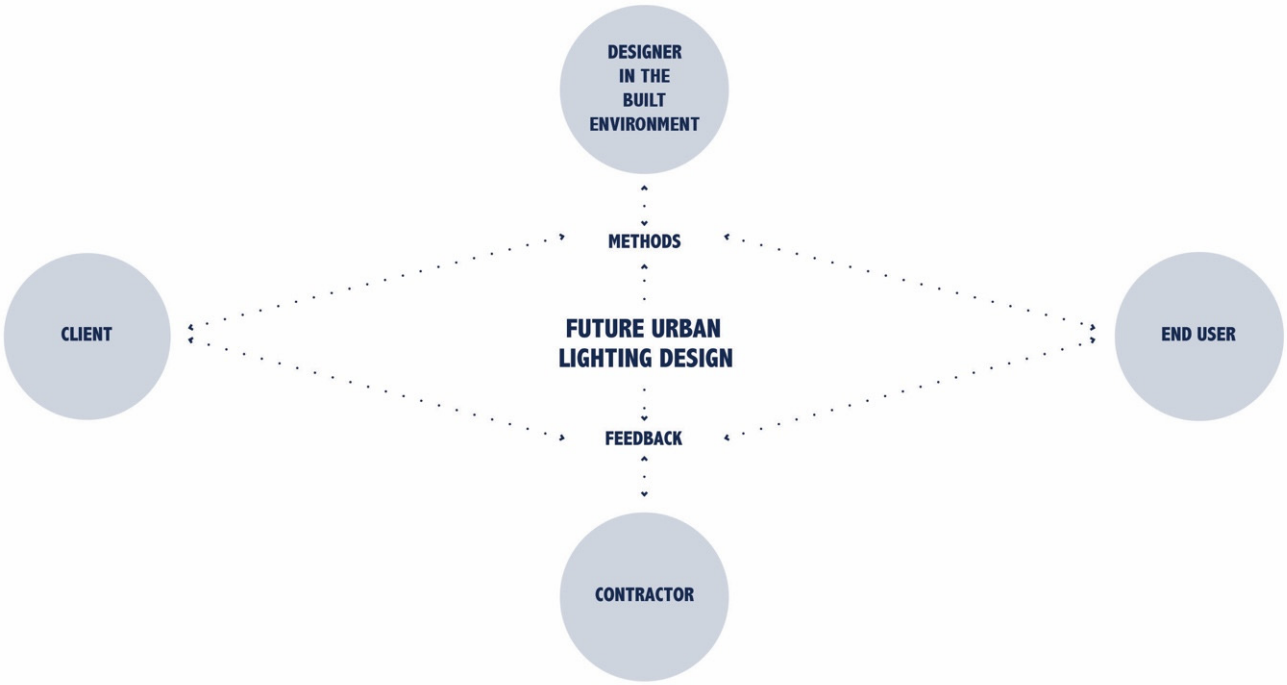

Figure 11. Future iterative urban lighting design process. Source: authors' own work based on experts' opinions.

All actors should communicate via methods and feedback. The traditional top-down approach, where decisions are driven by the *client*, *designer in the built environment* and *contractor,* has been enriched by a bottom-up approach where the *end user* (city residents, and *responsible lighting advocates*) actively participate in the design development. In contrast, a side-to-side approach allows the various *designers*, *engineers* and *researchers* to collaborate directly to achieve the best possible solutions by improved communication and a time schedule.

6.4.3. Proposed New Hierarchy in the Design Process

Future decisions on urban lighting in sustainable cities should involve three different approaches. (1) A traditional "top-down" approach where the leader (*client*, *designer in built environment/engineer*) makes decisions on the project progress, which is then disseminated to the lower levels in the decision-making hierarchy (*designer in built environment*, *contractor*). (2) A "bottom-up" approach where a large number of people (*end users*) work together to reach a decision that arises from their joint involvement. This allows for more experimentation and a better gauge of what is needed in the field. (3) A "side-to-side" approach where all established and new stakeholders make decisions horizontally, in a techno-meritocratic manner (Figure 12). A future research direction could encompass the development of new methods and feedback to improve the planning process between all the actors. Moreover, it is necessary to translate the complex research studies that exist about the impact of ALAN on humans, flora and fauna, into applicable knowledge in the form of lighting guidelines, procedures, standards and policies for urban projects.

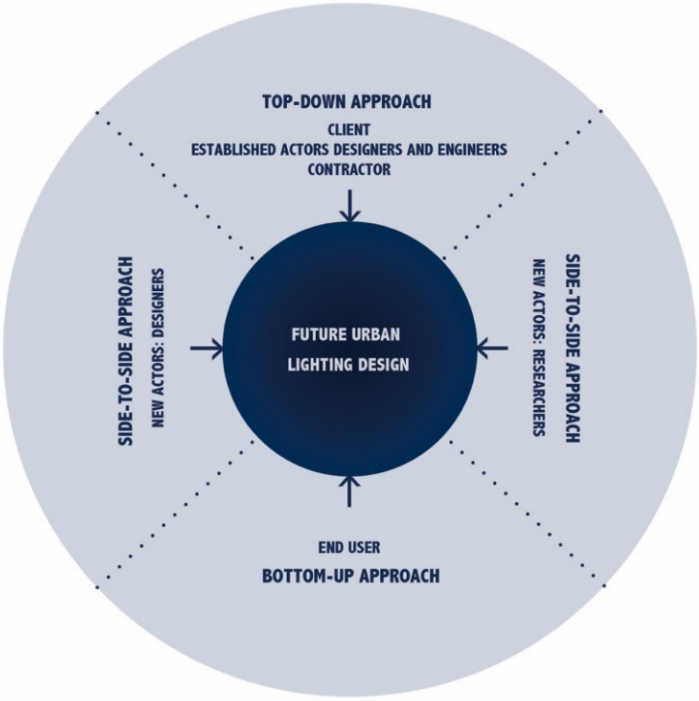

Figure 12. Proposed new hierarchy in the design process for future urban lighting design: top-down, side-to-side and bottom-up approaches. Source: authors' own work based on experts' opinions.

7. Conclusions

Today, there is an awareness of water, air, and soil pollution and the impact this has on the entire biosphere, including humans, flora and fauna (Figure 13). However, artificial lighting has only recently been considered as a potential pollutant [72] based on the growing body of lighting-related research in diverse fields.

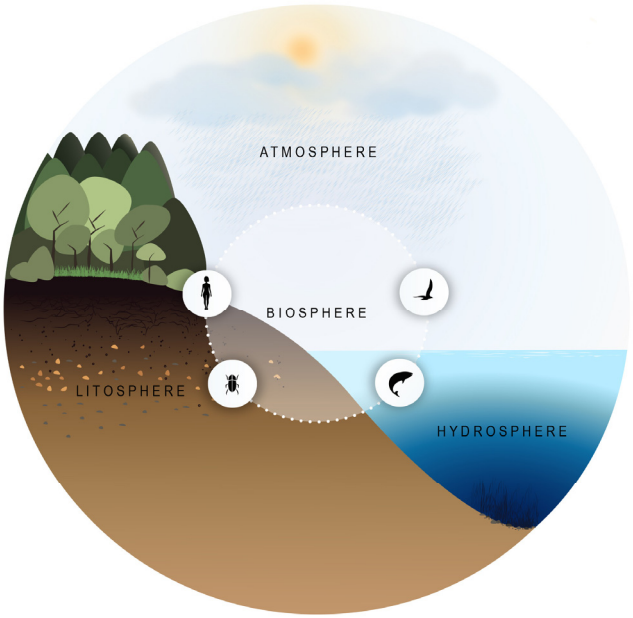

Figure 13. The earth consists of four major systems: lithosphere (land), atmosphere (air), hydrosphere (water) and the biosphere (all living things including humans). The biosphere is a global ecosystem made up of the parts of earth where life exists. It reaches from the deepest root systems of trees to the treetops of forests, deep into the oceans and seas, to the top of mountains [73,74]. Source: authors' own work.

Human existence and quality of life depend on these four interlinked essential systems (Figure 13). Artificial lighting directly interferes with them, causing their partial degradation; hence, the importance of reversing existing increased light pollution in urban and natural environments. Therefore, it is also critical to develop effective light pollution environmental modelling in different environments, such as the biosphere, atmosphere, hydrosphere and lithosphere, in order to better assess its future impact.

In December 2021, for the first time, the UN Human Rights Council recognized that having a clean, healthy and sustainable environment is a human right [75]. Therefore, in the future, other targets will be possibly included into Sustainable Development Goals. These could involve helping safeguard the health and wellbeing of humans, flora, and fauna via the application of responsible outdoor illumination or the absence of exterior lighting, as well as encouraging respect for natural darkness in the built environment by protecting access to dark skies and reducing light pollution in order to preserve this common ancestral heritage shared by humanity.

With the recent climate change emergency and environmental degradation, it is now urgent to apply a different development approach—one that is people-centred instead of the outdated traditional strategy. To protect the future of humanity and planet Earth, and in order to transform our world into a healthier environment, a new paradigm shift is also needed for the outdoor illumination of cities. This issue was already addressed in 2019, by the Deputy Secretary-General of the United Nations and Chair of the United Nations Sustainable Development Group. Amina J. Mohammed: "We need to put in place a truly new paradigm shift, both in terms of ambition, scale and speed to match the 2030 Agenda" [76].

Evidence is accumulating that there is a need for a changed approach in defining SDGs, with suggested new goals and targets not only related to artificial light at night, but in other areas connected to air quality, harmful chemicals, ocean acidification or human population growth [77]. Many researchers are now questioning whether the goals are fit for the post-pandemic age and if they are even achievable by 2030 [78].

In view of the above, the immense challenge for the implementation of future successful sustainable cities at night will be the skilful design of outdoor illumination based on research and the solid foundation of updated Sustainable Development Goals and their targets, so that the negative environmental, public health and wellbeing aspects of urban lighting are minimized.

This is the first time that the following proposed five-step strategic plan of actions have been introduced to aid these objectives:

1. Conduct interdisciplinary applied lighting research to obtain necessary knowledge from experts;
2. Establish regulatory lighting frameworks based on research to minimize impact on the environment, public health and wellbeing;
3. Apply appropriate lighting planning principles, processes, practices and tools to create improved outdoor illumination that is supported by research and regulatory frameworks;
4. Evaluate and assess existing lighting projects, and provide suggestions for necessary improvements;
5. Educate the general public by translating scientific research and complex knowledge into easy to understand information; request their participation and feedback.

In this context, it is recommended that researchers and lighting professionals, who were absent in the two-year intensive public consultations by the General Assembly Open Working Group on Sustainable Development Goals, should be invited to contribute to an updated SDG11 document. This should reflect the latest knowledge and research from various fields, such as environmental sciences, biology, medicine and astronomy in relation to sustainable cities at night. A strong team of interdisciplinary experts [53,79] working together has a greater chance of success to create more real life-related, applicable targets connected to sustainable cities and communities at night.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14106062/s1, Table S1–S16; Table A; Table T; Table S; Table N; Table C; Table P.

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