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Measuring and Mitigating the Impacts of Light Pollution with EWM-TOPSIS Method

Summary

Keywords: Entropy weight method, TOPSIS, ;

Contents

1 Basic Introduction

1.1 Background

Light pollution is a term used to describe the excessive or inappropriate use of artificial light, which can take the form of light trespass, over-illumination, and light clutter. These phenomena are often visible as a glow in the night sky in large cities, but they can also occur in more remote areas. Light pollution affects our environment, health, and safety by altering our view of the night sky, delaying or accelerating plant maturation, disrupting wildlife migration patterns, and affecting our circadian rhythms. Excessive artificial light can lead to poor sleep quality and may contribute to physical and mental health problems, while glare from artificial lights can increase the risk of motor vehicle accidents.

However, artificial light has both positive and negative impacts that can vary based on location. The effects of light pollution can depend on factors such as a location's level of development, population, biodiversity, geography, and climate. Therefore, assessing the extent of the effects and potential impacts of intervention strategies must be tailored to the specific location, and intervention strategies are needed to mitigate the negative effects of light pollution.

1.2 Problem Restatement

- The indicators of the EWM-TOPSIS model should be determined, in other words, it is equal to build a broadly applicable metric for identifying the light pollution risk level.
- Apply the indicators and the related data to the EWM-TOPSIS model, then analyse the result in the four diverse types of locations.
- Design 3 possible strategies for addressing light pollution, and how the indicators change with the strategies.
- Select 2 locations, and implement the most effective intervention strategies for each of them. See how the indicators change and the impact of the chosen intervention strategy.
- Write a 1-page flyer to community officials or local groups in a specific location to promote the most-effective intervention strategy tailored for the location.

1.3 Literature Review

Light pollution is a serious problem with implications for wildlife, human health, scientific research, energy consumption, global warming, and the ageless pastime of observing the night sky. Pristinely dark skies are very scarce in the developed world and most of the world's population—and nearly all of those living in the EU or the US—live under skies with at least some light pollution[1].

For biodiversity studies, nocturnal light ideally would be measured in biologically relevant ways, based on thresholds and spectral sensitivities of the species, because different light sources interfere differently with the large diversity of sensory systems in nature[2].

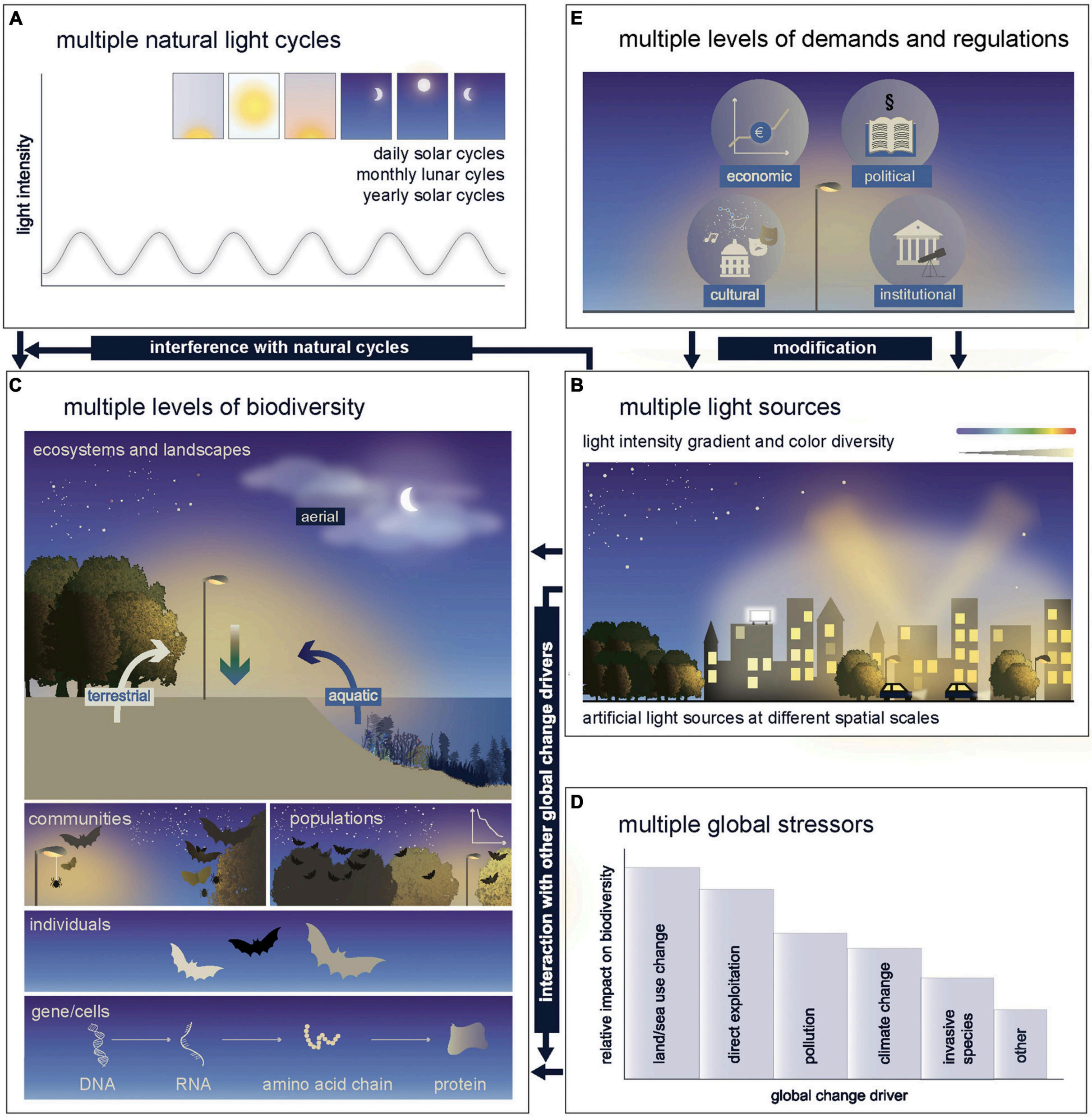

Figure 1: Artificial light at night: Potential sources, biodiversity impacts and responses are complex. Different natural light cycles (A) are affected by multiple forms of artificial light at night (B) at multiple levels of biodiversity in multiple realms (e.g. from bottom up: gene expression; phenotypes; population dynamics, e.g. decline; community composition; species dispersal and/or organismic fluxes across ecosystem boundaries and bioms) (C). Artificial light at night can interact with multiple global change stressors (D). Due to the potentially conflicting demands of artificial light at night a transition to a more sustainable use is extremely challenging and requires multiple levels of regulations (E) [3]

1.4 Our works

First of all, we selected 9 cities as evaluation objects and 9 indicators for the EWM-TOPSIS Model. Both benefit-attributed and cost-attributed indicators are taken into account. Then we use the Entropy Weight Method (EWM) to get the weight of indicators. After getting the weights, we use the TOPSIS method to determine the best option from a set of alternatives.

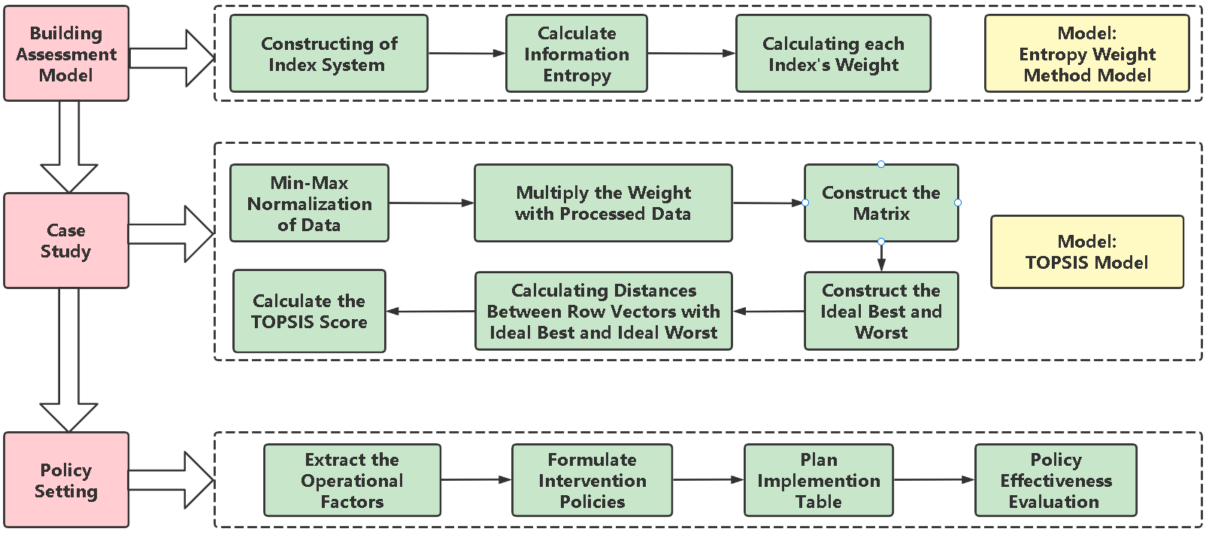

Figure 2: Our workflow.

2 Assumptions and Justifications

To simplify the problem, we make the following basic assumptions.

- Assume that all the light pollution is from night-time light, so we just need to consider night-time light intensity.

  Justifications: According to the Wikipedia[4], the definition of light pollution is the presence of anthropogenic artificial light in otherwise dark conditions.

- Citizens will not reduce the basic consumption of living illumination for the purpose of reducing light pollution.

  Justifications: To simplify the problem, we didn't take people's awareness of light pollution into account.

- Precipitation occurs in the day and night with equal probability.

  Justifications: As we use year precipitation to evaluate the cloudness of one location, and the light pollution occurs in the night-time, only rainy at night that the precipitation data is valid. So that the year precipitation can be comparable.

- Night-time light intensity is closely related with economics.

  Justifications: According to fractional logit models[1], both population and GDP are significant explanatory variables, similar to other types of pollution.

3 Notations

Symbols used and their definitions are defined below(Table 1).

Table 1: Notations of symbols

Symbol	Description
a_{ij}	The value of the j-th indicator of the i-th city to be evaluated.
$A = (a_{ij})_{i\times j}$	Data matrix composed by a_{ij}.
p_{ij}	The proportion of the i-th evaluation objective to the j-th indicator.
e_j	The entropy value of the j-th indicator.
w_j	The weight of the j-th indicator.
b_{ij}	The data from a_{ij} after standard 0-1 transformation.
$B = (b_{ij})_{i\times j}$	The decision matrix composed by b_{ij} after processing.
$C = W * B$	The weighted-normalised decision matrix.
C_i	The i-th roll of the C matrix.
$C^* = [b_1^{max}, b_2^{max}, \cdots, b_j^{max}]$	The positive ideal solution.
$C^* = [b_1^{min}, b_2^{min}, \cdots, b_j^{min}]$	The negative ideal solution.
s_i^*	The distance from C_i to the positive ideal solution.
s_i^0	The distance from C_i to the negative ideal solution.
f_i	The night-time light intensity of the i-th city.

4 The EWM-TOPSIS Model

4.1 Indicators of the Model

We selected 9 cities as evaluation objects. As the night-time light intensity directly reflects the extent of light pollution, so it is regarded as the direct evaluation indicator, and we chose 9 indirect indicators as evaluation indicator variables to evaluate the night light level of the city. The value of the j-th index variable of the i-th city evaluated is a_{ij}, building a matrix $A = (a_{ij})_{9\times 9}$.

The 9 indicators we selected are population density, night-time electricity consumption, per capita GDP, regional industrial structure, regional average working hours, the last bus time of public transport, night life index, year precipitation, limiting magnitude, etc. Among these indicators, only the limiting magnitude is an objective indicator and cannot be changed.

To explain the selection of indicators, We divide the indicators into two categories. One is the benefit-attributed indicators. The larger the data index, the higher the night-time light intensity. The other is the cost-attributed indicators. The smaller the data index, the higher the night-time light intensity.

For the benefit-attributed indicators, there are 6 indicators which are listed below.

1. **Population density**. With the increase of population density in a region, the illumination demand of this region's public space also increases, thus increasing the night-time light intensity.

2. **Night-time electricity consumption**. A large part of night-time electricity consumption is used for lighting, so it can also reflect the night-time light intensity to a certain extent, which is a benefit data.

3. **GDP per capita**. GDP per capita reflects the degree of local development. The more developed and prosperous the region, the more shopping malls and high-rise buildings in prosperous areas. And we believe the LED lights in shopping malls and the glass curtain walls of high-rise buildings lead to an increase in night-time light intensity, which may lead to the light pollution.

4. **Regional industrial structure**. The demand for illumination in various industries is different. The primary industry has little demand for light. Some industries in the secondary industry have requirements for light, and the tertiary industry service industry is extremely dependent on light to attract customers. So the industrial structure also has an impact on the local night-time light intensity, and we believe that the more the proportion of the tertiary industry, the higher the nighttime light intensity is.

5. **Nightlife index**. Nightlife is a collective term for entertainment that is available and generally more popular from the late evening into the early hours of the morning. As long as nightlife prevails, the lighting demand increases. The higher the nightlife index of a region, the higher the nighttime light level, which belongs to the benefit data.

6. **Year precipitation**. The more rainy days, the more precipitation, which also means the thicker clouds, thus increasing the reflectivity of light.

7. **The last bus time of public transport**. The operation guarantee condition of ground public transportation is lighting, so the lighting will naturally increase during the traffic operation time. And also to some extent, the last subway train time is connected with the night-time living. The later the last bus is, the higher the night-time lighting level will be, so it belongs to the benefit data.

For the cost-attributed indicators, there are 2 indicators which are listed below.

1. **The average working hours in the region**. The earlier people leave work, the earlier the end of the evening commute. So the demand for high-beam lights will become less, and the demand for night lighting time will become less, so it will affect the level of night-time lighting.

2. **Limit magnitude**. Limit magnitude refers to the darkest magnitude that can be observed through a telescope. The higher the limit magnitude that can be seen, the lower the brightness on the ground, that is equal to lower level of illumination at night, so it belongs to the cost data.

4.2 Data Collection

We got historical population density data in **Census.gov** [5], time ranging from 1910 to 2020.

4.3 The Entropy Weight Method (EWM)

We use the Entropy Weight Method (EWM) to get the weight of indicators. The Entropy Weight Method is an object weighting method, which uses the information entropy idea for reference. It is used to determine the relative weights of different criteria in a decision-making process. It determines the weight of the indicators by calculating the information entropy of the index, according to the impact of the relative change of the index on the overall system.

In other words, the weight of each indicator is given according to the difference degree of the indicator value, and the corresponding weight of each indicator is obtained. The indicator with relatively large change degree has larger weight.

The greater the entropy, the more chaotic the system is, the less information it carries and the less weight it has. Otherwise, the higher the entropy, the more orderly the system is, the more information it carries, and the greater the weight is.

The first step of the Entropy Weight Method is the standardization of measured values. The standardized value of the jth index in the ith sample is denoted as p_{ij}, and its calculation method is as follows:

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, i = 1, 2 \cdots, , 9, j = 1, 2, \cdots, 9$$

Secondly, in the EWM, the entropy value e_i of the jth index is defined as:

$$e_j = -\frac{1}{ln(9)} \sum_{i=1}^{n} p_{ij} ln(p_{ij}), j = 1, 2, \cdots, 9$$

The range of entropy value e_j is [0, 1]. The larger the e_j is, the greater the differentiation degree of index j is, and more information can be derived. Hence, higher weight should be given to the index.

Finally, the calculation method of weight is:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m} e_j}, j = 1, 2, \cdots, 9$$

Through the three steps, we can easily get the weight of each indicator.

4.4 The TOPSIS Method

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The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making method that is used to determine the best option from a set of alternatives based on multiple criteria.

First of all, we use Min-Max normalization to process the data.

For the benefit-attributed data,

$$b_{ij} = \frac{a_{ij} - a_j^{min}}{a_j^{max} - a_j^{min}}$$

And for the cost-attributed data,

$$b_{ij} = \frac{a_j^{max} - a_{ij}}{a_j^{max} - a_j^{min}}$$

All these data from the normalized matrix B. We then multiply each value in a column with the corresponding weight given, and get weighted-normalised decision matrix, which

$$C = W * B$$

Secondly, calculating the ideal best and the ideal worst. Now we need to calculate Euclidean distance for elements in all rows from the ideal best and the ideal worst. Here, s_i^* is the best distance calculated on the i-th row, where b_{ij} is element value and C_i^* is the ideal best for that column. Similarly, we can find s_i^0, which is the worst distance calculated on the i-th row.

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Finally, calculate the TOPSIS Score and Ranking. Now we have distance positive and distance negative, calculate the Topsis score for each row based on them in the end.

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4.5 Application of the Model on the Four Locations

4.5.1 A Protected Land Location:

4.5.2 A Rural Community:

4.5.3 A Suburban Community:

4.5.4 An Urban Community:

5 Strategy Making and Implementation

5.1 Strategies for Addressing Light Pollution

5.1.1 Avoid blue lights at night

Blue-rich white light sources are also known to increase glare and compromise human vision, especially in the aging eye. These lights create potential road safety problems for motorists and pedestrians alike. In natural settings, blue light at night has been shown to adversely affect wildlife behavior and reproduction, particularly in cities, which are often stopover points for migratory species.

Outdoor lighting with strong blue content is likely to worsen skyglow because it has a significantly larger geographic reach than lighting consisting of less blue. [6]

5.1.2 Strategy 2

5.1.3 Strategy 3

5.2 Tailored Strategy Implementation

5.2.1 Location 1

5.2.2 Location 2

6 Sensitivity Analysis

6.1 Sensitivity Analysis of the TOPSIS Model

7 Strengths and Weaknesses

7.1 Strengths

Our work aims at investigating trends of global language users and their distrubution situation. With this model, we put forward targeted proposal for a multinational service company, and optimize its planned number of offices. At last, we evaluate the effectiveness of our model. To sum up the above, the model and the policies proposed have the following strengths:

- Inclusive

The model involves 5 indicators, well presenting most of the major factors determining the trends of golbal languages and their distribution. This makes the data analysis and policy-making reliable and rigorous.

- Quantified

- Comparitive

7.2 Weaknessess

Despite the advantages, there are still some shortcomings in our models and the proposal:

- Ignoring External Shocks

As a major premise, we exclude catastrophic disasters and wars. Too big these changes are that we cannot precisely predict the trend of world population distribution and language development trends afterward. But in real world, all circumstances are possible, so our model is still limited.

- Ignoring the Second Generation of the Immigrants

We generally consider that native languages will not change after immigration to another cultural circle. But after 50 years, the next generation of the immigrants are born. Our model does not take their native languages into account.

8 Conclusion

9 Flyer

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