Environmental Science and Policy 89 (2018) 142–152

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

From global radiance to an increased local political awareness of light pollution

Lukas D. Schuler[a,b,*], Rolf Schatz[b], Christian D. Berweger[a]

[a] xirrus GmbH, Buchzelgstrasse 36, 8053 Zurich, Switzerland
[b] Dark-Sky Switzerland, P.O. Box, 8135 Langnau am Albis, Switzerland

ARTICLE INFO

Keywords:
Radiance conversion
Solar
Lunar luminance
Luminous intensity
Luminance
Political entity
Luminous intensity vs. road lighting energy
Security
Safety
Darkness
Crayfish
Darkness

ABSTRACT

We present a novel transparent method to analyze measurements of the Suomi NPP (Suomi National Polar-orbiting Partnership) satellite in night vision, into luminous intensity and luminance on the community level, with a special focus to address light planners and non-experts, and for the first time, to further address politicians, decision-makers and law-makers, and governmental agencies. We checked the propagated efficiency of road lighting and its impact on luminous flux, and identified a waste of light emissions in the largest city of Switzerland, Zurich. We looked at security (issues like criminal acts) and found no correlation with communities' luminous intensity. We assessed road safety (accidents) against local luminance and found no evidence of darkness being more risky when the overall distribution of illuminance on roads is considered. We screened crayfish habitats in the Canton of Zurich against local illuminance and found clear evidence of preferred darkness for the living. Based on this finding, we propose an upper limit for light immissions in the crayfish habitats. These four analyses have been chosen to demonstrate the usefulness of Suomi NPP's coverage in combination with our approach. We could apply it to ecological, social and economical topics. We hope others will follow and we can draw more attention of governments to take action to reduce the light pollution on local levels, like Langnau am Albis of Switzerland has exemplified.

1. Introduction

Three decades ago, scientific and public discussions of light pollution (i) emerged by astronomers losing visibility of faint stars, e. g. Crawford (1991), Crawford (1998). Later on, light pollution (ii) was reviewed by ecologists, e. g. Longcore and Rich (2004), Perkin et al. (2011), Bennie et al. (2015), (iii) went through official recognition as a loss in cultural heritage (La Palma declaration, UNESCO, 2007), (iv) influenced regulations in many countries or regions, e. g. La Palma Carlos (1988), U.S.A Schultz (2016), Czech Republic Clarke (2002), Italy Cinzano (2007), Slovenia Mohar (2007), France Morgan (2013), UK Department for Environment Food & Rural Affairs (2015) and (v) increased concerns which helped establish recognized International Dark Sky Reserves International Dark-Sky Association (2018). Recently, the negative influence of blue (cold) light at night (for e.g. humans, bats, insects) was discussed intensively, as with the introduction of white LED in public lighting, it was ignored by the lighting industries, see e. g. AMA (2016), Traverso et al. (2016), and Grubisic et al. (2018) (in press). Although in Switzerland, since 1985, the environmental law prevents nuisance or harmful effects by radiation The Federal Assembly of the Swiss Confederation (n.d.) and recommendations for a reduction of light emissions have been established in 2005 by the government Klaus et al. (2005), which was followed by the norm of the Swiss Society of Engineers and Architects (sia) Kobler et al. (n.d.) in 2013, only by end of this year Reichenbach et al. (2018) it should be enforced officially. While working for Dark-Sky Switzerland, we observed a lack of information in local politics and began to focus on measurable quantities as convincing arguments to provoke action.

The gap between existing regulations and the strive for more efficient lighting needed more attention not only on site, but country-wide. New data sources came in timely to fill this gap with knowledge.

In 2012, NOAA (National Oceanic and Atmospheric Administration) published imagery of earth at night derived from the Day-Night-Band data (DNB) captured by environmental satellite Suomi NPP in visible and near infrared (VIIRS) (Cole et al., 2012; Hillger et al., 2013). We recognized, for the first time in history, the resolution of 750 m at nadir allows to address local light emissions of political entities on a community or city level, anywhere, countrywide. For a global survey of artificial light emissions no better alternative public source does exist. We started to develop a concept of data interpretation intended to work

* Corresponding author at: xirrus GmbH, Buchzelgstrasse 36, 8053 Zurich, Switzerland.
E-mail addresses: lukas.schuler@xirrus.ch (L.D. Schuler), rolfschatz@darksky.ch (R. Schatz), cdb@xirrus.ch (C.D. Berweger).

https://doi.org/10.1016/j.envsci.2018.07.011
Received 25 April 2018; Received in revised form 9 July 2018; Accepted 10 July 2018
1462-9011/

on a global scale and into the future, to increase the awareness of sources of light pollution, and to take local politicians into responsibility.

Our experience evoked in parallel to the available data sources, and we included a quantitative interpretation, which we will discuss in this article, in the hope it will spread into further application on comparable global actions.

Although we first developed our method with data of Switzerland, it should be transferable to a global scale, since the source of VIIRS is nearly global (no night data in polar summer). Additionally we made an analysis of a small country (Luxemburg) and each of its 105 communities, which has been accepted and released by the ministry of sustainable development and infrastructure (Münichsdorfer and Schuler, 2017). Some more communities in Switzerland and Hungary asked us to further analyze their situation and, as a consequence, we will provide our research as a consulting service to environmental agencies and political entities.

We believe our method helps interpreting the data gathered by Suomi NPP and NOAA and increase the awareness for the impact of light pollution. We and our methods are backed by environmental laws seeking pollution problems to be solved at its sources (emission) and not at the place of impact (immission).

In Section 2, Database and methodology, we describe how we transform the available data source into valuable information for communities, Section 2.1, data and scales. For comparing to natural conditions, we calculated the maximal luminance of sun and moon from established quantities, Section 2.2. To increase political awareness we show a qualitative ranking of adjacent neighbors, Section 2.3. To exemplify some possible analysis combining different data sources with the calculated light emissions, we looked at energy consumption of public lighting in Section 2.4, and at crime, traffic accidents and crayfish habitats in Section 2.8. How to map on the community level we describe in Section 2.5. Section 3 will emphasis these findings and include the mappings we developed for status reports 3.2 and trends 3.3 countrywide and of every community, just showing one example we know well in Sections 3.4 and 3.5. For further methodological explanations, we recommend reading the Supplementary Material.

2. Database and methodology

The Earth Observation Group, NOAA National Geophysical Data Center provides a monthly series of the VIIRS Day-Night-Band Nighttime Lights online (Elvidge and Baugh, n.d.). The data contains geolocated radiation values captured in the weeks around new moon in nights without cloud coverage. The advantage of Version 1 is its nearly global availability, the resolution of 750m or better (projected 0m at poles), the covered time series since 2014 and the (partial) detection of most artificial light sources. Some disadvantages are the handling of large files, the necessity for corrections of outliers and stray-light, the lacking of spectral sensitivity below 500nm. We believe, the chances the careful analysis of these sources offers is larger than the errors introduced by lack of data and seasonal effects, since the collectors of data do their best to carefully prepare measurements to correctly reproduce geolocations, exclude clouds, moon and sunlight effects. In all these years working with the data for two small European countries, we saw only once an outlier effect (see Supplementary Material p. 24). On our journey to address the responsible people with relevant informations, we carefully thought through our concepts and developed these methods. Analysis of light emissions could be done in thousands of different ways, and we do not claim there is only one correct solution. But we have identified some key numbers and features and would like to share our findings.

2.1. Data and scales

The data from Suomi NPP are available at Elvidge and Baugh (n.d.). It is provided without or with stray-light correction Mills et al. (2013) of solar radiation. The satellite's sensor does not exactly cover the human visible spectrum V_λ as would be measured in the lighting industry, but from approximately 500 nm $\leq \lambda \leq$ 900 nm, compare Figure 2 in Miller et al. (2013). Measured radiance is declared light power per area per solid angle in nanoWatts/cm^2/sr, [$\text{nW} \cdot \text{cm}^{-2} \cdot \text{sr}^{-1}$]. It describes the energy represented by the photons integrated over the above declared wavelengths emitted from a (part of earth's) surface within a solid angle per time. Since this is not intuitive to politicians, environmental agencies and media, we defined other representations, which can be derived in three steps:

1. The luminous intensity I of a candle visible to humans can be represented equal to 1 candela [cd].
2. Further, it holds per definition (CGPM, 1979) for bright enough conditions (human daylight vision):

$$1 \text{ cd} = \frac{1}{683} \text{ W}\cdot\text{sr}^{-1} \tag{1}$$

3. The luminance L of an object is usually measured in luminous intensity per area [$\text{cd}\cdot\text{m}^{-2}$].

The combination of all above then leads to:

$$1 \text{ nW}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1} = 6.83\cdot 10^{-3} \text{ cd}\cdot\text{m}^{-2} \tag{2}$$

We are aware, since the satellite does not detect the standard spectrum of human vision (V_λ), it is not fully correct to apply this transformation. What is missing on small wavelengths (380–500 nm, blueish) has been added above (780–900 nm, reddish-heat), and as an approximation we can accept it for two reasons we explain in the Supplementary Material in detail, see page 3. In summary, we claim: *Firstly,* due to its spectral limitations, no public light source is fully missed by the satellite. *Secondly,* we assume as long as Suomi NPP stays operational and NOAA keeps it as a valuable data source, we can always compare different countries and emissions with our identical assumptions. Even if systematic errors would be introduced, it would be equal to all regions and relative comparison would still be valid. *Thirdly,* due to the switch of scale to luminance, international recommendations for public lighting such as norms and certificates do already exist, Supplementary Material, page 5.

To draw attention of the politicians towards light pollution, we show them the light emissions in their district or community. From quantitative measurements by NOAA we can derive simpler (qualitative) luminous intensities, that can be compared over time and compared with the peer communities. Our key understanding was, as environmental law in Switzerland/Europe states clearly, environmental pollution has to be addressed at its source and not at the place of impact.

2.2. The full moon's and sun's luminance on earth

Luminous units and numbers are difficult to intuitively appreciate and compare by humans, among other things, because human vision of light has a non-linear perception. We therefore decided to introduce the natural light sources, full moon and sun, for better perspicuous comparison. It is easy to understand, as nature and mankind have been exposed to these light sources for ages. However, artificial light is much more recent, and especially when brighter, it may be more distracting to the human eye and to nature. Another natural light source is the starry sky without moon. We do not consider its illuminance here, since it is currently below the detection limit of the satellite's sensor.

For the derivation of the numbers of solar and full moon's luminance on earth, please see the Supplementary Material, from pages 12–17, and Table 4.

For the upper limits (100% dry air and albedo 1.0) of the reflected