Lyytimäki Jari (2015) Avoiding overly bright future: The systems intelligence perspective on the management of light pollution. *Environmental Development* 16: 4-14. https://doi.org/10.1016/j.envdev.2015.06.009

Avoiding overly bright future: The systems intelligence perspective on the management of light pollution.

Abstract
Light pollution resulting from artificial lighting is a global environmental change that profoundly alters the nocturnal environment. Various ecological and health effects are caused by the alteration of natural levels of light and disruption of cycles of light and dark. Emissions of artificial light into the night environment have increased rapidly over the last decades and this trend is likely to continue due to the introduction of new cost-efficient light sources, urban sprawl, increasing traffic, population growth, and economic growth. Efficient measures to reduce light pollution are needed. Most measures so far have been based on top-down approaches such as legislation, technical norms and guidance. Based on the results from an online survey in Finland, household-level efforts aimed at reducing light pollution are reviewed and obstacles to action based on bottom-up approach are discussed. The systems intelligence is proposed as a context sensitive approach to light pollution management. Systems intelligence emphasises personal and active involvement in socio-technological systems, characterised by complex cross-scale interactions and feedbacks.

Keywords
Artificial light; Environmental management; Light pollution; Lighting system; Sustainability

Highlights
• Light pollution is a wide-spread novel environmental change.
• Stringent management measures are needed to curb light pollution.
• The repertoire of household level measures were identified.
• Wide array actions have been employed but the problem is seen as overwhelming.
• Systems intelligence may help to overcome four key issues related to light pollution.

1. Introduction

The Earth is facing different but intertwined environmental changes caused by various anthropogenic driving forces. The increase of night-time artificial light is perhaps the most easily observable global environmental change, but it has received relatively little public and scholarly attention. Over the past century natural darkness has disappeared from almost all inhabited regions. Based on information derived from night-time satellite pictures taken during 1996–1997, Cinzano et al. (2001) estimated that one fifth of the global land surface was above the threshold of light-polluted status (coloured areas in Fig. 1).

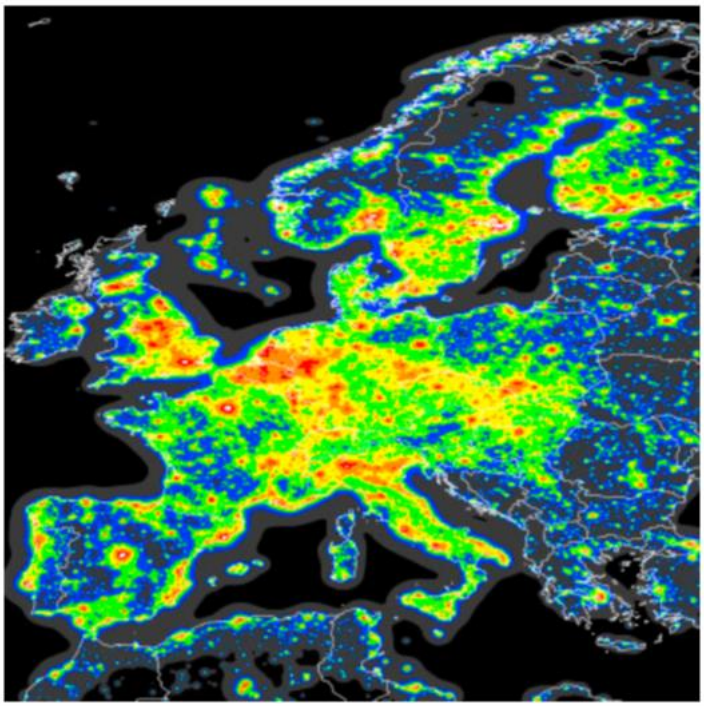


Fig. 1. Light pollution in Europe based on the First World Atlas of the Artificial Night Sky Brightness, describing the situation in 1996/1997 (Cinzano et al., 2001; http://www.lightpollution.it/worldatlas/pages/fig4.htm). Colours correspond to ratios between the artificial sky brightness and the natural sky brightness of: <0.11 (black), 0.11–0.33 (blue), 0.33–1 (green), 1–3 (yellow), 3–9 (orange), >9 (red). Finland is at the top right. The atlas was derived with a light propagation model working on Defence Meteorological Satellite Program (DMSP) satellite radiance data calibrated with Earth based sky brightness measurements.

In 2007, Victor and Ausubel (2007) presented maps illustrating how bright the night would look like if everyone in the world emitted light equalling the median per capita upward flux of artificial light of U.S. citizens. These maps suggested a potential for an unprecedented increase in light emissions from densely populated developing countries, particularly in South and East Asia. However, Victor and Ausubel (2007: 77) concluded with a techno-optimistic outlook: “Fortunately, more efficient illumination will surely lower the wasteful emission of light and the energy to produce it long before everyone lives like present Americans.”

Based on more recent data, this optimism was at least partially unfounded. For example, analysis of satellite data indicate that, in China, the percentage of land surface area with increasing brightness rose from 2.1% between the periods of 1992–1996 and 2000–2004 to 5.6% between the periods of 2000–2004 and 2008–2012 (Han et al., 2014). In many countries the use of light has increased together with the increase of economic affluence, and in some countries the increase in light emissions outpaces economic growth (Ghosh et al., 2013, Elvidge et al., 2014). Global aggregated emissions continue to increase, but in some industrialised countries the emissions appear to be stabilising or even decreasing, and several Eastern European countries have faced a considerable decrease in light emissions following the collapse of the Soviet Union (Bennie et al., 2014, Cauwels et al., 2014).

Professional and amateur astronomers have repeatedly attempted to bring attention to light pollution. Over the past years, the issue of light pollution has been brought up by various campaigns such as UNESCO's Starlight (2007) and Globe at Night (2015), web-pages (e.g. IDA, 2015), TV-documents (e.g. Cheney, 2011), YouTube videos (e.g. SciShow, 2014), articles in popular magazines (e.g. Owen, 2007), books (e.g. Cinzano, 1996; Posch et al., 2010; Mizon, 2012; IDA, 2012; Bogard, 2013; Lyytimäki and Rinne, 2013a; Meier et al., 2015), scholarly commentaries (e.g. Smith, 2009; Gaston, 2013), and even fictional TV-series such as The Simpsons (2003). Despite these, and other activities, public awareness about light pollution is not yet widespread (e.g. Falchi et al., 2011; Wong et al., 2014). Stringent abatement policies are rarely implemented, with exceptions in some countries such as Italy (Falchi, 2011) or Slovenia

(Morgan-Taylor, 2015) and locations near important astronomic observations sites, nature protection areas, or dark-sky tourist destinations (Luginbuhl et al., 2009; Rodrigues et al., 2015).

Light pollution is a nascent research field but the existing knowledge base is already sufficient to justify planning and management actions aimed at reducing light pollution (Falchi et al., 2011, Kyba et al., 2014, Olsen et al., 2014). In addition to "astronomical light pollution" affecting the night sky, the concepts such as "photopollution" (Verheijen, 1985) or, more recently, "ecological light pollution" (Longcore and Rich, 2004) have been coined to highlight the effects of artificial light on nocturnal nature and human health. Even very weak and temporary artificial light can disturb organisms that are adapted to natural levels and cycles of light. Documented cases include various effects on terrestrial and marine organism, as well as avifauna (Rich and Longcore, 2006, Gaston et al., 2014). Most of the knowledge on the topic concerns individual level effects, with only a few studies on ecosystem-level effects having been published (Davies et al., 2013, Gaston et al., 2013), meaning that the effects on ecosystem services remain largely unstudied (Lyytimäki, 2013). Moreover, little is known about the long-term cumulative effects of light pollution and other environmental changes such as climate change.

The negative effects related to night-time light use are not self-evident for day-active species such as humans. Artificial light is perceived through various heuristics with strong positive connotations (Hukkinen and Huutoniemi, 2014), and commercial lights in particular are perceived as an indication of economic progress, welfare, and positive development more generally (Lyytimäki et al., 2012, Edensor, 2015). Bright security lights may also give a feeling of control and safety, even when they do not improve security or reduce crime (Marchant, 2011).

The starting point for this article is the key role of individual actors, and the importance of local level activity and bottom-up approaches in solving the pressing environmental problems of our times (Lane and McDonald, 2005, Baker and Mehmood, 2015). This article uses light pollution as a case study to look at the role of individual human actors in the management of (global) environmental changes. The aim is to analyse what kind of household-level actions to combat light pollution are already in use, and to discuss the relevancy of these actions. Systems intelligence is proposed as a promising approach for the management of light pollution. The paper is structured as follows: first, based on the data gathered via an online survey, the repertoire of voluntary household-level light pollution abatement activities in Finland is reviewed. This data also allows for an analysis of public perceptions of the potential for individual human actor to influence and manage large-scale environmental changes. Second, the concept of systems intelligence is employed to discuss the role of individual actors in environmental planning and management, and finally, conclusions regarding environmental management aiming to connect individual human actions with the functioning of large and complex socio-ecological systems are made.

2. Material

Data for this study originates from an online survey that aimed to chart public opinions about the loss of darkness and light pollution. The Finnish context of the survey is important to note when interpreting the results. Finland is a sparsely populated and relatively recently industrialised Nordic country that has small but extensively illuminated cities. Urban areas cover only about 4% of the land area while sparsely populated rural areas cover 68.3% of the land area (see Helminen et al. (2014)). Summer residences are particularly important in Finland, as there are about 500,000 summer residences in a country of 5.4 million inhabitants (OSF, 2014). These second homes in rural areas are becoming better equipped and the extensive use of outdoor lighting is becoming more common.

Because of the northern location, Finland is a country characterised by high annual variability of natural light. The survey was conducted during the winter period of scarce natural daylight (24 November 2011–29 February 2012). The weather was milder than average and snow cover reflecting both natural and artificial light was absent from southern Finland during the first half of the survey period. The strong winter storms of 26–27 December 2011 caused exceptionally wide-spread and long-lasting blackouts.

The aim of the survey was not to collect a representative sample of the Finnish population, but to reach those people who are interested or worried about light pollution issues. In particular, the open-ended question studied here was designed to give insights of the repertoire of actions by concerned citizens in household level. The term light pollution ("valosaaste" in Finnish) was used since it was considered as a suitable expression covering all negative impacts of artificial light (Morgan-Taylor, 2015). The term "pollution" is loaded with negative connotations and this should be taken into account when interpreting the results. Various positive effects of artificial lighting were purposefully left out from this survey.

Respondents were recruited through an open call to participate. The invitation was published through a press release of the Finnish Environment Institute and it was advertised through social media channels (Facebook, Twitter), project web page and emails. A blog was established in order to provide an easy access and to make it convenient to share the link to the questionnaire. The invitation was forwarded by local astronomical associations and the Illuminating Engineering Society of Finland, but comprehensive information about the recipients is not available.

The online questionnaire was kept brief in order to attract responses. It included 20 Likert-scale statements and three open-ended questions. In order to improve the validity of the answers, background information describing respondent's age, gender, education level, place of residence and potential membership in astronomical or environmental organisation was required. The details of the questionnaire and online survey application, as well as overall summary of the results are presented and freely available elsewhere (Rinne and Lyytimäki, 2012).

Here, the focus is on responses to the one of the three open-ended questions: "Have you attempted to reduce light pollution or exposure to disturbing light? How?" This question was answered by 1532 respondents (Table 1), and most of these responses were obtained from cities and towns in southern Finland. Almost a third (30.9%) of the responses originated from the metropolitan area of the capital Helsinki. The respondents were well educated, as 55.9% of them had a university-level education. Slightly over a half (52.1%) of the respondents were male, and the average age was 42.9 years. Almost half (49.1%) of the respondents identified themselves as amateur astronomers or members of non-governmental environmental or nature-themed organisations. This ratio is a higher ratio than in the Finnish population. The average length of the answers was 14.9 words, with the length of answers varying from statements of few words to short narratives of about 50–100 words.

Table 1. Background information of the respondents.

	Gender		Education level		Place of residence	
	Female	Male	University	Other	City centre or apartment building area	Rural or semi-urban area
Members of astronomical NGOs	79	279	129	229	144	214
Members of astronomical and environmental NGOs	50	88	73	65	63	75
Members of environmental NGOs	153	103	168	88	126	130
Non-members	425	387	306	474	375	405
Total	734	798	676	856	708	824

A qualitatively oriented material-driven content analysis was carried out (Alasuutari, 2012, Krippendorff, 2012). The aim was to capture the full variety of individual level reactions to the light pollution problem, as presented by the responses. The data was screened for expressions describing the actions individuals took, aimed at influence lighting systems and reducing light pollution. Both manifest content, directly describing the actions taken, and latent content, indirectly pointing to such activities, were sought. Interpretations based on latent content were employed in cases where manifest content was inadequate to produce meaningful interpretations.

Based on the initial screening classes, different response types were outlined and typologies were iteratively developed through several rounds of reading. First, a comprehensive collection of different actions was identified and preliminary classes of response types were formed. Following the idea of abductive reasoning, the preliminary classes were formed based on the interpretations of the data and insights from the management and systems intelligence literature (Table 2; Hämäläinen et al., 2004; 2014). Second, material was double-checked in order to test how well the responses fit into the preliminary classes. This resulted in the eight final main categories of different response types. Illustrative examples of actions were identified during the whole interpretation process. If an answer described different kinds of actions, it was assigned to several categories. 42 responses did not contain meaningful information or focused on other issues than actions aimed to reduce light pollution. Some respondents (N=17) stated that they had attempted to reduce light pollution without giving any further details.

Table 2. The repertoire of personal level actions to minimise light pollution (modified from: Lyytimäki, 2015).

Type of action	**Examples**
Producing less light: minimising the use of light sources (N=952)	Switching off outdoor lights during the night Use of timer switches, movement and light detectors, and dimmers Use of high quality luminaires, careful direction of lamps Avoidance of harsh decorative lights and blinking LED-lights (e.g. bicycle lights) Careful use of car headlights and fog lights Favouring dim and comfortable overall lighting Using bright lights only where and when absolutely necessary Using light sources that emit only red light (narrow spectrum)
Taking cover: minimising the exposure to obtrusive light, or glare (N=159)	Using blackout curtains in windows Using sleeping eye masks Building constructs or planting trees or bushes that block light Using sunglasses or hats when driving or walking Covering the signal lights of electronic devices Closing eyes or looking away from light sources
Staying away: minimising exposure by changing one's own location (N=129)	Avoiding over-illuminated places (e.g. city centres, holiday destinations) Changing place of residence to the countryside Jogging and outdoor exercising in areas with no lighting Staying insides in order to avoid light that is disturbing Not informing municipality about broken street light
Consumer choices: influencing through market mechanisms∗ (N=69)	Avoiding the purchase of too powerful lights and harsh or bright decorative lights Boycotting fruits that have been grown in greenhouses Favouring of public transportation
The actions mentioned relatively rarely	
Decision-making: influencing public or private lighting decisions (N=46)	Participation in housing cooperative boards Direct contact with municipal authorities Direct contact with those responsible for lighting (e.g. sports fields) Giving feedback in environmental permit processes
Awareness building: increasing general awareness of light pollution (N=46)	Participation in housing cooperative boards Direct contact with municipal authorities Direct contact with those responsible for lighting (e.g. sports fields) Giving feedback in environmental permit processes
Learning darkness: getting accustomed to natural light (N=41)	Writing letters to editors of newspapers Informing local policy-makers Discussions with neighbours and work colleagues Drawing attention to the term “light pollution”
Other (N=34)	Breaking lamp posts and other illegal activities

∗ Only responses directly describing the actual or planned purchase decisions related to lighting.

3. Results: actions against light pollution

Relatively many respondents stated that they do not have any possibility to make an impact of light pollution (N=103) or that they are completely unaware of possible actions (N=13). Over a hundred (N=117) respondents stated that they had not taken any action without giving a specific reason for inactivity. A few (N=14) noted that they did not consider light pollution to be a problem requiring personal activity. The respondents generally considered their potential to influence the overall light pollution situation as limited, even though a majority informed about some personal actions to produce less light pollution (Table 2). A key reason was the unawareness about meaningful and efficient courses of action. For example, a respondent living in the centre of Helsinki stated, “Normally I keep the lights on only in the room where I am. At the workplace, I try to switch off all lights when I leave for home. I don't know what else I could do.” Another respondent who lived in an apartment building in a town in central Finland stated “I feel that I don't have any means to control light pollution. The only exception is that I don't use Christmas lights or other decorative lights”. Those living in apartment buildings in particular believed that there were no effective avenues available to them for making an impact on light pollution.

The respondents typically described activities directed to their immediate surroundings, both indoors and outdoors. Various examples of actions aimed at reducing unnecessary use of lighting were given, often related to the personal use of electricity and energy saving (Table 2). Respondents were motivated primarily by energy saving while others

considered energy saving as a co-benefit of avoiding light pollution. Commonly mentioned measures included switching off unnecessary outdoor and indoor lights, avoiding over-illumination of private gardens, and careful direction of light fittings. The survey was organised during the Christmas holiday season and partly because of this the respondents also emphasised that they do not use harsh, blinking, or colourful decorative lights. The appropriate timing of lighting was seen both as a method for energy saving and a method for reducing light pollution. Over-illumination was avoided by favouring dim overall lighting and by installation of lights that can be dimmed. Glare was avoided by careful direction of light fittings and by favouring indirect light sources. Appropriate timing of lighting was commonly referred and automatic timer switches were mentioned by 37 respondents. Motions sensors switching lights on only when there is someone moving outdoors were mentioned by 72 respondents. However, it was noted that the overly sensitive sensors caused a disturbance because they were easily triggered by wild animals or pets.

The responses focused on the private use of light, even though street and road lights were considered to be more common sources of light pollution and commercial lighting was considered to be the most annoying form of light use (Lyytimäki and Rinne, 2013b). However, attempts to have an influence on public lighting by municipalities (N=14) or commercial outdoor lighting (N=16) were only rarely mentioned. The probable reason is that the respondents lacked the potential to influence these light sources. Some respondents proposed that the municipalities should dim the street lights or switch them off during the quiet night time, but only nine respondents had made such proposals to the municipality.

Avoiding places or situations with heavy commercial or public lights was relatively often considered as the only effective way to react to the problem (Table 2). In extreme cases the respondents stated that they have changed the place of residence at least partly because of light pollution. For example, an amateur astronomer from southern Finland stated "I moved with my family to the countryside, away from the shining street lights." A man in his early forties with a university education stated that "As a teenager I used to throw stones at the lamps. Sometimes I managed to put them out by kicking. I should probably do it again." Hence, deep frustration with the lack of potential to influence public lighting was highlighted by responses contemplating illegal avenues of action.

The majority of respondents answered from the perspective of property owners, and described their activities in their permanent places of residence or in their leisure homes. In addition, some respondents (N=5) emphasised their experiences in tourist destinations. For example, a person who has spent the winter holiday in Finnish Lapland gave a rare example of an activity focusing directly to the public or commercial lighting. This respondent had asked the owner of a ski resort to remove the fuse of outdoor lights in order to allow them to view to the night sky. The lack of light switch for outdoor lights is also an example of technical issues making it difficult to switch the lights off in places where they are considered unwanted.

Work roles emerged only rarely (N=38). Most often the respondents mentioned that they switch off unnecessary lights in their workplaces. For example, one office worker described how she had tried to stop the night time illumination of empty office corridors, with little success. Some lighting professionals described how they have tried to combat the installation of searchlights directed straight upwards. Two teachers described discussing light pollution issues with their students.

Participation in activities run by non-governmental organisations was reported rarely, if compared with the high proportion of amateur astronomers and environmental or nature activists. The typical forms of activities of environmental NGOs, such as attempts to increase public awareness through campaigning, were only rarely mentioned (N=3). Only a few respondents reported direct contact with local authorities (N=14), discussions with neighbours (N=4), or public expressions of concern through letters to the editors of newspapers (N=5). Debates on social media were not mentioned.

Respondents with privately owned houses and gardens typically reported activities related to their own private use of light. The occupants of apartment buildings highlighted methods of protecting themselves from obtrusive light. Curtains or Venetian blinds were mentioned often (Table 2) but they were not always considered adequate to block the light from streetlamps from entering indoor spaces. Even though the occupants of apartment buildings generally felt that they lacked opportunities to make an impact, in four cases they had been able to reduce glare or obtrusive light by directly contacting the maintenance service responsible for lighting. Another method was the participation in the meetings of boards of the housing cooperatives responsible for decisions about the maintenance of apartment buildings. Respondents felt that it is possible to have light fittings redirected, but it is nearly impossible to have the lamps removed once they have been installed.

Experiences from contacting urban planners and city authorities were highly varied. In some cases, light sources that disturbed people were removed, or plans for new street or park lighting were altered because of complaints and comments from the respondents. In other cases concerns about excessive or disturbing lighting were not taken into consideration by planning officials. For example, a woman living in the Helsinki metropolitan area commented that "I contacted a city official, who advised me to move to the countryside if the city lights are disturbing me."

Respondents reported being disturbed by very small amounts of light. For example, one respondent described how she covered signal lights on all home electronics in order to improve her quality of sleep. Some respondents argued that in

many cases it is possible to cope without any artificial light or emphasised that it is important to allow the eye to adapt to low light levels and develop night vision (scotopic vision). Using torches or other portable lights was considered adequate, particularly during outdoor exercise or night-time activities at summer cottages. Moonlight was also emphasised as an adequate light source in rural areas.

4. Discussion: systems intelligence enhancing the management of light pollution

4.1. The concept of systems intelligence

Outdoor lighting can be considered to be a holistic system that includes different technologies, infrastructures, human actions, interests and values, as well as constantly changing natural conditions. Light pollution is one characteristic of this system. The survey responses commonly indicated a perception that the light pollution situation in Finland is worsening and that effective measures for tackling the problem are lacking. Thus, the results from our survey, as well as insights from elsewhere (Mizon, 2012, Bogard, 2013, Kamrowski et al., 2014, Ling, 2014), suggest that resignation to ever-increasing light pollution is a widely shared sentiment among the people who are concerned about the issue. The challenge of reducing light pollution is often considered overwhelming, especially in the absence of specific laws, ordinances, guidance, and institutionalised practices encouraging actions related to the issue.

The systems intelligent awareness of the lighting system may provide an escape from this resignation. Systems intelligence is defined as human ability to behave intelligently in the context of complex systems involving interaction, dynamics and feedback (Hämäläinen et al. 2014, p. 15). It builds from systems thinking that has been identified as an understudied approach in research focusing on the sustainability of built environment (Davidson and Venning, 2011). The concept was originally outlined by Hämäläinen and Saarinen (2004). The fundamental assumption of systems intelligence is that certain holistic entities deserve to be called “systems” and that the personal engagement in such systems involves “intelligence” (Luoma et al., 2011). The concept emphasises active, individual level involvement with systems characterised by complex cross-scale interactions. It views people and their environment as interconnected and interdependent and focuses on systems and organisational structures that shape human behaviour and at the same time provide leverage points and possibilities for action affecting the systems.

Systems intelligence is an intrinsic human characteristic and a person may act systems intelligently without consciously noticing it as such. Jones and Corner (2012) identify three main stages of systems intelligence. First, attentive systems intelligence reflects the individual's capacity to perceive systems and attend to them. At this stage, the actor has the capacity for abstract, rational thinking and an ability to see oneself and others within systems. Second, active systems intelligence is a phase where individuals are beginning to perceive and attend to multiple formal and informal systems with obvious and hidden characteristics, and are acting in ways that take those systems into account. At this stage, individuals evaluate situations from a third person perspective. Third, at the stage of inspired systems intelligence, individuals are capable of seeing beyond existing systems, defining new ones, leading others in systems, and dealing with the complexity of the system. A human acting with inspired systems intelligence actively observes his/her interdependencies with the system, and seeks opportunities to improve the functioning of the system (Luoma et al., 2011; Hämäläinen et al., 2014).

4.2. Systems intelligence as conflict resolution

When viewed through the lens of systems intelligence the types of actions identified from our survey form two major clusters (Fig. 2.). The cluster largely consistent with the systems intelligence approach contains actions where the actor tries to educate others, influences decisions about public lighting, makes decisions as a consumer or sets an easily observable example by minimising the one's own light use. The cluster largely inconsistent with the systems intelligence approach consists of actions focusing not on the increasing interpersonal systemic awareness on the prevention of light pollution but on the minimising the personal level exposure to unwanted artificial light.

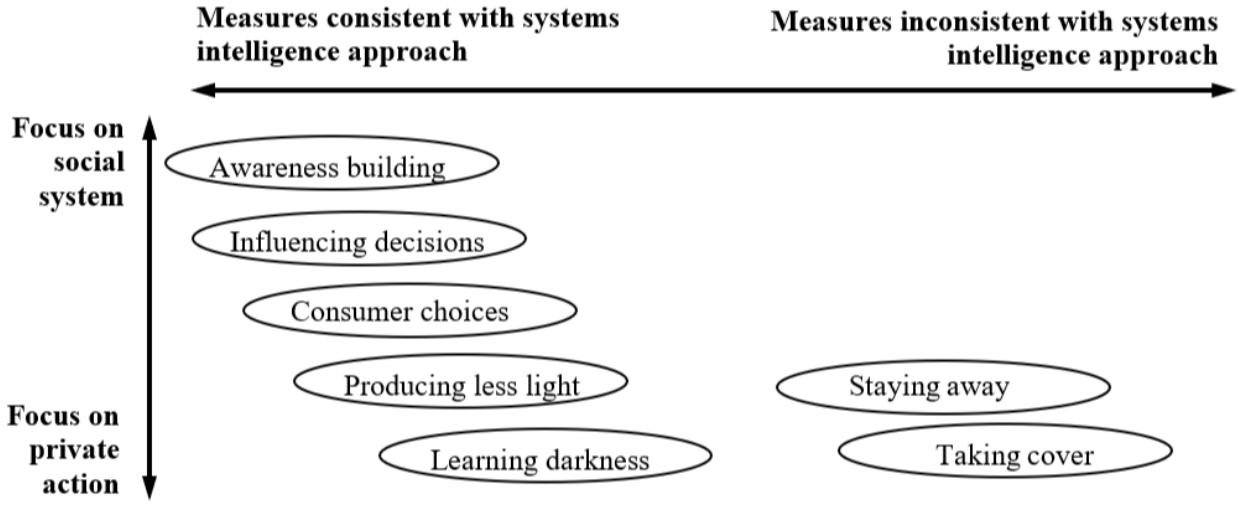


Fig. 2. Different types of the household level measures aimed to reduce light pollution and their compliance with the systems intelligence approach.

Elements of inspired systems intelligent behaviour (Jones and Corner, 2012) were most clearly present in responses focusing on awareness building. For example, one respondent reported how casual discussions with neighbours lead to increased awareness of the functions of lighting and eventually to adoption of new and more restrained outdoor lighting practices throughout the neighbourhood. In this case, successful intervention occurred through informal discussions with a friendly tone, focusing attention on light pollution. This illustrates the importance of human sensitivity in social interaction, which is one of the key characteristics of systems intelligent leadership (Viluksela, 2007). Also responses focusing on the making an influence on decisions indicated inspired systems intelligence. Measures focusing on consumer choices and concrete actions aimed to produce less light pollution typically represent attentive systems intelligence where the focus is on actors' own actions. Likewise, learning darkness was typically a form of attentive systems intelligence since the focus was on respondents own learning process or on teaching respondent's own children to appreciate natural darkness.

Human behaviour characterized by systems intelligence helps to prevent and manage conflicts arising when different preferences for the use of outdoor space collide. Such conflicts have been common in the history of lighting, especially during the periods of transitions when new technologies have been tested and implemented (Hasenöhrl, 2015). Increased awareness of both the negative and positive impacts of the functioning of lighting systems may alleviate or prevent the conflicts related to the ongoing transition towards LED-based outdoor lighting. However, new conflicts may arise when resignation turns into engagement and action. The first initiatives to curb light pollution are likely to give more attention to the issue and may induce new controversies rather than prevent them. Experiences from Hong Kong show that light nuisance complaints increased after some attention from the government and introduction of guidelines for best practices of external lighting (Ling, 2014). Several respondents in our survey described disagreements that were caused by different preferences, expectations, and practices related to lighting, highlighting the importance of personal level norms in communication about light pollution (see Kamrowski et al. (2014)).

One factor behind the lighting controversies is the collision of commercial lighting and non-commercial uses of natural darkness. Artificial light is often commercialised, whilst the starry night sky and other services provided by natural darkness are most often non-commercialised passive pleasures (Gallaway, 2010). However, light pollution management also creates commercial opportunities for manufacturers of high-quality lighting appliances and for tourism industry based on dark sky destinations attracting customers (Rodrigues et al., 2015). Comprehensive knowledge describing both the direct and indirect economic effects of night-time outdoor illumination is needed in order to avoid conflicts based on false assumptions (Pottharst and Wukovitsch, 2015). Successful resolution of the conflicts may open up new pathways for development, and show leverage points leading to a considerable reduction in light pollution. Identification of such systemic thresholds or leverage points is a key feature of systems intelligence (Hämäläinen and Saarinen, 2004).

4.3. Systems intelligence and background factors of environmental change

More generally, the systems intelligence approach may help to address challenges brought by four background factors of environmental change relevant in the context of light pollution (Lyytimäki, 2013, Kyba et al., 2014). These include path dependence, rebound effect, tragedy of commons, and shifting baselines (Table 3).

Table 3. Systems intelligence and the management of light pollution.

Key issues of the management of the light pollution	**Potential contribution by actors operating with systems intelligence**
Path dependence	Breaking "lock-ins" and opening up new avenues for development
Rebound effect	Showing the impacts of individual choices on the overall situation
Tragedy of the commons	Creating trust and shared action needed for preserving the darkness
Shifting baseline syndrome	Challenging the perceptions based on current environmental status

Firstly, systems intelligence approach can challenge the path dependence characterised by technological "lock-ins", rigid institutional structures and deeply rooted routines by adoption of new ways of thinking and action. Lighting systems involve strong path-dependencies, whereby past decisions influence the current situation. For example, the typical lifetime of a street lighting system extends through several decades. Not only physical infrastructures such as electricity grids and lighting installations but also formal education, learning from past experiences and social norms and legislation create certain expectations leading to lock-ins (Nygrén et al., 2015). Systems intelligence may break the path dependences of lighting systems by sparking new kind of awareness (attentive systems intelligence), action (active systems intelligence) and even innovation (inspired systems intelligence). An illustrative example is the CieloBuio association in Italy (Falchi, 2011, CieloBuio, 2014). This grass-root association has managed to enforce regional laws that currently cover most of Italian population. The association was initiated in the late 1990s by two individuals who collected signatures supporting a proposed law against light pollution in the most developed Italian region, Lombardy. The regional law was approved in 2000 and it has served as an example for legislation developed in other areas. However, as noted by Henckel and Moss (2015: 300), citizen participation is not well established in the context of outdoor lighting and management of the issue has in most cases focused on regulatory schemes based on top-down approaches leaving little room for bottom-up initiatives (Krause, 2015, Morgan-Taylor, 2015).

Secondly, systems intelligence fostering a comprehensive public understanding of the functioning and impacts of lighting systems may help to overcome the rebound effect. Historical examples suggest that more energy-efficient lighting technologies are likely to lead to the increase of overall energy consumption (Fouquet and Pearson, 2006, Tsao et al., 2010, Kyba et al., 2014). A rebound effect, i.e. the increased use of cost-efficient lighting technology causing increased energy consumption is also a possible future scenario based on our survey. For many respondents, financial savings were an important motivation for light pollution abatement, even though the electricity used for outdoor lighting typically does not add much to the household's electricity bill. This motivation becomes even less relevant as the purchase prices of energy-efficient LED-based lighting technologies become lower. Increased awareness of the wide effects of light pollution challenges the dominant eco-efficiency narrative highlighted by the lighting industry (Franceschini and Pansera, 2015) and directs attention to consumption of light in a way that may help to avoid the rebound effect caused by careless or excessive LED-based outdoor lighting.

Thirdly, systems intelligence may also provide a way out of the tragedy of the commons in relation to lighting (Hardin, 1968). Darkness can be seen as a common natural resource available to all, which is depleted due to individuals using artificial light (Gallaway, 2010, Gaston et al., 2013). Thus, light pollution represents a reverse tragedy of commons, where a natural resource is depleted not because something is taken out of the system, but because something (light) is added to it. Individuals operating with systems intelligence are able to acknowledge the need for the management of this common resource. For example, already attentive systems intelligence can help the advertisers to avoid competition, which leads to the introduction of ever brighter signage lights in order to attract attention. Inspired systems intelligence can help to preserve darkness as a resource for innovative commercial or decorative illuminations, building on the contrast between dark and light, not on increasingly powerful lights.

Fourthly, and perhaps most importantly, systems intelligent approach may provide a cure for the shifting baseline syndrome that partly governs the formation of the priorities of environmental policies and management actions. The concept of shifting baseline syndrome refers to the changing human perceptions of the state of certain system due to loss of experience of past conditions (Kahn and Friedman, 1995; Pauly, 1995). Based on their personal experiences, people may consider the current situation to be the typical or normal state, even when the system has changed considerably compared to earlier states. Because of wide-spread light pollution, people in the industrialised world are likely to suffer from the shifting baseline of the nocturnal environment (Cinzano et al., 2001, Lyytimäki, 2013). In particular, the children living in urban environments become accustomed to constantly illuminated nights. As indicated by some responses to our survey, providing children with safe opportunities to experience natural darkness can provide a motivation to learn and challenge the current perceptions of normal and desirable states of lighting systems. Already the presentation of the term "light pollution" challenges some of the deeply held culturally shaped perceptions of artificial light as something purely positive.

5. Conclusions: avoiding overly bright future

Inclusion of individual level determinants and dynamics of human action is needed in the management of light pollution since the lighting decisions of private persons make a significant contribution to the timing, amount and quality of light emissions. Moreover, citizens influence lighting systems indirectly through contacts with planners and through democratic institutions more generally, as well as through consumer choices. The concept of systems intelligence highlights that the bottom-up activities of private citizens can be an important part of light pollution management. However, a focus on systems intelligence on a household level does not imply that individual citizens should alone be responsible for systemic changes. On the contrary, planners, managers, policy-makers and even scientists can also employ the ideas of system intelligence, especially by providing opportunities for active participation by the people.

Fostering a systems intelligence may be the key to energy-efficient and low-carbon outdoor illumination that enhances human well-being, and simultaneously produces minimal amounts of light pollution. In particular, systems intelligence may help to overcome phenomena such as the path dependence forestalling the adoption of new innovations, the rebound effect in relation to new lighting technologies, the (reverse) tragedy of the commons related to the use of darkness as a natural resource, and the shifting baseline syndrome related to the human experience of night. However, a better knowledge base both regarding the extent and types of light pollution and regarding the determinants of systems intelligent behaviour is needed. Improved availability of satellite-based data and more sophisticated data treatment and modelling methods have already provided important insights for environmental planning and management concerning the extent and development of light emissions (e.g. Bennie et al., 2014; Elvidge et al., 2014; Olsen et al., 2014). Research on the impact of light pollution on health and ecosystems has also taken considerable steps towards identifying the most harmful forms of light pollution. Social sciences studies focusing specifically on the implementation and efficiency of management options regarding light pollution are, however, largely lacking (cf. Meier et al., 2015). Key research topics include the factors determining, enhancing or hindering individual's system intelligent behaviour. At least two major research areas can be outlined based on this study. Firstly, the roles played by various individual level factors such as (environmental) awareness, education, political engagement, age and gender should be explored more deeply. Secondly, the characteristics of specific social and physical contexts should be investigated in order to better understand structural factors influencing systems intelligence.

The systems intelligence approach holds many promises for environmental management. Actors operating in systems intelligent manner can connect science-based knowledge on light pollution and lighting systems with everyday experiences and choices (Hämäläinen and Saarinen, 2004, Hämäläinen et al., 2014). They also have the sensitivity required to connect culturally and socially shaped attitudes and values with management practices and institutions shaped by technical reasoning and legislative rationalities. This may help to bring together contradictive values and target efforts in positive and even synergistic ways. In the best case scenario, systems intelligent behaviour of a single human actor can set an example that may spark local level systemic changes that eventually lead to changes on national and even global levels.

Acknowledgements

I am deeply grateful to the three anonymous reviewers for constructive comments. This research is based on paper presented at the conference Future Infinite Academic: Sustainable futures in a changing climate, Wanha Satama, Helsinki, Finland. 11 June 2014.

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