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Future indoor light and associated energy consumption based on professionals' visions: A practice- and network-oriented analysis

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ABSTRACT

Through the insight and visions of Danish lighting experts, this manuscript investigates relationships between future lighting technologies and practices and the expected impacts on energy and lighting consumption. The light-emitting diode (LED) will be the dominant technology of the future *smart* light systems. Though, energy efficiency is expected to improve, new market players will appear and new lighting opportunites will be exploited that, in turn, will increase the demand for light. A rebound effect is expected. The overall impact on the future consumption of energy is uncertain, so we conclude that political guidance is needed if society wants to assure the reduction of energy consumption through widespread diffusion of smart LED lights.

1. Introduction

The provision of light is one of the societal needs that is expected to reduce its consumption of energy (; IDA, 2011; EPA, 2011; European Commission, 2012; Oosterhuis, 2007), with expected potential of saving up to 70% of the current level (European Commission, 2011). Consequently, many lighting innovations have attracted societal attention due to their promising benefits for energy saving (Bertoldi and Atanasiu, 2010; EPA, 2011; Haitz and Tsao, 2011; Lee, 2000; Mahlia et al., 2005; Menanteau and Lefebvre, 2000; Wall and Crosbie, 2009; Weiss et al., 2008).

However, several scholars highlighted that past increases of efficiency in the provision of lighting did not actually reduce the associated consumption of energy (Franceschini and Pansera, 2015; Nordhaus, 1998). Fouquet and Pearson (2006) identified four distinct revolutions in lighting services, and in each of them efficiency and consumption of light skyrocketed. Tsao and Waide (2010) reviewed three centuries of energy consumption for light and concluded that there is a massive rebound effect associated with an increased efficiency in the provision of lighting. Furthermore, Tsao et al. (2010) indicated that there is not sign of saturation in the future demand for light, warning about immense future rebound effects.

Given the prevailing societal strategy to reduce energy consumption through the diffusion of promising lighting innovations and the contrasting findings of the rebound effect literature on lighting services, it is not trivial to evaluate to which extent such promising lighting innovations will be able to fulfill their promises without a clear political guidance (Hekkert et al., 2007). For this reason, it is important to accompany analyses of technological transformation and market acceptance of novel energy efficient lighting technologies with analysis of the expected new lighting practices.

The rebound effect literature has tried to couple technological innovations with changes in practices of consumption, especially using long-term historical analyses (Fouquet and Pearson, 2012) or modeling of individual agents' behaviors in response to increase of efficiency (Lay et al., 2013; Min et al., 2014; Saunders, 1992). While these approaches can provide solid knowledge about past and present dynamics, they are less useful in analyzing future developments because they cannot easily account for potential future changes (Bijker and Law, 1994). Therefore, the present study proposes a complementary approach that explicitly accounts for qualitatively changing behaviors in future contexts.

Building on the traditions of foresight and scenario methods (Amer et al., 2013; Bootz, 2010; Kosow and Gaßner, 2008; Miles et al., 2008), this study suggests a future-oriented approach for analyzing novel lighting technologies, lighting practices and rebound dynamics. The approach is centered on cognitive mapping technique (Downs and Stea, 1973) that describes elements and relations between elements in practice, and hereby establishes a system and network perspective on use of new light innovations. More specifically, we interviewed professional experts and produced individual cognitive maps representing future visions for indoor non-residential light and lighting in the Danish context.

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We argue that future looking analysis of rebound effects can fruitfully draw on the systemic perspective on innovation and technology development that in recent years have received increased emphasis both within studies of innovation and technological change in general (Geels, 2004a; Hekkert et al., 2007) and within technology foresight and scenario approaches specifically (Andersen and Alkærsig, 2016; Saritas and Nugroho, 2012). At the core of the system oriented literature is the idea that sociotechnical change and innovation are dependent on interactions and co-evolvements of several, heterogeneous elements. One of the rationales for the increased emphasis on the systemic perspectives is to move away from technology deterministic and linear models of technology development and integrate demand aspects and socio-economic elements in the otherwise strongly technology-push and science-push oriented approaches that appeared in many technology foresight activities earlier (Georghiou and Cassingena Harper, 2011; Jørgensen et al., 2009; Smits and Kuhlmann, 2004).

The results of our study confirm that the future lighting scenario is dependent on the changing interconnections between technologies, policies, and practices. For example, the LED technology is not only considered more efficient than other lighting technologies, but also considered superior with respect to many other dimensions (e.g. versatility, customizability) and it is expected to encourage new practices that will increase the demand of light. Increasing efficiency will be accompanied by more attention to quality of light, human health, and effects of light on productivity. These dimensions are expected to increase the demand of light. New players are expected to appear to fully exploit the opportunities of the intelligent future light. The existence of such dynamics indicates the possibility of contradictory and unexpected dynamics for energy saving, with the time dimension as an essential component. In the short term, gains of efficiency will deliver important savings of energy. In the long term, changes in the drivers of market selection and the evaluative criteria of lighting solutions will result in an increase in the light demand. These results suggest that policy makers must carefully judge the systemic impacts of innovative policies in respect to new practices in the society to predict potential unexpected outcomes of policies that are designed to reduce environmental burden through efficiency only.

The paper has two contributions which are relevant for light practitioners, policy makers and scholars and experts of the rebound effect. Firstly, it provides new knowledge about the rebound effect thanks to a systemic approach which explicitly addresses rebound dynamics through the analysis of relationships and networks between elements of lighting innovations and practice. The case is lighting, but the approach can be used in any areas exposed to eco-innovative forces. Secondly, the paper provides new, practice-oriented knowledge to the current literature on light technology which mainly focuses on the technical dimensions of the diffusion of LED (light-emitting diode) technology.

The article is structured as follows: Section two briefly reviews the current rebound effect literature on light and provides a short, contextualizing description of the discourse about light, lighting, and energy in Denmark – the location of our study. Section three describes the methodology. Section four presents the results of the case study, and section five discusses them. Section six sums up the conclusions and highlights the main findings and limitations.

2. Energy efficiency and consumption in the provision of light: The literature background

2.1. The rebound effect literature about light and energy consumption

The work of the British Economist Jevons (1865) about the increasing consumption of coal due to the increase of the efficiency of coal engines is widely recognized as the initial milestone of the rebound effect literature has focused on understanding under which conditions an increase of the efficiency of utilization of any resource may lead to an increase of its consumption. For a general overview of the rebound effect literature readers are invited to consider, as starting points, the existing seminal works by Sorrell (2009a, 2009b) and van den Bergh (2011). Here we delimit ourselves to the works focusing on the energy rebound effect for lighting. Bright and Maclaurin (1943) reported that the total number of installed light bulbs increased because of the diffusion of the fluorescent light. Similarly, Bright (1949) and Nye (1992) reported that the overall use of light[1] increased when the incandescent light replaced the oil and gas lamps. Such dynamics have been confirmed by long-term historical studies which go beyond a specific technological change in the light bulb. For example, Fouquet and Pearson (2006) studied the evolution of lighting efficiency and consumption in UK over seven centuries and concluded that light consumption increased by 25,000 times in the last two centuries. Similar conclusion were achieved by Herring (2006) which noticed an increase of 400 times in the intensity of public road light per mile of road. Bowers (1998) suggested that throughout history people have used light to lengthen their day and to increase productivity, and found that gains in efficiency led to more usage of light. In addition, Franceschini and Pansera (2015) pointed out that the rebound effect for lighting is the result of the present dominant societal discourse about innovation which encourages new demand for lighting instead of energy conservation.

While the literature is unanimous concerning the importance of the rebound effect in cases of *fuel poverty* (Guertin et al., 2003; Herring and Roy, 2007; Roy, 2000), findings are more controversial about developed countries (as Denmark). On the one hand, Nadel (1993) suggested a smaller direct rebound of 10% or less for lighting, similar to the findings of Greening et al. (2000). Howarth et al. (2000) have investigated the US Green Lights programme and conclude that the rebound effect is not of great empirical relevance because the demand for light is cost-inelastic in the industry and tertiary sectors, a finding confirmed by Schipper (2000). However, on the other hand, Verbeek and Slob (2006) found that the diffusion of energy-saving lights has increased the consumption of energy in Dutch households because '*most people not only replaced existing bulbs with the new light-saving ones, but also used the new bulbs to illuminate places where there was no light before, such as the garden or the garage*' (p.4). Similarly, Mills and Schleich (2014) reported that luminosity is increased with 48% when German householders switch from the incandescent bulb to the LED light. Therefore, the magnitude of the rebound effect in developed economies is still a controversial issue which deserves more analyses.

In addition to the rebound effect literature that has highlighted the contradictory relationship between light efficiency and energy consumption, we explored the socio-technical, system-oriented literature about sustainable transition in the provision of light to gather knowledge about the ongoing dynamics. Lighting can be framed as a socio-technical function that "*has the purpose to fulfill the human need of performing visual tasks* "(Franceschini and Pansera, 2015, p. 77). The socio-technical approach encompasses not only the production side, but the diffusion, and the use of any innovation (Geels, 2004b), an essential aspect to understand the qualitative dynamics of the rebound effect. Surprisingly, we found very few works providing a ST-transition analysis of light. Moreover, most of these works focus on developing countries (Bensch et al., 2017; Harish et al., 2013; Lay et al., 2013; Rehman et al., 2010) and their ST-systems cannot easily be compared to the Danish ones. We found only two studies which explicitly analyze the ST-transition associated to new lighting technology in developed contexts. Smink et al. (2015) showed that lighting incumbents implemented institutional strategies to favor fluorescent light against the LED technology, before they passed a tipping point, after which they actively supported the LED technology. Marletto et al. (2016) highlighted the role of changing business models and political discourse

[1] 'Where once 5 or 10 fc were deemed adequate, from 50 to 75 fc are not now considered excessive' (Bright, 1949)