Lighting up transition in the LED sector:

How to overcome eco-innovation barriers at the niche level

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Abstract

The aim of this paper is to analyse the barriers to the environmental transition of lighting, especially in the current period of the emergence LED-based lighting solutions. These technologies can generate huge energy savings, but they require ecodesign improvements in order to maximise their environmental benefits at each stage of their lifecycle. In order to facilitate the realisation of these benefits, this paper analyses the barriers to these improvements at the niche level, in the case of the European R&D project "cycLED". This analysis enables us to bring out the key barriers that need to be addressed by firms' strategies and government policies in order to facilitate the diffusion of low environmental-impact LEDs into the dominant lighting regime. After introducing the academic and societal issues at stake, the lighting sector is briefly explained in Section 2, and a MLP on lighting is presented in Section 2 (landscape, regime, niche). In Section 3, the barriers to eco-innovation in an LED niche composed of four SMEs are analysed. Finally, key findings and recommendations are given in the concluding section.

1. Introduction

This paper analyses the barriers to the environmental transition of lighting, notably the ones faced at niche level by European SMEs when trying to produce ecodesigned LED (light emitting diodes) systems that can substantially reduce the ecological impacts of lighting. The latter concern the three types of ecological impacts of human societies (pollutions, exhaustion of resources, global environmental changes) and occur at each phase of the lifecycle of lighting systems. For example, in the production phase, chemicals are used and upstream mining activities lead to the exhaustion of metals such as Gallium or Indium used in light emitting diodes (LED). During the use phase most impacts will derive from the energy consumed and will thus depend on the local energy mix, which in most countries is carbon-intensive. Besides the global warming caused by energy use throughout all the lifecycle phases of lighting systems, another contribution to global environmental change is biodiversity, which is impacted e.g. by the mining activities supplying the lighting sector but also by light pollution. The end-of-life (EOL) phase of lighting solutions generates pollutions because of (hazardous) waste contained in lighting products (e.g. compact fluorescent lights (CFL) and other energy saving bulbs contain hazardous substances), but can also offset part of its impacts if valuable materials are recovered from "urban mines". New lighting solutions such as ecodesigned LED can contribute to overcome these environmental challenges by reducing the use of energy and other raw materials as well as lighting wastes. They can also help overcome societal challenges by creating jobs in a cleaner economic sector and by reducing the lighting gap, as evidenced by the diffusion of LED systems fuelled by renewables in developing countries (Adkins, Eapen et al. (2010), Harish, Raghavan et al. (2013)). As Hall, Matos et al.: 5) underline, "approximately two billion people currently do not have access to electricity and have to rely on candles and kerosene-based lighting, a dangerous, unhealthy, expensive and poor quality alternative".

From an academic point of view, a better understanding of the dynamics of socio-technical changes driving lighting trajectories might be useful to foster sustainable transitions in other sectors. Besides, if transitions scholars have investigated many sectors at this point, none has focused on lighting, a technology that has been operating for thousands of years and is now used by all kinds of socioeconomic actors in all countries in the world. Therefore lighting and LED innovation is an emerging topic (in a review of the literature on green technology and low carbon technology innovation from 1994 to 2010, Shi and Lai (2013) do not mention lighting among the key words used in this literature). Also the eco-innovation dynamics at niche level and for SMEs are underinvestigated.

In order to better understand the factors that might facilitate the transition to sustainable lighting systems, this paper proceeds in four steps. After introducing the academic and societal issues at stake, the lighting sector is briefly explained in Section 2, and a MLP on lighting is presented in Section 2 (landscape, regime, niche). In Section 3, the barriers to eco-innovation in an LED niche composed of four SMEs are analysed. Finally, key findings and recommendations are given in the concluding section.

2. The lighting sector in a nutshell

This section provides an overview of the evolution of lighting in terms of its main technological developments. Current developments will be examined in greater detail in the next section at each of the three levels of the multilevel perspective (MLP, see Section 3).

Looking a few thousand years back one finds that fuel combustion has dominated the long history of lighting. For example, DiLaura (2008: 23) explains that:

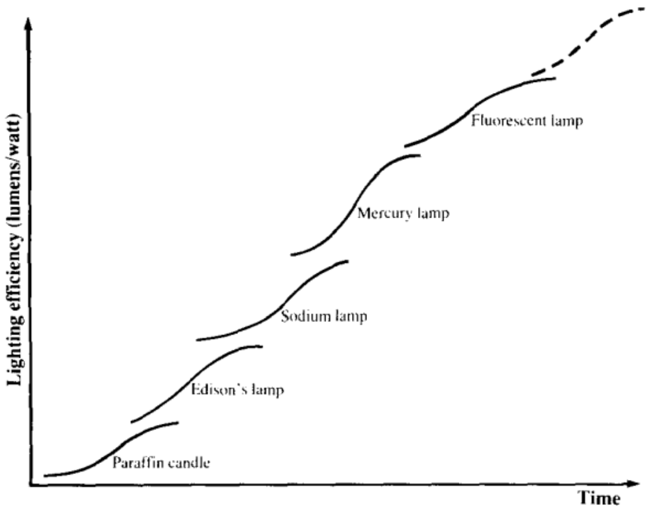
> "The first records of fire-making appear in the Neolithic period, about 10,000 years ago. In 1991, scientists discovered a Neolithic man, dubbed "Otzi," who was preserved in an Alpine glacier. Otzi carried on his belt a fire-making kit: flints, pyrite for striking sparks, a dry powdery fungus for tinder, and embers of cedar that had been wrapped in leaves."

More than 4,500 years ago, in modern day Iraq oil lamps were used to burn oils made from olives and seeds. In Northern Europe and colonial America, animal oils from fish and whales have commonly been used (animal grease was used in controlled fires 250,000 years ago). The author also explains that "Lascaux cave paintings produced in France 15,000 years ago were likely created using illumination from burning animal grease in lamps". The first candles appeared 2000 years ago in Rome but were too expensive for being used for ordinary lighting. It was only in 19th c. that chemical advances using stearine and especially paraffin in the 1860s replaced animal and vegetable oils and enabled improvements of more elaborated lamps like the one developed by Ami Argand in 1784 (Bowers (1980)).

The next important technological change appeared at the same period with the development of (at first coal) gas lighting, which enabled the large illumination of cities (the first public demonstration was in London on 4th June 1807, and the first gasworks was established in 1816 in Freiburg by German mineralogist W.A. Lampadius). At the end of the century, gas mantle burners using rare earth elements further improved luminous efficiency, and were only going to be challenged by the introduction of electric arc and incandescent lighting (first successful demonstration of electric street lighting in Paris in 1878, avenue de l'Opéra). Before the fast diffusion of the latter technologies, discharge lamps based on mercury (GEC in 1932) or sodium were also used, and today solid state lighting is about to take over the next wave of lighting technologies (the doted line in Figure 1).

Early work on incandescent lamps dates from about 1840, and following works by Joseph Swan, Thomas Edison showed in 1879-1880 the importance of deep vacuum and in October 1879 built and tested what he called a "filament" lamp. But the inventor did not stop there and by 1881, "Edison's company was manufacturing complete systems consisting of a dynamo, wiring, switches, sockets and lamps" (Bowers (1980: 27)). Besides, notices Freeberg (2013), thanks to his reputation (phonograph, moving pictures, telegraph, ...) he was connected to key stakeholders of the technological regime (in the patent office, in the media, ...), and knew how to stir desire for his product through press announcements.

Figure 1. Successive waves of lighting technologies



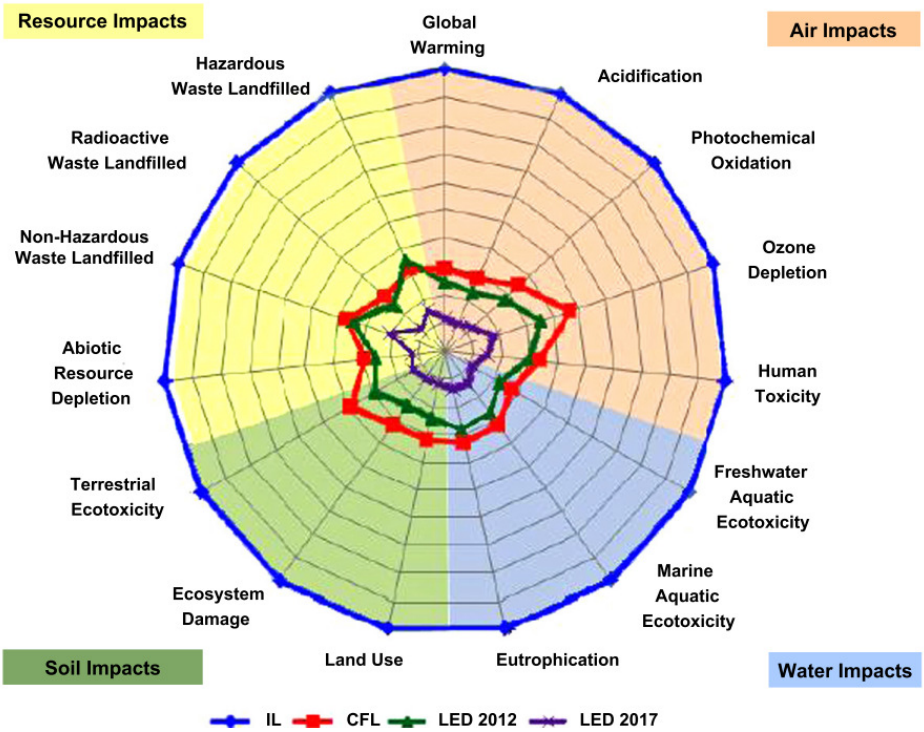
Source: Wissema (1982), quoted in Olleros (1986: 7).

This graph underlines that the history of lighting "is not one of smooth, linear, upward progression, but rather one of relatively short periods of linear progress punctuated by instances of discontinuous leaps". As Dosi (1982) showed, technological developments occur through paradigms following patterns of Schumpeterian creative destructions. In 19th c., lighting innovations evolved to the point of triggering a "quantitative lighting" fashion, by which streets and other public spaces or buildings were flooded with light (Ganslandt and Hofmann (1992)). But glare problems and harsh shadows led to the new lighting concerns such as aesthetics ones, that led to seek the control of excessive amounts of light (Clear (2013), Hickcox, Narendran et al. (2013). Lighting did not only require light sources anymore, but also whole infrastructures with their inner dynamics and trajectories. As we will see in the case of LED, they can also be source of innovation lock-in, incandescent lighting luminaires and panels not being able to provide the level of heat absorption required for LED to live up to their long lifespan. Besides, since e.g. to operate discharge lamps the current needs to be limited, control technologies needed to be added, which led to the diffusion of electronics in lighting technologies.

Regarding the social uses of lighting, it was initially provided to deter crime, and much later for other safety purpose such as preventing road accidents. As Holmes (1997: 25) puts it: "There are records of Parisians in 1367 and of Londoners in 1415 being required to hang lanterns outside their houses in the interests of order and safety". But people did not like this civic duty, and centuries later besides moral and medical grounds, gas lights were even protested on theological grounds: "Night is appointed to be darkness only broken at certain times by the Moon" (p. 26). This suggests that new lighting technologies have required not only technological changes but also cultural ones, whose changes do not happen in a wink. In turn, lighting innovations had enormous impacts on modern societies. For example, Freeberg (2013) claims that public lighting enabled the expansion of nightlife in urban cores, encouraging young people to leave their small towns and farms to settle down in cities. Offices and factories could operate longer hours and doctors have better operating conditions. As for households, the diffusion of lighting changed their living patterns, since family members no longer had to chat around a dim lamp but could go to read in their own rooms.

As far as environmental issues are concerned, the use phase of incandescent, compact fluorescent and LED lamps represents the 90% of total life-cycle energy use on average (Aman, Jasmon et al. (2013: 489)). The following figure shows a spider web that compares the environmental impacts of the three main lighting technologies.

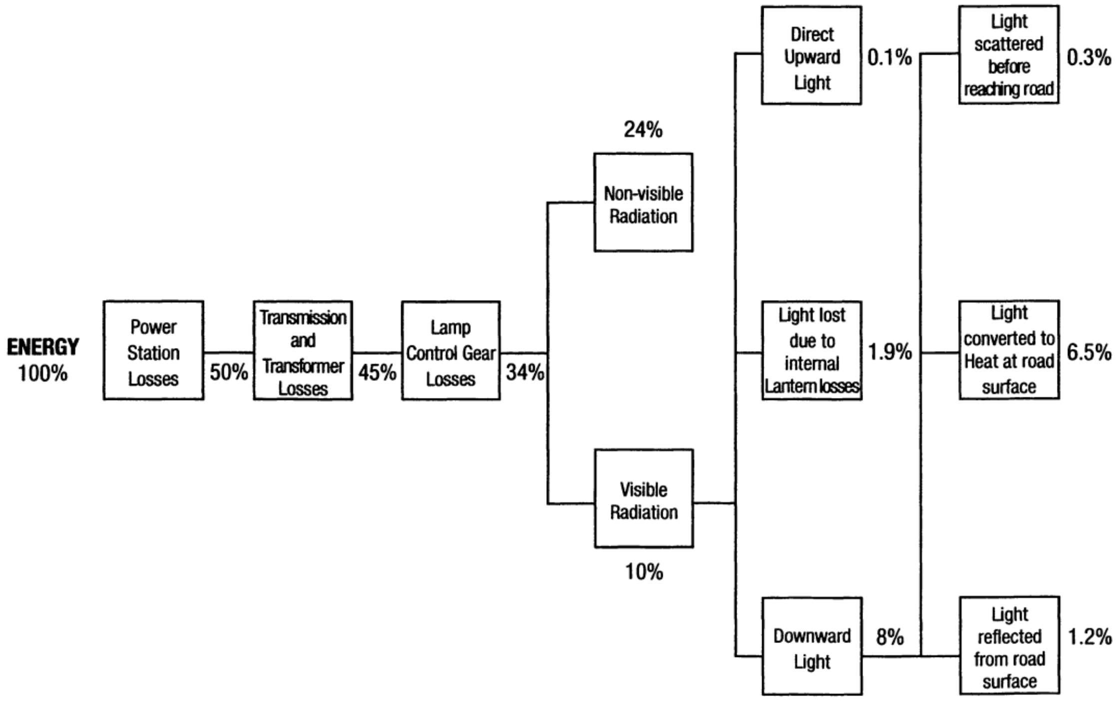
Figure 2. Life-cycle assessment impacts of IL-CFL and LED lamps



Another source of environmental impacts of lighting relates to the fact that as lighting innovations unfold (starting with gas lights), lighting sources are disconnected from the sources of energy fuelling them. As a consequence, as Holmes (1997: 28) puts it: “the overall process of obtaining light from a basic energy source, via electricity, is very inefficient”. Today, lighting represents almost 20% of global electricity consumption (similar to the amount of electricity generated by nuclear power).[1] But as evidenced in Figure 2 much of this consumption is caused by energy losses occurring along the energy/lighting chain.

[1] Source: http://www.iea.org/topics/energyefficiency/lighting/.

Figure 3. The energy chain from power station to road lighting



Source : Holmes (1997: 29).

The latest technological developments in lighting innovation, i.e. the switch to LED-based lighting systems, may reverse this phenomenon since its lower energy consumption could enable a decentralisation and decarbonisation of the energy supply of these systems, especially if smart grids live up to their promises. But as Hall, Matos et al.: 5) underline, "Although photo-emissive properties of semiconductor diodes have been known since the 1950s (...) it was not until 1997 when Japanese electronics company Nichia introduced a white 5 mm LED that produced a single 0.1 W white LED (WLED) sufficiently bright for reading in complete darkness". Finally, the LED sector is an innovation-intensive field since it bridges several fields of knowledge such as electronics and photonics. Indeed, as Zheludev (2007) point out "semiconductor lasers based on LEDs send modulated optical signals into telecom fibres, serving the ever-growing demand for broadband telecommunication and Internet". For Christophe and Takahiro (2013), LED innovation, in the case of gallium nitride, is driven by three contextual logics: "material logic (the materiality of substances, tools, and fabrication techniques); market logic (the needs, demands, and interests of intended users); and competitive logic". Hargadon and Douglas (2001) adds that lighting innovation is also geared by "robust design" strategies, as in the case of Edison who imitated the robust features of gas lighting "without requiring dramatic changes in the surrounding understandings and patterns of use".

3. Lighting transition: A multi-level perspective

Lighting provides crucial services to society but they all come at often hidden cost, including in the LED sector, especially when the sources of energy are fossil. Therefore, environmental changes are needed in the lighting and LED sectors, but many barriers are paving the way to this sustainable transition (technical, behavioural, infrastructure-related, ...). In order to better understand what these barriers are and suggest ways to support the sustainable transition of the lighting sector, as explained below the transition management approach provides a very useful analytical framework.

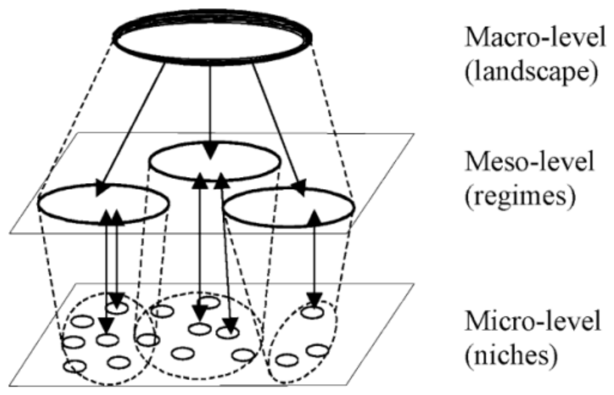
3.1. Theoretical background

Transitions are "long-term fundamental changes (irreversible, non-linear, multi-levelled and systemic) in the cultures (mental maps, perceptions), structures (formal institutions, and infrasystems) and practices (use of resources) of a societal system" (Loorbach, Frantzeskaki et al. (2010: 1195)). Various models or representations have been developed by transition scholars to shed light on how sociotechnical systems change over time and co-evolve with their natural environments. Those systems are not easy to capture because (p. 1196):

1. They are open and embedded in an outside environment with which they co-evolve,
2. There is a changing outside environment that influences the system,
3. The system itself exhibits non- linear behaviour in order to adapt to its environment.

These internal and external changes occur at various levels of society, which based on Kemp, Rip et al. (2001: 277) transition scholars have divided into landscapes, regimes, and niches.

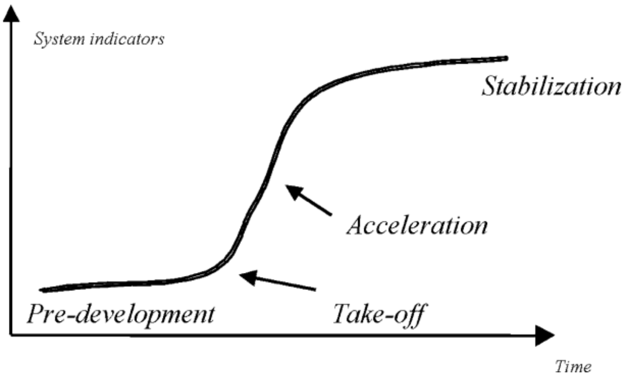
Figure 4. The multilevel concept



Source: van der Brugge, Rotmans et al. (2005: 167).

The landscape level concerns external and slow societal trends; societal regimes include the interwoven fabric of institutions, technologies, routines and other rules; while emerging innovations take place at the niche level. The transition approach analyses societal changes in a dynamic perspective:

Figure 5. The evolution of a transition



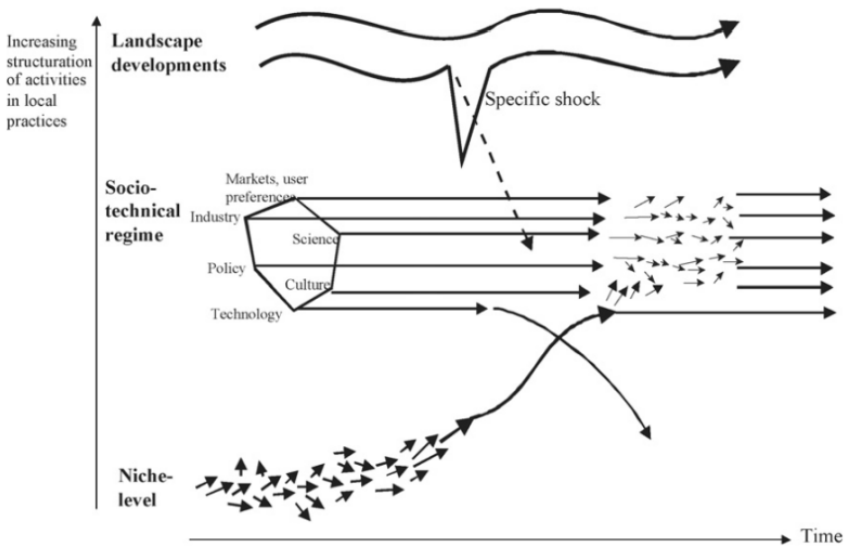
Source: van der Brugge, Rotmans et al. (2005: 166), adapted from Rotmans, Kemp et al. (2001: 17).

It also enables us to highlight the factors leading to changes in the analysed system, since each of the four phases has its own dynamics (Loorbach, Frantzeskaki et al. (2010: 1197)):

1) Predevelopment phase: a dynamically stable regime is gradually pressured by a changing landscape and emerging alternatives;
2) Take-off phase: a culmination of developments at different levels forces an opening up of the regime;
3) Acceleration phase: rapid changes materialize;
4) Stabilisation: a new dynamic equilibrium is reached.

The combination of the multilevel and dynamic perspectives provides an analytical approach that has permitted many scholars to decipher the factors having led to past transitions. For example, Figure 5 represents the transition from sailing ships to steam-powered ships following the decision of the British government to subsidise in 1838 a market niche for mail steamers.

Figure 6. Regime shift following an external shock



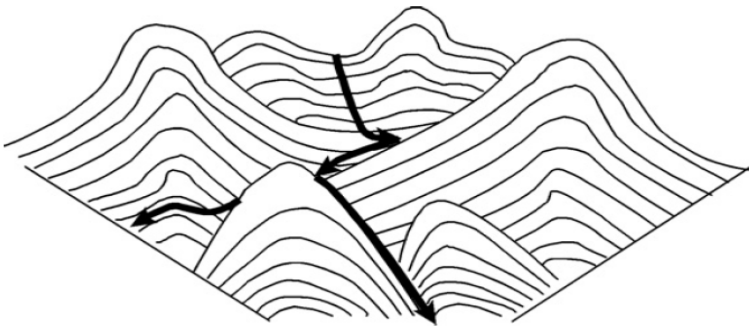
Source: Geels and Schot (2007: 410).

Several sociotechnical systems have been analysed[2] as in the cases of energy (Raven and Verbong (2007), Verbong and Geels (2007)), waste (Raven (2007) or water (Geels (2005)). Concerning lighting, very little research has focused on lighting despite its wide-ranging economic, societal and environmental impacts. For example, when discussing the challenges of the transition to a low carbon future, Hammond and Pearson (2013) does not even mention lighting. Only Holtz (2011) quotes two PhD theses, which analyse the consequences of the EU ban on the consumption of incandescent lamps and conclude that the ban will increase energy efficiency in the sector (Chappin and Afman (2013)).

3.2. The lighting landscape

According to Geels and Schot (2007), in the MLP landscape refers to the overall setting in which processes of change occur (social values, policy beliefs, worldviews, macro-economic & macro-political developments, etc.). It is the most difficult element to change and strongly constraints transitions. It can be represented as follows, the arrows representing potential routes for a technological trajectory (p. 403):

Figure 7. Representation of a landscape

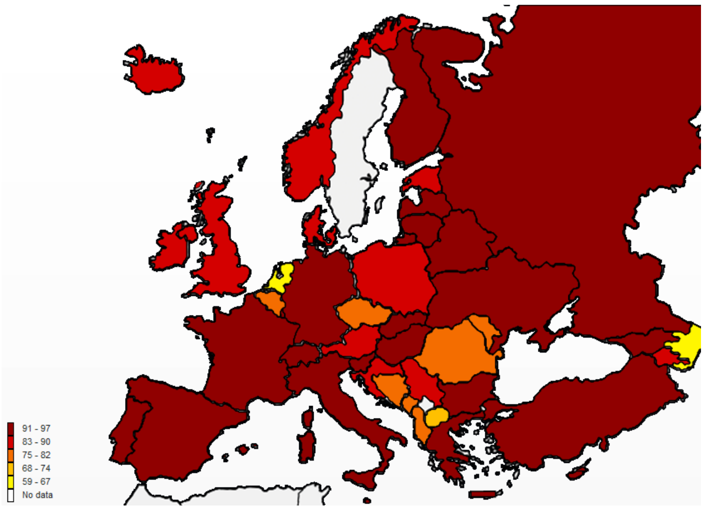


In the case of lighting, the current landscape in Europe is dominated by an economic crisis, which explains that the political priority for many countries is to support the creation and limit the destruction of jobs, including in the lighting sector. This is combined with an irreversible increase in the prices of raw materials, not only concerning energy but also precious metals used in new lighting technologies such as rare earth elements, which have been classified as "critical materials" by the US and the EU.[3] The following figure also suggest that Europeans are more aware of ecological crises, while recent polls point out that "low-carbon consumer behaviour is surging in emerging economies such as China, India, Indonesia and Mexico".[4] Another one estimates that there are in the world about 2.5 billion "aspirational consumers" who are uniting style, social status and sustainability values to

[2] See the list of relevant transition reference list produced by the Sustainability Transitions Research Network (STRN): http://www.transitionsnetwork.org/files/Reference%20list%20to%20transition%20publications.pdf.
[3] See http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm for the EU, and for the US : http://energy.gov/eere/amo/critical-materials-hub.
[4] Source: http://www.greenbiz.com/blog/2013/12/05/green-consumers-emerging-economies-china-india

redefine consumption.[5] Based on an international survey, Franzen and Vogl (2013) analysed the environmental concern of inhabitants in 31 countries. They find that the main determining factors are sociodemographic characteristics, age, gender, education, and income.

Figure 8. Percentage of people that agree or strongly agree that when humans interfere with nature it often produces disastrous consequences



Source: http://www.atlasofeuropeanvalues.eu

Therefore, even if the economic crisis seems to have affected people's environmental concerns,[6] there are many opportunities for energy efficient lighting solutions such as LEDs that can combine job creation with environmental protection. Moreover, concerning LEDs they benefit from a recent event that might qualify as a shock as in the case of the aforementioned steam mail subsidy in 1838 Britain: the phasing out of incandescent lamps in many parts of the world as in Europe, which is taking a sometimes criticised (Frondel and Lohmann (2011)) pioneering role,[7] the US,[8] or Australia.[9] Another shock fir Germany is the long term decision to change its energy mix by phasing out nuclear energy, which puts extra pressure on the country to save energy and deploy efficient lighting solutions. Also, from a geopolitical point of view, especially given the Crimean crisis, reducing energy dependency from Russia has climbed up in the political agenda.

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[5] Source: http://www.globescan.com/news-and-analysis/press-releases/press-releases-2013/98-press-releases-2013/291-two-and-a-half-billion-aspirational-consumers-mark-shift-in-sustainable-consumption.html

[6] See http://www.globescan.com/news-and-analysis/press-releases/press-releases-2013/98-press-releases-2013/261-environmental-concerns-at-record-lows-global-poll.html.

[7] See http://www.osram.com/osram_com/sustainability/sustainable-products/phasing-out-inefficient-lighting/.

[8] See http://energyblog.nationalgeographic.com/2013/12/31/u-s-phase-out-of-incandescent-light-bulbs-continues-in-2014-with-40-60-watt-varieties/.

[9] See http://ee.ret.gov.au/energy-efficiency/lighting/incandescent-light-bulbs-phase-out.

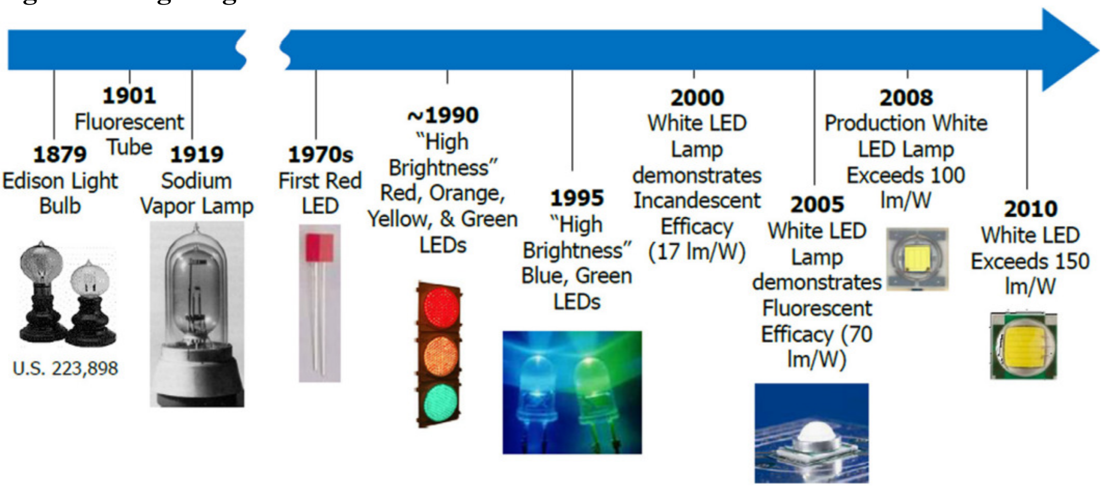
3.3. The lighting regime

The lighting sociotechnical system can be described with several key components that contribute to the stability of the technological trajectory: Technology, Markets, Industry, Policy, Science, Culture. We will focus on the first two components.

3.3.1. Lighting technologies

Since the invention of the incandescent lamp in 1879, several other technological improvements have been made, as shown in Figure 9. The incandescent lamp has dominated the sector for more over a hundred years, but it is being challenged by LED lamps.

Figure 9. Lighting milestones



In the mean time, the energy-efficiency of lighting technology has improved tremendously (IEA (2006)), as evidenced in Table 1.

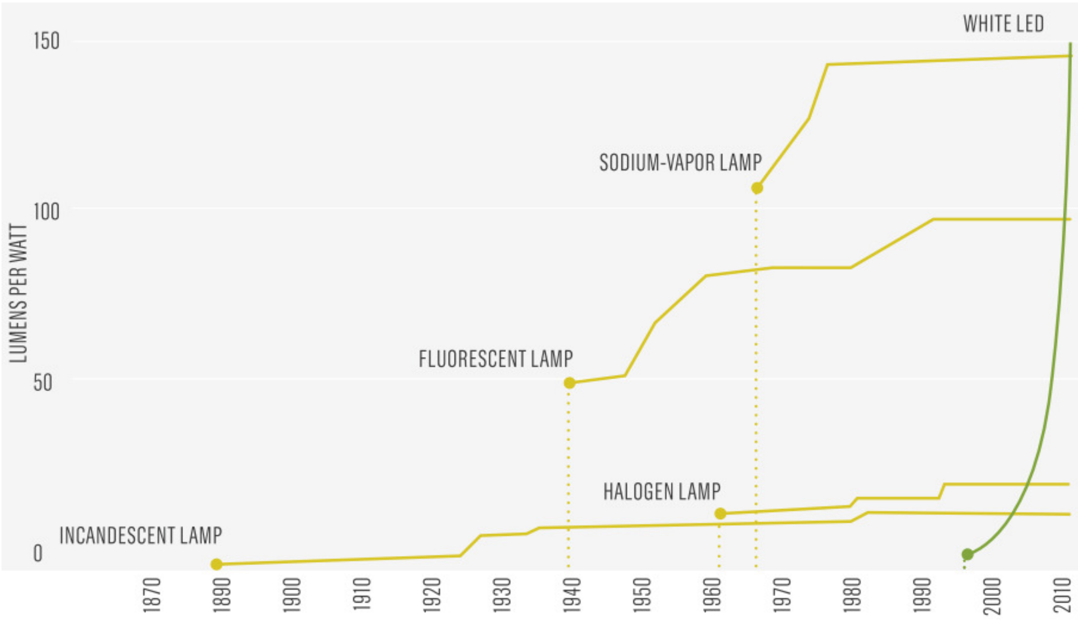
Table 1. Lighting technologies' characteristics.

Lamp type	Characteristics							
	Luminous efficacy (lm/W)	Lamp life (h)	Dimming control	Re-strike time	CRI	Cost of installation	Cost of operation	Applications
GLS	5–15	1000	Excellent	Prompt	Very good	Low	Very high	General lighting
Tungsten halogen	12–35	2000–4000	Excellent	Prompt	Very good	Low	High	General lighting
Mercury vapour	40–60	12,000	Not possible	2–5 min	Poor to good	Moderate	Moderate	Outdoor lighting
CFL	40–65	6000–12000	With special lamps	Prompt	Good	Low	Low	General lighting
Fluorescent lamp	50–100	10,000–16000	Good	Prompt	Good	Low	Low	General lighting
Induction lamp	60–80	60,000–100000	Not possible	Prompt	Good	High	Low	Places where access for maintenance is difficult
Metal halide	50–100	6000–12,000	Possible but not practical	5–10 min	Good	High	Low	Shopping malls, commercial buildings
High pressure sodium (standard)	80–100	12000–16000	Possible but not practical	2–5 min	Fair	High	Low	Outdoor, street lighting, warehouse
High pressure sodium (colour improved)	40–60	6000–10000	Possible but not practical	2–6 min	Good	High	Low	Outdoor, commercial interior lighting
LEDs	20–120	20,000–100000	Excellent	Prompt	Good	High	Low	All in near future

Source: De Almeida, Santos et al. (2014: 33).

The column “Cost of operation” of Table 1 highlights the historical findings of Fouquet and Pearson (2006), who in the case of the UK have shown a continuous decline in the price of lighting supported by a sharp reduction in the cost of energy used for lighting from gas to kerosene and then electricity. According to Kavehrad (2010), in the field of photonics white LEDs hold the potential “to be as transformational as the transistor was in electronics”. The following figure compares the lighting efficiency of existing technologies.

Figure 10. LED efficiency is rapidly surpassing that of incumbent lighting technologies



Source: The Climate Group (2012).

A positive side effect of this efficiency is for example that applying LED lighting systems in the EU could lead to energy savings of about 209 TWh, preventing the emission of some 77 Mt of CO_2 De Almeida, Santos et al. (2014: 46). Compared to other lamps, LEDs are made from non-toxic materials, could be recycled (see the evolution of this technology in Qiu (2007)), and attract insects less (insects are attracted by invisible light in the range of blue to ultraviolet and LEDs emit little UV, Bessho and Shimizu (2012)). According to the The Climate Group (2012), the deployment of LEDs in cities could enable them to save 60% energy. As for Bloom (2012), she argues that in the city of Glen Cove (NY) a state of the art LED lighting upgrade led to 77% energy saving and an investment recouped in a year time. Finally, benefit could extend beyond industrialised economies by helping bridge the “lighting gap” between North and South (Harish, Raghavan et al. (2013), Huang, Wu et al. (2010), Chun and Jiang (2013)).

But lighting also generates direct environmental impacts (energy-related ones or toxics) and indirect environmental impacts (e.g. rebound effects, see Chitnis, Sorrell et al. (2013), Hicks and Theis (2014), Saunders and Tsao (2012)). De Almeida, Santos et al. (2014) underline that lighting consumes one fifth of the electricity used in the world, and accounts for 650 Mt of primary energy consumption as well as 1 900 Mt of CO_2 emissions (i.e. 70% of the emissions of the world's passenger vehicles, three times more aviation emissions). Besides, a great amount of energy is being wasted, not only by inefficient lamps but also by lighting and electricity infrastructures fuelled by large, centralised and mostly thermal power stations connected to a high-voltage transmission grid. According to Chappin and Afman (2013: 17), "over 98% of the electricity used in converted into heat and not light". Before distributed gas lighting solutions, the light source was close to the energy source (candles, oil lamps, ...). As explained in Section 2, there is now a whole network of electric utilities companies, manufacturers and suppliers, investors, and customers that is involved in the evolution of lighting technologies.

3.3.2. The lighting market

As underlined in the previous section, if the incandescent lamp has been dominating the sector for over a hundred years it is being challenged by LED lamps (Qiu (2007), Pimputkar, Speck et al. (2009)) and soon by organic LED (Thejo Kalyani and Dhoble (2012)). Hence, notices McKinsey & Company (2012), the LED market is highly dynamic, notably because of fast growth and a changing environment (e.g. it is subjected to accelerated regulatory intervention worldwide). A recent report indicates that 36% of the 2 032 patent families filed between 1996 and 2013 in phosphor LED material technologies were filed over the last 5 years.[10]

At the moment, the commercial/tertiary sector represents 43% of the lighting market (31% for the residential sector and 18% for the industrial sector, De Almeida, Santos et al. (2014). Sales on the global lighting market will amount to more than 100 billion Euros in 2020 (80% for general lighting), and thus McKinsey & Company (2012) deems it the most promising technology in terms of commercial viability by 2020, ahead of electric vehicles. As a consequence, the LED share in general lighting will be 45% in 2016 and 70% in 2020 (ibid.), facilitated by standardisation efforts in the industry which could overcoming major technological hurdles such as efficient heat sinks or universal drivers designed for 50 000 hours. Residential is and will remain the main LED market segment followed by office and outdoor lighting. But Konnerth (2012) stresses the growing usage of LED products in commercial lighting has prospects to increase at an annual rate of 39% and sales of 4.5 billion dollars by 2015. With the rise of LED lighting solutions, economic value in the lighting sector will shift to fixtures and lighting systems, changing the balance of power among the actors of the lighting regime. Also, new business opportunities will be created such as in control systems for LED lighting, especially in offices.

In 2010, the global market for lighting products was estimated to be approximately € 80 billion, of which a very small, but fast growing, fraction is related to LED systems (De Almeida, Santos et al.

[10] Source: LED Phosphors and Down Converters Patent Investigation, Report Sample, http://www.i-micronews.com/reports/LED-Phosphors-Down-Converters-Patent-Investigation/14/392/.

(2014)). Indeed, the LED lighting market is anticipated to grow 45% per year through 2019: from $4.8 billion in 2012 to $42 billion in 2019[11] (for Bloom (2012) LED sales are projected to grow from $340 million in 2007 to $7.3 billion by 2014). In 2015, the market penetration of LEDs will be 16.8 % (Davis (2012)), and could reach 52% of the commercial lighting market by 2021.[12]

The diffusion of LEDs is facilitated by the fact that it is used in many different products such as:

- Backlighting of mobile electronic devices,
- Backlighting of LCDs for televisions and computers,
- Architectural and mood lighting,
- Traffic signals,
- Billboards, hoardings and advertising signs,
- Exit signs and emergency lighting,
- Vehicle lighting,
- Street lamps and outdoor lighting,
- Christmas lights,
- Road lighting (see Viikari, Puolakka et al. (2012)),
- Non-lighting designs (e.g. wave shapers in audio circuits),
- Invisible light (e.g. remote controls use infra-red LEDs just like night photography does).

According to the LED Magazine, the top-ten list of LED manufacturers for 2013 is:[13]

1. Nichia
2. Samsung
3. Osram Opto Semiconductors
4. LG Innotek
5. Seoul Semi
6. Cree
7. Philips Lumileds
8. TG
9. Sharp
10. Everlight

In terms of geographical location, Asia keeps leading the market demand (47% of 81 bl€ market in 2020), followed by Europe (22%) and North America (18%). Value is moving downstream (from

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[11] Source: Report "LED Lighting: Market Shares, Strategies, and Forecasts, Worldwide, 2013 to 2019", http://www.reportsnreports.com/reports/269046-led-lighting-market-shares-strategies-and-forecasts-worldwide-2013-to-2019.html.

[12] Source: http://lighting.com/pike-research-leds/.

[13] Source: http://www.ledsmagazine.com/articles/2014/02/strategies-unlimited-projects-packaged-led-market-to-hit-25-9b-in-2018.html.

backlighting to general lighting). Some countries like Korea has selected the LED industry as a new growth engine for the 21st century and is geared to become one of the world's top three LED manufacturers in 2012 (Jang (2010)).

The aforementioned changes raise at least two important questions. First, if it seems certain that LEDs will dominate the lighting market in the future, what type of LED will be on top of this market? Cheap ones with low quality and environmental performance? Second, where will the LEDs consumed in Europe be produced and recycled and how? There are important sustainability challenges for the sector and a role to play for players which are keen on supporting the sustainability transition of lighting technologies. The next section provides an example of a European project supporting the development of ecodesigned LEDs, a case of niche creation in the lighting sector.

3.4. Example of a lighting niche: the cycLED project

The transition management literature defines niches as follows:

- Places in which new things are done (possibly tested) or domains for specialized applications.
- Protected spaces such as R&D laboratories, subsidised demonstration projects, or small market niches where users have special demands and are willing to support emerging innovations.
- Because niches are protected from normal market selection, they act as incubation rooms for radical novelties.
- They provide locations for learning processes & space to build the social networks which support innovations...
- Rules at niche level are weaker than at regime or landscape levels.
- Niche actors (such as entrepreneurs, start-ups, spinoffs) work on radical innovations that deviate from existing regimes.
- Niche-actors hope that their promising novelties are eventually used in the regime or even replace it.

The next section introduces the case of a European project that qualifies as a technological niche, and Section 3.4.2.

3.4.1. The cycLED project: An LED niche

Menanteau and Lefebvre (2000) point out the importance of public programmes to create initial niche markets. It is precisely the objective of the cycLED project, which aims to optimise the flows of resources over all life-cycle phases of LED products.[14] The energy saving potential for LEDs is significant, and the strategic importance of the LED technology is reflected in current and upcoming

[14] See http://www.cyc-led.eu.

market developments. However, LED-based product systems contain many resources like indium, gallium or rare earth metals. Some of these substances are classified as critical raw materials at EU level. Therefore, if the current expansion of LED technologies is most welcomed from an economic and energy point of view, it requires optimising resource flows and addressing key societal issues. To strengthen the emerging LED market in Europe, cycLED focuses on improvement of the material flows and policy measures to remove barriers for LED technology dissemination. Innovation is needed to achieve an efficient management of the different materials used in LED systems, so that the growth of the LED-related markets is decoupled from resource depletion.

3.4.2. Barriers to eco-innovation in the LED sector

If ecodesigned LEDs are to contribute to the transition of a sustainable lighting sector, the barriers to eco-innovation in this sector need to be analysed. Many studies have sought to analyse barriers to innovation. In their analysis of revealed versus deterring barriers, D'Este, Iammarino et al. (2012) underline that these studies have focused on financial variables and that many of them have used econometric analyses and CIS survey data. On the other hand, few studies have explored a broader range of barriers or conducted case studies. Moreover, barriers to eco-innovation and SMEs' barriers have seldom been analysed.

In the context of the cycLED project, a qualitative analysis of these barriers has been conducted by carrying out case studies with cycLED SME partners. In a second phase, the analysis will be extended to other stakeholders, including government and EU officials, notably to better explore regulatory barriers. Case studies consisted in interviews carried out with the support of a questionnaire, in which potential barriers were collected from a literature review. The questionnaire contained 144 barriers organised in two groups: barriers within organisations (Vision and strategy, Finance, Human resources, ...); and barriers outside organisations (Policies and norms, Infrastructures, Values and beliefs, ...). Face-to-face interviews were conducted with the four SMEs of the project, which are in charge of delivering demonstrators of ecodesigned LEDs. For each barrier, SMEs were asked to estimate the importance of each barrier for their organisation: -1 (Not a barrier but rather a support to ecoinnovation); 0 (Irrelevant barrier to ecoinnovation for my organisation); 1 (Relevant barrier to ecoinnovation for my organisation); 2 (Major barrier to ecoinnovation for my organisation). After the interviews, a list of the most important barriers was compiled, for each SME and for the four of them. Summing up the scores obtained for each barrier, only one of them obtained a score of 5 (category 'Policies & norms': barrier 'Lack of certification mechanisms to check out the technical specifications of products put on the market'); and seven barriers obtained a score of 4 (e.g. category 'Technology': barrier 'LED drivers are barriers to ecoinnovation'; or category 'Finance': barrier 'Lack of in-house sources of finance'). On the basis of the ranking of barriers obtained for each SME, all the barriers with a score of 1 and 2 were singled out, and discussed during an ad hoc workshop that took place during a consortium meeting of cycLED in November 2013. During this workshop, with the help of the other project partners, SMEs were asked to explain which barrier could be overcome internally, and where could they seek help to do so. Results from this first phase are presented in the paper; they will be used in a broader analysis of barriers to eco-innovation in the LED sector that will survey stakeholders others that cycLED partners.

Results from this research will be useful for policy-makers to design policies that can help SMEs overcome barriers to eco-innovation, and to strengthen eco-innovation in the LED sector, notably in Europe. It will also enable innovation scholars to better understand the dynamics of eco-innovation in an emerging field, which has the potential to support the sustainability transition of lighting and display technologies by switching to ecodesigned LEDs. The below table summarises the main barriers that need to be given priority in order to support the development of ecodesigned LEDs. The first one received a score of 5 and the remaining seven a score of 4.

Table 2. Barriers to eco-innovation for European LED SMEs

Category of barrier	Barriers
1. Policies & norms/Policy instruments	Lack of certification mechanisms to check out the technical specifications of products put on the market
2. Policies & norms/Policy objectives	National policies do not provide adequate support to ecoinnovation and/or emerging LED technologies
3. LED industry	Increasing & unfair competition from non-European firms
4. LED industry	Technology is not cost-effective enough
5. FINANCE	Lack of in-house sources of finance
6. FINANCE	The gross intrinsic value is too low, which discourages innovation in recycling technologies
7. TECHNOLOGY	LED drivers are barriers to ecoinnovation (too fragile e.g.)
8. Global context/Macro-political	Critical materials like REEs are mainly exported by non-European countries

NB: barriers in capital font refer to barriers within firms.

4. Discussion

The eight aforementioned barriers have been highlighted by European LED SMEs as key factors blocking their efforts to develop eco-innovative LED products. These firms are currently developing such LEDs as product demonstrators within the cycLED consortium, i.e. at the niche level. In order to make it through the dominant lighting regime, barriers to the development of these LED products need to be addressed. Some of them can be addressed by the firm itself, others will required a broader efforts e.g. by involving regulators or industry associations. This is the case of the first and most important barrier, which will require a supranational effort along the lines of the US Lighting Facts label. The second barrier could be addressed at national level by more ambitious policies to support eco-innovation in lighting. The third barrier would also require government intervention to support lighting quality labels. The problem of cost effectiveness could be alleviated by providing subsidies to the most innovative firms. Lack of in-house sources of finance can be dealt with by giving access to SMEs to ad hoc funding mechanisms, provided that they demonstrate their environmental innovativeness. Regarding the sixth barrier, the low intrinsic value of lighting e-waste could be compensated by collecting larger quantities, or by imposing mandatory recycling targets regardless of their economic value. Concerning LED drivers, industry consortia could help improve their quality and identify reliable eco-producers. The last barrier concerns the dependency from China regarding the supply of rare earth elements. It could be overcome either by finding substitutes to REEs in lighting technologies, by using recycled REEs and lesser amounts of them, or by finding other suppliers.

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