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Accelerate SSL Innovation for Europe

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D3.6 Recommendations to overcome potential barriers and opportunities for implementation

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Executive Summary

The lighting profession started to recognize the importance of designing lighting installations that takes also non-visual effects of light into account. The International Commission on Illumination (CIE henceforth) proclaims that "we now know conclusively that photoreception in the eye leads not only to vision, but also to **effects on human physiology, mood and behavior**, often summarized as non-visual effects of light." Human Centric Lighting (HCL henceforth) describes lighting that attempts to make also use of non-visual lighting effects in a beneficial way by means of controllability features of various lighting attributes related to intensity, spectral composition, duration and timing of the light exposure. Obviously, any lighting solution addressing the non-visual effects of light[1], should also address the visual aspects. While innovative ways to beneficially affect human health, behavior and comfort started to be used, the market readiness of HCL still needs to grow to benefit from its full potential.

Aim and approach

This study investigates barriers and opportunities for HCL adoption, with the aim of recommendations on how to overcome barriers, and on opportunities for implementation. This report uses desk research and semi-structured interviews to explore the barriers and opportunities for wide market uptake of HCL. A total of 21 selected stakeholders from the lighting industry, the workplace sector, the educational sector, health care and cities[2] were interviewed for their views on benefits, barriers, opportunities and potential course of action. Data were analyzed using a directed content analysis approach[3]. Using an input/output methodology[4] we study the economic potential of the HCL industry and its possible employment effect in the EU.

Results

The results of the interviews on which the conclusions of this report are based show significant interest in HCL by EU lighting companies and early adopters.

Barriers

From the interviews four main types of barriers emerged for HCL market penetration:

a) informational;
b) administrative;
c) financial;
d) practical.

[1] Non-visual effects of lighting are also called non-image-forming (NIF) effects.
[2] The template of the survey is contained in the appendix.
[3] With a directed content analysis approach, analysis starts with relevant insights from the desk top research as guidance for initial codes.
[4] In economics, an input–output model is a quantitative economic technique, originally developed by Leontief, representing the interactions and interdependencies between different sectors within the economy. Based on the output from one industrial sector to another sector, for which it then becomes input, the impact on the overall economic activity is estimated resulting from a change in demand assumed for a particular sector, such as the Human Centric Lighting industry.

Top 10 barriers

The top 10 of most frequently mentioned barriers related to: (1) Lack of information and practical advice; (2) Lack of awareness; (3) Lack of products available on the market meeting customer requirements; (4) Lack of successful examples in practice; (5) Lack of evidence on benefits; (6) Cost; (7) Lack of knowledge on how light can be used; (8) Lack of a common approach from the supply side; (9) Lack of legislation favorable for HCL/existing legislation unfavorable for HCL adoption; (10) Risk aversion.

Informational barriers

The most important informational barriers perceived by the respondents in our study are: A lack of examples of successful HCL implementation in practice, a lack of information on best practice with respect to HCL, a lack of knowledge on procuring the right/best option, and benefits not clear as compared to reference installations.

This seems to be related to low awareness and knowledge of what can be done with light, lack of understanding of the HCL benefits as compared to other products available in the market, lack of specialized support from the industry and lighting designers as well as lack of evidence with quantifiable measures of HCL benefits (money value).

Administrative barriers

As far as the administrative barriers are concerned, we find that HCL market adoption seems particularly hindered by regulations on lighting installations which focus on energy use (e.g. setting limits to max capacity), ignoring key features of HCL that are not available in other competitor technologies (e.g. the dynamic character), thus biasing the purchase behavior of decision makers away from HCL supporting systems. Furthermore a need for standardization was identified, concerning compatibility of products, system components and software (ICT) between manufacturers and in time. Furthermore, a lack of standards for reliability, quality and performance was reported.

Financial barriers

Financial difficulties are also significant. They include upfront investment effort, lack of monetization of benefits and the recurrent principal agent problem, which is relevant in the context of HCL as its benefits are often acquired by a third party (the occupant) that is not directly sustaining the cost of installation (the owner of the building is).

Practical barriers

Finally, there are significant practical difficulties involved with the implementation of HCL. These include the lack of ‘ready to use’, easy to implement, user friendly ‘plug and play’ solutions on the market, the time to market of applications based on new insights, and limitations in the availability of components (e.g. long delivery times). It was frequently said that adequate HCL solutions (e.g. for application in office buildings or schools) have not yet progressed as far as the ‘prototype phase’, which has led to some stakeholders developing and building their own prototypes to meet their requirements. (Although, in practice, a growing number of components are coming available on the market that enable user adapted light and light variations.) Furthermore, retrofit difficulties in renewal of lighting systems were addressed.

Importance rating of barriers

Despite differences in *frequency* by which different issues were raised by the supply- and demand representatives, they seemed to agree remarkably well in terms of *average importance rating* of (a *pre-defined selection* of) barriers included in the questionnaire. The following aspects scored an average importance rating greater or equal to 4 on a 5-point scale (somewhat important to very important) in both groups: Lack of examples of previous successful HCL implementation in practice; Lack of information on best practice with respect to HCL; Investment cost; Lack of knowledge on procuring the right/best option; Benefits are not clear compared to reference installations.

Opportunities

A range of opportunities was brought forward in the interviews, summarized into 20 solution types (Chapter 2.3). The most frequently reported HCL opportunities include: (1) Lighting solutions supporting alertness and productivity in the workplace/education; (2) (Evidence based) solutions adapted to individual characteristics and/or needs, time of the day and activity; (3). Circadian rhythm lighting: Use the circadian rhythm supporting effects of light, i.e. supporting awakening in the morning, prevent 'after lunch dip' (e.g. in office) and support sleep at night. (4) Smart lighting with sensors, including features such as a structure that allows changes and improvement, flexibility to change and to add new features over time; (5) Lighting solutions supporting visual acuity for elderly; (6) Individually adjustable lighting solutions.

While energy savings may be the initial driver for upgrading to new lighting technology, increased awareness of the potential benefits of HCL coupled with the possibility of integration of lighting with other services can open up significant business opportunities. Since the benefits HCL promises are to be achieved by means of controllability features that allow to adapt lighting to the needs of individuals indoors, it follows that digitization of lighting, as embodied in SSL, is a prerequisite for HCL to be fully exploited.

Early adopters

In terms of potential markets, the health care sector, comprising hospitals as well as elderly care, was most frequently brought forward as the most promising application areas for HCL in terms of early adoption of HCL[5]. Health care organizations are more open to the HCL arguments and have proven to be early adopters of the new lighting technology. Although the overall potential may not be as big as in other segments, the benefits are easier recognized and thus drive market acceptance. The workplace (office market) and education are considered as the next most promising markets although implementation of HCL systems in these sectors is seen as limited for the time being. It is considered that once there is enough experience in other fields, these two will follow. The domestic market is potentially a very large market. In terms of early adoption however, it is considered likely to follow the application areas listed above.

[5] Out of the 9 interviewed lighting professionals 4 professionals considered hospitals and elderly care the sectors that would most quickly adopt HCL while 3 professionals considered it the second most promising area, 2 professionals considered the workplace (offices) to be the most promising application field in terms of early adoption while 3 professionals considered education the second most promising area. The domestic market was considered the third most promising application field for HCL adoption by 2 lighting professionals (with the comment that this is potentially the largest market).

Market stimulation measures

Our findings provide insight for both actors of the lighting industry and policy makers. Recommendations following from the stakeholder interviews include:

- ***Availability and accessibility of practical information*:** Practical application information is needed, "*understandable, honest and unbiased*". Stakeholder recommendations included: practical and technical information on best practices, a clear road map describing 'step by step' how to practically come to good HCL solutions, a 'recipe' for HCL application in practice, and a 'decision support comparison tool' for HCL systems. Furthermore, the need for specialized knowledge throughout the supply chain on HCL implementation was expressed. Coherent understanding and mutually comprehensible information is important to enable border-crossing collaboration between specialists in different fields.
- ***Research to strengthen evidence and improve products:*** Research on biological efficient lighting in 'real life settings' should be further strengthened to extend the knowledge base for what "optimal illumination" is for non-image forming effects. Specifically, large representative field studies (intervention studies) seem needed, to allow quantification of benefits. Preferably through Key Performance Indicators (KPIs) applicable in cost-benefit analyses, in order to increase the (limited) knowledge of customers about the HCL benefits.
- ***'Easy to use', 'easy to implement' systems:*** The development and increased availability of 'easy to use', 'easy to implement' HCL systems was recommended (proven to be reliable and to work well in practice), as well as solutions allowing 'easy retrofit'.
- ***Successful HCL application examples in practice:*** Stakeholders expressed the need for successful HCL application examples in practice, preferably within the peer group, providing a 'model' to look at.
- ***Increasing awareness and experience in practice:*** There is a need for information campaigns and demonstration projects to increase awareness about the HCL advantages in comparison with other lighting technologies.
- ***Collaboration within the supply chain:*** Closer collaboration throughout the supply chain (incl. architects, designers and lighting consultants) was deemed essential to accelerate HCL adoption.
- ***Legislation:*** It was recommended that state-of-the-art knowledge should become integrated in existing norms and standards (e.g. accounting for the dynamic character of HCL lighting by which 'max capacity' no longer seems an adequate indicator of expected energy use). A revision of the lighting requirements, e.g. by making mandatory the minimum requirements for lighting quality, in addition to energy use based requirements, could also be made to incorporate the aspects of the non-visual biological effects of artificial lighting.
- ***Publicity and advertisement:*** Publicity is needed on successful HCL solutions and case studies, best practices, and user experiences, to raise interest. This should include articles in a broad spectrum of media types to reach the professionals within the supply chain as well as the professionals and the general public within the demand side.
- ***Standardization:*** Standardization of HCL systems, components and software between manufacturers (and in time) was recommended. Preferably, the HCL system solutions should be open both in terms of hardware and software, enabling the replacement of faulty components and the addition of new HCL features, independent of manufacturer (open systems). Furthermore, a need for internationally agreed quality standards for lighting equipment was mentioned.

- ***Incentive schemes:*** The efforts on increasing awareness and support through adequate legislation can be complemented by government backed financial incentive schemes meant to reduce potential financial constraints hindering investments in value enhancing lighting.

Job creation potential

We estimate that with a hypothesized market size of 1.4 billion of euros by 2020 of the HCL industry[6], which represents around 7% of the European general lighting market and 20-25% of its high-end market segment, there will be a total of 9,758 new jobs in the EU area. The employment multiplier of the HCL industry, measuring the amount of direct, indirect and induced jobs created in the area, is 2.91. This implies that for every HCL job, in total 2.91 jobs (direct, indirect and induced) are created in the economy.

Application recommendations for biologically effective lighting

Based on the literature review (incl. the SSL-erate review "Lighting for health and wellbeing", downloadable from http://lightingforpeople.eu/), stakeholder interviews and input from experts, cities and SMEs over 10 application recommendations were derived, at least 2 recommendations for each of the 5 application areas. These are further elaborated in Chapter 5.

Report structure

The report is organized as follows. In Chapter 1 we identify the key stakeholders to enable value enhancing deployment of HCL by application field and uncover their concerns and their resulting choices. Chapter 2 provides an overview of the main current barriers as well as opportunities for HCL market penetration that emerged from the interviews. Chapter 3 describes recommendations on market stimulation measures. Chapter 4 explores the job creation potential of the HCL industry. The application recommendations for biologically effective lighting are given in Chapter 5.

[6] Estimate of HCL market size taken from A.T. Kearney, ZVEI and LightingEurope (2013), "Human Centric Lighting: Going Beyond Energy Efficiency".

1 Stakeholder Analysis

1.1 Stakeholder Considerations

Probably one of the most challenging tasks is to provide a ubiquitous definition of HCL, as the various definitions provided by different stakeholders illustrate:

- "*…photoreception in the eye leads not only to vision, but also to effects on human physiology, mood and behavior, often summarized as non-visual effects of light… We are learning now that these photoreceptors influence many other processes as well. In recent years the catchphrase Human Centric Lighting has come to describe lighting that is intended to address all of these effects*" (International Commission on Illumination - CIE);
- "*Lighting (systems) designed to have a short term or long term beneficial effect on health and wellbeing of people*" (LightingEurope);
- "*HCL is light adapted to the individual need. The best light for each individual. Ability for the light to adapt to the needs of individuals*." (participant in our study);
- *"HCL is light that works together with people's normal circadian rhythm"* (participant in our study)*;*
- *"Human Centric Lighting is a way of trying to imitate outdoor lighting…because that is the best lighting for the human eyes and the human system"* (participant in our study)*;*
- "*Evidence-based lighting solutions for optimal vision, wellbeing and performance*" (participant in our study).

The definitions above illustrate that HCL emphasizes an integrated view of lighting and the specific contexts in which people use it. HCL goes beyond visual effects of lighting, e.g. with characteristics adjusted to human circadian rhythms, and to accommodate to individual illumination needs. As such, its benefits are multiple and range from visual acuity to better mood and cognitive performance. This report aims to identify the challenges and opportunities related to turning the HCL assets into desirable experiences that customers are willing to acquire.

Our analysis of the barriers and opportunities to market adoption of HCL starts with the identification of the key stakeholders in HCL projects across different market segments and the description of their concerns and their resulting choices. According to Freeman (1984), a stakeholder is defined as "… any group or individuals who can affect or are affected by the achievement of the organization's objectives". Consequently, the concept of stakeholders covers financial as well as non-financial interests, including indirect and less tangible involvement. The stakeholders of an HCL project generally include (regardless of market segment): the lighting and luminaire industry; the architects and the lighting designers; the installers; the public and private owners of buildings and infrastructures; and last but not least the end-users, including tenants.

In what follows, we consider each separate market segment and examine its specific stakeholders, their interests and their most likely choices.

1.2 Workplace (offices)

Lighting companies in the market for offices seek to offer tailor-made lighting solutions that create comfortable and well-lit workspaces, while at the same time reducing energy use and lowering maintenance costs. Moreover, controls and connectivity mean that lighting can be personalized at an individual level.

If anything else, scientists seem to agree that there are considerable individual differences in light level preferences in offices [e.g. Begemann, van den Beld and Tenner (1997), Boyce, Eklund and Simpson (2000), Logadóttir and Christoffersen (2008), Newsham, Aries, Mancini and & Faye (2008) and Smolders (2013)). In particular, a series of studies (e.g. Veitch, Donnelly, Galasiu, Newsham, Sander and Arsenault (2010), Veitch, Newsham, Mancini and Arsenault (2011) Veitch JA, Stokkermans MGM, Newsham GR (2013) and Dickel, Veitch, Burns and Mancini (2015)] find that when people are able to work in conditions that broadly match their personal preferences, they judge the lighting to be of higher quality and the office to be more attractive. These people tend to be in a more positive mood, to be more focused on their work, and to show better wellbeing at the end of the workday. These field investigations found that being in lighting one judges as better, also may lead to fewer health problems and greater job satisfaction and organizational commitment. Thus, by enhancing light quality and comfort, and by giving workers more control over their environment, HCL may act as a "**virtuous cycle**", where employee satisfaction and HCL enhanced productivity work in a feedback loop to reinforce each other.

The workplace (office) stakeholders can be grouped in internal vs. external:

a) employees, employers, trade unions, facility managers, property owners and developers are examples of internal stakeholders;
b) architects, lighting designers, installers, wholesalers and lighting companies, health insurance companies and authorities like governments and municipalities can be considered external stakeholders.

While there is some overlap between the major interests of some of these stakeholders, the report shows that each stakeholder has its own individual and well defined area of concern. Table 1 describes the role of each of the identified stakeholders in the context of HCL promotion/adoption in the workplace and their interaction.

Employers and employees

The fulfillment of the employees' needs is at the core of efficiency and productivity. Employers and employees share this concern for the existence of optimal working conditions. Working in good-quality lighting is good for individuals but also for their employers: it benefits organizational productivity both by facilitating work focus and by reducing costs for such things as time off and employee turnover. The concerns of the employers are related to the provision of optimal working conditions at limited overall costs while meeting the security and safety requirements, preserving a good company 'image' (for commercial reasons) and being perceived as an attractive employer (in order to attract the best personnel).

Trade Unions

Trade unions are commonly actively involved in the driving up of standards of safety and workers´ wellbeing within worksites (Griffiths, Maggs and George, 2007). They can enable changes in relation to both employers and own members by raising awareness of the benefits of adequate lighting and

putting pressure on employers to bring about improvements at the workplace conducive to health (HCL promotion). The prerequisite is of course that such knowledge on optimum light conditions exists and is made readily available.

Property owners and developers

Property owners and developers are typically concerned with the return they can hope for on their investment, the ease with which they can sell or rent out the building and the flexibility to meet the needs of different users. For these reasons, their choices of lighting systems will favor proven lighting concepts, with a clearly predictable and agreeable payback time, and easily adaptable lighting solutions. Facility management involves people responsible for managing and operating the technical aspects of a building. Their concerns include low running and minimum maintenance costs, energy efficiency and security and safety issues (see for instance the Phillips course on office lighting application[7]).

Engineers, lighting designers, architects and installers

Next, within the group of external stakeholders we can identify engineers, lighting designers, architects and installers who select and specify the type of installation, execute the design and install the equipment. As prescribers, they act as gatekeepers, information brokers or influencers responsible for the final choice of illumination system the decision makers will make. So, in order to reach the decision makers, lighting professionals will need to convince to the gatekeepers that their proposed lighting system will benefit the decision makers.

Authorities like governments or municipalities

Instruments are regulations, incentive programs, information dissemination, financing of research activities and promotion of certification activity.

The Principal Agent Problem

Both our literature review (Mind the Gap, Quantifying Principal Agent Problems in Energy Efficiency (2007), A.T. Kearney, ZVEI and LightingEurope (2013)) and the feedback from stakeholders during interviews suggested that the office sector is particularly prone to landlord-tenant issues, also called the principal agent problem. This issue is often cited as one of the major obstacles to any type of investment aiming at building improvement, as the benefits of better quality lighting and lower energy bills may not accrue to the party most likely in a position to invest in the enabling technology. This is the case whenever the owner and the occupant are two different entities. The developer or landlord wants low capital cost which often leads to higher running costs for tenants. Figure 1 illustrates the interactions between the stakeholders typical for the commercial office sector.

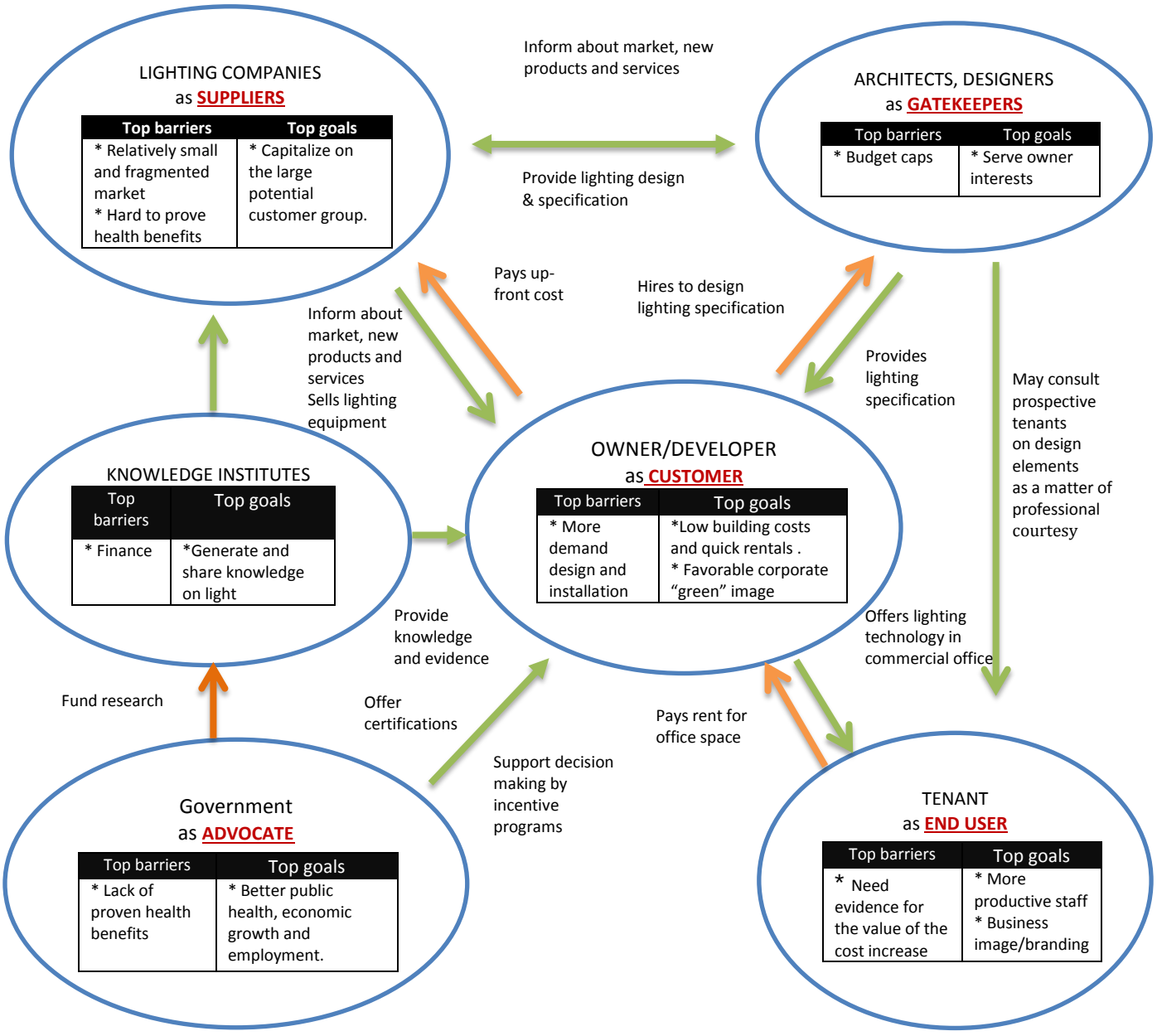
[7] http://www.lighting.philips.com/main/education/lighting-university/lighting-university-browser/course/office-lighting-application.html

Table 1: Office Stakeholder Overview

Stakeholder	Interest	Potential role	Competency	Examples of practice
Internal Stakeholders				
Employees	Higher productivity & accuracy. Reduced stress. Positive work environment, comfort	Positive experiences from HCL are taken into the wider community by this group.	Direct beneficiaries of HCL.	
Employers	Profit oriented. A healthy, productive workforce to remain competitive. Branding as a good workplace to attract best personnel. Image (e.g. of being innovative, advanced,..)	Create a supportive working environment including adequate lighting. Employers are accountable to government for the health and safety of their employees, the protection of the environment (safety regulations)	Indirect beneficiaries of HCL.	Philips Lighting's Connected Lighting, where Power over Ethernet (PoE) connects office lighting fixtures to the building's IT network. Employees can control and access building services using smartphones to light areas where and when needed.
Trade Unions	Trade unions are commonly actively involved in the driving up of standards of safety and workers´ wellbeing within worksites.	Enablers of change – may raise awareness among members of the benefits of adequate lighting, once there is established knowledge of optimal lighting conditions. Advocates of change - putting pressure on employers to adopt improvements at the workplace which are conducive to health.	Effective communication mechanisms with both members and employers. Promoting members wellbeing is a legitimate and historical role of trade unions.	
Property developers **Facility managers**	Property developers are typically concerned with the return they can hope for on their investment, the ease with which they can sell or rent out the building and the flexibility to meet the needs of different users.	The owner level of awareness and interest for quality lighting eventually drives the level of advanced lighting integration into the design of the building.	Provide the main bulk of the project's financial requirements, if accepted.	Different incentives between the owner who pays the capital costs but does not enjoy the benefits and the tenant who pays the energy costs but is not involved in the investment decision.
External Stakeholders				
Health insurance companies	Health insurance companies collect fees from employers / employees to finance the health care costs of those they insure. Having a healthy client base reduces treatment costs.	Raise awareness	Able to act as advocate of good practice.	
Lighting Companies Wholesalers	Optimizing sales by adapting products & services according to market. Capitalize on the large potential customer group.	Can influence purchasing patterns through pricing and marketing.	Technical expertise Standardization initiatives Provider of service	
Installers, Architects, Designers	They typically serve the interests of the developers/building owners. Hence, costs and length of time for ownership will be prominent factors in their choices and attitude. Boost their portfolio' and image to allow them to show their track record of impact impressive designs to acquire new customers.	Architects and engineers may advocate quality *lighting* during the programming and schematic stages of a project. They may consult prospective tenants on design elements as a matter of professional courtesy.	Their ability to leverage advanced lighting technologies depends on the interests of the owner. Guarantee performance for owners / investors.	
Authorities like EU, government and municipalities	Government at all levels has responsibility for disease prevention and health protection at a societal and community level.	Ensure that the policy framework in which organizations operate includes HCL. Commissioners and providers of capacity building	Instruments are regulations, incentive programs, information, research activities and certifications.	

Source: Authors' ideas and literature review (Griffith, Maggs and George (2007), de Boer et al (2012))

Figure 1 – Stakeholders in the Office market and key interactions. Principal Agent problem is present. The owner/developer of the building is the customer. The tenant is the beneficiary end user. The suppliers are the various lighting companies. The architects and the designers are the gatekeepers as they prescribe the most adequate lighting system to the customer. Finally, the government can act as an advocate.



1.3 Education

Lighting for education covers lighting solutions for a wide range of educational establishments from nurseries to universities. What all these institutions have in common is that they must stimulate students to learn and interact in various spaces where new teaching styles are gaining ground, and at the same time they should reduce energy use and lower maintenance costs. To meet these needs, companies in the lighting market may offer lighting solutions aiming at the creation an overall sense of comfort and wellbeing and thus assist educational institutions in their core mission to educate.

Schools share unique aspects: unlike other buildings, managing schools combines the responsibility for public funds, children education and safety issues. These can generate strong reactions from concerned parents and the general public. Schools are also unique in their high building occupant density. Finally, schools' budgets are typically tighter than those of many other occupied structures.

A broad range of stakeholders have an interest in light related interventions in schools. Table 2 describes the main stakeholders in the education sector along with their concerns, their roles and examples of practice. These include *internal stakeholders*, represented by students, teaching and research staff, administrators and managers, and *external stakeholders,* represented by parents, educational authorities, suppliers and service providers and different external associations (i.e. alumni association). Figure 2 illustrates the interactions between the stakeholders typical to the educational sector.

Students and teachers
The primary stakeholders in the education sector are students and teachers, meaning that an understanding of their needs should guide the choice of lighting in educational buildings. Their needs go beyond "vision", extending to enable concentration and alertness, and to reduce agitation. While students and teachers are among the direct beneficiaries of the HCL system, they do not have any influence in the purchase decision process.

School board
The most important stakeholders in the decision making process are the members of the school board, the school sponsoring body or the public authority responsible of financing school buildings and installations.

Parents
As external stakeholders, parents of students have a direct interest in the wellbeing and performance of their children. They determine or influence the school choice of their children. Furthermore, as they are increasingly called on to provide financial support to their children over the entire duration of studies (in more private education systems) or as tax payers (in public education systems), parents are likely to become an increasingly powerful stakeholder in the education sector.

Suppliers
The suppliers are different companies in the lighting industry. The main advantages of this market segment are large long-term market potential (large number of people - students, teachers and parents - getting familiar with and experiencing the advantages of better lighting solutions), large available amount of floor space and big political priority. Limited proof of effects, budget restrictions and conservative cost minimizing procurement principles are important obstacles in the education.

Engineers, lighting designers, architects and installers
Architects, lighting providers and installers are in a position to give recommendations on the optimal lighting solution options that are available on the market.

Authorities like governments or municipalities
Instruments are regulations, incentive programs, information dissemination, financing of research activities and promotion of certification activities.

Figure 2 – Stakeholders in the education sector and key interactions. The school board is decision maker (or customer). Students and teachers are the beneficiaries. The government is the advocate.

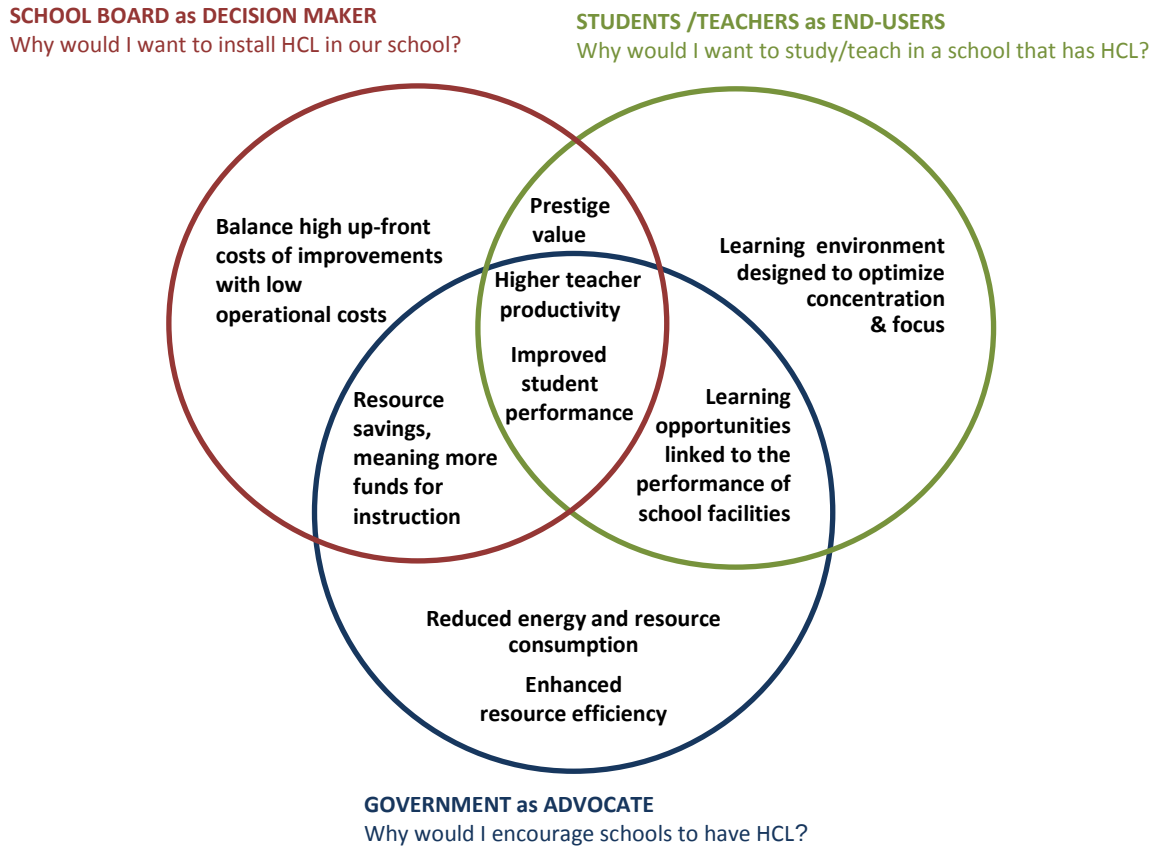


Table 2: Education Stakeholder Overview

Stakeholder	Interest	Potential role	Competency	Examples of practice
Internal Stakeholders				
Students	Direct beneficiaries of HCL. Improved social climate Improved performance Improved wellbeing (comfort)	Carry into later life an awareness of the value of good lighting conditions.		
Teaching & research staff	Direct beneficiaries of HCL. Improved student performance. Optimal teaching conditions Reduced stress			
Administrators (technical maintenance team, supervisor and non-teaching staff, ...)	Reduce energy consumption and cut maintenance costs.		Operate and maintain the lighting solution	
Senior management (head teacher, school director, school board,…)	Branding potential as innovative school.	Create a supportive learning environment including ensuring adequate lighting.	Provide the main bulk of the project's financial requirements, if accepted.	School in Kongsberg (Norway) Private school in Vilnius (Lithuania)
External Stakeholders				
Parents, parents associations	Direct interest in the wellbeing and performance of their children.	Influence school choice of students	Influence board decisions (indirectly)	
Educational authorities (school inspection, …) **Public authorities (with a competence of managing the school building and installations)**	Improved student academic performance, health and safety.	Commissioners and providers of capacity building. Ensure that the policy framework in which schools operate includes HCL, once light benefits are proven.	Instruments are regulations, incentive programs, information, supporting and collaborating in research activities and certifications.	Malmo is working with user driven innovation for HCL with a focus on the own development and installation of Human Centric School Lighting in a classroom.
Lighting Companies Suppliers and service providers (who manage the services and equipment, supply the school)	Capitalize the available large long term market potential the education sector presents.	Can influence purchasing patterns through pricing and marketing. Work on agreements on standardization.	Technical expertise Provider of service (providing attractive "easy to use, easy to implement" products/services)	

Source: Authors' ideas and literature review (Griffith, Maggs and George (2007))

1.4 Health & Care

Due to complexity and budget policy the lighting demand in *Health & Care* facilities is non-trivial and there is a need for unique solutions that benefit both staff and patients. HCL solutions currently available on the market promise to create a calm and relaxing environment for the patients which they could further customize according to their needs as well as a functional and well-lit environment for health professionals that could support them perform more effectively. Last but not least, these flexible solutions are designed to help healthcare facilities reduce their energy consumption and costs.

The main stakeholders in the Health & Care sector are patients, staff (i.e. nurses, physicians, etc.), hospital owners/directors, nursing home owners/directors and regulators. This set of stakeholders has different, sometimes opposing, themes on which they concentrate. More than in other application areas, there are specific challenges the decision makers and lighting designers need to face in lighting these 24/7 complex worksites. Table 3 describes the main stakeholders in the health care sector along with their concerns, their roles and examples of practice. Furthermore, Figure 3 illustrates the interactions between the stakeholders typical to the health care sector.

Patients, Staff
Needless to say, patients in the health care sector should be at the core of any decision, lighting systems included. Important efforts go towards offering a positive experience to hospitalized patients. While both health research and energy-savings concerns meet in pointing out to dimming lighting for better nighttime sleeping, staff members must stay alert and need adequate visual quality to perform complex and highly responsible tasks. The work environment for nurses and physicians in hospitals is already quite stressful and inadequate lighting is likely to compound the burden of stress which may finally lead to errors.

Health facility owners / Directors
Hence, health facility owners and directors have to find a compromise between allowing patients to maintain a normal day/night cycle, while providing lighting for adequate visual quality for staff and keeping the nursing staff alert. In charge of lighting tenders, these stakeholders will also have to seek the options that will reduce design and maintenance costs while making the hospital look both high quality (modern and equipped with the best advanced technical solutions) as well as homey and comfortable.

Suppliers
The main advantages of this market segment are an increased interest in health and wellbeing, the fact that health care facilities are already used to invest in advanced technology and great political priority. A main obstacle is procurement that focuses on lowest possible cost.

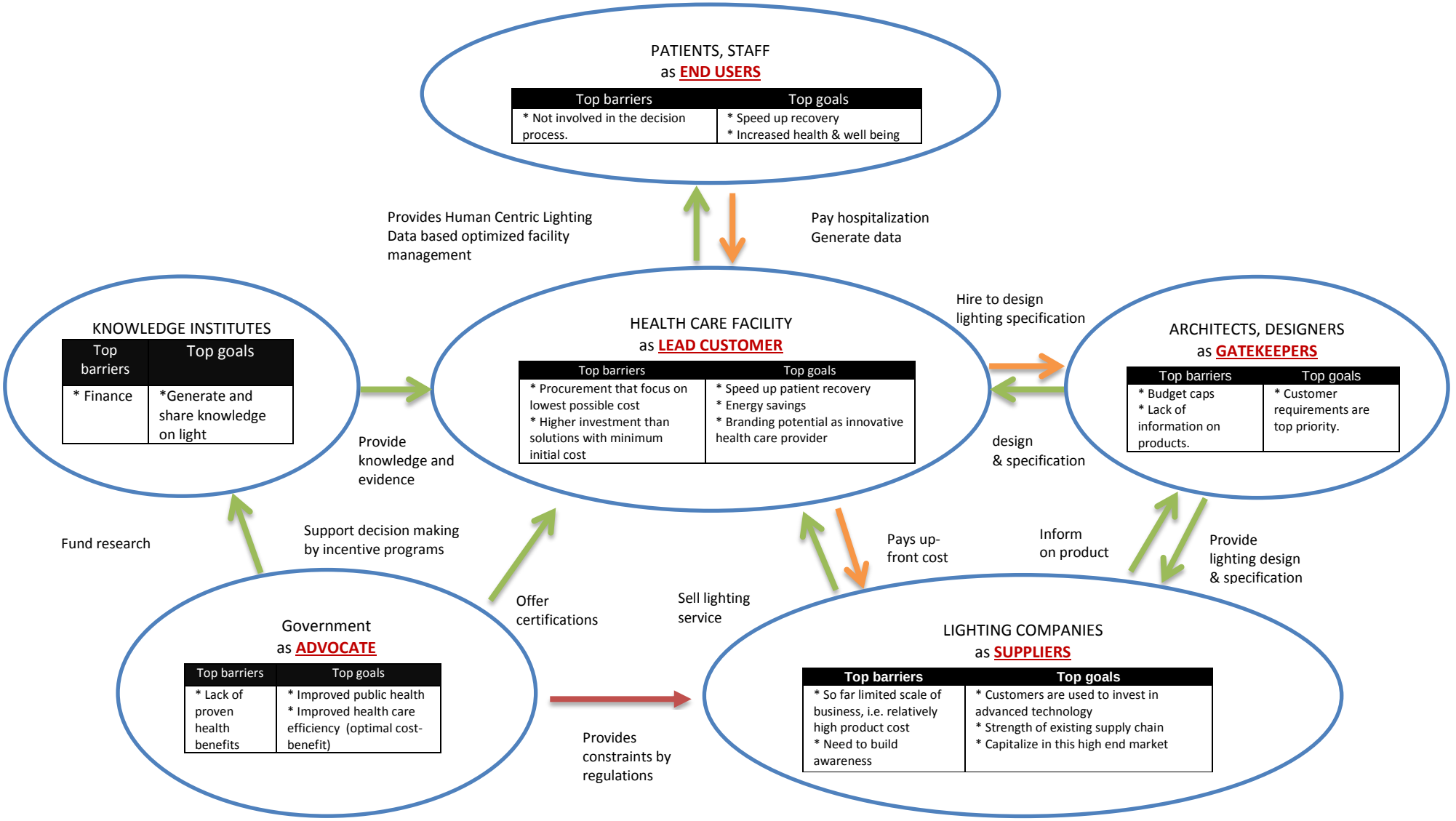
Engineers, lighting designers, architects and installers
Architects, lighting providers and installers are in a position to give recommendations on the optimal options available.

Table 3: Health & Care Stakeholder Overview

Stakeholder	Interest	Potential role	Competency	Examples of practice
Internal Stakeholders				
Patients	More rapid recovery. Better hospital experience (comfort, wellbeing). Improved sleep quality		Direct beneficiaries of HCL.	
Nurses and doctors	Maintain alertness to perform complex and highly responsible tasks. Visual quality.		Direct beneficiaries of HCL.	
Senior management (health facility owners and directors)	Provide better health services. Branding potential as innovative healthcare facility. Identify cost saving opportunities.	Create a healing hospital environment including ensuring adequate lighting. Interest for quality lighting drives the level of advanced lighting integration into the building design.	In charge of resource allocation. Customers in the HCL market. Provide expertise to other public sector organizations (sharing expertise within their peer groups).	Guy's and St. Thomas hospital in London http://luxreview.com/article/2015/06/alexandra-hammond-interview
External Stakeholders				
Health Unions	Improve member working conditions.			
Ministry of Health Local and municipal governments	Promote change in the health sector towards improved health services. Cost efficiency in health care (effective spending of taxes).	Introduce rebate programs for organizations adopting energy saving solutions. Ensure that the policy framework in which organizations operate includes HCL.	Provides the financial resources to the hospitals under their management. Responsible for public health and safety. Commissioners and providers of capacity building.	
Lighting Companies	Profit oriented.	Can influence purchasing patterns through pricing and marketing.	Technical expertise Provider of service Standardization initiatives	
Installers, Architects	They typically serve the interests of their customer, i.e. the health facility owner.	Architects and engineers may advocate quality lighting during the programming and schematic stages of a project.	Their ability to leverage advanced lighting technologies partly depends on the interests of the customer.	

Source: Authors' ideas and literature review (Griffith, Maggs and George (2007))

Figure 3 – Stakeholders in the Healthcare sector and key interactions. No Principal Agent problem. The Healthcare facility (hospital, elderly care, etc.) is the customer. The patients, the doctors and the rest of the medical staff are the beneficiaries or the end users. The suppliers are the various companies in the lighting industry. Architects, consultants and the designers are the gate-keepers as they prescribe the most adequate lighting system to the customer. The government can acts as an advocate, universities and research institutes as knowledge institutes.



1.5 Cities

The outdoor lighting solutions currently available on the market compete in energy efficiency as well as sophisticated lighting design. Fancy design emphasizes uniqueness and style to enhance outdoor social life and recreation and to attract more tourists for the city and customers for local commerce.

The key stakeholders in a citizen centric lighting strategy are municipal government, local citizens, shopkeepers, lighting industry, knowledge institutes and energy companies. Table 4 describes the main stakeholders in the smart cities sector along with their concerns, their roles and some practical examples. Furthermore, Figure 4 illustrates the interactions between the stakeholders typical to cities.

City Council[8]

The European Commission Green Paper "Lighting the Future" (2011) identified European cities as potential **lead markets** for speeding up the wider deployment of innovative SSL solutions. In other words, local authorities in cities can act as customers and development drivers (leading customers not only for outdoor lighting but for indoor lighting as well). Key reasons that might provide a rationale for SSL adoption in the city include: (a) Savings in energy costs and maintenance since (conventional) public lighting accounts for about 50-60% of the electricity consumption in cities ("Lighting the Cities", European Commission, 2013); (b) Already developed starting point for ICT and lighting infrastructure; (c) Smart outdoor lighting is visible innovation and has city branding potential; (d) Use HCL as a data collection infrastructure; by communicating data to a central hub, intelligent LED street lights can provide many advantages to city and traffic managers including meteorological, environmental and traffic data, power usage data, easy 'on/off' scheduling and instantaneous alerts in the event of an outage, as well as improved maintenance tracking and remote troubleshooting.

Citizens and tourists

The end users are the citizens (inhabitants, car drivers, cyclists and pedestrians), the local shopkeepers and the tourists visiting the city. They are the direct beneficiaries and concerned with the quality of their living environment. Good quality lighting can influence the perception of their living environment e.g. through city beautification (aesthetic attractiveness), by creating a pleasant or lively atmosphere, and by minimizing disturbance by lighting during evening and night time. This may ensure their support for SSL adoption.

Government

The government is in a position to initiate and approve regulation in support of SSL adoption, such as the ban on incandescent lighting. Different tax policies and other financial incentives or support schemes can be used to accelerate the uptake of high-quality SSL technology. Finally, government can support the use of SSL by financing research and initiating a process of standardization.

Suppliers

The suppliers are different companies in the lighting industry. The main advantages of this application area include: strong political energy saving priority, already developed starting point for

[8] According to national spatial planning and road legislation, the planning and approval of outdoor lighting installations are normally under the responsibility of the park and road authorities within the municipalities ("Lighting the Cities, Accelerating the Deployment of Innovative Lighting in European Cities" (2013), Digital Agenda for Europe, European Commission).

ICT and lighting infrastructure, basis for smart supervision and interconnection with Big data, a group of relatively affluent customers, etc. On the other hand, limited renewal level in the present projects, limited proof of (quantifiable) benefits of human centric urban outdoor lighting to health and wellbeing, procurement rules that focus on lowest possible cost are important barriers in faster market penetration of HCL in the cities.

Architects, installers

Architects and installers are in a position to give recommendations on the optimal options available. They however need to have the availability of state-of-the-art practical knowledge to allow them to do this.

Knowledge institutes

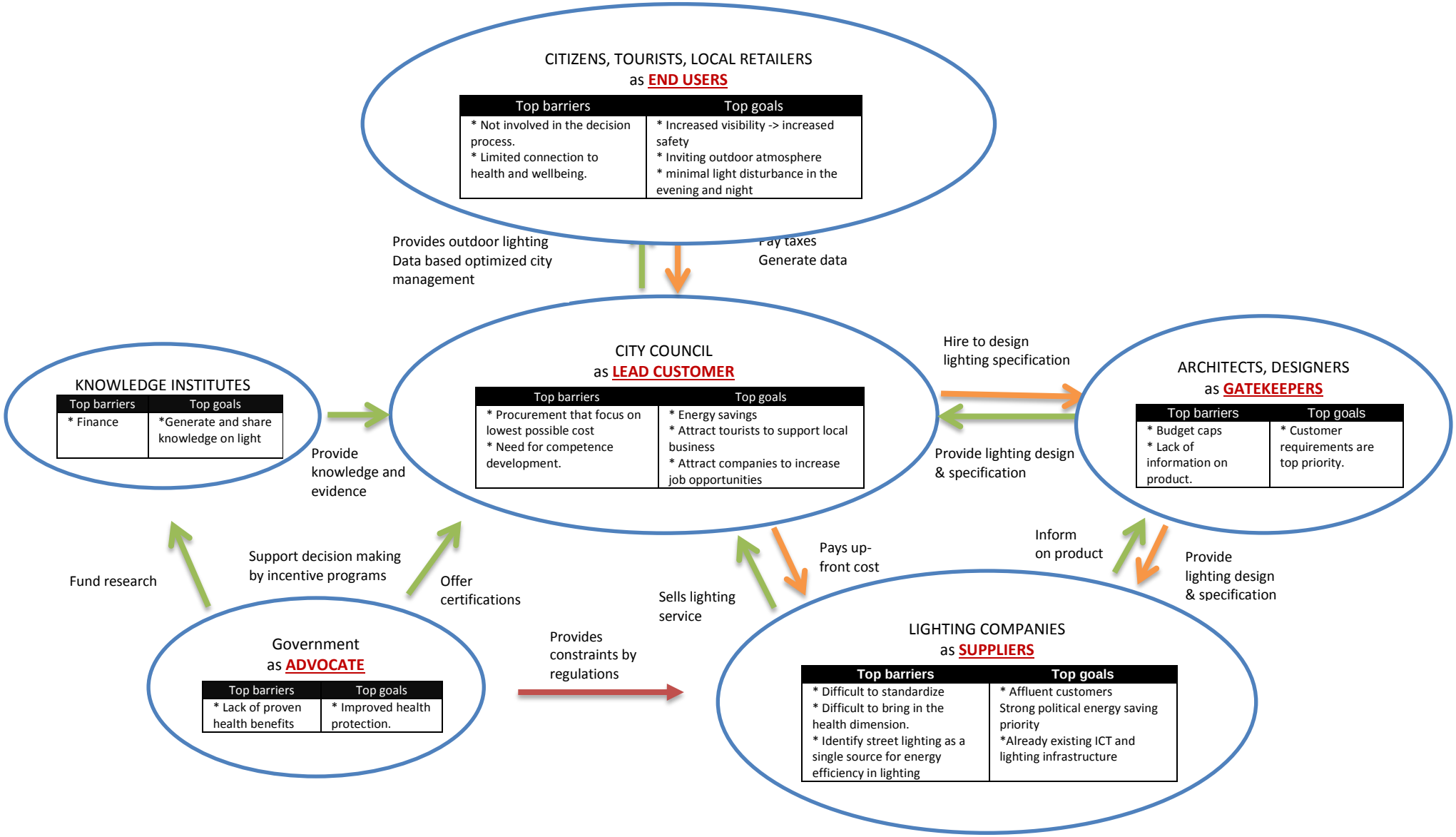
The knowledge institutes (universities and other knowledge and research institutes) play an important role in generating and sharing knowledge on optimal lighting. Based on this information the demand and supply requirements are being described. Collaboration within the so-called “triple-helix” (government/business/knowledge institutes) is increasingly widely seen. More recently, the “end-users” become now also more and more involved in this collaboration (“quadruple helix”).

Table 4: Cities Stakeholder Overview

Stakeholder	Interest	Potential role	Competency	Examples of practice
Internal Stakeholders				
Citizens (road users, pedestrians), tourists, local shopkeepers	Safety, Security, Mobility. Attractive living environment. Recreation. Aesthetics, pleasant atmosphere.		Direct beneficiaries of HCL.	
Municipal governments (lighting, environmental, planning departments)	Safety, pleasant city atmosphere. Increase city attractiveness. Identify energy cost saving opportunities. Enhancement of local economy Local job creation Attract tourists and business. Branding potential as Smart City.	Put a price on good city lighting.	In charge of resource allocation. Leading customers in the HCL market. Provide expertise to other public sector organizations.	Eindhoven – Smart City Lighting Event 2015 http://www.smart-circle.org/lighting/ Veldhoven, ring road (Oerse baan): HCL application, mimicking the phases of natural lighting during the night. Lyse – platform for exchange of experiences
External Stakeholders				
Tourists	Safety, security, mobility, pleasant atmosphere.		Direct beneficiaries.	
Research centers			Provide evidence	http://www.tvilight.com/
Lighting Companies	Optimizing sells by adapting products & services according to market.	Can influence purchasing patterns through pricing and marketing.	Technical expertise Provider of service Standardization initiatives	It offers city light systems with dimming lights that turn themselves on as residents move about.
Consultants Installers Architects	They typically serve the interests of their customer, i.e. the health facility owner.	Architects and engineers may advocate quality lighting during the programming and schematic stages of a project.	Their ability to leverage advanced lighting technologies depends partly on the interests of the customer.	
Public authorities	Energy savings	Advocate	Support SSL adoption. Use taxes to give further incentives for SSL adoption. Finance research. Help the standardization process.	The ban on incandescent lighting

Source: Authors' ideas and literature review.

Figure 4 – Stakeholders in cities and key interactions. Principal Agent issue. The lead customer is the city. It adopts HCL a) to save in energy costs and maintenance and to improve the attractiveness of the city and b) as a data collection infrastructure. The city pays the up-front cost. The beneficial end users are the citizens and the tourists visiting the city. The suppliers are various companies in the lighting industry. Architects & designers are the gatekeepers. They are the ones who prescribe the most adequate lighting system to the customer. The government can acts as an advocate.



1.6 Domestic

The domestic application area is partly characterized by similar relationships as the previously described areas. With the clear difference that individual households typically have a limited budget to spend as compared to decision makers in the other application areas. Yet, because of its extremely large number of potential customers, this is potentially the largest market.

Principal agent conflict: Renters vs. home owners
In cases where the resident is the home owner, there is typically no principal agent conflict. The one who makes the purchase decision and the end-user are the same. Thus, the one who pays the up-front cost of equipment/service also enjoys the benefits. This is different when the resident rents the dwelling. In this case, the landlord, housing corporation or real estate manager is the one who makes the purchase decision and has to pay the upfront cost, while the renter enjoys the benefits.

Suppliers
The suppliers are the various companies within the lighting industry, often through retail. A key advantage of this market segment is the large long-term market potential (the extremely large potential number of customers). Budget restrictions (higher cost as compared to conventional lighting solutions) and lack of awareness are important obstacles in the domestic sector. Easily accessible showrooms for the general public, to experience the assets of advanced lighting solutions, may generate interest within this group of potential customers.

Architects and designers
Architects, designers and installers are the ‘gatekeepers’. For them, the owner requirements are top priority. They are in the position to provide recommendations and propose attractive lighting solution options available for their customers. Again, however, they need to have the availability of state-of-the-art practical knowledge to allow them to do this. In addition, they are facing budget restrictions.

2 Barriers and Opportunities

2.1 Study Methodology

This section describes the main results from the stakeholder interviews. Twenty semi-structured interviews (approx. 1 hour) were carried out, largely by telephone but on occasion in person. In addition, one open consultation on views on barriers and opportunities was held with 1 lead scientist on HCL. The objective of the interviews was to obtain a picture of the current most relevant issues related to HCL deployment and the conditions required for higher future market uptake. Effort was made to ensure that the stakeholders interviewed represented the whole range of interests in the HCL market and could offer insights especially from the viewpoint of a potential buyer (demand side). The study is, however, relatively small scale.

We interviewed 6 representatives of the lighting industry, 5 representatives for cities, 4 representatives of the educational sector, 3 representatives of the workplace sector, 1 representative of the health care sector. Furthermore, we interviewed 1 representative of prisons and 1 representative from science. From the 21 stakeholders 9 may be viewed as representatives of the 'supply-side', 11 as representatives of the 'demand-side', complemented with 1 representative of 'science'.

2.2 Barriers

From the analysis of the interviews emerged four main categories of barriers that have a particular impact on market penetration of HCL: informational, administrative, financial and practical. They are generally similar across sectors and building types, although they affect differently the decision makers in various application areas. The reason behind a differential impact on decision makers is related to the fact that each sector may attach a different degree of importance to upfront cost, energy efficiency, lifetime, light intensity, color warmth and design features. We pay special attention to the public sector as a leading customer across various application areas in its position of building owner, administrator and employer as well as important potential promoter through public procurement.
At the end of this Chapter, the barriers are categorized illustrated by quotes from the interviews in Table 5.

Top 10 most frequently brought up barriers
During the interviews, representatives from both the supply side and the demand side referred to issues which they perceived as barriers withholding customers from HCL adoption. The top 10 most frequently mentioned barriers (see Figure 5a), included issues relating to:

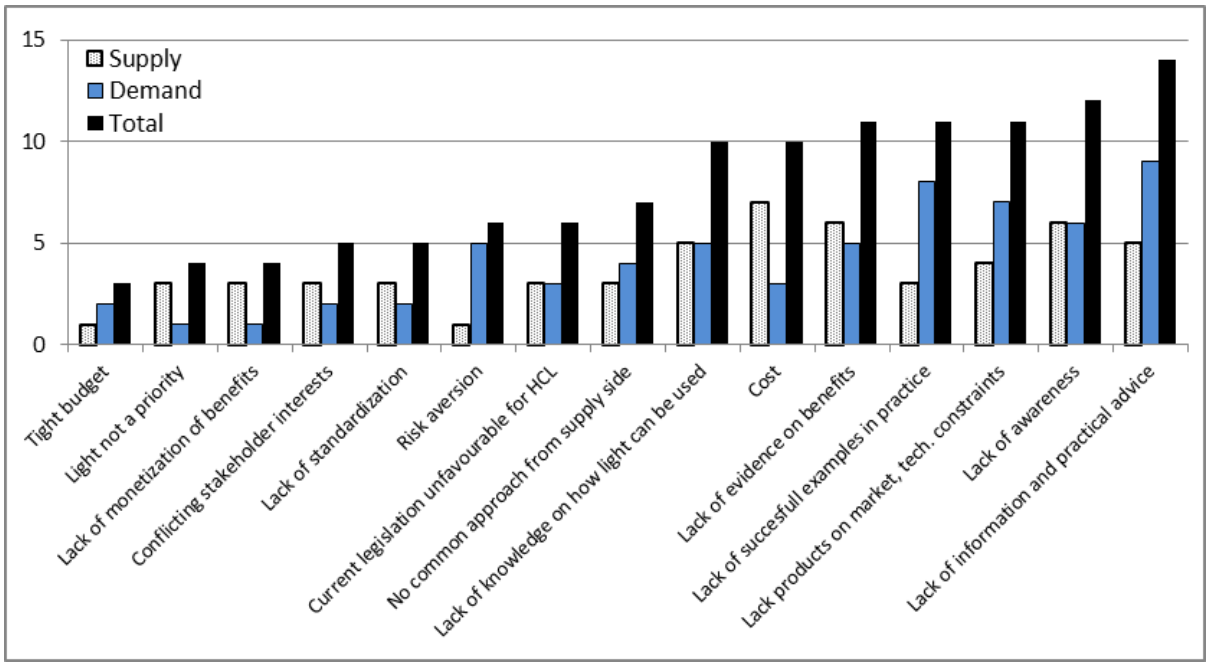
1. Lack of information and practical advice;
2. Lack of awareness;
3. Lack of products available on the market meeting customer requirements;
4. Lack of successful examples in practice;
5. Lack of evidence on benefits;
6. Cost;

7. Lack of knowledge on how light can be used;
8. Lack of a common approach from the supply side;
9. Lack of legislation favorable for HCL/existing legislation unfavorable for HCL adoption;
10. Risk aversion.

Supply versus demand: Differences and similarities in barrier perception.

Figure 5a shows that a notable difference in barrier perception seems to exist between the two stakeholder groups (supply versus demand side). The supply-related stakeholders most frequently addressed the issues of cost, followed by lack of evidence and lack of awareness, while the demand-related stakeholders mostly addressed issues related to a lack of practical or technical advice, a lack of successful examples in practice, and a lack of available products meeting customer needs (e.g. products that can be bought as a 'complete package'; easy to use, easy to implement).

Figure 5a – Barriers: Reasons why stakeholders believe that customers have not yet adopted HCL (frequency of quotes relating to the different types of issues).



Barrier importance rating

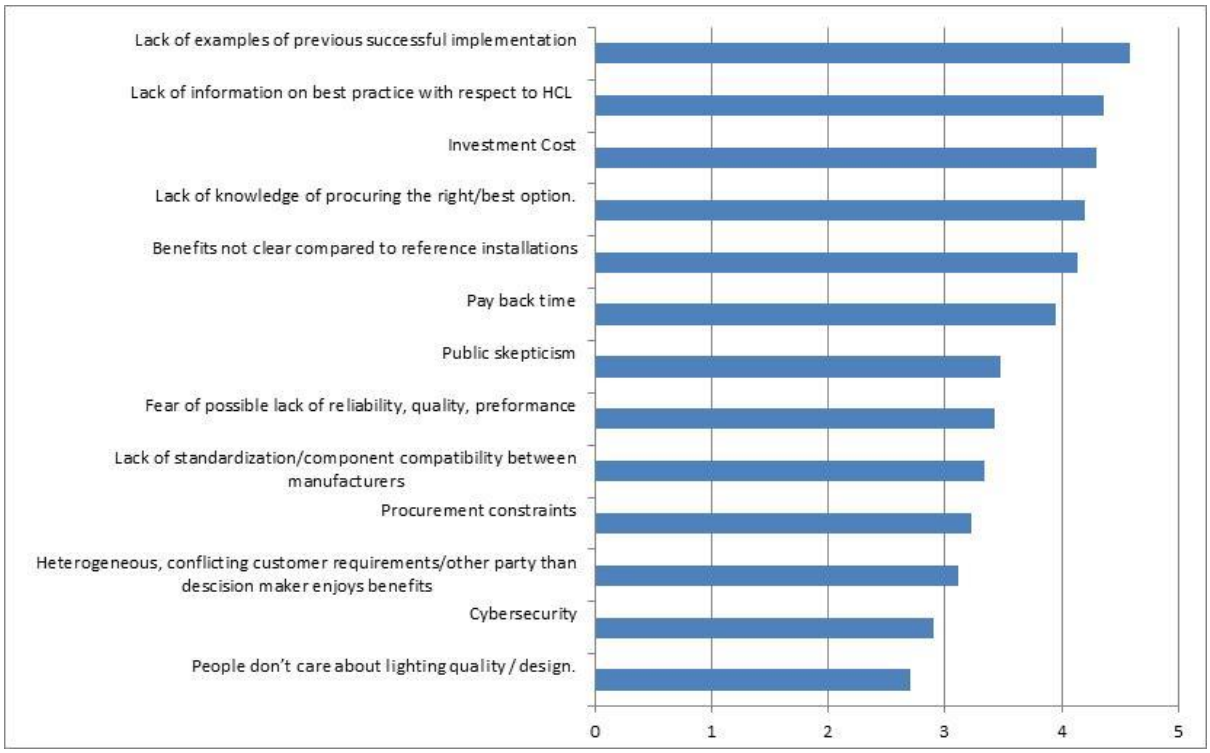
Despite differences in *frequency* by which different issues were raised by the supply- and demand representatives (Figure 5a), both groups seemed to agree remarkably well in terms of *average rating of importance* of (a *pre-defined selection* of) barriers included in the questionnaire. The top 5 of barriers contained the same topics for both groups, with only minor differences in order and average importance score. Overall, the following barriers were perceived as most important:

1. Lack of examples of previous successful HCL implementation in practice;
2. Lack of information on best practice with respect to HCL;
3. Investment cost;
4. Lack of knowledge on procuring the right/best option;
5. Benefits are not clear compared to reference installations.

The average rating of perceived importance of these 5 barriers was comparable between both groups, with a score greater of equal to 4 (4: somewhat important, 5: very important) in both supply- and demand side stakeholder subgroups.

The only item where the rating importance between the two groups seemed to diverge (difference in average rating score > 1), related to the statement 'people don't care about lighting quality/design'. This was perceived (on average) as much less important by demand representatives (average score 1.9), than by supply representatives (average score 3.4).

Figure 5b – Importance rating of barriers by stakeholders (Average rating; Scale: 1–not at all important, 2–not so important, 3–neither important nor unimportant, 4–somewhat important, 5–very important)[9].



2.2.1 Informational barriers

When asked to list the main barriers for slow HCL market adoption, respondents invariably mentioned some type of barriers relating to a lack of information and practical advice, a lack of awareness, a lack of successful examples in practice, and a lack of (scientific) evidence on benefits.
This is consistent with the importance attached to various informational difficulties. Thus, respondents from both the demand and the supply sides attach high importance to the lack of examples of previous successful implementation in similar institutions, to the lack of information on best practice with respect to HCL, to the lack of knowledge on procuring the right/best option, and to

[9] Note: For the majority of barriers, importance rating scores were available for at least 18 respondents. Since the interview was refined after a 1st round (incl. addition of prominent barriers emerging from the 1st round). Rating scores for these extra items were available for a smaller number of respondents, only, including: 'cybersecurity' (N=10), 'lack of information on best practice' (N=11), 'procurement constraints' (N=13) and 'lack of examples of successful implementation' (N=12).

the lack of understanding of the HCL benefits compared to other products currently available in the market.

Limited awareness

Two years after the A.T. Kearney, ZVEI and LightingEurope's (2013) market study on HCL, we find that limited awareness of its potential benefits among decision makers is still an important barrier to market penetration of HCL. The lack of information and practical advice does not only apply for the end-users but also for architects, engineers and policy makers. The resulting skepticism with respect to the claims of HCL reinforces the consumer purchase decision making centered on cost.

Among the reasons for the pervasive lack of awareness and information on HCL we have:

- Lack of a common definition of HCL among lighting specialists;
- Knowledge gaps in terms of specialized knowledge among stakeholders in the supply chain who should ideally be able to provide and promote these solutions (including installation advisors/consultants, designers, …);
- Lack of a general approach to the market by the lighting industry and lack of collaboration within the supply chain (e.g. architects, lighting designers and manufacturers);
- Limited practical experience and a lack of succesfull HCL implementation examples in practice demonstrating the concept; There are not yet good hard facts from "real-life" intervention studies about quantified benefits and therefore there is neither an established knowledge of what exactly is the right lighting (in terms of spectral composition, intensity, duration, timing);
- Knowledge gaps among different departments in organizations that might become potential clients;
- Inconsistency in findings from scientific literature on benefits;
- People arguing in favor of HCL tend to publish in specialized media while the antagonists argue in the mainstream media;
- Lack of easily accesible practical information (what might be good solutions, how to implement HCL, how use it, how useful it is in terms of benefits, etc.);
- Lack of priority for light quality for the consumer group.

Based on interviews with stakeholders from the lighting industry, local municipalities, public organizations and academia, Yu (2015) finds that "in general, decision-makers in the public sector have a limited awareness of SSL and its benefits (not lighting experts), so they typically position lighting as a technical subject, even though the subject of lighting is multi-dimensional and includes important issues other than technical, like health, comfort, productivity, wellbeing, etc."

Limited knowledge of what can be done with light

In general, there is limited knowledge (amongst people who decide) of the biological or physiological effects of different types of light as well as of the new technical opportunities to tailor the light according to given specific needs. Failing to see the potential benefits combined with not knowing how to go about implementation practically, and uncertainty about costs, decision makers tend to "play it safe". Lack of knowledge of how to integrate lighting in their respective practices is partly due to the fact that HCL is very new, to the lack of knowledge on procuring the right or best option, and the lack of (information on) evidence based 'market-ready' HCL solutions which may be easy to buy, easy to use, and easy to implement, and to insufficient positive experiences in similar institutions.

Lack of information and practical advice

The situation is worsened by a lack of specialized knowledge, support and advice from stakeholders within the supply chain (incl. e.g. architects, lighting designers, installation consultants) and shortage of available practical information from the supply side. Stakeholders from the demand side remarked they perceive that skill shortages exist in both the lighting industry, responsible for effective delivery of HCL solutions, as well as in professional services, with few builders, architects and designers familiar with how to set up an HCL system.

Lack of successful examples in practice

A lack of previous successful applications in practice, preferably in similar institutions or situations, inhibits any bold decision-making.

Lack of conclusive evidence

The fact that benefits are not really clear to the customers relates to the fact that there are not really good hard facts on quantified key performance indicators of the impact of light on people. Interviewees expressed a particular need for evidence based quantitative information on specific 'application area relevant' benefits (e.g. sick leave or productivity for the workplace, patient recovery for the health care sector, etc.). The ability to translate such quantified benefits into euros seemed important for several application areas, for some more than for others. Respondents in our study believe that what is needed are more reliable field studies (i.e. large scale field studies, allowing to take a broad range of other influencing factors into account). In the past, research often investigated effects of light within relatively young study populations (typically students), and typically under laboratory conditions. That is no longer seen as satisfactory evidence. Well described intervention studies, performed in 'real life' situations (not in the laboratory), with a representative population for the application area, are considered necessary.

2.2.2 Administrative barriers

The credibility and reliability of information is essential to build and maintain confidence whenever a new technology is introduced in the market, but is difficult to guarantee. At the same time, regulations on lighting installations do not address all key features of HCL, thus biasing the purchase behaviors of decision makers away from HCL supporting systems.

Procurement constraints

The guiding principle for taking a decision on renovation of lighting installations is still to choose the option that minimizes cost. This procurement principle seems to be relevant in all application areas considered in this report. Moreover, as purchasing decisions are taken in the context of annual budgets, the long term benefit may be ignored in the process. The constraint appears to lose its importance given price decreases for LED based products and installations and the increased usage of models of service contracts ("Lighting the Cities, Accelerating the Deployment of Innovative Lighting in European Cities" (2013), Digital Agenda for Europe, European Commission).

Furthermore, the criteria for funding lighting upgrades tend to focus on the efficiency with which the source provides visible light from electricity, not on quality. "At present, a large source of funding for SSL is the money that is available for energy saving LED investments… There are numerous sources of guidance and funding for energy saving investments locally, regionally, nationally and from the European Union."

Finally, HCL is a new technology with different characteristics than conventional lighting. However, it is not yet clear what procurement specifications to ask for in order to allow for innovative design of lighting solutions. There is no lighting performance metric that addresses all lighting relevant aspects. One of the interviewed stakeholders recommended that action is needed to influence procurement, to think of 'buying a function', rather than just 'buying a lamp'.

Lack of standardization / compatibility of components between different manufacturers
Another perceived obstacle is lack of standardization. Compatibility of electrical supplies and control interfaces will be required to reduce costs and increase flexibility. From the viewpoint of customers, standardization is desirable as it allows the customer to avoid becoming 'trapped' with one brand (having to buy everything from the same brand from then on). Standards hence allow comparison and evaluation.
During the interviews respondents addressed the following standardization issues:

- Standards for reliability, quality and performance are lacking;
- For function control in integrated systems, ideally standardized protocols are needed which can be 'read' by light fixtures from different manufacturers. System elements should remain compatible in time;
- "The lack of compatibility between components, software from different manufacturers should be solved".

At the same time, one of the respondents didn't perceive a lack of standardization as important barrier, with the reasoning that: "The operating systems nowadays are almost all 'DALI'. This is a universal operating system. So this works well together with the elements. Almost all is standardized nowadays".

Fear of possible lack of reliability, quality and performance
Customers need guarantees that the products they buy will achieve the promised results, especially when the initial price is high compared to other substitute products. Therefore, value enhancing labeling efforts can be important in establishing credibility and thus ease the process of figuring out which is the right product, from the right manufacturer and so on. At the moment, lack of such recognition, adds a premium to the reputable, already established players in the market.

Legislation
Current legislation was viewed as hindering HCL, both by a lack of HCL *supporting* legislation, as well as by existing legislation being *unfavorable* for HCL innovations. Amongst the reasons that were brought forward during the interviews we cite:

- "Legislation puts a cap on energy use for new buildings and for major refurbishments. If you do a simple calculation HCL might seem to use more energy";
- "Building managers or building contractors have to meet certain minimal requirements (legal standards) at minimal cost. Compliance with these minimal requirements is often considered enough";
- "Policy action is needed: To have other goals than only to save energy, but also to think about light that can be important part of wellbeing";
- "Regulations related to 'cybersecurity' are an important barrier to have the freedom to innovate";
- "State-of-the-art knowledge is not yet integrated in existing norms and standards for office lighting. It is still a key aim of investors in office lighting to comply with those, and to get

energy certificates. This hinders innovation. For example, the environmental certificate sets limits to the (max) capacity (even if it is not constantly used in dynamic systems). It still assumes the 'old fashioned' situation, where light would be on continuously with the same intensity and light character. In the 'new' situation, the (max) capacity is no longer 'automatically' reflected in higher energy use per se. Since temporally higher intensities at moments when it is needed, are being compensated by lower intensities, when possible. Currently, environmental certificates prescribe limits to 'potential use', assuming lighting is on continuously at its max capacity, while they should address 'actual/real' use".

2.2.3 Financial Barriers

An evaluation of the economic benefits of HCL must balance the higher initial price with the longer term energy savings and non-monetary human beneficial effects, which however are difficult to monetize. Although HCL and the supporting technology may be more expensive than conventional lighting on a first-cost basis, higher operating efficiency and longer operating lifetime (reduced maintenance/replacement costs) can ensure that it is highly competitive on a life-cycle basis[10].

Lack of monetization

A recent attempt to monetize the benefits of HCL is the market study of A.T. Kearney, ZVEI and LightingEurope (2015). The research examines the benefits at a micro level (perspective of individual investors, e.g. facility owners) and at the macro level (perspective of the general public e.g. health insurances). They estimated that at the micro level, the largest quantified benefits may be realized in industrial segments due to the dominant impact of hypothesized productivity increases. The market study found little quantified benefits at the micro level in the medical and elderly care segments, as most savings cannot be realized by the investor, but by other stakeholders, e.g. insurance companies. According to the report, a business owner might realize EUR 111,000 ($124,000) annually in productivity increases from a 200-person workforce. Furthermore, the study estimates that total benefits for Europe, measured as increased GDP (gross domestic product), could be €0.87 billion, or up to €12.8B if market penetration were to reach 100% by 2020. Interviewed stakeholders addressed the lack of evidence based quantitative information on how the expected benefits translate into 'euros' (e.g. by increased productivity) as a barrier. As part of the reason, the lack of scientific evidence on (quantitative) benefits was mentioned. Furthermore, it was noted that the 'extra' benefits of HCL in terms of e.g. increase in productivity are extremely hard to quantify, because there is little information available on this, and the activities of different employees (with different tasks, activities and roles) are difficult to compare in terms of 'productivity increase'.

Separation of costs and benefits

The concerns, interests and resulting decisions of various stakeholders are sometimes conflicting. As described in more detail in the previous section on stakeholders' considerations, building owners and developers will be more likely to install a less advanced lighting system in an attempt to minimize costs. Tenants or purchasers of the building will then have to pay for the higher operating and maintenance costs. In other words, the benefits of HCL are for the occupant who is not the same party as the owner of the building. As far as the public sector is concerned, the trend is for government agencies to become building tenants. Therefore, they are less likely to lead by example.

[10] A life-cycle cost analysis (LCCA) gives the total cost of a lighting system, including all expenses incurred over the life of the system.

High up-front cost

Given that cost is still the primary driver of the lighting purchase decision, it comes as no surprise that one of the most important hurdles for change over to SSL products that support biological efficient lighting has been the burden of high initial investment before benefits become visible. High early adopters cost, was mentioned as a barrier, with the first users of HCL currently still being confronted with high cost. It did not help either that decision makers such as hospital administrators, school directors and city officials are commonly more concerned with the initial cost, and as a consequence long term benefits may not be adequately taken into account. Typically the average operating costs in the health industry are divided as following: 90% staff costs in salaries and benefits; 9% in rental costs; and 1% in energy costs (Source: World green building council).

With respect to the cost, there are two important issues our interviewees have pointed out. First, the cost is considered high, especially because customers are not sure about the benefits. Second, the focus is on energy savings.

This is particularly unfortunate as the institutions typically targeted such as schools or healthcare facilities have tight budgets and other competing more pressing investment needs. For example, school boards will most often feel more willing/greater urgency to invest in employment of personnel (teachers) and in schoolbooks etc.

Payback time

The payback period is the time it takes the consumer to recover the initial purchase cost as a result of lower subsequent operating costs. It seems that the European lighting sector is still characterized by a culture of focusing on energy and cost savings (e.g., see Yu (2015)). In office and healthcare settings, with long hours of daily operation and high occupancy rates, this payback period should be shorter than in education facilities for example. Uncertainty if HCL installations will 'pay back' within the amortization period was listed as a barrier. The payback time for such new and advanced systems is much harder to predict as compared to conventional solutions.

Risk aversion due to uncertainties of delivery of product promises

Yu (2015) finds that uncertainty of product performance as well as of the potential benefits of SSL, especially the benefits for human health and wellbeing, is impeding the Swedish public sector to adopt SSL. "This is due to on one hand; there is strong skepticism towards this topic among decision makers, even though there is strong scientific evidence. On the other hand, as there is few experiences (successful projects) available, everyone is afraid to be the first mover, so waiting for others to start."

2.2.4 Practical Barriers

Last but not least, there are significant practical difficulties involved with the implementation of an HCL project. In addition to previously mentioned system element compatibility concerns, these include the time to market of new insights, the lack of availability of a practical/technical 'recipe' providing guidance for HCL implementation, the lack of evidence based, 'market ready', easy to buy, ready to use, easy to implement solutions, and the availability of essential components. (A growing number of components are coming available that enable stakeholders to develop and build own prototypes to meet their requirements in terms of adapted light and light variations.)

Furthermore, retrofit difficulties in renewal of lighting systems were addressed ("there is always material in place that may not be old enough yet to replace, while changing to more modern types of

systems may require a change of other components also (e.g. changes to electricity supply, rewiring etc.)".
As an example of time to market of new insights, it was addressed that existing knowledge on the 'ageing eye' is not yet adequately implemented in practice, partly because this requires personalized system solutions which were not yet commonly available in the past, but are now coming within reach. "Technology has proceeded further than what is currently applied. But it is a large step from technological invention towards practical application".

The need for 'market ready', ready to use systems was brought forward by several stakeholders. The need was expressed for systems that have proven to be reliable and work well in practice. It was stated that customers typically do not like to be the 'test rabbit' (or early adopter). It was noted by stakeholders from the demand side that they felt that adequate HCL solutions for e.g. office sector of educational, have not even progressed as far as the 'prototype phase' (leading early adopters to build their own prototypes, in order to meet their requirements). They expressed the need for good products on the market that can be bought as a 'complete package'.

2.3 Opportunities

Top 6 most frequently brought up opportunities
From the questions concerning the stakeholders´ views on opportunities, the top 6 by stakeholders most frequently mentioned opportunities related to:

1. Lighting solutions supporting alertness and productivity in the workplace/education (N=6);
2. (Evidence based) solutions adapted to individual characteristics and/or needs, time of the day and activity (N=5);
3. Circadian rhythm lighting: Use the circadian rhythm supporting effects of light, i.e. supporting awakening in the morning, prevent 'after lunch dip' (e.g. office) and support sleep at night (N=5).
4. Smart lighting with sensors. Features that were listed included: A structure that allows changes and improvement, flexibility to change and to add new features over time (N=3);
5. Lighting solutions supporting visual acuity for elderly (N=3);
6. Individually adjustable lighting solutions (N=3).

Other opportunities that were brought forward (by 1 or 2 respondents) included:

7. Personalized lighting solutions, taking into account (physiological) differences between people;
8. Lighting solutions with the ability to reduce stress levels (e.g. in office employees: leading to increased productivity, reduced sick leave, going home less tired, improved sleep quality, getting back to work less tired the next morning);
9. 'Market ready', 'ready to use' systems are needed, that are proven to be reliable and to work well in practice;

10. Lighting systems to be used as a tool to support learning, by allowing to provide (more) structure to the lessons (e.g. with pre-defined settings). To help making clear to students what is expected from them during lessons;[11]
11. Integrated system for managing indoor environment in buildings, including lighting (Building management system that integrates the different functions in one product, such as lighting, ventilation, temperature and humidity control);
12. Flora and fauna friendly lighting solutions: Outdoor lighting which is better in tune with the ecosystem (HCL solutions for outdoor lighting in cities and surroundings);
13. Smart lighting to ease maintenance and operation, including dimming;
14. Lighting solutions directed to providing a better 'city nightscape' (enhancing aesthetics, ambience, attractiveness, liveliness);
15. Lighting solutions for accident prevention at the workplace (preventing reduced alertness at specific hours during the night);
16. 'Plug and play' solutions for retrofits: 'ready to use' solutions which can be added easily in existing buildings, without having to change the whole system and related structural adjustments (cabling, wiring, ceilings, electricity supply,...), with 'easy to implement' control panels;
17. Application of HCL in traffic, focused on driving comfort and safety, taking into account minimizing disturbance of sleep-wake cycle (and minimizing disturbance for flora and fauna);
18. Sensor enriched solutions (stakeholders mentioned e.g. "*Dynamic lighting compensation with sensors*" and *"Bidirectional with sensors"*;
19. (Outdoor) illumination of *buildings* (to enhance city attractiveness);
20. Selling 'good light' instead of a product.

The opportunities are categorized and illustrated by quotes from the interviews in Table 5 at the end of this Chapter.

Opportunity importance rating

In addition to the open questions related to opportunities, interviewees were invited to rate a list of pre-selected opportunities in terms of importance. From this list, energy efficiency (average rating: 4.4) was still viewed as the most important opportunity, and may thus be viewed as a main driver to accelerate sales of HCL solutions and 'green' business' development. Smart lighting, i.e. integration of lighting with other non-lighting services closely follows (average importance rating: 4.3). Human Centric Lighting (average rating: 3.9) is the third best rated opportunity by the respondents in our study. 'Aesthetics, beautification, emotion' (average rating: 3.8) and selling light instead of a product (average rating: 3.7) are the fourth and respectively the fifth best rated business opportunities, closely followed by 'retrofit opportunities' (average rating: 3.6)[12]. These opportunities are followed at distance by 'complex energy service' (integration of production and energy use) and leasing of lighting installation instead of selling (financial solution), with average rating scores of 3.1 and 3.0 respectively.

[11] Note that 2 different types of solutions were brought forward: 1) HCL mimicking the natural changes in daylight over time in terms of intensity and spectral composition to support the biological circadian rhythm; 2) HCL solutions with predefined settings for different types of activities (e.g. concentration, relaxation etc.) to allow providing structure to lessons and providing an extra tool for teachers to make clear to students what is expected from them at a certain moment in time.
[12] In this ranking list the items for which rating scores were available for at least half of the respondents are included only.

Concluding remarks

Therefore, we conclude that while energy savings may be the initial driver for upgrading to new lighting technology, increased awareness of and confidence in the potential visual and non-visual benefits of HCL coupled with the possibility of integration lighting with other services can open up significant business opportunities. The benefits that HCL promises are to be delivered/achieved by means of controllability features that allow adapting lighting to the needs of individuals. Hence, before HCL can be fully developed, digitalization of lighting needs to be completed. To facilitate adoption, more 'market ready', 'ready to use', 'easy to implement' and user-friendly components and systems are needed, that are proven to be reliable and to work well in practice.

2.3.1 Smart lighting that allows for personalized systems

If the aim of HCL is to offer optimal light for each individual or in other words to offer light that adapts to the needs of the individuals, then personalized solutions are required which current technological developments do allow for. More rather than less controllability is mentioned when asked about future needs with respect to lighting. Respondents from the demand side expect solutions that not only allow for adjustments to certain settings, but ones that are easy to change and to have new features added over time or which have sensory systems that are able to learn.

On the professional side, too, the trend is towards higher individualization and design improvements ("Lighting the Cities", European Commission, 2013). The first-generation smart lighting systems that are currently available on the market offer the possibility of integration with building automation systems. According to the lighting professionals we have interviewed, the lighting systems of the future could be linked to indoor positioning through smartphone applications, users may enter their current activity as well as some key parameters to support personalized lighting settings such as age and type of person ('morning' or 'evening' person).

Major trends that are likely to impact the demand for smart lighting solutions include:

- ***Technology:*** it refers to acceleration of market adoption of solid state lighting that will enable smart (energy) building management, linking of lighting to adjacent systems and remote (wireless) commissioning and control towards smart grids.
- ***Energy efficiency and green building****:* As energy prices worldwide continue to rise, the importance of ***sustainable building design*** is becoming increasingly acknowledged. Active daylighting is one of the top solutions being used today to reduce energy bills.
- ***Smart Appliances - connected home market:*** Thanks to Bluetooth and Wi-Fi technologies, lamps can be controlled through mobile apps, which further reinforce the importance of tablets and smartphones at home. Considering the rapid decline in prices of such devices, their possession rates should rise rapidly, putting smart LEDs in reach of more households.
- ***Smaller households as a result of urbanization:*** This implies more customers for smart appliances.

2.3.2 Biologically effective lighting for health and wellbeing

HCL may benefit the wellbeing of patients in hospitals, and has been hypothesized to support prevention of chronic diseases through improvement of sleep quality. As health and wellbeing of patients is the core business of healthcare facilities (hospitals, elderly care), these organizations appear to be more open to the potential benefits of HCL. It is for this reason that the healthcare

sector is seen to be the application area most promising in terms of early adoption by lighting professionals.

Lack of knowledge of choosing the best option, procurement constraints and lack of standardization, rather than skepticism of how lighting can influence patient outcomes, are the main barriers towards making healthier lighting a reality in healthcare facilities. The penetration model could be the following: HCL adoption starts as a pilot project in some part of the hospital with the aim of getting experience and evaluation results. Full scale implementation is performed only later when the chance of a large renovation appears.

Major trends that are likely to impact the future demand for lighting solutions in the healthcare sector include:

- ***Ageing Population**:* Europe currently has the world's highest proportion of older individuals and this is going to persist for the next 50 years. About 37 percent of the European population is projected to be 60 or over in 2050 (2014 Global health care outlook). Ageing population in Europe will then require additional healthcare facilities for elder care and treatment of age-related conditions. Moreover, light requirements change with age which makes ageing population a top target group for HCL solutions.
- ***Increased demand for healthcare infrastructure vs cost pressures:*** construction of healthcare facilities in Europe is mainly driven by governments. To the extent that economies in Europe start growing at a faster pace than presently observed (which would allow that austerity measures are not translated into public spending cuts in areas including health care), construction of health care buildings can take up driven by the previously mentioned demographic changes, the need to replace outdated facilities, and a heightened focus on quality and safety.

2.3.3 Biologically effective lighting that improves cognitive performance

As second most promising application area in terms of early adoption of HCL, the office market is brought forward. Increased productivity in the workplace — as a result of light enhanced focus and alertness, reduced stress, absenteeism and fatigue — is considered one of the most important benefits by lighting professionals and customers alike. The explanation lies in the fact that improved productivity allows both buyers and sellers to translate the benefits of HCL application into monetary returns.

The office market is closely followed by the education sector. The HCL benefits of supporting concentration, reducing fatigue and features allowing invigorating structure to the lessons, are important aspects in schools where light can be pedagogically used to help students obtain better performances. Nonetheless, the implementation of HCL systems in both of these sectors is seen limited for the time being by lighting professionals for the reasons previously outlined in the section on barriers.

Major trends that are likely to impact the future demand for lighting solutions in these sectors include:

- ***Population growth:*** The global population is projected (UN) to reach almost 10 billion by 2060, representing an overall increase of 39.8 % compared with 2013. The EU-28's population

however, is projected (by Eurostat) to increase by only 3.5 % over the same period[13]. From a lighting viewpoint, the need to find energy efficient solutions to a growing population will support the switch to SSL technology.

- ***Increased urbanization*:** Increased urbanization is a consequence of the above mentioned population growth.
- ***New patterns of workplace activities*** include diverse work patterns, work everywhere, ageing workforce and later retirement. Also, the population in many countries is ageing and there is need to have older people who can remain healthy and economically active, the requirements for high levels of workability among employees, the need to recruit and retain high-value employees, etc.
- ***The workplace – a priority setting for health promotion*:** The workplace offers an ideal setting and infrastructure to support the promotion of health of a large audience. Key reasons for this include: the significant proportion of time spent at work, the large proportion of the adult population that can be easily reached with messages about health and wellbeing, as well as the possibility to obtain far reaching benefits as the impact upon the physical, economic and social wellbeing of the workers will carry further on their families, the economic wellbeing of the organization and that of the wider society.

2.3.4 Emotionally effective lighting to create stimulating environments

Light plays a primary role in aesthetically pleasing environments (architectural lighting). There is growing acceptance that productivity at work has as much to do with feeling comfortable in one's own environment (Hawthorne effect) as it does with the skills and dedication to the task at hand. In the same way, comfortable classroom environments have been shown (Sheryl Reinisch) to help children feel safe and valued, which in turn increases self-esteem and motivates students to engage in the learning process. Last but not least, enhanced comfort during hospitalization helps in the recovery process.

Major trends that are likely to impact the future demand for lighting solutions that create stimulating environments include:

- ***Major shifts in workplace, recreational, and hospital design have occurred (less so in schools)*** For instance, the hospital environment has long been institutional and perceived as lacking warmth. Recently however, partly driven by a competitive healthcare environment, there has been an increasing effort in improving the facility conditions with the aim of a more positive patient experience (offering hotel-like amenities, contributing to the feeling of 'being in a hotel'), embracing the concept of 'healing environments' contributing to the wellbeing of patients.

2.3.5 A new business model is needed.

A business model describes managerial pathways to engage with consumers about how value is created and captured. In other words, a business model is a system that helps identifying the customers; engaging with their needs, delivering satisfaction, and monetizing the value (see Baden-Fuller and Haefliger (2013)).

[13] http://ec.europa.eu/eurostat/statistics-explained/index.php/The_EU_in_the_world_-_population

The present dilemma the lighting industry is facing is that energy efficient bulbs have an extended life which reduces the frequency of purchase. As a result, manufacturers can no longer rely on bulb burn out and thus need to rely on innovation and attractive products in order to boost sales.

In addition, in many of the applications surveyed the lighting application purchase decision is not made by the party that pays the electricity bill or that finally enjoys the HCL benefits. These interests now in conflict create an opportunity for the introduction of a new business model in which a third party acts as light service provider. The idea is to give to the same player both the purchase decision and the right to make use of light and take advantage of the gains from reduced operational and maintenance costs (e.g. lighting consultancy firms offering their LED solutions complete with finance packages - http://www.energysavinglighting.org/).

2.3.6 Unique aspects of the European market

The unique characteristics of the European market are likely to support earlier market adoption of HCL in Europe than in other regions. The European market is unique in several respects:

a) ***Europeans tend to be eco-conscious*****.** For them, better light does not equate to more light.

b) ***Europe at present is leading in lighting*** based on its solid competences in this domain, i.e.: the number one and two lamp companies have their roots in Europe, while more than 1000 companies, most of them SMEs, are active in luminaire and lighting design.

c) ***Photonics is another emerging European stronghold***, the industry growing nearly twice as fast as the world market.

d) ***Country and regional preferences may play a role in shaping category sales***: Depending on consumer preferences and natural light conditions, some categories may perform better in some regions than others, forcing manufacturers to better understand and adapt to consumers' habits.

Table 5: Opportunities vs. Barriers: Categorized and illustrated by quotes from the interviews

Opportunities		
Biologically effective lighting that heals		"In entrainment of the body clock of ageing persons (in general), to make body clock work better. Also in those with specific conditions (e.g. Alzheimer's disease, Seasonal Affective Disorder (SAD))"
Biologically effective lighting that improves cognitive performance		"So far have focused on awake kids in a class, and how to calm." "When we put on the 'focus light', kids know right away how they are supposed to work."
Emotionally effective lighting to create stimulating environments		"These are light system specifically developed for hotels, with pre-programmed-settings supporting e.g. overcoming jet lags. To date, such systems have been implemented in a number of hotels, within a larger hotel chain, in the luxury segment"
Smart lighting that allows for personalized systems		"Personalized systems are under development (is future). Lighting may be linked to indoor positioning (through smartphone), users may enter their current activity, and may provide some key parameters to support personalized lighting settings (e.g. age, and type of person: 'morning' or 'evening' person. To personalize lighting settings 'on the go'"
New business model		"The benefits of the HCL lighting system are for the occupants, who is not the same party as the owner of the building (owner vs. user)"
Unique aspects of the European market		"I think Europe is well advanced, of course if we can keep our advanced position and would be able to make good business, then of course we would have strong European lighting industry, securing employment in the lighting industry and may be even being able to create further jobs in Europe and prevent companies moving from Europe to some other places in the world"
Barriers		
Informational	Limited awareness	"They just don´t know, they just don´t understand because the basic mechanisms have only been detected like 10-15 years ago, so this knowledge which was there in the research community has not been transferred to the general public."
	Lack of advice / information	"Overall everybody is quite happy with it. The system is fairly easy to operate, but there is a lack of competence on how to use it, what to do/what not. We can ask nobody, what we should do. This is a challenge."….."You currently need to be almost an engineer"
Administrative	Procurement constraints	"Energy goals: if you do a simple calculation HCL might seem to use more energy. Legislation puts a cap on energy use for new buildings and for major refurbishments"
	Lack of standardization	"Standardization. That is always making it easier for customer; they do not want to feel 'trapped' within one brand (having to buy everything from a same brand from then on)."
	Fear of possible lack of reliability,	"Many systems still produce flicker or have other problems that give HCL a bad reputation."
Financial	Lack of monetization	"There is a lack of evidence based quantitative information on how the expected benefits translate into 'euros' (by increased productivity)"
	Separation of costs and benefits	"Benefits lie with children and teachers, but others (e.g. school boards) decide on the purchase."
	High up-front cost	"Cost technology does cost more, and you need more advanced lighting controls"
	Risk aversion due to uncertainties of delivery of product promise	"They (public organizations) have problems (when buying through procurement). They tend to routinely keep doing things the way they have always done. There is a lack of 'being brave' to lead and try something new, with all the risks that may appear (e.g. unexpected high cost etc.). They tend to 'play safe'. As a consequence: nothing happens."

3 Market Stimulation Measures

Finally, we explore potential strategies to overcome the perceived barriers. Views on the solutions are listed below.

3.1 Stakeholder recommendations

Top 10 most frequently brought up recommendations
The recommendations and needs that were put forward most by the stakeholders that were interviewed included:

1. Understandable, honest, unbiased practical information (N=14);
2. More research in real-life conditions (large scale field studies, intervention studies etc.) to provide and strengthen evidence, and to allow quantification of benefits. Furthermore, research is needed to provide a basis for developing new products, and for optimizing HCL products (N=10);
3. Development and availability of 'easy to use', 'easy to implement' HCL products (N=8);
4. Successful examples in practice (N=8);
5. Increasing awareness (N=7);
6. Collaboration within the supply chain (N=7);
7. Legislation and standards favorable of HCL innovation (N=6);
8. Publicity and advertisement (N=6);
9. Standardization and compatibility of products and elements (N=5);
10. Policy action directed to stimulating HCL implementation (N=4).

Other recommendations included:

11. Application of existing (scientific) knowledge into (new) products;
12. Technological developments (divers), including transitional period of dynamic light changes, control of flicker, development of integrated building management systems (multiple functions related to controlling indoor environments into 1 product).
13. Monetization of benefits;
14. Ergonomists as advocate of the importance of optimal lighting conditions (workplace);
15. Improvement of availability of essential components, by solving long waiting time (e.g. due to long shipping time and/or making the fixtures).

Reducing the obstacles dampening the HCL adoption would require a synergistic effort to address the issues mentioned in the following sections.

3.1.1 Availability and accessibility of practical information

The need for practical application information was expressed very strongly. This information should be understandable, honest and unbiased. Stakeholders expressed the need for information on best practices, for a clear 'road map' describing step by step how to practically (incl. technically) come to good HCL solutions, for a 'recipe' for HCL application in practice (how to put the elements together to get a properly functioning system, the programming of dynamic changes in intensity and color

temperature, ramping time, which management system to use etc.), for specialized knowledge within the supply chain how to adequately install it to help customers to implement HCL, for a 'product comparison system' to allow customers to compare the different available products systematically, for an overview of scientifically proven effects, for an overview of vendors, and (more general) for common knowledge of what HCL is, for making clear how HCL may affect the customer (benefits), and for appreciation of value as supposed to cost. It was suggested an independent body (e.g. at EU level) should be made responsible for collecting information on best practices from different countries and make this accessible.

3.1.2 Research to strengthen evidence, and improve products

Research on biological efficient lighting should be further strengthened and accelerated to support customers' change of spirits about the benefits of HCL. Customers need more evidence supporting the benefits associated with HCL adoption. Large, representative well described field studies in practice ('real life' intervention studies) are needed to strengthen evidence and allow quantification of benefits. Providing evidence for 'monetizing enabling' end points, such as sick leave was identified as an important challenge. It was brought forward that field studies are needed also to aid further improvement of prototypes ("*Most essential knowledge you get by trying*"), while they can also provide the desired 'successful examples of HCL application in practice' to be exchanged between peers. Also, the need for more knowledge on (the prevention of) flicker was expressed.

3.1.3 Development of easy to use and to implement solutions

Another recommendation that was frequently made concerned the need for 'market ready' to use systems and products, that have proven to be reliable and to work well in practice. Important product requirements that were identified included: Simple controls, easy retrofit solutions, easy to implement ('plug and play') in existing buildings *without a need for structural adjustments* (to e.g. cabling, wiring, electricity supply, ceilings), easy to implement control panels, user friendly (easy to use, easy to understand).

3.1.4 Successful HCL application examples in practice

Widely known and successful application of HCL can be stimulating for all application areas. The need for successful examples of HCL application, preferably within the peer group (e.g. within the same application area), was heard often. Such examples are desired to raise interest.
Furthermore, it allows positive experiences of benefits, as well as 'best practice information' getting shared amongst peers. Stakeholders expressed the need for a 'model' to look at. Having a place to go to, preferably within the own application area (e.g. a nearby school or office) to experience the possibilities of HCL, may further support adoption.

3.1.5 Increase awareness

To the end of increasing awareness**,** information campaigns and demonstration projects with high replication potential can be used (Yu (2015)). Public action was deemed necessary directed to creating public awareness, on HCL and on its potential ("…*what good light can achieve*") and on evidence of benefits. As target groups the entrepreneurs were assigned priority, followed by managers and end users: "*Sensitization is needed for all the actors of the lighting project, from the*

electrical installer to the final user, from the architect to the electrical engineer". Furthermore, action to influence procurement (from "buying a lamp" to "buying a function") was considered important.

3.1.6 Collaboration within the supply chain

Intensification of collaboration within the supply chain of HCL was recommended by multiple stakeholders, including architects, (lighting) designers and installers. Furthermore, collaboration within an even broader context was proposed, including other industries related to providing optimal conditions inside buildings (e.g. suppliers of systems for optimization of the indoor environment with respect to air quality, thermal comfort, noise, …). It was recommended that the end user should be involved in the design process. Some illustrative quotes include:

- "*In the future the installer, the architect and the lighting industry have to get together, because today it is not a good link between them…..we have to have an integrative design group of people, made of: the architect, the engineer, the energy supplier, the technology supplier of the lighting solutions, also the installer and also the user*";
- "*We need more collaboration between architects, lighting designers, lighting industry*";
- "*Suppliers do not understand that they need to collaborate to make it happen, they need help from building management industry etc*.";
- "*Connecting science, technology and practical application, should be stimulated. Bring together scientists, innovative technique developers, suppliers, product designer, the decision makers, and the (citizens) end users*".

3.1.7 Legislation, regulations and standards

With respect to legislation recommendations were made related to legislation on ***lighting quality*** (e.g. "*It would be helpful if there is a reference to these existing norms [CEN application norms, which provide requirements for minimum light quality per application] in EU regulations, and legislation*" and "*Legislation (norms/standards for quality of light) are needed, e.g. building regulations adapted with this kind of requirements*") and standards for ***lighting equipment*** (e.g. "*Internationally agreed standards for the quality of lighting equipment"*). Furthermore, a concern was expressed related to current legislation being unfavorable for HCL implementation ("*An important barrier for HCL adoption in offices: state-of-the-art knowledge is not yet integrated in existing norms and standards for office lighting. It is still a key aim of investors in office lighting to comply with those, and to get energy certificates"*). Therefore it was recommended to take action to solve these problems. For example, by basing assignment of environmental certification on 'actual energy use' rather than on 'potential use (max capacity), to take into account the dynamic character of human centric lighting. Another example given, included the need for norms/standards for the amount of light falling onto the eye, instead of the desk (workplace).

It is desirable that a future revision of the energy requirements for lighting incorporates also the aspects of the non-visual biological effects of artificial lighting, including its dynamic character. To optimize the biological effects through lighting, temporally higher lighting levels than required for pure visual effects may be needed for certain parts of the day.

3.1.8 Publicity and advertisement

Publicity on successful HCL solutions, as well as on the results of successful case studies, best practices, and user experiences, can raise interest. It was recommended that publicity should include articles in a broad spectrum of media types: Ranging from magazines and journals for professionals in the 'lighting advise' sector and building sector, to popular media such as e.g. newspapers or magazines. Publicity should cover topics related to available solutions/products, benefits in general, and benefits for the customer more specifically.

3.1.9 Standardization and compatibility of products and elements

A number of recommendations were made relating to the need for standardization of products, (system) components, and software/ICT by the participants of our study:

- A "f*ixed (standardized) protocol"* is needed for the control of functions in integrated building management systems (heating, lighting, ventilation,…), which can be 'read' by fixtures from different manufacturers, and which remains compatible in time;
- Standardization of products and system components is needed to prevent customers to get 'trapped within one brand';
- Internationally agreed standards for the quality of lighting equipment are needed;
- Standardization is needed to assure compatibility between components and software from different manufacturers.

3.1.10 Policy action directed to stimulating HCL implementation

It was recommended to stimulate HCL implementation in several ways:

- Connecting science, technology and practical application, by bringing together scientists, innovative technique developers, suppliers, product designers, decision makers, and end users (e.g. by ***subsidizing*** possibilities of such development and application initiatives);
- ***Incentive schemes*** may aid the adoption of HCL application;
- Furthermore, ***policy*** (national as well as European) can support adoption by prioritizing, and by influencing choices that need to be made with respect to lighting (e.g. lighting quality requirements).

3.1.11 Monetization of benefits

Along with increased awareness, translation of the HCL benefits in monetary terms and thus incorporation into "total cost of ownership" and payback calculations are paramount to wider customer acceptance. Next, utility rebates and other government or manufacturer financial incentive schemes can help remove potential, financial constraints in lighting. Whether health and safety will be accepted as cost-effective in the long run could be helped by administrative systems that integrate capital and operational budgets. Furthermore, innovative public procurement, i.e. public procurement of innovative solutions, by acting as the first buyer or lead customer, can help to initiate and subsequently boost the HCL market.

4 Job Creation Potential

In this section, we analyze the macroeconomic impact of increased market uptake of Human Centric Lighting (HCL) with particular attention to employment effects.[14] To analyze the new job creation generated by increased adoption of HCL we use both a survey technique and an input-output model.[15]

Transition in skill requirement

The conducted surveys have highlighted how HCL requires different skill qualifications than those commonly applied in lighting solutions. This implies that in addition to business people, engineers and physicists, who have been traditionally hired in the lighting industry, HCL also requires the involvement of researchers, health consultants, lighting designers, lighting consultants, integrator engineers (related to integrated system and building management system), psychologists, etc. The required additional job skills go back to the difference between conventional lighting and HCL lighting. While conventional lighting is product based, made to fit in multiple applications and rests its sales on the concept of "total cost of ownership" (energy efficiency), HCL lighting is system based. This means that HCL is not a one fit-for-all solution, but application dependent and hinges its marketing strategy on the concept of "total benefits of use" (better vision, productivity, wellbeing).

Our analysis indicates that with an estimated market size of 1.4 billion euros generated by the adoption of HCL[16] by 2020, which represents around 7% of the European general lighting market and 20-25% of its high-end market segment, there will be a total creation of 9,758 full-time jobs throughout the EU economy by the year 2020. This will result in a net GDP increase of roughly 2 billion euros in annual terms.

Sector specific estimates indicate that the increase in HCL product adoption is expected to generate a net job gain for many economic sectors. Overall, the biggest gain is in the HCL sector itself, for which projections forecast a total net increase of 3,358 jobs by 2020. The electrical equipment sector (CPA_C27), excluding HCL, would gain additional 1,878 jobs. Furthermore public administration and defense; compulsory social security (CPA_O84), retail trade, except of motor vehicles and motorcycles (CPA_G47), activities of households as employers, undifferentiated goods- and services-producing activities of households for own use (CPA_T) and professional, scientific, technical, administrative and support service activities (CPA_M-N)[17] are also forecasted to register significant net job gains.

[14] Given the absence of data regarding the HCL industry, results in this section depict possible scenarios that are sensitive to the underlying model and assumptions. The study is conducted using a conservative approach in order to limit the risk of overvaluing outcomes.

[15] The input-output model depicts inter-industry relationships showing how outputs from an industry become inputs to another industry. We will estimate how different sectors relate to Human Central Lighting industry both as customers and suppliers in order to estimate the potential job creation effects.

[16] As estimated by the A.T. Kearney HCL market model, the conservative scenario.

[17] CPA_M71 are the architectural and engineering services; technical testing and analysis services; CPA_M72 are the scientific research and development services.

4.1 Methodology

Two types of studies, answering different questions about employment creation, are considered:

1. First, based on stakeholder consultation (mostly representatives of the lighting industry) we attempt to uncover which types of jobs are important in the development, production, sales and operation of HCL solutions, whether there is need for different types of jobs and in which sectors they are to be found. The analysis at this stage is a descriptive one.
2. Second, we estimate the macroeconomic impact in the overall economic activity as a result of a change in demand for HCL using the Input-Output approach (see D'Hernoncourt, Cordier and Hadley (2011)). Based on the comprehensive system of interactions and interdependencies in the input-output model, we aim to estimate how different sectors relate to the Human Central Lighting industry both as customers and suppliers in order to estimate its job creation potential. Unfortunately, published input-output tables do not reach the desired level of detail to analyze HCL as separated industry from the macro sector "Manufacturing of electrical equipment". Ideally, we would like to know how much output the HCL sector produces which is bought by other economic sectors and how much input from other economic sectors the HCL sector acquires. However, as mentioned the available statistics provide inputs bought/sold by the aggregate sector "Manufacturing of electrical equipment" (CPA_C27)[18] of which the HCL sector forms part. To solve the above problem and isolate HCL we rely on the work of Wolsky (1984) and disaggregate "Manufacturing of electrical equipment" (CPA_C27) into two distinct sectors, one of which is HCL and a second one that includes all the remaining activities in CPA_C27.

4.1.1 Measured Output and Employment Impacts

We distinguish between **direct** employment creation (those employed in the HCL sector itself), **indirect** employment creation (those employed in sectors supplying the inputs required by the HCL sector) and **induced** employment creation (those employed in sectors that provide goods and services to meet the consumption demand of additional directly and indirectly employed workers). We therefore calculate both type I and type II multipliers (Table 6).

Table 6: Composition of Total Impact

Type I Multipliers	Type II Multipliers
Direct Impact + Indirect (Businesses) Impact	Direct Impact + Indirect (Businesses) Impact + Induced (Households) Impact
Total Impact	Total Impact

Type I multipliers account for the direct and indirect impacts based on how goods and services are supplied within the studied economy. Direct impacts represent direct or initial injection of new economic activity (increased output of HCL to meet the increased demand), while indirect effects represent the indirect spending or businesses buying and selling to each other (the sum of inter-

[18] A more detailed analysis would have required to disaggregate the "Manufacture of electric lighting equipment" (CPA_C27.4) instead of "Manufacturing of electrical equipment" sector (CPA_C27). Unfortunately as indicated input-output tables are not provided with this level of detail.

industry purchases). Indirect effects are typically largely linked to the manufacturing stage of the original demand increase. Total indirect employment creation thus depends on the output purchased from each sector (strength of the inter-industry relationship) as well as the employment per unit of output in each of these sectors (labor intensity).

Type II multipliers not only account for these direct and indirect effects, but they also account for induced impacts which reflect the household spending earned from the direct and indirect effects (impacts associated with employee expenditures). In particular, induced employment is the additional employment generated to meet the extra consumption demand arising from the higher household incomes created by direct and indirect effects, following the initial increase in demand for HCL. For instance, the extra workers in the fixtures industry, architecture industry, spend their incomes on a whole range of goods thus creating extra employment in these sectors, and yet further spending may result from these incomes.

We start our empirical analysis from the input-output table (also called transaction matrix) which specifies how different sectors of the economy buy (purchase inputs) from and sell (deliver outputs) to each other. Its rows represent suppliers and contain data on the repartition of sales to respective purchasing industries and final consumers. Read by column, the input-output table shows how much an industry buys from all other industries. For consistency between different types of goods and services, the table expresses each element in monetary or value terms.

For the EU27, the latest input-output tables available are from 2011[19]. These tables have 65 industrial sectors. We aggregate the input-output table to match the number of sectors available in the KLEMS dataset that are used to extract series of labor productivity by sector [20]. This aggregation process leads us from the original 65 sectors to 34 main macro-sectors contained in Table B1 that are used in the study.

The initial monetary entries in the transaction matrix can then be converted into ratios called technical coefficients. This is achieved by dividing each cell of the transaction matrix by its column sum/total (output at basic prices).

The technical coefficients matrix indicates how much output a specific given industry requires from each industry in the economy to produce one euro of its own output. In this sense, it illustrates the immediate indirect[21] impact on all sectors if the output in a specific industry increases with one euro. We indicate this matrix with A_{II}. The assumption of constant technical coefficients is essential here. It implies that the demands for factors of production remain strictly proportional to output as well as to any changes in the future. Therefore, effects of any technical efficiency improvement are not included.

Along with inter-industry relationships an important role is played by the “household” sector (i.e., final consumers and employees). Without the inclusion of the household sector the structure of the

[19] http://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/data/workbooks. Notice IO tables for a wide range of countries over long time periods are not available. Therefore, the results might underestimate the total effect if over time there is a significant increase in the HCL adoption rates. The broad production processes are relatively stable over time. However, the finely classified inputs might change over time. For example the “Manufacture of electric lighting equipment” may over time switch from “traditional lighting” to HCL. However, the overall amount of “lighting” used by the “Manufacture of electric lighting equipment” sector is unlikely to undergo major changes.

[20] The EU KLEMS project, a study of Productivity in the European Union can be accessed on the following website: http://www.euklems.net

[21] Direct are the impacts on the same industry for which the demand increases. Indirect are the effects on other industries.

input-output model does not allow to capture induced effects generated by an expansion of the final demand. In other words, when excluding the household sector we do not account for the extra impacts coming from households spending their additional income. Consequently, in order to calculate the type II (direct + indirect + induced) output and employment impacts, we need to include households in the analysis. In other words, we treat households as a separate sector (for final consumption and labor provided to the rest of the economy) and therefore include in the total impact the induced effects generated by additional household disposable income.

More specifically, we add an extra row and column in the input-output model (see Table 7) and as well in the Technical Coefficient matrix for "Compensation of employees" and "Final consumption expenditure by households" coefficients respectively.

Table 7: Diagram of the Input-Output Model

<table>
<tr><td colspan="2"></td><td colspan="4">Purchasing sectors (buyers)</td></tr>
<tr><td colspan="2"></td><td colspan="3">Intermediate Demand</td><td colspan="2">Final Demand</td><td>Total Output</td></tr>
<tr><td colspan="2"></td><td>Other industries</td><td>Electrical Equipment (without HCL)</td><td>HCL</td><td>Of which Household consumption</td><td>Total final demand</td><td></td></tr>
<tr><td rowspan="4">Producing sectors (sellers)</td><td>Other Industries</td><td colspan="3" rowspan="3">Inter industry transactions

Businesses purchase from other businesses to produce their own goods / services.
This is intermediate demand or xij (output of industry i sold to industry j)</td><td rowspan="3">Households buy the output of businesses</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Electrical Equipment (without HCL)</td></tr>
<tr><td>HCL</td></tr>
<tr><td>Compensation of employees</td><td colspan="3">Households sell labor & other inputs to business as inputs to production</td><td></td><td></td></tr>
<tr><td>Total Input</td><td colspan="5"></td></tr>
</table>

The modified Technical Coefficient matrix A reads:

$$A = \begin{bmatrix} A_{II} & A_{IH} \\ A_{HI} & A_{HH} \end{bmatrix}$$

where A_{II} is the original Technical Coefficients matrix, or the amount of industry i required per unit of industry j. A_{IH} is the amount of industry I required per unit of total household income from all sources. A_{HI} is the income paid to households per unit of output of industry i (compensation of employees divided by the total output of the industry). Finally, A_{HH} is the household expenditure per unit of exogenous household income. The latter is set to zero.

4.1.2 The Disaggregation Challenge

As previously indicated in order to isolate the impact of the HCL industry we use Wolsky (1984)'s disaggregating solution to separate the HCL sector from the macro sector "Manufacturing of electrical equipment" (CPA_C27). Wolsky (1984)'s solution combines relatively detailed knowledge of a particular industry with the information about the rest of the economy embedded in the available economy-wide matrices.

The exercise consists of disaggregating the sector CPA_C27 "Manufacturing of electrical equipment" into two subsectors: i) HCL; and ii) the rest. The most important parameters of this procedure are the weighting factors of each of the newly distinct sectors. Thus, as first step we have to estimate, for the year on which the available input-output table is based, the ratio of the gross output of the resulting new sector (HCL) to the gross output of the aggregate in which that sector has been lumped. As a general proxy, the gross output is replaced with the demand value of the specific sector. We indicate with w_2 the HCL output ratio (over the total aggregate) and with w_1 the portion of the rest of the sector. Note that $w_1 + w_2 = 1$.

Using information reported in A.T. Kearney market study we estimate $w_2 = 0.0008$ (A.T. Kearney reports an HCL demand of 0.1 billion in 2011 while demand of the entire sector from the I/O table was 129 billion leading to $w_2 = 0.1/129=0.0008$). The values of w_1, w_2 and the aggregated matrix can be used to bound the rest of the unknown parameters necessary to construct the new disaggregated technical coefficient matrix (AA). More technical details are to be found in the Appendix.

Finally, we compute the type II Leontief inverse matrix which contains the total (direct + indirect + induced) impact in the economy of a one unit increase in output in a particular sector. It is calculated using the following formula:

$$L = (I - AA)^{-1}$$

Where L is the Leontief type II matrix, I is the identity matrix and AA is the disaggregated matrix of technical coefficients or the Direct Requirements Matrix[22].

4.1.3 Impact Analysis – Employment Multiplier Calculation

Based on the Leontief inverse matrices, we calculate the indirect and induced impacts of the increase in demand for HCL on the input of each sector of the EU economy described by the matrix.

Output effects

$$\boldsymbol{O_{MULTj}} = \sum_{\boldsymbol{i}} \boldsymbol{L_{ij}}$$

We compute the output multiplier ($\boldsymbol{O_{MULTj}}$) for a particular industry as the column sum of industry rows from the specific Leontief inverse matrix. Further, multiplying a change in the final demand for an individual industry's output by that industry's type I (respectively type II) output multiplier generates an estimate of direct and indirect (respectively direct, indirect and induced) impacts on output throughout the economy.

Employment effects

[22] The type I Leontief inverse matrix is computed as $L = (I - A_{II})^{-1}$.

The employment effects $(E_{eff,j})$ estimate reflects the impact upon employment throughout the economy (direct and indirect effect if type I inverse matrix is used, augmented by the induced effect if type II inverse is used) arising from a change in final demand for industry j's output of 1 unit.

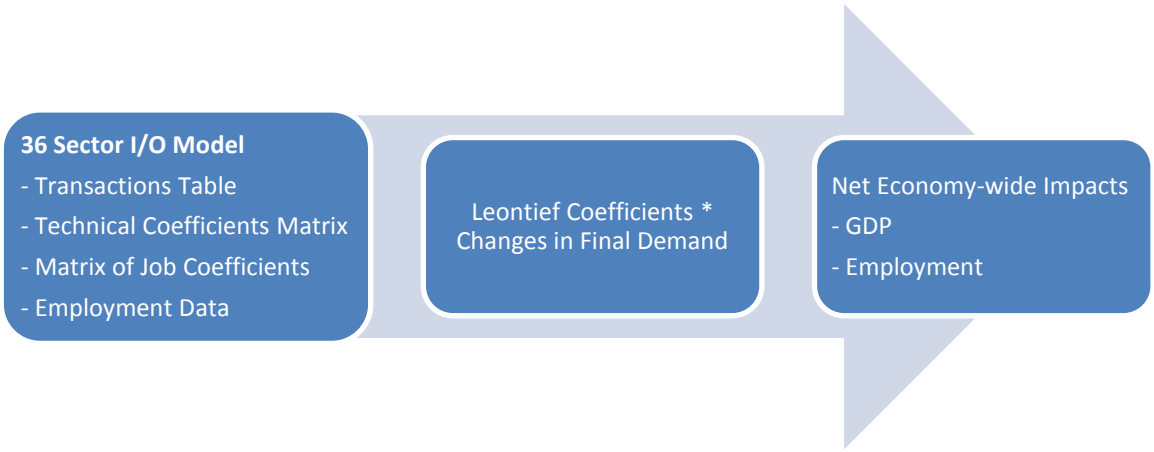
$$E_{MULTj} = \sum_i w_i L_{ij} / w_j$$

$$E_{eff,j} = \sum_i w_i L_{ij}$$

Where E_{MULTj} stands for the employment multiplier. In its simplest terms, the employment multiplier measures the amount of direct, indirect and induced jobs created in the area. Direct jobs are related to the specific industry, while indirect jobs are those that support the industry. Induced jobs are those that are a result of direct/indirect employee's spending money in the community. If for example the HCL industry has an employment multiplier of 2.91, then for every HCL job in total 2.91 jobs (direct, indirect and induced) are created in the economy.

Figure 6 provides a graphical representation of all steps followed in our analysis.

Figure 6 - Input-Output Model



Simplifying assumptions underlying the multiplier calculations

The basic assumptions in the input-output analysis include the following:

- Fixed prices - there is unlimited labor and capital available at fixed prices – so that, any change in the relative demand for productive factors will not induce any change in their relative cost.[23] In other words, additional workers with the necessary new skill profiles are readily available at prevailing wage rates. Hence, no relative price changes. The fact that we do not consider prices in the I-O analysis produces approximate estimates that could under or overestimate the real effect.

[23] Computable general equilibrium (CGE) models can relax the assumption of fixed prices in the I-O models.

- Lack of resource constraints – multipliers assume that extra output can be produced in one area of activity without taking away resources from other activities. Hence, no crowding out effects.
- The relationship between labor and output in all industries is linear, that is, if one FTE employee produces 100 units of output, then two FTE employees would produce 200 units of output. In other words, each industry exhibits constant returns to scale in production.
- Fixed ratios for intermediate inputs to production and outputs from production in each industry. Since relative prices do not change, there will be no changes in the mix of inputs used in production.
- Absence of budget constraints – changes in household or government consumption occur without reducing demand elsewhere.

4.2 Results and Discussion

Based on the survey results, from the additional questions on job opportunities, we found that HCL requires more diverse qualifications than non-HCL solutions. Thus, in addition to business people, engineers and physicists who have been usually hired to date in the lighting industry, HCL will also need researchers, health consultants, lighting designers, lighting consultants, integrator engineers (related to integrated system and building management), psychologists, etc.

As already pointed out previously in the report, scientific evidence for HCL benefits in practical applications in real life settings is scarce. Hence, there is ample opportunity for job creation in research and development. As one respondent put it "*when a product stops being a light to show a task and becomes a psychological and/or physiological intervention, the required rigor for proving the benefits of the product / application will increase, but industry currently cannot do this internally*." In addition, the lighting plan for an indoor space is important. Thus, the position of the lighting designer will become more and more important, although at the moment it isn't.

Different parts of the HCL value chain may experience different changes in employment. The development process is seen in need of people with disparate knowledge. For sales of HCL solutions, knowledge of physical and economic benefits is important but current sales forces do not appear to be adequately prepared for this task which leaves room for consultants to advise building owners and architects on the additional benefits of HCL lighting. Furthermore, the changes in the employment engaged in the operation of HCL solutions may depend on the application fields deploying them. "*Simple HCL systems can be fully automatic requiring no user input. Slightly more advanced system may allow users to choose lighting based upon how they currently feel or what their current needs are. HCL for schools could be another level up requiring an amount of training to understand what is good or not. However HCL for hospitals for example could require a large amount of manual intervention which will require trained users who understand the implications of what they are doing*". Finally, HCL specific maintenance is forecasted to become a significantly pressing issue and would require more HCL specialists. While the basic fundamentals of the maintenance process might not change, the need for prompt repair of any failures is thought to become very important because any problems could potentially change the HCL impact, and possibly in an unwanted direction.

Next, we describe the results from the input-output analysis. Based on the Input-Output Model, we estimate that if HCL sales were to increase up to 1.4 billion euros (A.T. Kearney market volume estimate for 2020, conservative scenario), annual GDP would increase by approximately 2 billion euros and employment would increase by 9,758 jobs in 2020. Also, we find that if HCL sales were to increase up to 0.5 billion euros (A.T. Kearney market volume for 2018, conservative scenario), annual GDP would increase by 0.6 billion euros and employment would increase by 3,000 jobs in 2018. Table 8 contains the impact (multiplier) on total employment and output in the HCL industry.

Table 8: Economy -wide Output and Employment HCL Multipliers & Effects

HCL Demand Increase up to 1.4 billion	Human Centric Lighting	
	(type I)	(type II)
Output		
Multiplier	1.38	1.55
Effects (net change in billion)	1.8	2.0
Employment		
Multiplier	2.40	2.91
Effects (net change employees)	8,057	9,758

Source: Authors' calculations

We interpret the type I employment multiplier as follows: when the HCL sector increases employment by one employee, total employment in the EU economy increases by 2.4 jobs from direct and indirect linkages. In turn, the type II employment multiplier shows that when the HCL sector realizes a one employee change, total employment in the EU area changes by 2.91 jobs from direct, indirect and induced linkages. Also, for a 1 euro extra unit of final demand for HCL, the total direct, indirect and induced impacts amount to 1.55 euros.

Table 9 presents a breakdown of output and employment effects across different economic sectors. Sector specific estimates show that the increase in market uptake of HCL is expected to generate additional economic activity and net job gain for all economic sectors. Overall, the biggest gain is in the HCL sector itself, which is projected to experience a total net increase of 3,358 jobs by 2020. This is the direct employment created as a result of the increase in HCL market uptake. Electrical equipment (CPA_C27), without HCL, would gain an additional 1,882 jobs. Public administration and defense; compulsory social security (CPA_O84), Retail trade, except of motor vehicles and motorcycles (CPA_G47), Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use (CPA_T), Professional, scientific, technical, administrative and support service activities (CPA_M-N)[24] and Postal and courier activities (CPA_H53) are the sectors forecasted to register significant net job gains.

Note that the combined level of indirect and induced employment (output) generated by the increase in HCL market uptake is larger than the direct employment (output) itself. Ignoring these effects is therefore likely to give a misleading picture of the impact of HCL increase on total employment (output).

[24] CPA_M71 Architectural and engineering services; technical testing and analysis services; CPA_M72 Scientific research and development services

The input-output results presented so far reflect total effects; i.e., they add up the direct, indirect and induced effect of a change in demand for HCL on employment across all industries in the EU economy. Next, we present direct and indirect effects only of the previously analyzed increases in demand for HCL. The concern is that we might overestimate the induced effects.

The reason is the following. We use the total household expenditure statistic from the input-output table (or final use at purchasers' prices) as denominator when calculating the household expenditure coefficients (A_{IH}). This statistic includes household purchases that are bought with unearned income (pensions, dividends, etc.). In other words, not all household expenditure results from "Income from employment" paid to households. As a consequence, the resulting type II Leontief inverse matrix tends to overestimate the induced effects of changes in the economy by artificially inflating the effect of earned income in generating further rounds of household spending.

Considering the direct and indirect effects only, we estimate that if HCL sales were to increase up to 1.4 billion euros (A.T. Kearney market volume estimate in billion euros for 2020, conservative scenario), annual GDP would increase by 1.8 billion euros and employment would increase by 8,057 jobs in 2020. Also, we find that if HCL sales were to increase up to 0.5 billion euros (A.T. Kearney market volume in billion euros in 2018, conservative scenario), annual GDP would increase in 2020 by 0.6 billion euros and employment would increase by 2,476 jobs.

Again, we breakdown the direct + indirect output and employment effects across different economic sectors in Table 10. As before, sector specific estimates show that the increase in market uptake of HCL is expected to generate net job gain for all economic sectors. Overall, the biggest gain is in the HCL sector, which is projected to experience a total net increase of 3,357 jobs by 2020. Electrical equipment (CPA_C27), without HCL, would gain an additional 1,878 jobs. Public administration and defense; compulsory social security (CPA_O84), Basic metals and fabricated metal products, except machinery and equipment (CPA_C24-C25) and Retail trade, except of motor vehicles and motorcycles (CPA_G47) are some of the sectors forecasted to register largest significant net job gains.

Table 9: Sector Specific Total Output and Employment Impacts

Code	Sector Description	Total Output Effects 2018 (million euro)	Total Output Effects 2020 (million euro)	Total Employment Effects 2018 (employees)	Total Employment Effects 2020 (employees)
CPA_A	AGRICULTURE, FORESTRY AND FISHING	2.36	7.67	26	85
CPA_B	MINING AND QUARRYING	1.56	5.09	3	9
CPA_C10-C12	Food products, beverages and tobacco	5.44	17.69	19	61
CPA_C13-C15	Textiles, wearing apparel, leather and related products	1.34	4.35	8	26
CPA_C16-C18	Wood and paper products; printing and reproduction of recorded media	4.17	13.58	20	66
CPA_C19	Coke and refined petroleum products	2.96	9.64	1	2
CPA_C20-C21	Chemicals and chemical products	6.87	22.36	13	43
CPA_C22-C23	Rubber and plastics products, and other non-metallic mineral products	7.45	24.23	35	114
CPA_C24-C25	Basic metals and fabricated metal products, except machinery and equipment	27.04	87.97	116	377
CPA_C26	Optical equipment	3.97	12.93	15	50
CPA_C28	Machinery and equipment n.e.c.	0.34	1.10	1	5
CPA_C29-C30	Transport equipment	4.20	13.66	11	36
CPA_C31-C33	Other manufacturing; repair and installation of machinery and equipment	4.41	14.34	26	83
CPA_D_E	ELECTRICITY, GAS AND WATER SUPPLY	4.13	13.44	8	25
CPA_F	CONSTRUCTION	10.65	34.64	70	228
CPA_G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	4.43	14.43	20	66
CPA_G46	Wholesale trade, except of motor vehicles and motorcycles	2.94	9.57	10	33
CPA_G47	Retail trade, except of motor vehicles and motorcycles	15.82	51.48	139	453
CPA_H49-52	Transport and storage	6.29	20.46	18	58
CPA_H53	Postal and courier activities	13.34	43.40	126	410
CPA_I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	0.87	2.84	11	35
CPA_J58_J60	Publishing, audiovisual and broadcasting activities	4.66	15.16	21	68
CPA_J61	Telecommunications	2.19	7.12	5	15
CPA_J62_J63	IT and other information services	3.10	10.08	18	59
CPA_K64_K66	FINANCIAL AND INSURANCE ACTIVITIES	3.30	10.74	13	41
CPA_L68B_L68A	REAL ESTATE ACTIVITIES	10.79	35.12	10	31
CPA_M_N	PROFESSIONAL, SCIENTIFIC, TECHNICAL, ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES	13.89	45.18	128	417
CPA_O84	Public administration and defense; compulsory social security	28.12	91.51	292	949
CPA_O85	Education	0.95	3.11	14	47
CPA_Q86-Q88	Health and social work	1.22	3.96	17	56
CPA_R90-R93	Arts, entertainment and recreation	1.59	5.17	18	60
CPA_S94_S96	Other service activities	1.18	3.84	19	61
CPA_T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	1.73	5.64	138	449
CPA_C27 (disaggregated)	**Electrical equipment (without HCL)**	149.5	486.3	**578**	**1882**
CPA_C27 (disaggregated)	**HCL**	266.7	867.9	**1032**	**3358**
Total		**619**	**2016**	**2999**	**9758**

Table 10: Sector Specific Direct + Indirect Output and Employment Impacts

Code	Sector Description	Direct & Indirect Output Effects 2018 (million euro)	Direct & Indirect Output Effects 2020 (million euro)	Direct & Indirect Employment Effects 2018 (employees)	Direct & Indirect Employment Effects 2020 (employees)
CPA_A	AGRICULTURE, FORESTRY AND FISHING	0.529	1.723	6	19
CPA_B	MINING AND QUARRYING	1.112	3.617	2	6
CPA_C10-C12	Food products, beverages and tobacco	0.668	2.174	2	7
CPA_C13-C15	Textiles, wearing apparel, leather and related products	0.435	1.416	3	8
CPA_C16-C18	Wood and paper products; printing and reproduction of recorded media	3.166	10.301	15	50
CPA_C19	Coke and refined petroleum products	1.672	5.440	0	1
CPA_C20-C21	Chemicals and chemical products	5.577	18.148	11	35
CPA_C22-C23	Rubber and plastics products, and other non-metallic mineral products	6.538	21.274	31	101
CPA_C24-C25	Basic metals and fabricated metal products, except machinery and equipment	25.857	84.136	111	360
CPA_C26	Optical equipment	3.630	11.811	14	46
CPA_C28	Machinery and equipment n.e.c.	0.005	0.015	0	0
CPA_C29-C30	Transport equipment	3.841	12.497	10	33
CPA_C31-C33	Other manufacturing; repair and installation of machinery and equipment	2.660	8.657	15	50
CPA_D_E	ELECTRICITY, GAS AND WATER SUPPLY	3.230	10.511	6	20
CPA_F	CONSTRUCTION	6.969	22.677	46	149
CPA_G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	2.728	8.876	12	40
CPA_G46	Wholesale trade, except of motor vehicles and motorcycles	1.374	4.470	5	15
CPA_G47	Retail trade, except of motor vehicles and motorcycles	12.049	39.205	106	345
CPA_H49-52	Transport and storage	2.452	7.979	7	23
CPA_H53	Postal and courier activities	9.215	29.984	87	283
CPA_I	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	0.582	1.895	7	23
CPA_J58_J60	Publishing, audiovisual and broadcasting activities	0.917	2.985	4	13
CPA_J61	Telecommunications	1.084	3.528	2	8
CPA_J62_J63	IT and other information services	1.533	4.989	9	29
CPA_K64_K66	FINANCIAL AND INSURANCE ACTIVITIES	2.558	8.324	10	32
CPA_L68B_L68A	REAL ESTATE ACTIVITIES	5.572	18.129	5	16
CPA_M_N	PROFESSIONAL, SCIENTIFIC, TECHNICAL, ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES	4.035	13.129	37	121
CPA_O84	Public administration and defence; compulsory social security	21.843	71.073	227	737
CPA_O85	Education	0.604	1.965	9	30
CPA_Q86-Q88	Health and social work	0.506	1.648	7	23
CPA_R90-R93	Arts, entertainment and recreation	0.117	0.380	1	4
CPA_S94_S96	Other service activities	0.255	0.830	4	13
CPA_T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.692	2.250	55	179
CPA_C27 (disaggregated)	**Electrical equipment (without HCL)**	**149.152**	**485.320**	**577**	**1878**
CPA_C27 (disaggregated)	**HCL**	**266.597**	**867.470**	**1032**	**3357**
Total		**549.75**	**1788.82**	**2,476**	**8,057**

5 Application Recommendations for Biologically Effective Lighting

The recommendations detailed below are based on the guidance provided by stakeholders during interviews and literature reviews (including the review performed in SSL-erate "Lighting for health and wellbeing", downloadable from http://lightingforpeople.eu/), complemented by feedback received from experts, cities and SMEs. This effort led to over 10 application recommendations.

5.1 Workplace

Application recommendation 1

Evidence based solutions, with the aim to support alertness and productivity, adaptable to individual characteristics and/or needs, time of day and activity. Encourage the use of light in support of the circadian rhythm, i.e. help awakening in the morning, prevent 'after lunch dip' and contribute to *good sleep at night.*

→ *Combination of LEDs (which are available for a variety of well-defined color-spectrum ranges)* with ICT to develop dynamic lighting solutions for buildings, enabling flexible adjustment of spectral composition and intensity of the light throughout the workday;

→ It is recommended to provide light during the day with sufficient light intensity, and with a relatively high 'blue' content (and resort to natural light as much as possible), while avoiding blue-rich light and cool tons of white light (high color temperatures) in the evening and night time (with the exception of workplaces where it is important that the employees stay highly alert during those times, to avoid mistakes or accidents, such as e.g. surgery rooms) (see also SSL-erate literature review "Lighting for health and wellbeing");

→ Specialized software driving the dynamic changes in the spectral composition and intensity of light, allowing a high degree of customization, to allow implementation of new scientific insights coming available in time (such as knowledge on how to optimize lighting for individual needs which may differ based on subjects, time of year, type of task, etc.);

→ Increased light intensities are recommended for people who spend limited time outdoors during the day;

→ Solutions where the light is not too focused and illuminating larger areas, are recommended to increase the comfort for people;

→ The importance of keeping solutions individually adjustable was noted frequently, and should be taken account of.

Application recommendation 2

Smart lighting with sensors, in future proof design, allowing to adapt lighting to individual needs (depending on individual presence, time of the day, and activity). Paving the way for personalized lighting solutions, taking into account (physiological) differences between people and personal preferences. Desirable features that were mentioned by stakeholders include:

→ A structure that allows changes and improvement;

→ Flexibility to change;

→ Possibility to add new features over time.

5.2 Education

Application recommendation 1

Similar recommendations for application as for the workplace are proposed for educational applications (see Section 5.1). The two distinct sectors share similar needs in terms of lighting supporting alertness and productivity, while contributing to good sleep at night (important for memory consolidation and recovery), with a desired level of flexibility to adapt to individual characteristics and/or needs, time of day and activity.[25]

→ Provide lighting solutions with software driven dynamic changes in lighting spectral composition and intensity;

→ Provide lighting to pupils with a relatively high 'blue' content along with natural daylight during the day time to support alertness;

→ Provide dynamic lighting, depending on time of the day, with higher light intensity along with higher blue content, using cooler tones of light and higher color temperatures during morning hours (see SSL-erate review "Lighting for health and wellbeing");

→ Solutions where the light is not too focused and illuminating larger areas, to enhance comfort.

Application recommendation 2

Lighting systems to support improvement of the learning experience by providing more structure to classes during schooldays (e.g. with pre-defined settings) and making clear to students what kind of activity is expected at a certain moment in time. Lighting solutions to support different levels of concentration in order to perform tasks with a variable degree of complexity, as well as relaxation during breaks.

This may include the following practical recommendations (SSL-erate literature review "Lighting for health and wellbeing"):

→ Presets for different activities for example 'concentrated working' (providing higher light intensity, together with higher blue content in the spectral composition, and using higher color temperatures);

→ Presets for 'relaxed working' / supporting relaxation (providing lower light intensity, together with warmer light tones in the spectral composition).

Figure 7 – Miesbacher Merkur (2013). HCL design in a classroom (FL-Technology, Bavaria).

[25] General note: Lighting within electronic device screens (computers, tablets, smartphones) can also influence the circadian rhythm. Thus, the color temperature of such screens should be adjustable so that it can be lowered in the evening. In educational settings this is relevant for e.g. evening classes. Software allowing such time and location dependent dynamic changes in screen lighting exists (e.g. f.lux).

5.3 Health care

Application recommendation 1

Personalized lighting solutions, taking into account (physiological) differences between people, e.g. lighting solutions supporting visual acuity for elderly.

→ There is a clear need to provide solutions that are individually adjustable depending on personal needs and preferences;

→ 'Older age' lighting solutions, providing elevated light levels but homogeneous light distribution and lower brightness contrasts, in order to support aged users to remain engaged in more demanding visual tasks, e.g. reading, needle work for prolonged periods without (visual) fatigue.
Note: This recommendation is also applicable in the domestic environment.

Application recommendation 2

Dynamic lighting solutions to support mental wellbeing, to treat and/or prevent depressive symptoms.

→ Target times during which humans are more sensitive to light, with specific attention to the morning and evening times;

→ Mind that use of high intensity (and blue-rich) lighting in the 2 hours prior to bedtime delays sleep onset and is disruptive for sleep;

→ Increased light intensities are recommended for people who spend limited time outdoors during the day;

→ The SSL-erate literature review "Lighting for health and wellbeing" notes that two forms of artificial light treatment regimens (for depressive symptoms) exist (either of them applied in the morning):

- White light of strong intensity (>= 6000 lux) for the elderly or white light of 3000 lux for the middle-aged (when selecting intensities, exposure duration is a relevant parameter);
- Dawn simulation.

Application recommendation 3

Dynamic lighting solutions simulating natural daylight quality as much as possible, in terms of intensity and spectral composition, for application in health care facilities where people reside long term (e.g. nursing or elderly homes). This includes:

→ Dawn simulation;

→ Day-light exposure of sufficient intensity during the day;

→ Provide light with a relatively high 'blue' content (and natural daylight as much as possible) during the day time;

→ Avoid high light intensities and blue-rich light (dim the lights and use warm tones of light, such as reddish light or low color temperatures) during the evening and night time;

→ The intensity of day- and evening light should be individually adjustable, while the change in spectral composition may occur automatically.

The importance of no (or limited) light and noise during the night (darkness and quietness) to support sleep quality was stressed. This may be particularly important for the vulnerable patients in e.g. intensive care units.

5.4 Cities: Outdoor lighting

Application recommendation 1

Smart lighting with sensors to achieve a structure that allows changes and improvement, flexibility, and allows to add new features over time. Providing lighting at the time and place where it is needed.

Application recommendation 2

Flora and fauna friendly lighting solutions: Outdoor lighting which is better in tune with the ecosystem (HCL solutions for outdoor lighting in cities and surroundings).

→ Avoid blue-rich light at night time;

→ LED-based light sources with low circadian action are available and should be promoted;

→ Light having strong green wavelength emission should be promoted (since current scientific knowledge indicates this type of spectral content would enhance mesopic vision, limit discomfort glare, and be more energy efficient, while it may also produce less sky glow and attract fewer insects as compared with blue rich light sources (SSL-erate literature review “Lighting for health and wellbeing”).

Application recommendation 3

Lighting solutions directed to provide a better ‘city nightscape’ (enhancing aesthetics, ambience, attractiveness, liveliness). This may include:

→ Outdoor illumination of buildings (to enhance city attractiveness);

→ Focusing light on natural objects, such as the greenery (which may enhance the perceived safety, restorative capacity and preference of pedestrians).

5.5 Domestic

Application recommendation 1

Domestic applications for intelligent human centric lighting solutions focus on targeting those parts of the day during which humans are more sensitive to light (early morning and late evening).

→ Intelligent light solutions which simulate the natural time course of outdoor light for an ‘average day’;

→ Use a photoperiod of about 12 hours light (preferably with sufficient brightness) and 12 hours of reduced light (relatively dim light, blue-deprived light or darkness);

→ During day time (e.g. between 8:00AM and 8:00 PM), light at home needs to promote alertness and should be of sufficient intensity and of cooler color temperature in rooms where natural light cannot appropriately enter either because of small windows or because neighboring buildings cast shadows;

→ Tuning light to lower levels and warmer tones to optimize relaxation and prepare for sleep in the evening.

Application recommendation 2

Lighting solutions to support awakening (gradual dynamics like dawn simulation may promote a smoother more effective and more pleasant waking up). Furthermore, dynamic lighting, increasing to

high brightness within the first 2 hours after waking up, can help to support awakening and support the sleep/wake cycle, using the circadian rhythm supporting effects of light.

Application recommendation 3
Solutions allowing to create lighting conditions to set atmospheres for social activities (or studying, or working) at home.

5.6 General recommendations (multiple application areas)

Some additional recommendations can be listed:

Application recommendation 1

Integrated system to manage the indoor environment in buildings, including lighting, ventilation, temperature, humidity etc. (Building management system that integrates these different functions into one product).

Application recommendation 2
Development of open HCL system solutions both in terms of hardware and software, enabling the replacement of faulty components and the addition of new HCL features, independent of manufacturer.

Application recommendation 3
'Market ready', 'ready to use' systems are needed, that are proven to be reliable and to work well in practice. In particular: 'Plug and play' solutions are needed, for application in retrofits: 'ready to use' solutions which can be added easily in existing buildings, without having to change the whole system and related structural adjustments (cabling, wiring, ceilings, electricity supply, ..), with 'easy to implement' control panels.

Application recommendation 4
Selling 'good light' instead of a product.

General note
Artificial lighting solutions are needed to optimize indoor lighting conditions, but not as a replacement of natural daylight. Improving indoor lighting conditions, includes both optimizing the use of daylight where possible, and artificial lighting to complement daylight where needed to fulfill the needs of people.

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Appendix A: Interview Scheme

Guide for Human Centric Lighting (HCL) Interview

Focus group: Lighting Professionals[26]

Informed consent

The SSL-erate research team welcomes your participation and thanks you in advance for participating in this interview.

This European project aims to accelerate the uptake of high-quality solid state lighting (SSL) technology in Europe. This subtask aims to evaluate perceived benefits, barriers and opportunities for implementation of 'Human Centric Lighting' applications of SSL by the different stakeholders.

Insights from the interviews will be summarized in a report. Results will be presented in an anonymized way. The completion of the interview should take approximately 30-45 minutes.

By participating in the interview you acknowledge that you agree to participate in this research, with the knowledge that your participation is voluntary you are free to withdraw your participation at any time.

Contact information

If you have concerns or questions about this study, please contact Attila Morotz at attila.morotz@lightingeurope.org (task leader).

Interviewee Information

Name:
Occupation:
Company:

Questions

SECTION I: AWARENESS OF HCL

Q1. We are going to talk about Human Centric Lighting. If someone were to ask you to explain HCL, what would you say?

……

……

Interviewer provides definition:

When speaking about "Human Centric Lighting" during this interview, this concerns:
Lighting (systems) designed to have a short term or long term beneficial effect on health and well-being of people.

Q2. What do you see as the most important HCL benefits?

1) ……

2) ……

3) ……

Other: ……

[26] This questionnaire was adapted into application area specific versions.

Q3. Can you tell me what kind of products/services does your company offer in the field of HCL and where does that puts it in the supply chain (business to customer OR business to business)?

……

……

Q4. Which type of jobs is important in the development, production, sales and operation of HCL solutions?

……

……

Q5. What is the difference, as far as the involved jobs are concerned, between HCL solutions and commonly applied simple lighting solutions? Are these jobs to be found in the lighting industry or outside it?

……

……

SECTION II. BARRIERS

Q6. What are the reasons, or 'main barriers', in your opinion, why customers have not yet adopted HCL?

1) ……

2) ……

3) ……

Other: ……

Q7. How important do you think each of the barriers below is to customers / end-users?

Please rate them from 1 to 5, where 1 means not at all important, 2 – not so important, 3 neither important nor unimportant, 4 – somewhat important, 4 very important. One answer on each line.

	Not at all important	Not so important	Neither important not unimportant	Somewhat important	Very important	No opinion
Investment cost	1	2	3	4	5	99
Payback time	1	2	3	4	5	99
Cybersecurity	1	2	3	4	5	99
Lack of information on best practice with respect to HCL.	1	2	3	4	5	99
Fear of a possible lack of reliability, quality, performance.	1	2	3	4	5	99
Lack of knowledge of procuring the right / best option.	1	2	3	4	5	99
People don't care about lighting quality / design.	1	2	3	4	5	99
Lack of standardization / compatibility of components between different manufacturers.	1	2	3	4	5	99
Benefits are not clear compared to reference installations.	1	2	3	4	5	99
Public skepticism	1	2	3	4	5	99
Benefits are enjoyed by some other party than the one making the purchase decision	1	2	3	4	5	99
Lack of examples of previous successful implementation in other similar institutions.	1	2	3	4	5	99
Procurement constraints	1	2	3	4	5	99
Other (please specify).....	1	2	3	4	5	99

SECTION III. OVERCOME BARRIERS

Q8. What conditions would help overcome the barriers (make it more attractive or make it easier) for the customer to buy HCL?

……

……

Q9. If lack of information: What kind of information would be helpful and for whom?

……

……

Q10. In case of technological issues: What´s missing on the technology side? What should be the direction of development of the technology?

……

……

SECTION IV. OPPORTUNITIES

Q11. In your own experience, what do you find to be the features your customers mostly value about HCL supporting systems?

1) ……

2) ……

3) ……

Other: ……

Q12. What opportunities for business do these customer preferences present to your firm?

1) ……

2) ……

3) ……

Other: ……

Q13. What do you consider the 'top 3' potential most promising application fields for HCL to be used in?

1) ……

2) ……

3) ……

Other: ……

Q14. How important do you think each of the opportunities below is?

Please rate them from 1 to 4, where 1 means not at all important, 2 – not so important, 3 neither important nor unimportant, 4 – somewhat important, 4 very important. One answer on each line.

	Not at all important	Not so important	Neither important nor unimportant	Somewhat important	Very important	No opinion
Selling light instead of a product (performance contract)	1	2	3	4	5	99
Leasing of lighting installation instead of selling (financial solution)	1	2	3	4	5	99
Energy efficiency	1	2	3	4	5	99
Complex energy service (integration of production and energy use)	1	2	3	4	5	99
Smart lighting (integration of lighting with other non-lighting services)	1	2	3	4	5	99
Aesthetics, beautification, emotion	1	2	3	4	5	99
Human centric lighting	1	2	3	4	5	99
Retrofit opportunities	1	2	3	4	5	99
Other (please specify) ……	1	2	3	4	5	99

Q15. In your opinion, is policy action needed to promote HCL? What type of action?

……

……

CLOSURE

Q16. Would you like to add anything else that you feel might be relevant that we have not discussed?

……

……

Thank you for sharing your knowledge with us.

Appendix B: Input-Output Analysis

Disaggregating in the input-output model

The disaggregated technical coefficient matrix is the sum of an augmented matrix and a distinguishing matrix. Aaug (the augmented matrix) augments the aggregated technical coefficient matrix A by assuming that the pertinent sector to be disaggregated arose from the aggregation of two essentially identical sectors. More specifically, the pertinent column of A is replaced by as many identical columns as there are sectors to be created. The matching row of A is replaced by the same number of rows, each of which is the product of a weighting factor and the original row of A.

$$Aaug = \begin{bmatrix} A(1{:}n-1,1{:}n-1) & A(1{:}n-1,n) & A(1{:}n-1,n) \\ w_1 * A(n,1{:}n-1) & w_1 * A(n,n) & w_1 * A(n,n) \\ w_2 * A(n+1,1{:}n-1) & w_2 * A(n,n) & w_2 * A(n,n) \end{bmatrix}$$

To disaggregate, more information than the one embedded in the augmented matrix needs to be considered. This is because the augmented matrix describes the newly created sectors as being essentially the same. However, we must distinguish them one from another.

$$Adist = \begin{bmatrix} 0(1{:}n-1,1{:}n-1) & w_2\delta_i ones(1,1{:}n-1) & w_2\delta_i ones(1,1{:}n-1) \\ ones(1,1{:}n-1) * \sigma_i & \left(\frac{1}{2}\delta_n + \gamma\right)w_2 + \sigma_n & -\left(\frac{1}{2}\delta_n + \gamma\right)w_1 + \sigma_n \\ -ones(1,1{:}n-1) * \sigma_i & \left(\frac{1}{2}\delta_n - \gamma\right)w_2 - \sigma_n & -\left(\frac{1}{2}\delta_n - \gamma\right)w_1 - \sigma_n \end{bmatrix}$$

Where δ_i represents the difference between the nth and (n+1)th sectors in their demand for input from the it^{h} sector; σ_j represents the departure from average in what the nth and (n+1)th sectors supply to the jth sector; δ_n, σ_n and γ manifest like quantities for intra-aggregate exchanges. Following Wolsky (1984), we use knowledge of w1, w2 and A to bound the above parameters. The disaggregated input-output matrix takes the following form:

$$AA = Aaug + Adist$$

Table B1: Industrial Sectors Aggregation

	Code in 65x65 IOT	Description in 65x65 IOT	Code in 34x34 IOT	Description in 34x34 IOT
1	CPA_A01	Products of agriculture, hunting and related services		
2	CPA_A02	Products of agriculture, hunting and related services	CPA_A	Agriculture, forestry and fishing
3	CPA_A03	Fish and other fishing products; aquaculture products; support services to fishing		
4	CPA_B	Mining and quarrying	CPA_B	Mining and quarrying
5	CPA_C10-C12	Food products, beverages and tobacco products	CPA_C10-C12	Food products, beverages and tobacco products
6	CPA_C13-C15	Textiles, wearing apparel and leather products	CPA_C13-C15	Textiles, wearing apparel and leather products
7	CPA_C16	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	CPA_C16-C18	Wood and paper products; printing & reproduction of recorded media
8	CPA_C17	Paper and paper products		
9	CPA_C18	Printing and recording services		
10	CPA_C19	Coke and refined petroleum products	CPA_C19	Coke and refined petroleum products
11	CPA_C20	Chemicals and chemical products		
12	CPA_C21	Basic pharmaceutical products and pharmaceutical preparations	CPA_C20-C21	Chemicals and chemical products
13	CPA_C22	Rubber and plastics products	CPA_C22-C23	Rubber & plastic products;other non-metallic mineral products
14	CPA_C23	Other non-metallic mineral products		
15	CPA_C24	Basic metals		Basic metals and fabricated metal products, except machinery and equipment
16	CPA_C25	Fabricated metal products, except machinery and equipment	CPA_C24-C25	
17	CPA_C26	Computer, electronic and optical products	CPA_C26	Computer, electronic and optical products
18	**CPA_C27**	**Electrical equipment**	**CPA_C27**	**Electrical equipment**
19	CPA_C28	Machinery and equipment n.e.c.	CPA_C28	Machinery and equipment n.e.c.
20	CPA_C29	Motor vehicles, trailers and semi-trailers	CPA_C29-C30	Transport equipment
21	CPA_C30	Other transport equipment		
22	CPA_C31_C32	Furniture; other manufactured goods		Other manufacturing, repair and installation of machinery and equipment
23	CPA_C33	Repair and installation services of machinery and equipment	CPA_C31-C33	
24	CPA_D35	Electricity, gas, steam and air-conditioning		
25	CPA_E36	Natural water; water treatment and supply services		
26	CPA_E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	CPA_D_E	Electricity, gas and water supply
27	CPA_F	Constructions and construction works	CPA_F	Constructions and construction works
28	CPA_G45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	CPA_G45	Wholesale and retail trade and repair services of motor vehicles and motorcycles
29	CPA_G46	Wholesale trade services, except of motor vehicles and motorcycles	CPA_G46	Wholesale trade services, except of motor vehicles and motorcycles
30	CPA_G47	Retail trade services, except of motor vehicles and motorcycles	CPA_G47	Retail trade services, except of motor vehicles and motorcycles
31	CPA_H49	Land transport services and transport services via pipelines		
32	CPA_H50	Water transport services	CPA_H49-52	Transport and storage
33	CPA_H51	Air transport services		
34	CPA_H52	Warehousing and support services for transportation		
35	CPA_H53	Postal and courier services	CPA_H53	Postal and courier services
36	CPA_I	Accommodation and food services	CPA_I	Accommodation and food services
37	CPA_J58	Publishing services		
38	CPA_J59_J60	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	CPA_J58_J60	Publishing, audiovisual and broadcasting services
39	CPA_J61	Telecommunications services	CPA_J61	Telecommunications services
40	CPA_J62_J63	Computer programming, consultancy and related services; information services	CPA_J62_J63	Computer programming, consultancy and related services; information services
41	CPA_K64	Financial services, except insurance and	CPA_K64_K66	Financial and insurance activities

		pension funding		
42	CPA_K65	Insurance, reinsurance and pension funding services, except compulsory social security		
43	CPA_K66	Services auxiliary to financial services and insurance services		
44	CPA_L68B	Real estate services (excl. imputed rents)		
45	CPA_L68A	Of which: imputed rents of owner-occupied dwellings	CPA_L68B_L68A	Real estate activities
46	CPA_M69_M70	Legal and accounting services; services of head offices; management consulting services		
47	CPA_M71	Architectural and engineering services; technical testing and analysis services		
48	CPA_M72	Scientific research and development services		
49	CPA_M73	Advertising and market research services		
50	CPA_M74_M75	Other professional, scientific and technical services; veterinary services	CPA_M69_M75, CPA_N77_N82	Professional, scientific, technical, administrative, and support service activities
51	CPA_N77	Rental and leasing services		
52	CPA_N78	Employment services		
53	CPA_N79	Travel agency, tour operator and other reservation services and related services		
54	CPA_N80-N82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services		
55	CPA_O84	Public administration and defence services; compulsory social security services	CPA_O84	Public administration and defense services; compulsory social security services
56	CPA_P85	Education services	CPA_P85	Education services
57	CPA_Q86	Human health services	CPA_Q86-Q88	Health and social work
58	CPA_Q87_Q88	Social work services		
59	CPA_R90-R92	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	CPA_R90-R93	Arts, entertainment and recreation
60	CPA_R93	Sporting services and amusement and recreation services		
61	CPA_S94	Services furnished by membership organizations		
62	CPA_S95	Repair services of computers and personal and household goods	CPA_S94_S96	Other service activities
63	CPA_S96	Other personal services		
64	CPA_T	Services of households as employers; undifferentiated goods and services produced by households for own use	CPA_T	Services of households as employers; undifferentiated goods and services produced by households for own use
65	CPA_U	Services provided by extraterritorial organisations and bodies	Not used as all its values are zero.	