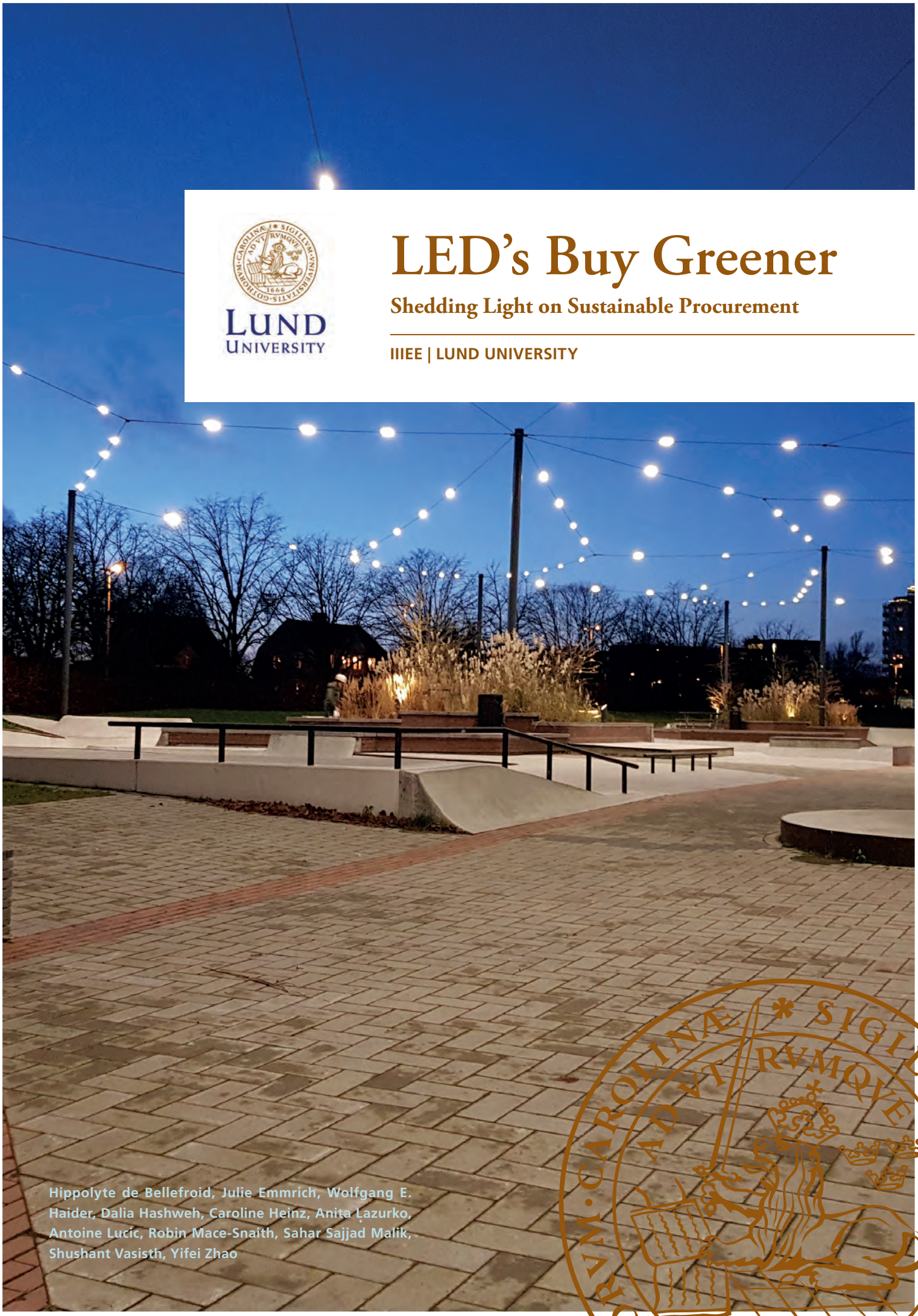

LED's Buy Greener

Shedding Light on Sustainable Procurement

IIIEE | LUND UNIVERSITY

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INTRODUCTION

How to Promote LED Procurement

In last decade, the lighting industry significantly changed with the development of light emitting diodes (LEDs) and their corresponding penetration of the market. The new technology increases energy efficiency and longevity compared to other types of lamps. As a result, LEDs can improve the sustainability performance of cities and towns, contributing to the mitigation of climate change and cutting costs over the long term. This report reviews LED procurement from multiple perspectives, formulated as a guide to help public and private stakeholders make more effective and sustainable decisions when buying lighting products.

This publication is the collective work of students involved in the Masters of Environmental Science, Policy and Management (MESPOM) programme, currently enrolled at International Institute for Industrial Environmental Economics (IIIEE). The research has been performed for the European Union Interreg Lighting Metropolis Project, which involves institutions, designers and producers, and municipalities in the Öresund (or Greater Copenhagen) Region of Denmark and Sweden.

The first two chapters of the report dive into the initial and final stages of the life cycle of LEDs. These chapters connect the impacts and risks of raw material extraction and supply chains to lighting procurement, and provide recommendations for the integration of end-of-life considerations into the procurement process. Chapter three analyses various national policies that contribute to promoting LEDs in public procurement. Chapter four examines the drivers and barriers for implementing innovative business models through the mapping various actors and their relationships. Finally, chapter five explores the decision-making process and the drivers and barriers of municipalities when procuring lighting solutions. Together, these five chapters provide a comprehensive set of recommendations to improve decision making for sustainable lighting solutions.

Lighting Metropolis

The Lighting Metropolis project plays a major role in the transition toward LED lighting in the European Union. By providing a platform for knowledge sharing and innovation in the Greater Copenhagen region, Lighting Metropolis helps ensure this transition provides human-centric and sustainable solutions and supports the role of municipalities in facilitating change.

RAW MATERIALS AND SUPPLY CHAINS FOR LED LIGHTING

Risks and Response for Procurement in the European Union

By Anita Lazurko & Robin Mace-Snaith

Lighting procurement decisions have the potential to mitigate climate change and cut costs, while also delivering effective lighting to customers. Light emitting diode (LED) technologies can help solve some of these issues simultaneously, and many believe the LED lighting revolution is underway in the European Union (EU). There is clear evidence that a change to LEDs can reduce the impact of the use phase of lighting through improved energy efficiency,[1] but the impacts of raw material extraction used to produce LEDs and the recovery of those resources at the end-of-life phase are still unclear.[2]

LEDs contain a variety of components including several rare earth elements (REE) and strategic metals that create severe impacts in non-EU contexts and carry significant supply chain risks.[3] The nature of procurement processes increasingly requires buyers to adopt a life cycle perspective and take greater responsibility for distal impacts. This paper presents the current environmental and social impacts of raw material extraction and trends in the LED supply chain. This information is targeted toward procurers of lighting to highlight the distal impacts and potential risks from large-scale procurement choices. The article concludes with recommendations on how such buyers can continue to benefit from LED lighting purchases, while limiting procurement risk and protecting the environment and society.

Raw Materials in LEDs

The raw materials used in the production of LED lighting can vary somewhat according to the design and producer, but the core materials are largely the same. LED producers like OSRAM and Philips rarely disclose the material make-up of their LEDs, and most components (such as the LED driver) are manufactured further upstream in the supply chain. LED-based bulbs and luminaires contain materials such as plastic and aluminium at differing quantities depending on the desired cost, use and aesthetic requirements of the producer and the consumer. Figure 1 illustrates the components of an LED bulb currently sold by OSRAM, using data from a 2011 life cycle analysis study that is still used for the material declaration sheet.

The proportions of each material (i.e. material mass) in the latest LED technologies vary

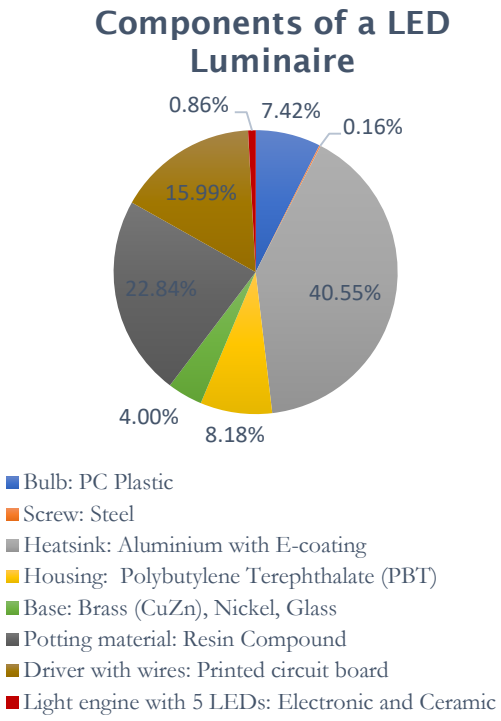

Figure 1 Components of an LED lightbulb [4]

widely. These proportions may reflect those in Figure 1, but future trends may shift material use, such as a possible movement toward plastics (i.e. PBT) over aluminium.[5]

Future design trends also impact the materials used in the luminaires that house LED bulbs, as these can be driven by external factors such as cost, legislation, and customer expectations. As stated, it is anticipated that the use of certain elements of LED lighting, in particular plastics and aluminium (housing and heatsink), will continue to fluctuate in the future. However, the materials used to generate the light itself are highly specialised (e.g. those in the LED module and circuit board) and will likely continue to utilise proportional amounts of REEs and strategic metals in the coming decades. These fundamental materials are the focus of this research. A list of such materials that make up components and sub-components in LED-lighting modules is illustrated in Figure 2.

Rare earth elements are used in LED phosphors that influence the light emittance and its colour, while other elements including indium, arsenic and gallium are used for the electronic LED driver or semiconductor wafer. The wafer is a substrate that can be doped with elements like zinc, nitrogen, silicon, germanium or tellurium to allow for conductivity and other properties.[6,7] White light LEDs usually combine either a blue-emitting gallium nitride (GaN) or indium gallium nitride (InGaN) phosphor with a yellow-emitting cerium-doped yttrium aluminium garnet (Ce^{3+} YAG) phosphor.[6] Various other combinations of colours

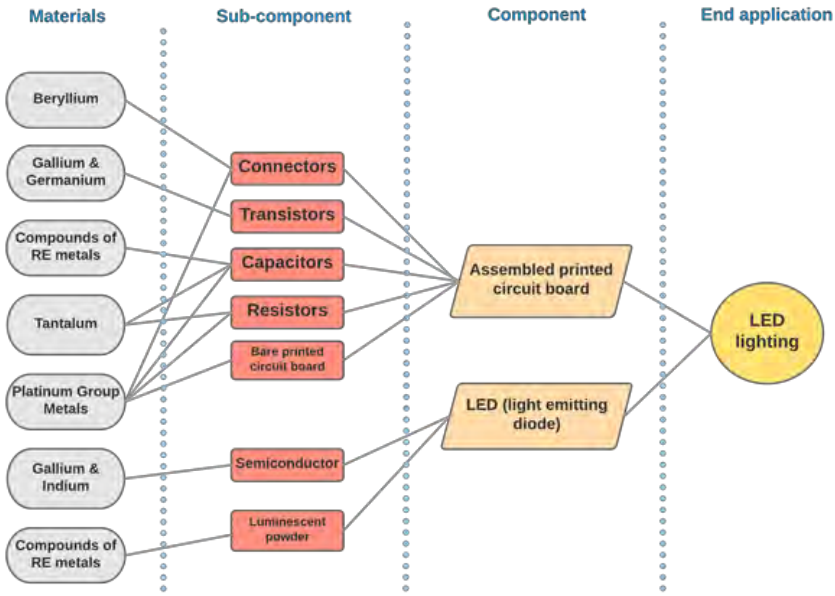

Figure 2 Raw Materials and their Usage in LED Lighting [8]

now exist using the gallium nitride (GaN) material system (e.g. aluminium gallium indium phosphide (AlGaInP) for yellow and orange; aluminium gallium arsenide (AlGaAs) for red and infrared; gallium phosphide (GaP) for yellow and green).[6] These elements are often uneconomical to mine alone, so these elements are recovered from host ores or in specialised REE mines.[3] Gallium is primarily recovered from bauxite, but it is also present in small amounts within deposits of zinc, iron and coal.[9] Indium is primarily recovered from zinc ores, but is also present in low concentrations in several other elements including silver.[10]

Environmental and Social Impacts of Raw Materials

The extraction of the raw materials required for the production of LEDs have positive and negative impacts. As discussed previously, many of the materials used in LEDs are strategic metals and REEs; their extraction creates local social and environmental consequences. One key factor is that the majority of the REEs, gallium and indium occur only in small quantities within mineral ores, so challenges in separating them from undesired material results in many by-products and wastes.[11,3] These waste products have chemical implications, as they are commonly stored on-site, leading to the release of toxins into the soil, air and watercourses.[12] Such toxins are often combined with further leakages during the refining phase, where chemicals are added to process extracted ore. Many toxins have radioactive properties that lead to severe impacts on local ecosystems and human health. Box 1 and 2 contain details about the environmental and social implications of Mountain Pass Mine in California and Bayan Obo Mine in China.[12]

REEs are usually found in-situ with thorium and uranium (highly radioactive elements) and create the potential for leakages of these into groundwater. It is worth noting that many developed countries with deposits of some REEs have banned mining due to concerns over radioactivity, including Australia, Europe and Malaysia.[11]

Beyond local mining impacts, manufacturers and buyers of light should also consider the impact of greenhouse gas emissions from raw material extraction and processing. These emissions are strongly linked to the intensive energy use in the refining and smelting phases for metals like aluminium. In 2012, the aluminium industry accounted for emissions equating to 861 million tonnes of CO_2eq. Of this, China accounted for 56%.[14] This high proportion for China is due to the large electricity requirements for smelting and China's reliance on coal

Box 1 Mountain Pass Mine, California

Between 1965 and 1995, Mountain Pass Mine in California, was the world's largest producer of REEs.[13] In 1998 the California Environmental Protection Agency suspended the mining of thorium, from which the REEs were extracted, due to environmental degradation from a series of radioactive wastewater leaks and concerns for human health. These included the potential for increases in cases of cancer, respiratory diseases and dental loss for those living in proximity to the mine.[11] In 2002 the mine was completely closed due to a drawn out history of polluting spills into the local environment, including heavy metals, acids, and radioactive elements. For example, in 1996 11 m^3 of wastewater leaked, including radioactive materials and lead, into Ivanpah Dry Lake. After the REE price increase in 2011, the mine was re-opened to help the U.S.A. secure its own domestic supply. A large investment was made to increase prevention and treatment of radioactive waste; it now accounts for all U.S. production.[11]

for electricity production. This is particularly noticeable when compared to other countries with higher amounts of renewable energy, such as Iceland and Norway, where the emissions per kilogram of aluminium produced is up to four times lower. **This raises the question, what responsibility designers and manufacturers should take in preventing these harmful environmental and social impacts by their suppliers?**

Supply Chain Risks

The cradle-to-grave supply chain for LED lighting spans an array of actors from the mining of raw material to recycling. Some materials with specialised properties are classified as 'strategic' or 'critical' materials by several countries and the EU,[15] including REEs, indium, and gallium. Aluminium should also be considered, as LED lightbulbs can be made up of as much as 40 percent aluminium by mass.[4] These metals have complex supply chains, as primary extraction or recovery from other processes often occurs independently of full separation and refinement of the resource.[3] Manufacturing of component parts is often performed by independent entities, and each of these stages may occur in different countries. Some metals use atypical supply chains, like the intermediaries used in the aluminium supply chain to store large volumes, resulting in oversupply and slow market response to changes in demand.[16] These opaque supply chains introduce uncertainty and can be very difficult to trace beyond smelters back to mine-scale impacts.

Additional supply chain risk is introduced with the supply chain geography, as mining, processing, and component manufacturing of REEs and strategic metals take place inside the EU. REE markets experienced price spikes and supply restrictions in 2010 and 2011, forcing the European Union to confront these risks. As of 2010, China controlled 97% of REE mining, 97% of oxide separation, and almost 100% of oxide refining.[3] At that time, China had recently adjusted its regulations to stop

Box 2 Bayan Obo Mine, China.

During the 12 years Mountain Pass was closed much of the supply shifted to China, where lower costs due to less stringent regulation allowed China to become the market leader in REE extraction and supply. In many of the Inner Mongolia regions where there are large deposits of REEs and subsequent mines are in operation, there are large quantities of toxic waste polluting the environment, with ecosystems and locals being greatly impacted. An estimated 10 million tonnes of highly acidic and radioactive waste is being released without treatment in the Baotou village area, where rare earth ore (REO) from Bayan Obo is processed.[17] Bayan Obo is currently the largest REE producing mine in the world. It has been accused of killing livestock and crops due to leaching of these substances from tailing ponds, displacing farmers, destroying livelihoods and increasing rates of cancer and birth defects among inhabitants. If the leaching reaches the Yellow River, as many as 150 million people may be exposed to its risks.[12] In response, China evacuated whole villages between Baotou and the Yellow river that stand next to the many REE refineries after reports of high cancer rates and other health problems.

In recent years, China has moved to control its REE resources more stringently for economic reasons. As a result, it has pledged considerable funding to promote a clean-up of its mining regions and implement stricter regulation.[18] Concerns remain over the many illegal mines that operate without a licence (ca. 20 000-30 000 tonnes of REO illegally mined in the 2000s) and the further shift of REE to lesser developed countries, where there are less stringent environmental regulation.[16]

illegal mining and improve environmental standards. An unstated policy objective behind the new regulations was to allow Chinese companies to access REEs at a discount, accelerate industrial upgrades, and satisfy a growing domestic REE demand.[19] Since 2011, some countries have started stockpiling critical resources, and several mines have ramped up production, including the Lynas Corporation Mount Weld Mine in Australia and the Molycorp Mountain Pass Mine in California, USA.[20] Large investments have been made in geological explorations and technology development around the world.[21] These measures have resulted in a drop of Chinese control to 83%.[12]

Similarly, the EU depends on China for 58% of its indium and 69% of its gallium.[22] Seventy percent of global indium is used for LED lighting, and the European Commission expects demand of both metals to peak in 2020 due to increasing resource efficiency in solar panel production.[22] Still, the LED transition and potential future display applications for LEDs beyond lighting could continue to drive resource pressure.[23] Though both gallium and indium are relatively abundant in the earth's crust, low extraction volumes and dependence on other material markets create supply risks.[10,24]

Alternative supply sources for both elements exist in the EU,[22] and technological developments in mining and recovery techniques may increase profitability of gallium and indium mining.[3] Some countries also maintain stockpiles of both gallium and indium, including Japan, South Korea, and China.[25] Table 1 highlights the role of the European Union at various steps in the supply chain of REEs, indium, and gallium, and Figure 3 is an alternative representation of the REEs supply chain by country.

Aluminium has similarly disparate entities controlling the market, with the largest primary production companies located in the USA, China, India, Norway and Russia.[16] Though geopolitics and domestic markets in China still play a part, the aluminium market price also consistently fluctuates due to other factors, like macroeconomic changes and slow industry

Table 1 The role of the European Union in rare earth element, indium, and gallium supply chains for LED lighting [7]

Supply chain step	Description	Role of the EU
Mining (or recovery of secondary) raw material	Extraction of raw material and host materials for those recovered as by-product or companion metals	• 83% of REE production was concentrated in China as of 2016 [12] • 55% of production processes concentrated in China in 2012 • Few producers of strategic metals exist in the EU, but Umicore is headquartered in Brussels and is the leading secondary producer of indium
Separation	Separation of In, Ga, and REEs from ores	
Refining or reduction	Numerous chemical, physical, and electromagnetic processes to transform separated element into desired form for use	
Component manufacturing and suppliers	Manufacturing of electronic and physical components for LED lighting and suppliers	• 78% of LED component manufacturing was in Asia in 2011 • Only one large diode manufacturer in the EU
LED companies	Further manufacturing and assembly of LED lighting	• 2 EU companies are in the top five global LED lighting manufacturers • OSRAM, Philips, and Havells Sylvania accounted for 60% of EU sales in 2012
Recycling	Recovery of REEs, In, and Ga if possible	• No separation of REEs, In, and Ga from LED lighting products in the EU

response to demand.[16] The scrap metal market also plays an important role in the aluminium supply chain. The aluminium supply chain is also closely tied to the gallium by-product supply chain, which has its own previously stated risks and complexities.

Demand Changes and Drivers

In 2012, greater than 50% of global demand for the REEs of yttrium, europium, and terbium came from phosphors for lighting applications, but predicting the future response of REE to LED growth is difficult.[11,20] The quantities of yttrium and europium are one to two orders of magnitude lower for LEDs compared to other types of lighting, so the transition to LEDs will likely see a peak in demand for REEs in the coming decade.[23] However, total global demand for REEs is expected to increase 50% by 2020,[26] demanding strategic sourcing for LED applications. Some conclude that short-term disruptions from market forces of geopolitical events do not indicate that long-term resource constraints will threaten the LED transition.[3] Others state that "competitive, reliable, and sustainable" access to REEs has still not been secured.[26]

As with REEs, estimating future markets for gallium and indium is difficult, though increases in recovery circuits at mining and manufacturing sites, recycling of end products, and exploration of new mining sites are expected to satisfy growing industrial demand.[3] Projections for aluminium use in LED lighting are also unclear. Aluminium has been important for the LED transition due to its ability to serve as a heat sink and as extrusions for custom housing design, leading to "the potential for growth in extruded aluminium use for LED light fixtures…is virtually limitless"[27]. However, the industry is also experiencing some transitions to thermoplastics for some heat sink and housing applications, which may limit this growth.[28]

Technological trends in the lighting sector may change the total demand of REEs, gallium, and indium. The rare earths efficacy, or the weight of rare earths required per lumen of light produced is much better for LEDs than other lighting options. Fluorescent bulbs and LEDs have a rare earths efficacy of 54 and >1000 lumens per gram, respectively, therefore a transition to LEDs reduces REE use by 15 to 20 times.[29] In addition, the efficiency and long life span of LEDs is expected to reduce the net demand for lighting in the coming decades.[23] The resource supply crisis in 2010 and 2011 prompted innovations in many sectors that reduce the type and amount of REEs, gallium and indium required.[26] The most relevant innovative technology is organic LEDs (OLEDs), which do not require REEs or gallium. OLEDs emit light based on the same electroluminescence effect as other semiconductor LEDs, but organic-based layers are evaporated onto a pre-coated and treated conductive piece of glass.[29] OLEDs are expected to broadly penetrate the market by 2025, though they are expected to dominate in screen displays and as

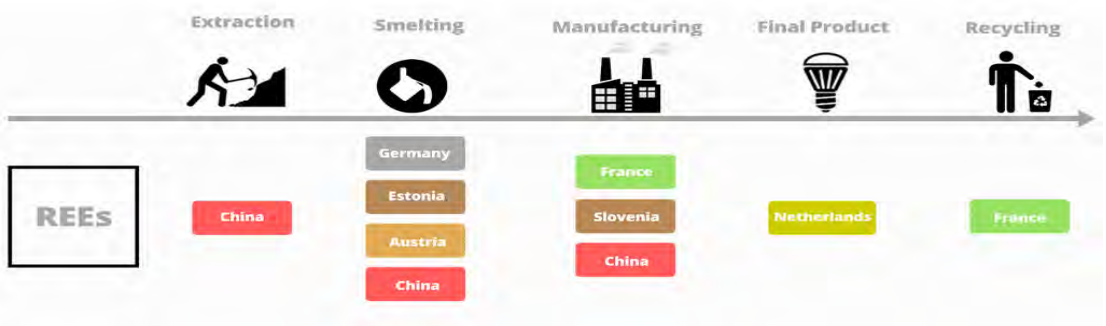

Figure 3 Example of countries in the supply chain of rare earth elements for LED lighting in the Netherlands [7]

a complement to traditional LED lighting. This is due to their ability to reproduce the look of natural sunlight more effectively than traditional LEDs, but their inability to produce intense light in bulb form.[30] These technological innovations will continue to drive changes in the demand for strategic resources.

A trend toward recycling and recovery of materials can also reduce the demand for raw materials. The EU does not directly recycle REEs, gallium, and indium from LEDs due to high recovery costs and low waste volumes.[3] Researchers are constantly improving methods to remove several metals from new sources or wastes like tailings, including REEs, gallium and indium.[31] Beyond LED lighting recycling, it is expected that the supply of gallium will be further secured by increasing recycling during manufacturing processes that use more gallium than is embedded in the final product. New sources for recovered indium, including extraction from new ores or tailings, can also reduce the demand for virgin indium from traditional sources.[3] European countries are already experimenting with recovery of REEs from electronic waste using urban mines, though this still represents a small proportion of raw materials required for the technology sector.[11] Japan has demonstrated effective techniques for recovering large volumes of gallium from scrap metals.[10] The practice of recovering strategic resources from wastes will present opportunities to avoid the environmental impacts of raw resource extraction and reduce supply risk in the future.

Recommendations

The transition to LED lighting is expected to lower overall REEs and energy consumption,[12,23] but the move toward life cycle thinking demands more efforts to connect distal mining and processing impacts and supply chain risks to procurement. The following recommendations aim to provide procurers with concrete actions that can potentially reduce environmental and social impacts, while also limiting risks to the organisation from their purchasing choices.

First, procurers must seek more knowledge about the issues associated with LED raw materials and supply chains, and communicate these issues with beneficiaries. Greater knowledge allows procurers to choose best available technologies through procurement processes that push for the leading edge of energy efficiency and material use. For example, despite the opacity of most of these supply chains, aluminium is traceable to the smelting stage where emissions and mining impacts are far worse in China than the rest of the world. Knowing that traceability is possible opens opportunities for procurers to act. Another example is the emergence of OLEDs as a technology that could provide more sustainable, innovative, albeit limited solutions in lighting. Clear knowledge of its potential applications could help procurers experiment with new technologies in a manner that has good performance outcomes and reduces REE supply chain risks.

Second, procurers can act collectively to exert influence on raw material supply chains. The European Union is taking action to maintain and strengthen its ability to secure strategic metals through research and development, policy coherence, and recommendations for forming alliances like a European Resource Alliance.[26] Seeking advice from, or association with, such groups can help align purchasing decisions with broader EU-level goals. In addition, some large LED manufacturers are in a unique position to exert influence to increase supply chain transparency and potentially reduce environmental impacts. Procurers should consider including procurement criteria that address supply chain transparency with a focus on social and environmental issues. Buying partnerships can enable procurers of all sizes to pressure manufacturers to im-

prove these issues due to greater leverage and buying power.

Third, procurers can support LED and strategic metal recycling and recovery as a way to secure resource supply and reduce environmental impacts. Closing the loop of REEs and other strategic metals can significantly reduce the EU's reliance on international suppliers and reduce the impacts of raw material extraction and end-of-life processes simultaneously.[12] Currently, EU policies do not require the removal of strategic metals from its LED lighting recycling, as they exist in small fractions and are not economical to remove, but Japan has proven that it is possible at a relatively large scale. Public entities can define recyclability as a procurement requirement and pressure national governments and the European Union to adopt policies that increase recycling levels of LED lighting.

The LED lighting transition provides an opportunity to reduce the life cycle impacts of lighting, but significant environmental and social impacts combined with complex supply chains continue to imbue risk into large-scale lighting purchasing decisions. These recommendations provide actions to reinforce the social license of procurers. Some of these recommendations may result in a small price premium, but they also result in reduced environmental, social, and supply chain risk that could result in more secure supply, cost savings in the long term, and a more sustainable future.

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END-OF-LIFE MANAGEMENT OF LEDS

The Need for its Integration in the Procurement Process

By Wolfgang E. Haider, Antoine Lucic & Sahar S. Malik

Light emitting diodes (LEDs) are taking over the lighting industry to cater to the rising demand for technologies that help achieve global climate mitigation targets. LED technology has helped fulfil the fundamental requirements to reduce the environmental footprint of lighting equipment: energy efficiency, longevity and environmental compatibility. As a result, conventional incandescent light bulbs, compact fluorescent lamps (CFLs) and halogen bulbs are being replaced by LED products, which will likely cause LEDs to dominate the market in the near future. As prices fall, LEDs are increasingly attractive to consumers for their energy efficiency and long life span. In addition to price, LED technology has significantly improved compared to the first generations on the market. Additionally, consumers are attracted to the enhanced quality of light, elaborate design options and the absence of mercury (Figure 1).[1] Taking the rising consumption into consideration, the end-of-life management of LEDs must be integrated into the procurement process.

There are still however, some factors which are limiting the market penetration of LEDs. According to a 2011 European Commission (EC) survey of the various stakeholders in the European lighting market, 14% of respondents stated that two unconsidered factors are limiting this market penetration. These two factors are scarcity in some raw materials used in LEDs and issues with recycling.[1]

The current composition of LEDs makes them critical for recycling. Though LEDs do not contain mercury, they still contain minor quantities of potentially valuable elements such as gallium, indium, gold, silver, and some rare earth elements like europium and yttrium.[1] This composition makes it vital to develop a proper recycling system which can help recover these elements and contribute to closing the material loop. In addition to promoting circularity, recycling reduces the need to mine these elements, avoiding the risks associated with resource depletion, social inequity and environmental degradation.[2]

Currently, waste LEDs are handled based on the Waste Electrical and Electronic Equipment Directive or WEEE Directive (EU 2002/96/EC and recast 2012/19/EU) under Extended Producer Responsibility (EPR). EPR is one of the proposed mechanisms that allow member states to fulfil obligations set by the European Union (EU) to meet the require-

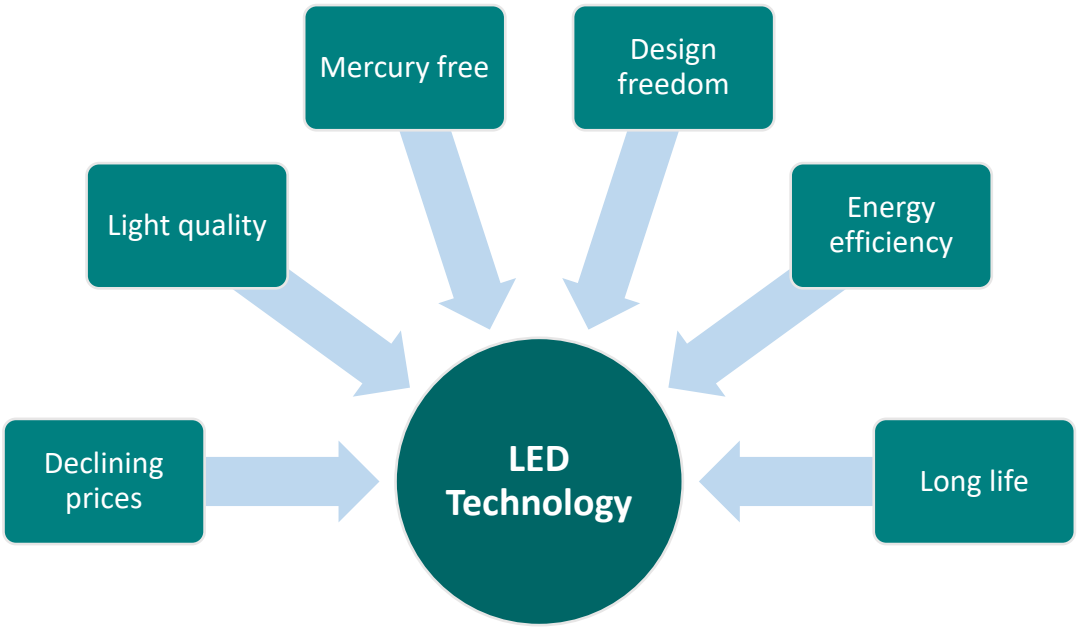

Figure 1 Factors triggering the growing consumer acceptance for LEDs

ments of the Circular Economy Package, adopted by the EC in December 2015.[3]

Drivers for new end-of-life management systems

As LEDs continue to become more prolific, there is a need to adapt recycling systems. If current trends continue, LEDs may soon make up the majority of lamps returned for disposal; the manner in which the lamps are recycled must be dynamic. One could also predict that as LEDs replace older technologies, an increase of other types of lamps (e.g. incandescent bulbs) in the waste mix would be expected. This, however, is not the case. According to Nordic Recycling AB, LED lamps as a proportion of the waste mix is actually increasing. Hence, increased consumption along with technological innovation and breakage or malfunctioning LED units are driving the immediate need for end-of-life management consideration.

Continued increase of consumption of LEDs

The number of LED installations grew from 99 million units in 2009 to 1.6 billion in 2015, while the stock of incandescent lamps fell from 741 million to just 65 million in the same time frame.[4] The recycling process of lamps will need to be revisited as the materials to be dismantled and processed are changing. For example, machinery may become redundant if the materials in disposed bulbs shift away from metals toward more plastics. Therefore, proactive integration of these end-of-life management considerations into policies and practices is critical to plan for the future escalation of LEDs in the waste mix, resulting in a smoother transition.

Technological Innovation

The energy efficiency of earlier generations of LEDs is falling behind as opposed to the newer generations, making it more cost-effective for some large-scale procurers to purchase the newer lamps. Furthermore, advances are being made in LEDs with the ability to emit various colours, therefore consumers are replacing LEDs that are still functioning in favour of more suitable hues. As a result, LEDs are finding their way into the recycling mix before the end of their lifespan. This phenomenon will likely continue as new technology becomes more efficient and has other favourable attributes, such as dimming capabilities, which may

cause consumers to shift to new bulbs prematurely.

Breakage and Malfunctioning Units

In addition to previously described reasons, this could also be attributed to breakage, malfunction or faulty production. Faulty production was found to be common in early generations and cheaply produced LEDs. Therefore, it is important to start thinking about the end-of-life implications during the design, production and procurement phases.

Current situation and Outlook

According to trends described by Nordic Recycling AB (the only recycler of used lamps in Sweden, Norway, Estonia, Lithuania and parts of Denmark), the amount of LEDs being returned for dismantling and recycling of parts has risen to approximately 8% of all returned products (Figure 2). This growth trend is expected to continue. Currently, this proportion of LEDs is collected and handled together with other lamps, leading to inefficient recycling as mercury-free LEDs are contaminated by mercury-containing lamps. The recycling firm is collaborating with Chalmers University to design a machine with the ability to more efficiently sort different types of lamps. This would result in more efficient sorting and recycling of materials and avoid cross-contamination. Nordic Recycling AB was recently bought out by a French waste management company named Veolia. Therefore, some future uncertainties could be on the horizon; however current managers at Nordic Recycling AB do not expect any drastic alterations.

Currently, the only policy municipalities follow relating to the end-of-life management of lamps is the WEEE Directive. Minimal action is taken during the procurement phase, but according to Malmö, some collaboration between municipalities to synchronise tenders with end-of-life management implications is occurring. This collaboration is meant to push manufacturers towards more effective manufacturing for end-of-life management. It appears that Malmö is also the only municipality in Greater Copenhagen with policies that go beyond the WEEE Directive. For example, Malmö follows the Green Digital Charter, a voluntary instrument that uses smart digital solutions to improve efficiency and prolong the life cycle.

Presently, the Swedish National Agency for Public Procurement does not integrate end-of-life into their requirements. Municipalities can have vertical influence on the agency by creating tenders with end-of-life stipulations, which in turn, would encourage the agency to add end-of-life thinking into their policies.

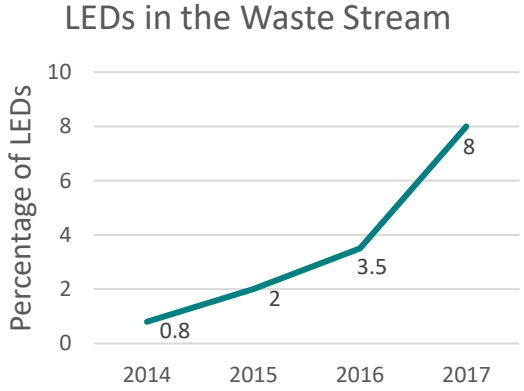

Figure 2 Proportion of LEDs in the waste stream

Organic LEDs are beginning to gain traction as a future product. As the main material of this product is plastic, there may be significant reduction in the monetary value of recyclable materials in returned lamps. Plastics do not promote circularity and could reduce the profitability and thus, the incentive to effectively recycle lamps. However, OLEDs have different performance abilities and many believe they will not be a direct substitute for traditional LEDs in the near future.

A Way Forward

To better integrate end-of-life management into the procurement process of LED lighting, three interlinked perspectives can play a major role. The potential of **strengthening tendering contracts** represents a key perspective in incentivising better products. Furthermore, **creating greater links of communication, accountability, and stake** between the producer responsibility organisations (PROs), the recyclers, the producers, and municipalities would lead to a better understanding of each player's needs. Aligning these needs with best practices would yield the most effective result. The final valuable perspective from which the conversation can move forward is through the **consideration of green design principles and material marking** during the manufacturing stage. This can help reduce the impacts of the end-of-life stage of the life cycle. In essence, integrating end-of-life management systems requires innovation that incentivises producers to design or provide the service of end-of-life management throughout the procurement process. Decision-makers are tasked to make relevant policies that reflect this coordination.

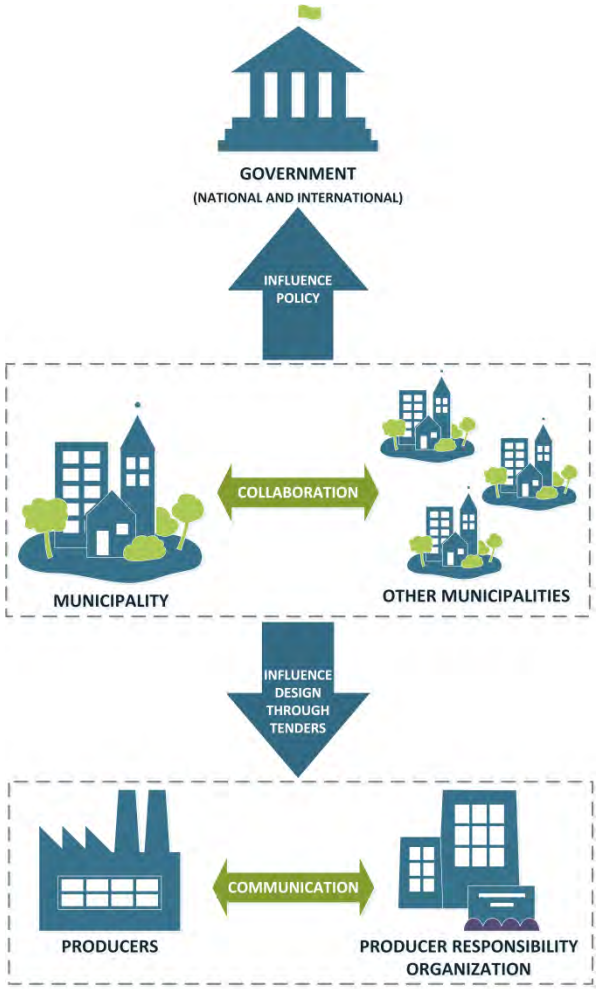

Figure 3 Potential impact Municipalities can have on other stakeholders to integrate end-of-life considerations

Figure 3 illustrates the connections that allow municipalities to play an integral role in the development of end-of-life management systems through both vertical and horizontal influence. Any municipality, through its tenders, can lay out criteria for producers to meet in order for them to be considered for a contract. If all municipalities lay out different criteria, it becomes challenging for producers to meet all criteria. If municipalities collaborate they can lay out similar or supporting tenders, which not only makes it easier for producers and their representing PROs to comply, but also gives municipalities the power to influence design for easier end-of-life management. Therefore, through horizontal communication, municipalities can collaborate to influence producers to manufacture more recyclable products. Moreover, municipalities can use their foothold in the political sphere to push national (for example the Swedish National Agency for Public Procurement) and international bodies (for example the European Union) to integrate end-of-life into waste management policies. These actions help ingrain environmentally conscious design and waste systems directly into policy.

Strengthening tenders

The public sector, as a large-scale consumer, has the ability to influence the market through its tenders. Despite recognising the value of LEDs in reducing CO_2 emissions, the EU guiding document called Green Public Procurement barely mentions the environmental impacts and end-of-life management of LEDs. The sole reference to end-of-life comes in the form of life cycle costing, which fails to link

the issue to environmental impacts. This lack of consideration results in insufficient consideration of material circularity.

Strengthening tendering standards for end-of-life management with environmental and social criteria has the potential to address inefficiencies and improve accountability. A study based in the United Kingdom promotes procurement as an effective tool for innovation, as it provides flexibility and incentives, and it fosters an exchange of communication between parties. By avoiding rigid specifications, tenders that use a more holistic approach for assessing outcomes allow suppliers to propose more innovative solutions. This study found that too many specifications during the procurement process may act as a barrier to innovation, as the freedom of design for manufacturers becomes restrained. It is similarly important to state that legal restrictions apply to too specific criteria in tenders that can hinder fair competition, stemming from unfair advantage.[5] As such, stressing outcomes or performances (i.e. recycling rates, integrated end-of-life management) should play a role in the tendering process as it allows the industry to innovate from within.[6,7]

Municipalities may gain leverage from pooling together financial resources as a means to encourage and secure market demand. Longer and more lucrative contracts that simultaneously harmonise standards may reduce the uncertainty associated with the fragmentation of public demand.[5]

Increased Stakeholder Communication and Collaboration

Such emphasis on tenders naturally requires greater communication and collaboration between stakeholders. Studies point to the "lack of engagement between procurers and suppliers" as a key barrier to innovation.[5] This is particularly important when trying to assert changes within procurement policies. While "suppliers will adapt to the signals of public demand and respond with innovative solutions if they see the public sector as a demanding customer",[5] it requires municipalities to engage with these actors to align their needs. An interview with El-Kretsen shed light on two valuable points that inform the following suggestions.

The first point addresses **the need to capitalise on communication streams between stakeholders**. While EPR systems have played a defining role in end-of-life management, they were formed as a measure to deal with waste and should not be solely be relied upon for end-of-life management. Furthermore, the way in which EPR is applied could be enhanced in the future, with the integration of preventative measures on top of the end-of-pipe solutions it already incorporates. It is therefore necessary to encourage conversations and actions towards integrated thinking from raw material extraction to design and end-of-life between all relevant stakeholders.

The second and most prominent of the two points discussed, implies **the need to standardise a distinguishable element on LED products with an identification mark**, such as a symbol, colour or barcode. This would help differentiate LED products from others to avoid mercury contamination upon collection. Furthermore, taken the low-cost of the product, hand separation does not compete with low-cost and rapid mechanical sorting. To enable the deployment of such machinery, despite the potential material shift from aluminium and glass to plastics, a mark on the product itself could ensure pure waste streams by simplifying sorting. Further elaborated in the next section, detachable parts and the identification mark can also play a role in facilitating such treatment.

An alternative option could entail **the mixing of LED products with general electronic waste**. The EPR model offers an undervalued platform to exchange ideas, shed light on current uncertainties and anticipate future needs. All parties would gain from municipal involvement with the EPR system, as this would

unlock and facilitate the integration of producer interest in tendering standards. Initiatives such as the Global Lighting Challenge exemplify the idea of greater collaboration, while public involvement in the EPR network would help reflect end-of-life in procurement and ensure inefficiencies are avoided.

A final option could **mimic the Japanese Top Runner Program**. It uses the top performers to set a base for new standards as time goes on.[8] This pushes the lower performers to eventually meet the top performers' standards, thus elevating the overall quality of all products and stimulating innovation. By transposing end-of-life standards in tenders whilst keeping in mind the overall value of the product (efficiency, cost, etc.), improved overall environmental and economic performance can be encouraged.

Design for End-of-Life Management

The design and material requirements of LEDs are a central consideration when integrating the end-of-life into procurement processes. Incandescent lamps typically have an average of about 3 parts, CFLs average about 5 parts and LEDs contain approximately 15 parts.[9] Therefore, including criteria for modular design in tenders would allow for easy material separation upon arrival at recycling stations and allow for more efficient recycling.

According to Nordic Recycling AB, this may only be feasible and beneficial if LEDs are constructed with valuable and reusable materials such as aluminium. Lamps made primarily of plastic would not necessarily require modularity as plastic does not have a high value and does not need to be separated if it ends up being incinerated. Modularity in lamps made with various materials would be more essential and would reduce cost and loss of potentially valuable materials in the end-of-life phase. These measures should be taken early in the lamp development stage, due to the high variability in their designs.[9] Encouraging modular design now could push the producers in the right direction before designs become more ingrained and universal, thus more difficult to change.

There are several criteria that municipalities could put into tenders which could significantly reduce the end-of-life impact of LEDs.[10] Some of these criteria are:

- design for easy disassembly without destruction
- reduction of the number of parts
- reduction in the use of adhesives
- design for replaceable parts
- use of easily identifiable materials with minimal variation in the type of material

While a shift in LED material composition may affect revenue creation in the recycling sector, ensuring identifiable material types will enable high-purity recycling streams and contribute to overall desired outcomes. If these criteria cannot be met by enough producers to be viable criteria, municipalities should communicate with producers, notifying them that these criteria will soon be added. Such information is valuable for all stakeholders, as it encourages research and development and incentivises top runners.

Conclusion

LEDs are considerably less harmful to the environment in the end-of-life phase of the life cycle compared to other lamp types.[2] This is predominantly due to the absence of mercury and lead. Despite this, LED waste must still be dealt with as responsibly as possible. Through collaboration, policies and tenders, municipalities can play a pivotal role in the coordination of collaboration between PROs and recyclers.

By enabling better design of LED products, as well as fostering improved end-of-life management systems, environmental impacts can be minimised. This focus on end-of-life should be prioritised, as trends lead us to believe that

over time, LEDs will become a more significant portion of the lamp waste mix. Municipalities have significant influence on the market as large-scale consumers. They ought to take on a leadership role to reward positive actions by suppliers and producers and demonstrate their commitment to environmentally responsible behaviour.

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GOVERNMENTAL LED POLICIES

Mapping out LED Policies in Selected Countries

By Hippolyte de Bellefroid & Yifei Zhao

Supportive governmental policies, at the municipal, national and regional level have been and will continue to be an important driver for LED lighting procurement. Governments usually play a role as early LED adopters, helping to remove and ease obstacles, allowing the LED industry to scale up through policy implementation. This chapter looks at different LED policies around the world and maps out how governmental policies can promote green public procurement and investments.

Sweden and Denmark

Sweden takes part in the Global Lighting Challenge,[1] which is an initiative started by the UN in 2015 to promote high quality and high efficiency lighting products.[2] Through the LED transition to LEDs, Sweden could reduce its energy consumption stemming from lighting by six to seven TWh. One of the target groups of this challenge is the public sector.[1]

The Global Lighting Challenge involves diverse actors, including private companies, like IKEA and Philips, and countries such as Sweden. These actors aim to promote and accelerate a lighting transition to LEDs. Under the umbrella of the Global Lighting Challenge, Sweden has created the Swedish Lighting Challenge (SLC).[3]

In the framework of the SLC, measures have been put in place to encourage public and private actors to work together. This is meant to help Sweden become a driving force in developing and spreading lighting solutions. As a result, the Swedish Energy Agency (SEA) conducted several activities in 2016. First, the SEA is driving close dialogues between climate change advisers and Swedish consumers, such as municipal energy providers. The aim of these discussions is to communicate the advantages of LEDs. Second, the Swedish state collaborates closely with local, regional and central government authorities regarding public procurement. It encourages leading actors to join the Global Lighting Challenge. SEA is also working closely with the National Agency for Public Procurement. Public and private actors would then be supported in their procurement of efficient and high-quality lighting.[4]

The Danish government initiated a programme to shift public procurement in a manner that supports the transition to a more circular economy. Members of the programme want to encourage the use of alternative materials such

as non-toxic chemicals, cycling of materials, and extended product lifespan for LEDs. For example, the Odense Municipality built 40 new residences for youths with disabilities. In the building of these new residences, the energy solutions include LED lighting.[5]

This initiative was implemented to create a partnership for Green Public Procurement (GPP), which is a partnership between Danish regions, municipalities, and the Ministry of Environment and Food. These partners integrate green objectives in their procurement policies, which includes procurement of lighting and alternative technologies like LEDs. The main goal of this partnership is to create a coalition of governmental bodies to increase procurement volumes in order to have a larger impact on the market. The key activities of GPP revolve around capacity building, collaboration, and the sharing of experiences and knowledge.[5] The total value of procurement under this partnership is EUR 5 billion.

In summary, many of the implemented measures, such as the Swedish Lighting Challenge, did not have significant impacts at the municipal level. Moreover, the information provided about these measures lack concrete and detailed descriptions. Sweden and Denmark have the opportunity to take more concrete, measurable actions with greater impacts at the municipal level. For example, municipalities can promote LED public procurement by offering incentives to municipalities acquiring LED lighting, supporting both environmental and financial goals.

EU policies in LED public procurement

The EU does not directly promote LED lighting in the public procurement of its member states. Nevertheless, it indirectly contributes to making LEDs more accessible by providing information through labelling reporting, collaborating with LED producers in South Korea.

EU report

The EU report "Accelerating the deployment of innovative lighting in European cities" evaluates innovations in the lighting sector in European cities.[6] A special task force collected tangible experiences of entities using LED lighting. The report provides guidelines that encourage municipal services and cities to develop and implement more long-term, innovative, and sustainable urban lighting strategies. The Vice-President of the European Commission, Ms Neelie Kroes, hopes that this report will be an incentive for European cities to share their experiences, results and lessons learned from the deployment of LED lighting in the whole of Europe.[6]

Partnership with South Korea

The EU-Korea partnership is an annual business event that began in 2012. These events are valuable opportunities for EU public procurement agencies to network and develop concrete partnerships with qualified South Korean companies in the LED lighting sphere. The Korean Trade-Investment Promotion Agency (KOTRA) coordinates the meetings focused on LED lighting. Products are selected to conform to the standards of EU Public Procurement and the Free Trade Agreements between the two economies. In addition, informative seminars on public procurement are organised. The EU-South Korea partnership allows the EU to access higher quality products and receive important information about LEDs for public procurement.[7]

LED Policies Outside EU

Increasing energy and environmental concerns are driving the development of green public procurement in other parts of the world. These concerns are especially focused in developing countries, where energy and environmental

problems have become key factors that restrain their economic development. Under such situations, many countries have launched green purchasing policies incorporating key lighting projects. In addition to the large market potentials and positive industry outlook, the current efficiency of LED lighting has made it a globally recognised environmental friendly product. As a result, LED policies and programmes have emerged around the world.

Japan and the "21st Century Lighting Project"

Japan is considered to be one of the earliest countries to initiate LED policies, with its "21st Century Lighting Project" which started from 1998. The project aims to promote semiconductor lighting technology and expand market demand (Figure 1). To achieve this, the Japanese government released a series of LED policies, which includes the integration of the leaders of the LED industry, the promotion of LED standards and the adjustment of taxes on LED products. As a result, Japan became the first country to achieve a LED market penetration rate of 50%. [8]

LED Rebates and Incentives in China

Since early 2011, the LED lighting industry has been soaring in China. At that time, the Chinese government chose to prioritise the upgrading of the lighting industry in its Twelfth Five Year Plan (2011-2015). In the plan, "strategic emerging industries" were singled out including LED lighting for special support.[9] In 2012, the National Development and Reform Commission in China issued the "Notice of Annual Financial Subsidies to Promote the Work of the Semiconductor Lighting Products", which is an important policy that subsidises the LED lighting industry through bidding. The companies that won the bidding were entitled to subsidies from the government.[10] Thereafter, an increasing number of local governments in the country, such as Shenzhen, Guangzhou, Beijing, Hangzhou, launched local subsidy policies for LED lighting development. In 2013, the Ministry of Finance announced the governmental procurement list for energy-saving products, including LED lamps, LED street lights and LED down lights.[11] In addition to the huge and growing domestic market, the state initiatives and proactive local policies undoubtedly spurred investment and procurement for LED lighting in China.

India and the LED Procurement "Roadmap"

The Indian LED market may still be in a de-

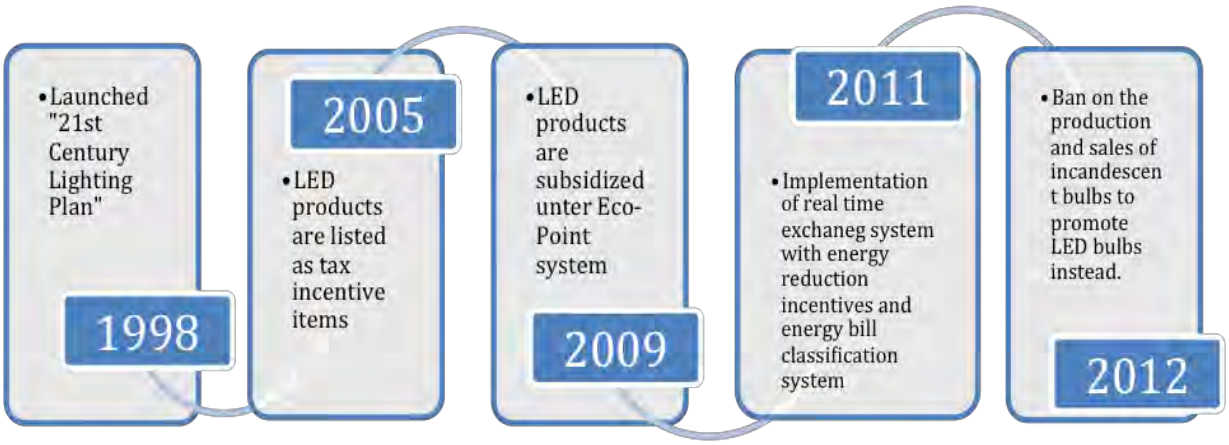

Figure 1 Japan's "21st Century Lighting Plan"

velopmental stage, but the government has already put policies with significant impacts on its domestic LED industry in place. The Indian government began to launch carbon reduction policies in 2014, and is in the process of replacing 750 million incandescent bulbs with LEDs.[8] Starting in early 2015, the Indian government announced a series of key public lighting projects and procurement policies. These include the installation of LEDs in government buildings, residences streetlights, which fall into the LED project called as "Prakesh Path". More than 180 Indian cities participated in the residential LED lighting replacement project. The country also set up the "Super Efficient Equipment Program", which aims to replace residential lighting and street lights with LEDs in 100 cities by 2019. For street lights, India brought forward the Street Light National Programme, targeting 35 million street lights nationwide to reduce energy usage by 9 billion kilowatts.[12] Furthermore, the government launched the LED lamp government procurement "roadmap", which involves 302 governmental departments. Since 2015, the Indian government also provides subsidies for LED bulbs as a strategy to spur local procurement. Many local municipalities have also implemented subsidy policies as a response (Figure 2).

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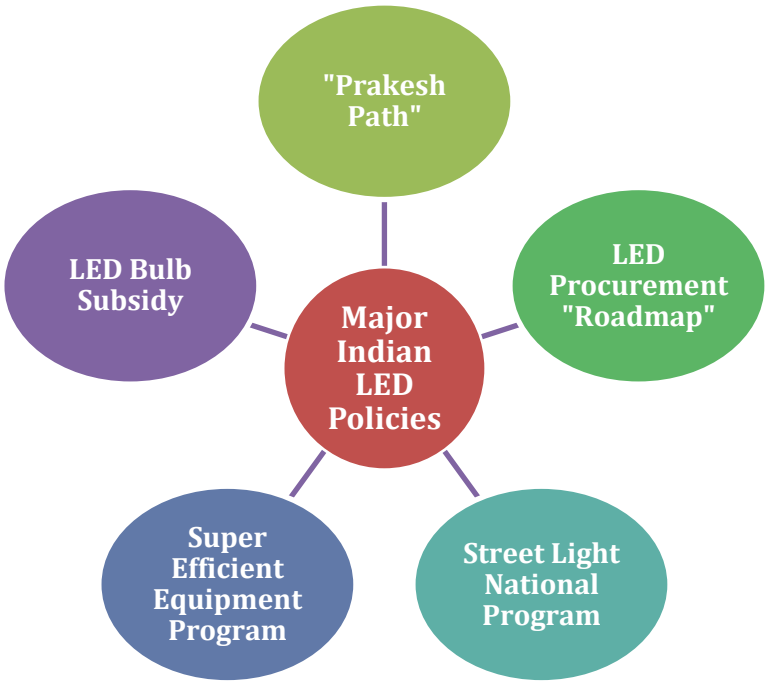

Figure 2 India's LED Policies

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BUSINESS MODELS FOR INNOVATIVE LIGHTING

Present Challenges and Key Drivers in the Swedish Context

By Dalia Hashweh and Shushant Vasisth

Municipalities and utility companies in Sweden have undertaken several innovative LED lighting projects as part of the Lighting Metropolis. Implementation of such projects often entails the use of different procurement and business models. As various actors are usually involved, the uptake of more innovative lighting projects may come with challenges. Hence, exploring the LED public procurement activities of various municipalities and utility companies can provide a better understanding of how to implement business models and meet consumers' satisfaction. Understanding the challenges and drivers with the procurement of innovative lighting is essential in order to identify main the considerations and a way forward.

Mapping the different actors involved in the procurement of LED lighting can increase understanding and help identify challenges and drivers. Mapping also reveals the relationships between actors and the allocation of responsibility according to different perspectives.

Innovation is important for lighting, as outdated indoor and outdoor lighting infrastructure in various municipalities consume substantial amounts of electricity. The gaps in knowledge and information flow between various actors involved in innovative lighting procurement are of major concern; these factors will be elaborated on in this report. Innovative business models have the potential to solve some of these issues and promote sustainable lighting solutions.

Essentially, innovative business models can encourage **effective use of products** through proper maintenance and reuse. They also **promote resource efficiency**, **recycling and remanufacturing** of products or components, and design changes that **increase the product lifespan**.

In this paper, we aim to provide a **summary of different business models** and outline the **challenges and drivers** from the perspective of different actors that are relevant for the application of sustainable lighting projects. To do this, we aim to examine the **role of different actors and their relationships** in the procurement process. Although several successful LED projects also exist in Denmark, our findings are based on a review of literature and five interviews from the Swedish perspective, including

Swedish municipalities (Lund and Malmö), utility companies (Kraftringen and E.ON), and other actors involved in Lighting Metropolis.

Procurement

The procurement process involves continuous improvement of procurement methods and stakeholder collaboration, ongoing monitoring of installed luminaires to ensure proper maintenance, and technological improvements. As such, periodic tenders are often issued alongside on-going field trials. Municipalities usually call upon manufacturers to offer bids to increase competition and increase innovation.

Key factors to consider when developing procurement models are:

- Availability of capital,
- Need for external expertise,
- The desire for asset control, and
- The city's risk aversion.

Once these elements have been identified, choosing an appropriate procurement model is easier.[6]

Business Models

According to the interviews, the most common business model is the self-financing business model, which is used by municipalities (Lund and Malmö) and utility companies (Kraftringen and E.ON). In this model, utility companies are dependent on the municipalities.

The costs required to scale up LED lighting remains a significant barrier, but different models can accelerate the development of LED projects in cities. Several interviewees have implemented different models also found in literature, the most relevant of which are highlighted below.

Self-financing

A municipality can allocate funding from its own annual capital budget. This capital is often raised from bonds or other forms of credit issued by the municipality. Although this is a simple and efficient method of financing, LED projects must compete with other projects for capital. According to the interviews, this model is the most conventional procurement model used by municipalities.

Leasing

Instead of purchasing the lighting products, the city may choose to rent the lighting infrastructure. In most cases, an LED manufacturer or finance institution provides the funds for the retrofit and initially maintains ownership of the assets. Later, the manufacturer transfers the ownership of the infrastructure to the municipality at the end of the contract. However, national tax laws often determine how the lease operates. Although this model has not been implemented by any of the interviewed parties, it is often discussed and perceived as an innovative business model. This low-risk business model may prove vital for smaller municipalities in Sweden, as municipalities do not independently bear the financial or technical risks.

ESCO Contracting

In this model, the capital is provided by specialized Energy Service Companies (ESCOs). In an ESCO, energy savings are shared between the ESCO and the client over a period of time. The ESCO assumes the performance risk by guaranteeing a specified level of savings.[3] Based on a study by Bertoldi et al. (2003), the main barriers to the full development of the ESCO industry in Sweden are the lack of awareness of energy performance contracting, lack of trust in ESCO solutions, lack of accepted contract conditions by municipalities, and lengthy bureaucratic measures that favour large projects over small innovations.

Kalmar region implemented a large ESCO contract for LED street lighting under the Streetlight-EPC project of EU.

Joint Procurement

Joint procurement is a two-stage model in which a number of municipalities join to form a collectively-owned non-profit company. In the first stage, the non-profit company competitively selects the supplier to manufacture the products. In this stage the non-profit company also selects the operator that provides service over the full project lifecycle, including designing, maintenance, and interfacing with local utility companies. At the second stage of the model, the non-profit company negotiates a framework agreement with the operator, which allows each municipality to independently negotiate the specific design and expenses of their lighting system.[2]

Joint procurement is being used to retrofit street lighting in the province of Ontario, Canada, where clusters of 444 municipalities represent 13.6 million inhabitants. This model could be replicated in Sweden, where there are several similar municipalities that would like to implement sustainable lighting solutions but face obstacles including the gap in knowledge and information. This model and growing in-house competence for implementing such solutions can help Swedish municipalities overcome these barriers.

Product Service System (PSS)

Selling light as a service instead of a physical product is another innovative business model. PSS has not yet been implemented by any of the interviewed actors. However, some voiced their belief that implementing such models could have a significant impact on the transition to more sustainable lighting solutions. Philips, a leading LED manufacturer, has actively implemented a PSS business model as seen in the figure below.

PSS is already being implemented in three other Swedish municipalities for various types of public services. In Tierp Municipality, Uppsala County uses this model for indoor lighting of a school. In Sala Municipality, Västmanland County also uses this model for refurbishment of street lighting. Lastly, in Oskarshamn Municipality, Kalmar County uses a PSS model for lighting on bike lanes.[7]

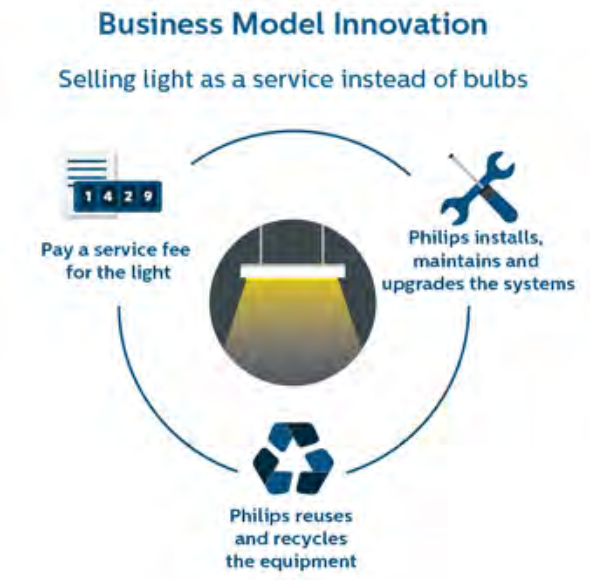

Figure 1 Phillips' PSS model (source: Ellen MacArthur Foundation case study)

Present Challenges

The main concerns to procuring new innovative lighting solutions are **formulating needs**, **exploring the market** and **evaluating options**. According to different actors in the Swedish lighting sector, present challenges include the following[5]. The following challenges are not a comprehensive list, but are referred to in literature and are common challenges of the interviewed actors.

Product Quality

Product quality may become a concern for municipalities as external producers offer increasing amounts of lower quality solid-state lighting products.

Compatibility between old and new

Existing outdated infrastructure may also be an impediment to these business models. Updating

infrastructure may require an added investment cost to transitioning towards innovative lighting.

Allocation of responsibility

There are different actors generally involved in the procurement processes of lighting. Additionally, the degree of interaction between the different actors involved plays a role in the procurement of innovative lighting solutions.

Mapping the Various Actors

The interviews conducted with four actors (Malmö Municipality, Lunds Kommun, Kraftringen Lund, and E.ON) helped understand the requirements and roles for sustainable lighting projects from the different perspectives of municipalities and utility companies. The perspectives below are based on interviews and are not representative of all of Sweden.

The diagrams on the following two pages (figures 2 – 5) show a comprehensive view of the perceived roles and relationships between the different actors involved in the procurement of innovative LED projects under Lighting Metropolis.

Each box represents an actor, and the arrows represent the relationship between the connected actor. The direction of the arrows shows the direction of the flow of support between the two actors. The thickness of the line depicts the relative strength or level of dependency between actors, with a thicker line denoting a stronger relationship or higher level of dependence.

Key Drivers Moving Forward

There are several drivers for the uptake of innovative lighting projects; **energy conservation** and **energy efficiency** are regarded as the biggest drivers, which also result in cost savings. A second driver is the **longevity of LED** lights in comparison to incandescent bulbs and compact fluorescent lamps (CFL). Additional key drivers that arose during the interviews, include **public health and safety.** For example, LED lighting helps pedestrians navigate through footpaths. In order to achieve that, some municipalities encourage public participation and social engagement.

Furthermore, **cooperation between the various involved actors** is key to further the promotion of innovative LED lighting projects. Lighting Metropolis provides a platform for such cooperation to exist and take place.

Conclusions and Main Considerations

One of the **most common shared challenges** is the lack of information and knowledge exchange between various municipalities and utility companies. As exemplified by the previous diagrams, there seems to be a discrepancy regarding the perspective of the different actors and what they perceive their role to be in procuring more innovative LED projects. Additionally, larger municipalities have better access to resources and in-house competence in comparison to smaller municipalities. Therefore, such discrepancies may lead to a lack of exchange of information and knowledge. Despite the fact that such platforms for knowledge exchange exist (Lighting Metropolis), **what seems to be missing** is the direct channels and networks of knowledge sharing between the actor (i.e. municipalities and utility companies), as actors perceive the roles of others in a different light. Seeing as the type of relationship and perceptions of the role of different actors involved is unclear, the flow of information and knowledge exchange has been rather limited.

We argue that a **main consideration** to moving forward and adopting innovate business models for LED lighting is laying out a clear framework of the actors involved and mapping out their expected roles prior to the uptake of the project.

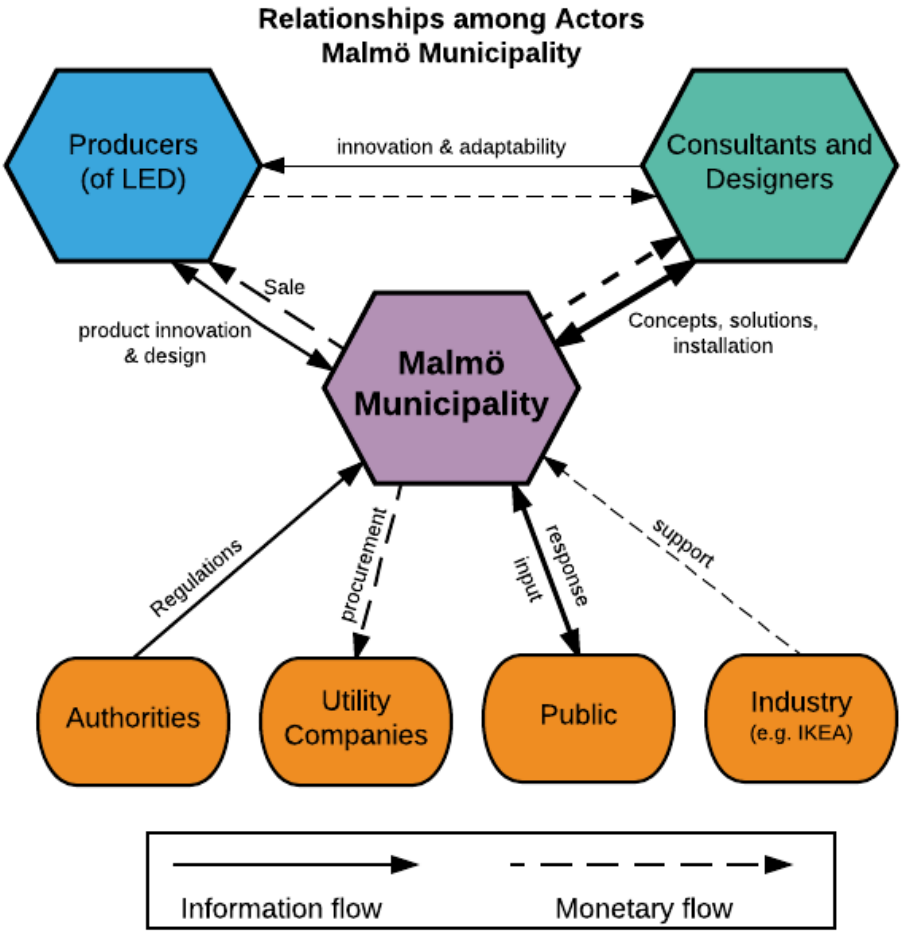

Figure 2 Relationships among actors according to Malmö Municipality

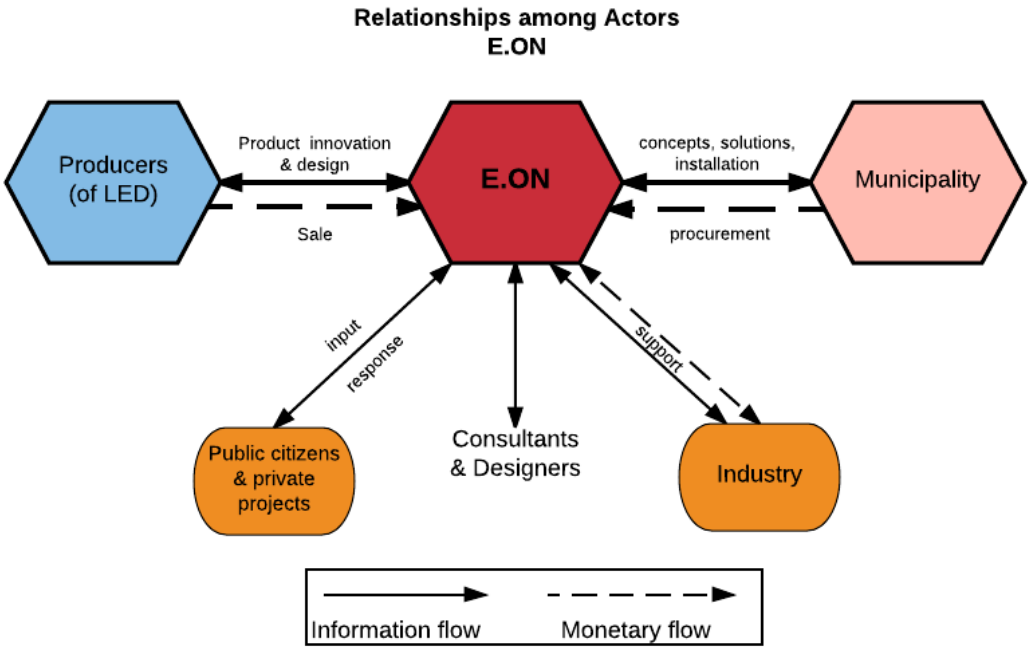

Figure 3 Relationships among actors according to E.ON

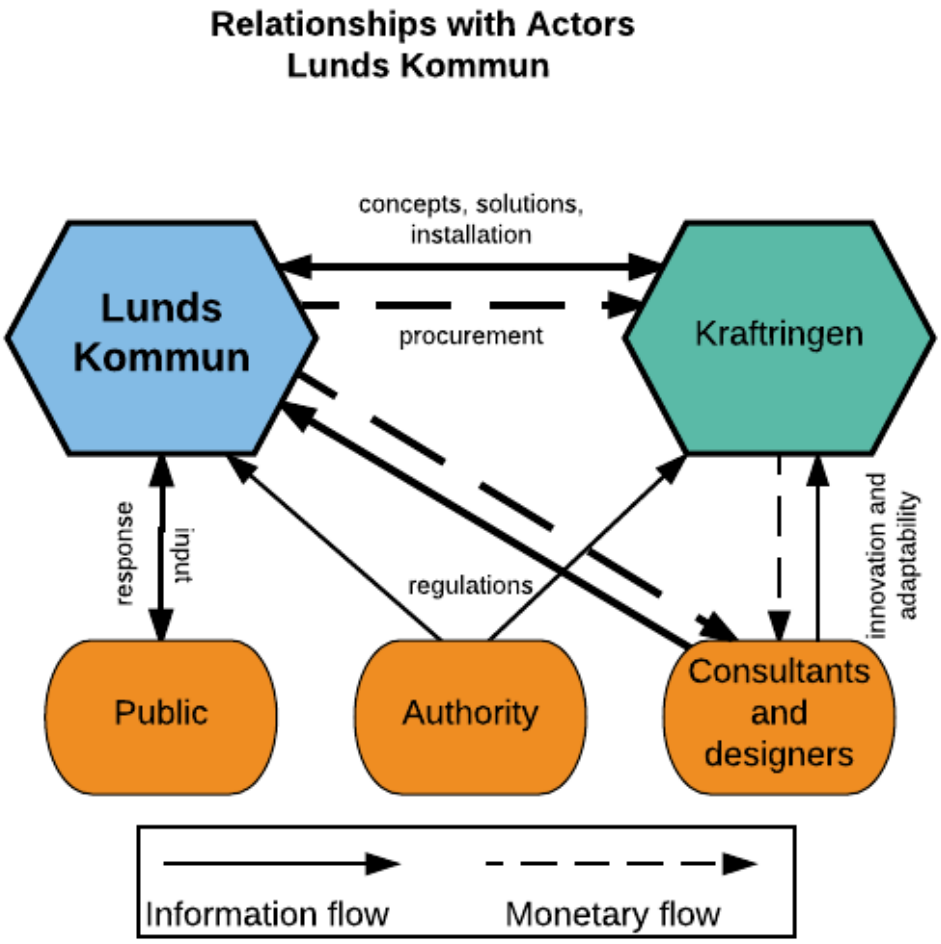

Figure 4 Relationships among actors according to Lunds Kommun

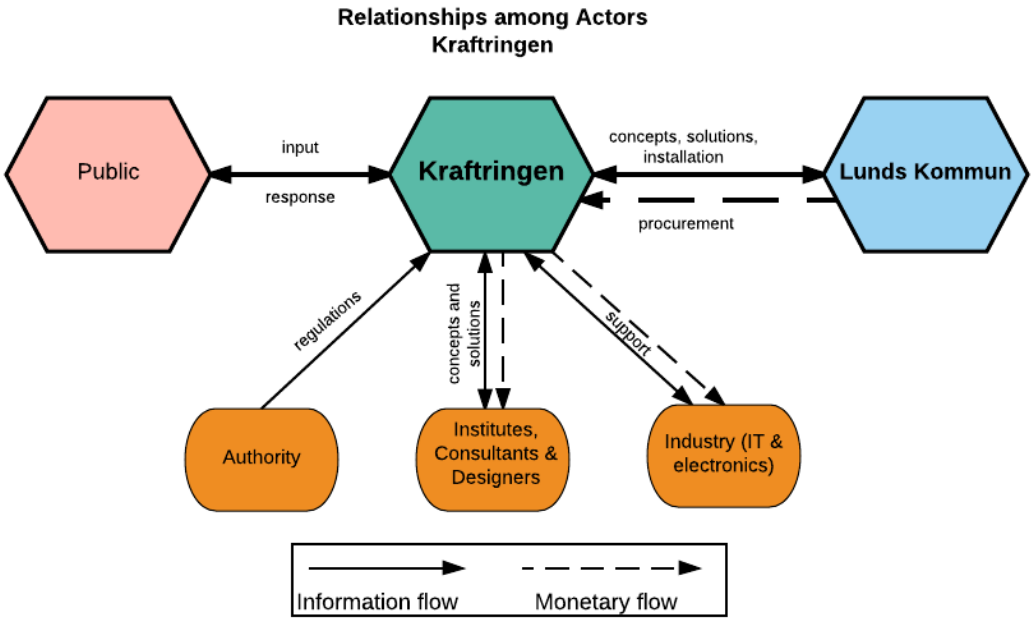

Figure 5 Relationships among actors according to Kraftringen

In regard to the uptake of innovative business models in procuring LED lights, a main challenge deduced from the interviews and literature review is the lack of awareness concerning the concept of what a business model ensues. Nevertheless, there seems to be large interest and potential in adopting more innovative business models. The main task is identifying the key actors and the inclusion of different actors - such as designers, consultants, and educational institutions - for initiating such business models.

In essence, as actors move toward procuring lighting for an innovative LED lighting project, a primary consideration is to recognise which innovative business model they aim to adopt, what this would entail for the roles of other actors, and the existing channels of knowledge exchange and support between them.

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LED'S UNDERSTAND MUNICIPALITIES

Challenges with Decision Making for Light Procurement

By Julie Emmrich and Caroline Heinz

Procurement can be a crucial step to the transition decision of moving towards more sustainable lighting solutions. Analysing the decision process on a public level helps to understand what elements influence decisions and what considerations are critical. This explorative study aims to better understand the decision-making process of a distinct set of municipalities part of the Lighting Metropolis (LM) project which explores innovative lighting solutions for climate smart cities.

The project was conducted in the Greater Copenhagen Region. The area covers the Region Skåne in Sweden, Capital Region of Copenhagen, and Zealand in Denmark, overall, consisting of 3.8 million inhabitants. In total, ten in-depth interviews were conducted with representatives of municipalities as shown in the map on the next page, in addition to two network partners of LM: Gate21 (Denmark) and Innovation Skåne (Region Skåne, Sweden) and the Lund-based energy company Kraftringen.

The paper is structured as follows. It starts by giving a general overview of the decision-making process for lighting solutions in municipalities. The following sections reflect the structure of the conducted interviews. First the decision structure is addressed, illustrating how it differs across the different municipalities. Subsequently, information which influences the decision-making process is elaborated, as well

Main findings box

The decision process differs greatly among municipalities.

The resources available to a municipality strongly influence the lighting strategy adopted.

Overall, experience is sourced from networks, conferences and workshops, while consultancies can provide support for product selection, lighting strategy and lifecycle concerns.

Municipalities show interest and acknowledge the fact that lighting solutions need to be addressed but do not necessarily recognise their potential to lead change.

Municipalities have or seek to take control over their lighting infrastructure rather than outsourcing. It is due to the split incentive dilemma of companies.

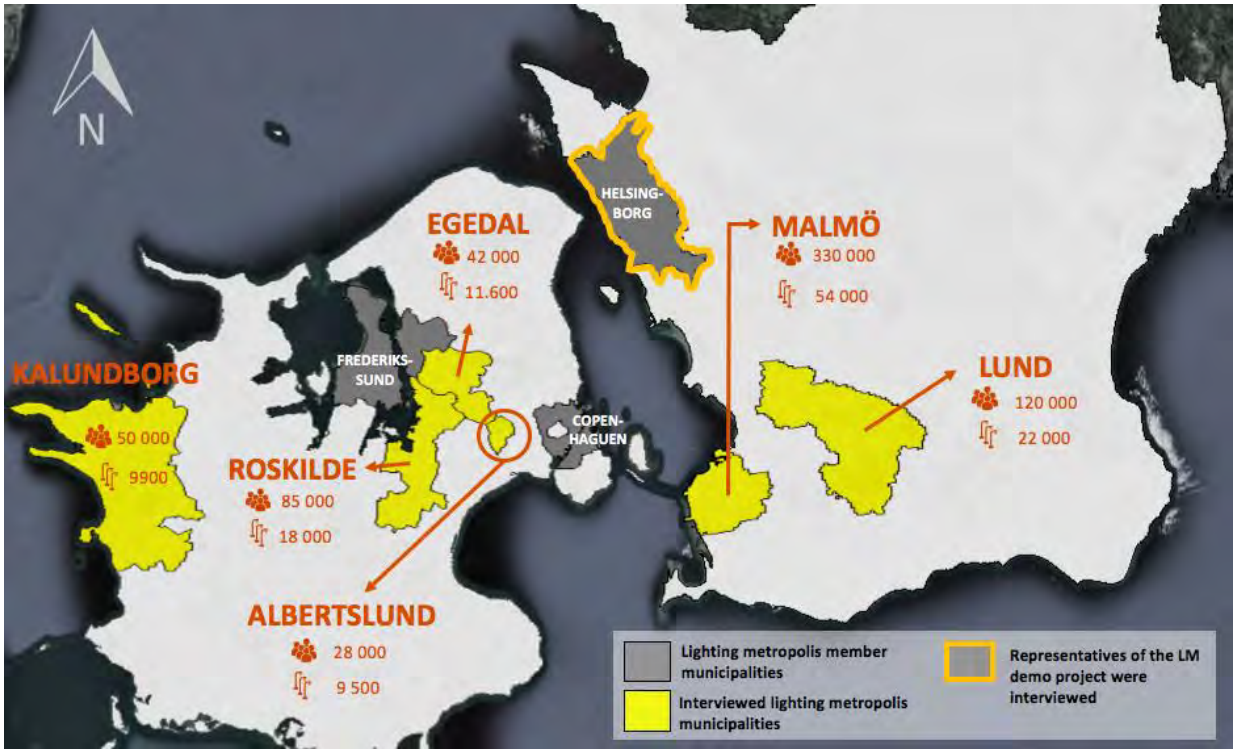

Figure 1 Lighting Metropolis covered area and member municipalities as of December 2017. Source: Authors' own figure. Data: Google Earth, 2017, and authors.

as where it is sourced from. The paper then discusses the role of municipalities in light procurement. Finally, the paper concludes with a set of recommendations and a future research.

Procurement process

In general, municipalities either own the public lighting infrastructure themselves or it is owned by an energy utility company. The procurement process of lighting strongly depends on the ownership. However, most commonly within the studied area, the procurement of urban lighting or lighting upgrades represents a political decision made by city councils and is based on a politically adopted lighting plan or strategy. When discussing the projects managed in the context of LM, however, the purchasing decisions might be more dependent on the actors involved and the project manager's final say.

What is clear when analysing the findings is that the decision-making process and the knowledge base immensely rely upon the resources and people responsible for the lighting projects. While the project manager in charge of a municipality's involvement in LM is often not a lighting specialist or responsible for the procurement process, the decision process often happens in collaboration with the lighting department of a municipality, an expert or external consultant.

The discrepancies between municipalities in their roles and proactiveness; with regards to developing a sound lighting strategy and procurement criteria for LEDs, is often influenced by various factors:

- the size of the municipality,
- the financial means or willingness to allocate budget for lighting,
- the awareness level of the project manager,
- or the 'champion' role of a person within the municipality driving the issue forward.

Thus, while some municipalities are at the forefront, it is often very difficult to fully grasp every aspect of lighting solutions.

Lighting strategy

Municipalities have different approaches when developing a lighting plan or strategy. While it can solely consist of changes to the existing infrastructure, such as restoration work or lighting upgrades, it is often part of a city's master plan or development strategy. Thereby, certain environmental benefits of LEDs are not actively being considered but help their diffusion.

While lifecycle thinking is a rather abstract concept, the opportunities offered through low maintenance, flexible savings behaviour, or the lifespan are perceived as positive benefits of LEDs.

There are several examples of the distinctiveness of what drives lighting solutions can be found in some of the following examples. One such example is Egedal, where one third of the light bulbs were changed to LEDs in 2015 in order to obtain energy savings that could add to the goal of cutting down the municipality budget by 2% annually. Another example can be illustrated by Malmö's masterplan that is based on four rules. These consist of the following:

1) Light where it is needed;

2) Light shows the way;

3) Light where it's beautiful; and

4) Darkness is needed.

While Lund does not have a specific lighting strategy, upgrading is characterised by a collaborative effort with lighting designers. This helps the municipality to determine locations where better lighting is needed and to invite citizens to make better use of them. A guideline for superior goals further informs the distinct projects around the need to "design, install and test different lighting installations for walking and biking paths which create attractiveness, safety and increased usage of public space".

LEDs … to obtain energy savings … cutting down the municipality's budget by 2% annually.

Policies

While policies specifically play a role to inform municipalities of what to do with lighting and where to start, they are generally taken into consideration when upgrading or procuring lighting[12]. Some of the policies that play a more specific role are the EU Directive on Public Procurement, National procurement legislation, or the EU ban of certain light sources to name a few. However, **they often act as background information and are not perceived as a real driver for change.** Some municipalities also understand the role of lighting as a contributor to their energy plan, while others are rather critical with regards to its actual contribution to CO_2 emission reductions. An example of how far municipalities' ambitions can go and even reach beyond national policy is illustrated by the DOLL project initiated in Albertslund. The municipality perceives lighting as part of attaining bigger targets, such as its goal of becoming carbon neutral by 2025.

Some municipalities also understand the role of lighting as a contributor to their energy plan, while others are rather critical with regards to its actual contribution to CO_2 emission reductions.

Decision Structure

The decision structure varies greatly amongst the municipalities and affects the considerations taken when procuring lights.

Who is involved

The decision-making process for procuring public lighting up to the point of releasing a tender is a rather variable procedure. The interview findings, point towards differences in the constellation of actors involved in the procedure. While some municipalities have a designated person for the task others have a more complex decision structure in place.

In the case of the Roskilde municipality, working groups have been set up for the various projects. This follows a matrix management strategy[3], where people from different departments are chosen to work jointly on a given project. This approach is especially useful to overcome knowledge barriers and to ensure an interdisciplinary approach[3,4]. It was evident from the interviews conducted that not a single person is fully involved in the process in its entirety. Challenges with the matrix approach include the loss of responsibility and accountability as the project is not allocated to a specific person or department[4]. Therefore, it is crucial that the gathered knowledge is not lost once a project has been concluded but that it is documented and available to future decision makers.

Key actors for developing a municipality's master plan are the urban developers and landscape architects. In fact, they usually incorporate lighting to some extent. In parallel, the department in charge of light operation and maintenance is also relevant to the decision process, as they are routinely involved with the municipality infrastructure.

People from different departments … to work jointly on a project… is especially useful to overcome knowledge barriers and have an interdisciplinary approach.

Priorities

Lighting is generally not high on a municipality's agenda, and rarely represents the sole responsibility of a department. Yet, upgrading to LED technologies can lead to energy savings and consequently to cost reductions. The electricity, operations and maintenance costs from street lighting are typically the driver for change. In several cases, this has triggered the desire for municipalities to own their own lighting infrastructure, which sometimes includes taking over the control of operations and maintenance.

Energy utilities have a much lower motivation to invest in new infrastructure, which is called a split-incentive.

Due to split incentives, energy utilities companies have a much lower motivation to invest in infrastructure upgrades[5]. The potential energy savings, however, make a good business case for municipalities, which require a quick payback period compared to other public infrastructure.

Lighting represents a higher priority for bigger cities, which is partly influenced by the different lifestyle of the inhabitants, but also because of the lower transaction cost due to economies of scale. In less urban municipalities, lighting cycle lanes or major intersections has been mentioned but generally lighting has a lower priority overall.

Public participation

It is typical for municipalities to make use of public participation tools. Albertslund has integrated public participation into its decision-making process by setting up a purchasing

committee made up of one representative from each of its 54 districts. The municipality has had difficulties involving its citizens due to the technical factors posing a challenge for communicating the benefits of lighting upgrades.

The success of this committee's engagement in lighting can be illustrated by DOLL, an exhibition of public lighting that has become internationally renowned to showcase future light solutions. Similarly, Malmö has a showcase and testing area for pre-selected light products in its harbour area. Malmö has also made use of the local newspaper to get its citizens involved in the discussion around light.

Part of the strategy is to involve citizens in decision-making using showcase areas or surveys.

In a more rural municipality such as Kalundborg it is easier to organise meetings with representatives directly.

Private sector

Municipalities often refer to the private sector for expertise due to the lack of in-house knowledge. However**, companies that need to win tenders based on specific criteria have no interest in the inclusion of particular requests for innovation, environmental and social criteria that go beyond the legislative framework as it limits their competitiveness.**

The private sector provides the supply of lighting solutions, from which the municipalities can choose products and services. The LM demo projects that have been initiated by the partner municipalities, however, represent a great platform to exchange ideas and initiate stronger cooperation between the public and private sector. The municipalities and the organisations interviewed acknowledge the benefits of the platform.

More understanding of public-private partnerships is needed to drive knowledge exchange and innovative procurement.

Informing the Decision Process

Municipalities gather information through various channels to inform their decision-making for public lighting. The urban development department is typically at the forefront of municipal infrastructure projects, although various other actors may also be involved. This section discusses the information sourcing procedure of these relevant actors.

Context

The scope of information sourced before procuring lighting solutions depends on the resources available to a municipality and specifically the resources allocated to lighting. The interview findings have underlined these discrepancies. Additionally, the aforementioned decision structure also influences the information flow.

Inter-municipality

Firstly, municipalities are public institutions bounded by law to act transparently. This is a positive prerequisite to share information and experiences. Contrastingly, private entities compete on the market and are bound by secrecy. Municipalities can share their experience of products, companies, and conducted projects, such as contracts for operations and maintenance of street lighting. Therefore, municipalities can learn from past mistakes or negative experiences encountered by other municipalities. Whereas most municipalities mentioned other municipalities' experiences to inform their decision process, this seems to be a very informal procedure and geographically limited.

Municipalities can freely share information, which gives them an advantage over the private sector.

The most interesting finding in inter-municipality communication is the partnership between Albertslund, Ballerup, Egedal and Frederikssund. Ballerup procured a lighting control system from Svargo, but encountered difficulties with the product. The neighbouring municipalities joined together and used Ballerup's experience to increase their leverage in negotiations with Svargo. This increased leverage led to a better implementation of a control system for urban lighting

Lighting Metropolis

The Lighting Metropolis is generally seen as a fruitful network of information. The project offers various publications on its website, but most importantly it conducts workshops and conferences for participants to share experiences. The so-called demo projects in collaboration with partner municipalities are showcased. Each project uses the triple helix structure based on the creation of a partnership between a municipality or municipal entity, a private actor and a university or research institution.

While the LM network drives innovation in the interaction between humans and light, the environmental requirements are being neglected.

At present, there is no particular requirement regarding environmental or social factors in the procurement of lighting solutions. Yet, all interview participants agree that this is a rising concern and refer to the need of a second phase of LM to pick up on these matters.

Some municipalities also have partnerships with universities to drive innovative lighting systems, yet most of these partnerships do not seem to include environmental or social considerations.

Consultancies and agencies

Most municipalities refer to consultancies or agencies, such as Gate21, to source expert knowledge on lighting solutions. Yet, **Gate21 and Innovation Skåne do not formally make recommendations on purchasing decisions for lighting.** They do however, organise networking events, workshops and conferences to share experiences from municipalities and companies.

Apart from the Lund municipality that specifically works with an advisor on public lighting from Kraftringen, other municipalities periodically hire consultants as required, for instance before procuring public lighting. Therefore, information sourcing is not long-term orientated and constant.

Information sourcing is fragmented.

Typically, reports and recommendations from consultancies take environmental and social factors more into account compared to municipalities. For example, before Egedal upgraded 3600 light points (31% of total) in 2014, it hired consultants to inform their decision process. The report included concepts on Best Available Technology, Lifecycle Cost and the EU ECO Design Directive. On the contrary, Malmö has put in place a long-term strategy based on the replacement of 2500 light points per year on average (5% of total) and its information sourcing is more constant.

In-house expertise

The **municipalities with access to proper resources allocated to lighting (development) are inherently able to source information on a continuous basis.**

Albertslund, Malmö and Roskilde have all shown to have an in-house expert that has overarching knowledge on lighting. These experts can attend conferences and workshops and are part of several networks such as Gate21, LM or the Lighting Urban Community International (LUCI) Association. Furthermore, the dedicated person is able to represent the municipalities' interest and negotiate with companies to achieve better outcomes for the municipalities. This may lead to higher transaction costs, but replaces the need for consultancies and is beneficial overall.

Role of municipalities

While municipalities represent the biggest consumers for lighting, their lighting choices and strategies have not only an important impact but can also contribute towards achieving national emission reduction targets. However, the political agenda and priorities are often focused on more pressing issues. Therefore, while they are surely important actors in the transition towards change and innovations they need to think foremost about the functionality of light for their citizens.

However, the LM network has helped to further ambitions and changes by not only spreading the interest in the sustainable application of lighting, but also fuelling the uptake from the market. Some municipalities have shown that they are further ahead than the national government since they care about making a positive impact on the municipality's future.

It is increasingly important that the benefits of lighting are highlighted through a good business case so that the municipality can weigh it in its priorities, especially since it is still far away from being perceived as an urgent issue. Furthermore, not all citizens are prioritizing sustainability, which is why lighting often acts solely as an added value instead of the main driver for change and innovation.

> *These 'champions' reflect an increased awareness of how lighting needs to be pushed onto the political agenda and how it can contribute to a smart city integration.*

The case of big municipalities coming together, such as Malmö and Copenhagen, illustrates the leverage that they can have in influencing companies' offers for more innovative solutions and options. Lighting should, therefore, not only be perceived as a part of the future infrastructure but also as a gateway towards influencing interactions of citizens with their municipalities. The example of Svebolle, the living lab of the Kalundborg municipality, highlights how lighting will be integrated in educational activities and help to drive innovation even in small municipalities in the future.

The blurring of the lines between sustainable lighting and smart city can, therefore, offer an opportunity to integrate one with the other. Some of the main drivers for these developments are found in the incentives based on cost savings, the ability to raise awareness and to offer new services in line with targeted locations to increase their use and benefits for citizens.

Financial barrier	Technical barrier	Knowledge barrier	Capability barrier
High upfront cost	Uncertainty about the quality of light sources with regards to their lifetime, colour rendering, flickering	Holistic long-term planning crucial for successful lighting solutions	Lack of availability of necessary skills
Competition with more important priorities in municipal budget	Concerns around durability of different components	LEDs perceived as important to be part but benefits not as clear	Lack of necessary resources and expertise
Need of a good cost benefit analysis	End of life (manufacturing and reusability)	Difficulty of involving citizens in lighting due to the technicalities of it	
Not enough national or regional public funding	Compatibility of fixtures with LEDs	Utility companies hold the expertise and knowledge that municipalities need to ensure the inclusion of specific criteria in tenders	

Challenges

Municipalities face various challenges when procuring lighting solutions. The table above summarises the main obstacles, based on the conducted interviews as well as on the works of Novikova et al.[5] and Plepys and Richter[6].

Conclusion and recommendations

Reflecting on the findings, the first phase of procuring lighting solutions for municipalities includes considerations for functionality and opportunities offered by LEDs. Hereby, LM has been helpful in the dissemination of information about new technologies and innovations. The decision making of municipalities also includes a concern for better accessibility, security, human health and animal wellbeing.

Outlined in the recommendations boxes are various steps that municipalities can take in order to improve the procurement process of lighting solutions. Future research could further look into how the power and leverage dynamics between the various actors that are part of the network can influence information flows or the decision-making process of lighting solutions. Another research aim could be to look at what municipalities are doing in regard to lighting solutions that are not part of the LM network. This could help to investigate how they inform their decisions and how important being part of a network really is.

Recommendation 1:

The role of innovation and contribution to change should be further highlighted.

Here, practices from other areas can be taken over and guidelines set up that can better inform a municipality's decision-making process. An example could be to become part of a national group for ethical buying, 'Etisk upphandling', that discusses what criteria to set in the tenders for materials used in buildings. Or to raise the need for including lighting within the scope of these roundtables.

Recommendation 2:

LM should continue to offer a platform for municipalities to continuously build on the gained experience.

The need to share knowledge has been well underlined throughout the findings and illustrates that there is an immense need to share more on issues related to sustainability. A consideration for how to transfer the knowledge gained through demo projects and how to include these in future decision-making processes should also be addressed. Ideas such as creating a knowledge bank or other ways to exchange information effectively should be thought of to be able to continuously build on gained experience.

Recommendation 3:

Issues that need to be addressed further:

1) The **development of more innovative procurement processes.** Municipalities should be aware of the leverage they have when it comes to including more stringent environmental criteria in their tenders or procurement processes.

2) **A better collaboration with utility companies** could contribute to the development of more innovative business and procurement models.

3) **Different departments could work closer together** in order to implement a long-term strategy.

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This year the MESPOM cohort of 2016-2018 had the opportunity to venture into LED lighting procurement processes. This insightful journey involved gathering scientific studies, published literature and collecting data through field visits and interviews to create a picture of the existing situation, the measures taken by various actors to address the issues in various procurement phases of LED, and finally to propose actions for the future.

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MESPOM Masters in Environmental Science, Policy, and Management

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The Authors

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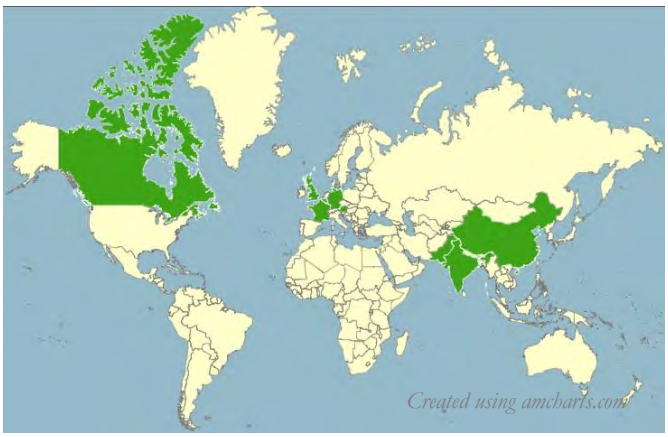
Students study in at least three out of six consortium universities: Central European University (Hungary); University of the Aegean (Greece); Lund University (Sweden); Manchester University (United Kingdom); Middlebury Institute of International Studies at Monterey (United States); and University of Saskatchewan (Canada).



MESPOM batch 12 consists of 22 students from 17 different countries. The 11 authors of this text are studying at the International Institute of International Economics (IIIEE) at Lund University during the autumn 2017 semester. These 11 students represent Austria, Belgium, Canada, China, France, Germany, India, Palestine, Pakistan, and the United Kingdom.

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