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Update on the Status of LED-Lighting world market since 2018

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Executive Summary

This report, based on the compilation of more than 160 recent documents, is an update of previous analysis published by the JRC in 2018, 2014 and 2013. It brings new insight into the progress of Solid-State Lighting Technology and Lighting Systems as well as an overview of the world market evolution by world region and by end-use sector. The last evolutions in the industrial ecosystem are also covered. Furthermore, the impacts of technology evolution, like smart lighting, on the energy, environment and natural resources are highlighted. The initial effects of the Covid-19 pandemic are also included, even if it is rather early to draw final conclusions.

Artificial light energy consumption is around 2 900 TWh, corresponding to 16,5% of the world's annual electricity production. Even if this quantity is still very high, it should be noticed that until the beginning of 2010, electrical light sources were considered responsible for an energy consumption of around 2 651 TWh, which represented roughly 19% of world's total electricity consumption. This tendency suggests the beginning of a harnessing of consumption that can be explained by the increase of light system efficiency when keeping service levels stable (measured in quantity of light).

Today, the importance and application of these "legacy" lighting technologies is decreasing. During the last decade, SSLs-Solid-State Lighting, based on components like LEDs, OLEDs and LDs, challenges conventional technologies. In particular, LED has turned into a game changer beating conventional technologies on all aspects. It is therefore anticipated that in the short term, all electric lighting will be based on SSLs. Today, SSLs proceed to the projected conclusion: replacing all legacy technologies; a major change in the lighting market that is considered revolutionary. The current LED-based systems penetration is 40-45% and growing. The massive adoption of SSLs in the next years alone can contribute to reduce electricity use for lighting, up to 4% by 2030, but a "rebound effect" can seriously undermine this prediction. One potential solution to avoid that negative effect consists in switching to smart human-centric lighting driven by both "application efficiency" and quality of light. This just means that next gen lighting systems should provide the "Right Light" with the best efficiency and quality, when and where it is needed.

Last years' technological advances concern both components and lighting systems. Performances of packaged W-LEDs are still improving every single year, even if some signs of saturation start to appear. The improvements concern several characteristics like luminous flux and luminous efficacy (LE), white colour quality and CRI. Furthermore, cost per generated lumen by packaged LEDs is still decreasing.

Today, the production of white light from phosphor converted LEDs (pcw-LEDs) is a fully mature technology, while package's LED is still improving. The forecasted ultimate goal for packaged pcw-LEDs is as high as 255 lm/W. In many developed countries, the efficacies of LED lamps available for residential use are already 110 lm/W to 130 lm/W, and they need to increase to an average of 160 lm/W by 2030 to meet DOE's SDS ambitions. Organic light-emitting diodes (OLEDs) have also been considered for several years as a promising technology for solid-state lighting sources, thanks to their high-quality and healthy white light. Their penetration in the domain of lighting is more complex but still possible. To fully penetrate lighting, OLEDs must overcome the challenges in reducing cost and in commercialising the high-efficacy performance that has been demonstrated in the lab. The idea to replace blue LEDs by blue laser diodes (LDs) has been demonstrated in early 2000's. Since then, several academic laboratories and industry development departments across the world are interested in the technology and its potential extension to lighting.

Professional market analysts estimated that the global lighting market size reached US$ 118,33 billion in 2019 and is projected to reach US$ 163,72 billion by 2027, exhibiting a CAGR of 4,3% during the forecast period. In 2019 general lighting represented 79% of the above figure, followed by the automotive lighting segment. Further forecasts show that the market for SSL source components will grow from US$ 20,4 billion in 2018 to US$ 32,3 billion in 2024, at 8% CAGR between 2018 and 2024. COVID-19 pandemic has already impacted the lighting market across the globe, and undoubtedly it will continue to show its effects. Further, the world trade of lighting fixtures among the 70 countries representing the whole global production and 97% of global consumption has expanded in terms of both imports (US$ 42 billion; +4,3% YoY) and exports (US$ 42 billion; +5,1% YoY). The European Union (EU) lighting market is expected to grow from € 16,3 billion in 2012 to € 19,8 billion in 2020 [CBI-14] and it will surpass a remuneration of US$ 30 billion by 2024.

Historically speaking, past century's research and development focused on single energy efficacy enhancement. As SSL technology matures, maximising the energy savings from connected SSL systems will become

increasingly dependent on the successful integration into the built environment. Furthermore, we are witnessing a transition from the conventional “analogue” lighting technologies to “digital” lighting. Intelligent lighting will become the backbone for smart homes and smart cities. This way, lighting will become the heart of the “Internet of Things”. Consequently, we knowingly were not serving society as effectively as we could. Industry has coined a new term “human-centric lighting” (HCL) to draw renewed attention to its primary effort to be successful in meeting society’s needs.

1 Introduction

The human race has always known that fire and heated objects emit light that can be used for lighting purposes; this knowledge led up to the discovery of artificial lighting. Since the end of the 19th century, artificial lighting has been the subject of a continuous and fascinating evolution; 20th-century scientists and development engineers worldwide created such a wide range of lighting solutions for every lighting application. Today, the importance and application of these “legacy” lighting technologies is decreasing. In fact, as the International Energy Agency underlines, the momentum created by the ongoing phase-out of incandescent and halogen lamps as well as declining shares of fluorescent technologies is raising lighting efficiency globally. This is a considerable improvement relative to the early 2000s when incandescent lamps were being partially replaced by equally low-efficiency halogens in many parts of the world, including Europe [IEA-19].

Figure 1: A rapid summary of global lighting impact today (the equivalent CO_2 emissions per capita are from [WBG-14])

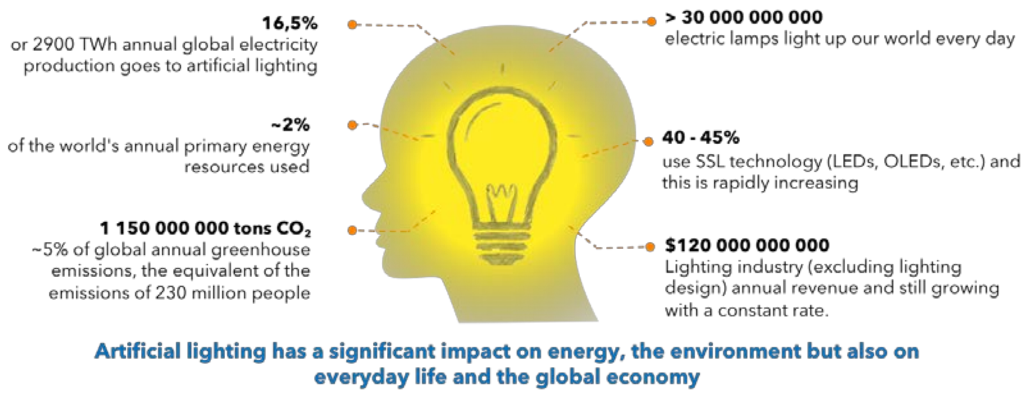


Figure 1 gives a rapid overview of the importance of artificial lighting today. Artificial light production absorbs around 2 900 TWh [UND-17] corresponding to 16,5% of the world’s electricity annual production[1]. Even if this quantity is still very high, it should be noticed that until beginning of 2010, electrical light sources were considered responsible for an energy consumption of around 2 651 TWh [IAE-05] (3 418 TWh per annum following Brown who included the associated power losses in electricity transport lines [BRO-09]), which represented roughly 19% of the world's total electricity consumption. This tendency suggests the beginning of a harnessing of consumption that can be explained by the increase of light system efficiency when keeping service levels stable (measured in quantity of light). This is more than encouraging because in 2013 projections by the International Energy Agency (IEA) shown that if governments only rely on legacy policies (e.g. exclude ban of incandescent/halogen lamps), global electricity use for lighting will grow to around 4 250 TWh by 2030, corresponding to an increase of more than 40% [IEA-13]. As a comparison, it should be noticed here that some projections show that electricity consumption for data centres and associated IT will rapidly overcome lighting, accounting for 20% of the world’s electricity by 2030 [COU-20].

During the last decade, SSLs-Solid-State Lighting based on components like LEDs, OLEDs and LDs, challenges conventional technologies. In particular, LED has turned into a game changer beating the conventional technologies on all aspects. It is therefore anticipated that in the short term, all electric lighting will be based on SSLs. Yole’s analysts forecast that the SSL source market will grow from US$ 20,4 billion in 2018 to US$ 32,3 billion in 2024, at 8% CAGR between 2018 and 2024. [YOL-19]

Today, SSLs proceed to the projected conclusion: replacing all legacy technologies, this major change is considered revolutionary in the lighting market. The massive adoption of SSLs alone in the next few years can contribute to harness electricity use for lighting, up to 4% by 2030. Further, as shown in Figure 2, the adoption of Minimum Energy Performance Standards (MEPS) or/and the use of the Best Available Technology (BAT) can lead to more drastic savings (up to an additional 21%). From its side, the US Department of Energy (DoE) estimates that if BAT efficiency follows the expected track, the savings attained by 2035 could amount to 4,8 quads (~1 400 TWh) per year in the US only [DOE-20].

Moreover, according to an IHS report in 2017, LEDs lighting helped to avoid half a billion tons of CO_2 from our atmosphere. The analyst wanted to share these savings among the main packaged LED manufacturers based

[1] World electricity production in 2017: 17 535 TWh [ENR-19]

on the market shares. [IHS-17] Developing and emerging economies could save US$ 40 billion worth of electricity and prevent 320 Mt of carbon pollution annually simply by transitioning to LED lighting. [HOR-17]

Figure 2: Variation of electricity Savings/Losses for lighting till 2030 following different scenarios. The "Base" line is calculated extrapolating observed consumption values, the reference year is set to 2017; BAU (Business as usual) scenario admits massive replacement of legacy light sources by LEDs; MEPS scenario suppose the adoption of Minimum Energy Performance Standards worldwide; BAT scenario supposes the use of the Best Available Technology in the market. Data from [SCO-17] modified by G. Zissis

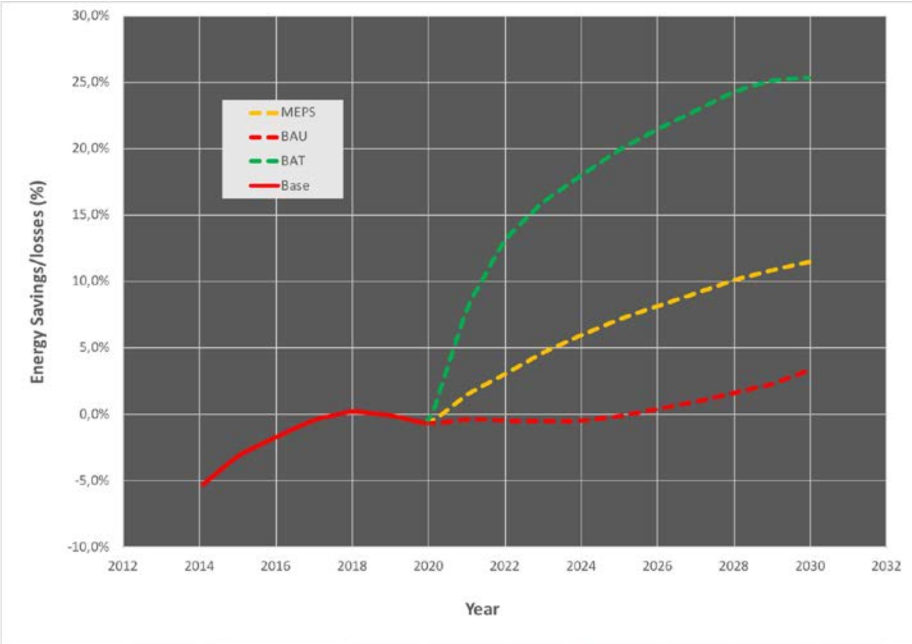
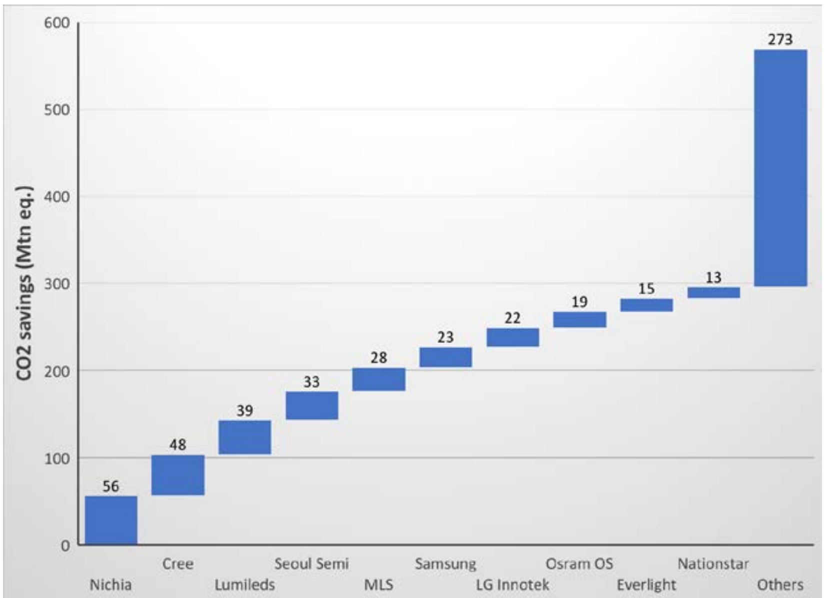


Figure 3: Greenhouse emission savings thanks to LED lighting reattributed to packaged-LED manufacturers. Data from [HIS-17]



However, this model doesn't take into account the behaviour of the end-user and excludes the action of the "**rebound effect**"[2] that tends to offset the beneficial effects of the new technology or other measures taken.

[2] In energy economics, the rebound effect is the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioral or other systemic responses.

For instance, the energy savings could be eroded as people find new uses for the inexpensive lights[3]. As related by the Pulitzer Prize-winning Phil McKenna, Thomas Theis (director of the Institute for Environmental Science and Policy at the University) said "I am doubtful that we will save any energy by going to LED lights". [MCK-15] Hicks et all elaborated various scenarios to illustrate the rebound effect on the average annual US household consumption. [HIC-15]

Figure 4: Results of rebound effect on the average US-household annual electricity use for lighting. Original data from [HIC-15] modified by G. Zissis

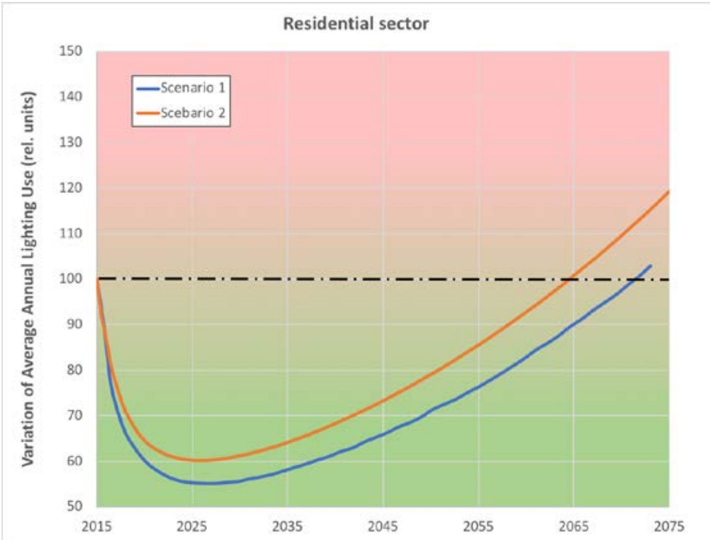
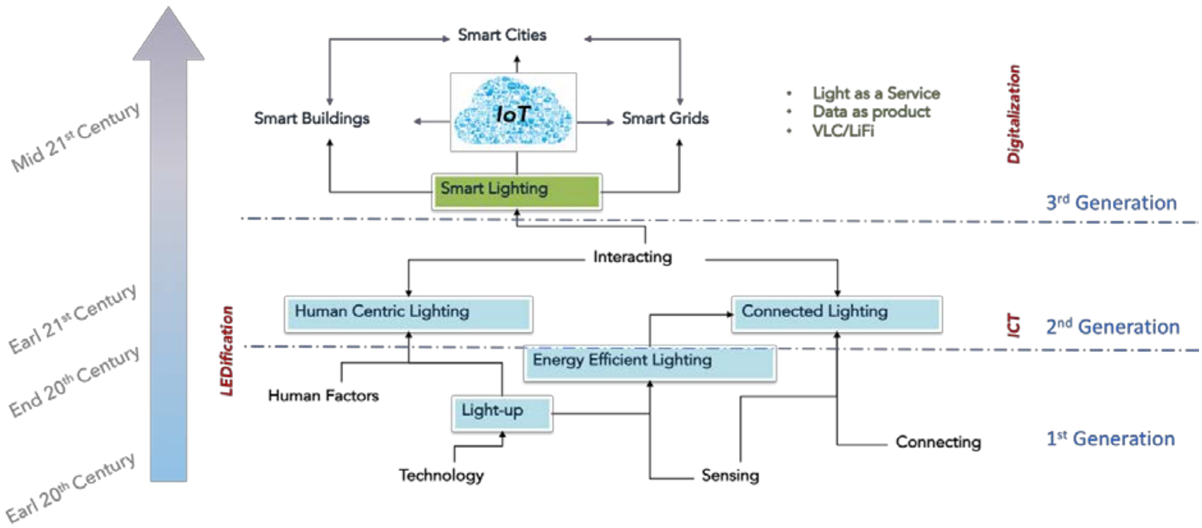


Figure 4 shows the impact of the rebound effect under 2 scenarios – Scenario 1: Individual households don't use more light as the cost of lighting decreases but population growth and increasing in housing size over time result in increase of energy demand for lighting; Scenario 2: Energy use increases over time because individual households demand more light as the cost of lighting decreases and lit areas increase as a result of population and housing area growths. Both scenarios show that the LED "effect" will vanish somewhere in between 2065 and 2070. This is not acceptable; solutions are then necessary to solve the issue. One potential solution consists on switching to smart human-centric lighting driven by both "application efficiency" and quality of light. **This just means that next gen lighting systems should provide the "Right Light" with the best efficiency and quality, when and where it is needed.**

[3] This has been demonstrated in the historic paper by Tsao et al: LEUKOS **6**(4), pp. 259–281, doi: 10.1582/LEUKOS.2010.06.04001 (2010)

Figure 5: The evolution of modern lighting systems responds to society and consumers needs [ZIS-20]



Historically speaking, past century's research and development focused on single energy efficacy enhancement. As SSL technology matures, maximising the energy savings from connected SSL systems will become increasingly dependent on the successful integration into the built environment. Figure 5 traces the evolution in electric lighting systems from its invention until mid-21st century.

Furthermore, we are witnessing a transition from the conventional "analogue" lighting technologies to "digital" lighting. Intelligent lighting will become the backbone for smart homes and smart cities. This way, lighting will become the heart of the "Internet of Things".

Consequently, we knowingly were not serving society as effectively as we could. Industry has coined a new term "human-centric lighting" (HCL) to draw renewed attention to its primary effort to be successful in meeting society's needs.

As LightingEurope [LEU-13] said, "For a long time, the lighting industry has designed products to fulfil our visual needs. With the economic crisis persisting and the awareness of sustainability increasing, customers, policy makers and industry have discovered the energy savings potential of light sources, such as compact fluorescent lamps and LED. While energy efficiency and durability of LED modules is widely known in the market, little attention has been paid to their advanced controllability and related applications. However, **modern trends of people migrating to cities, spending more time in interior rooms, and living longer have amplified efforts to provide a healthier indoor environment**. **Lighting is not neutral in terms of human health**, and adverse effects, such as disturbance of sleep/wake cycles, mood disorders and possibly even cancer pathologies may be the consequences of ignoring new findings on non-visual effects of light. For this purpose, a diversity of light sources with different biological effectiveness, bigger surfaces that reflect or emit light and light management systems that control the proper timing of lighting are needed. Improving lighting quality has a known impact for vision and health. Therefore, there are possibilities for application in nearly all situations of our daily lives."

As SSL technology matures, maximizing the energy savings from connected SSL systems will become increasingly dependent on the successful integration into the built environment. The replacement of legacy lighting infrastructure with LED products offers the potential for future **connected lighting systems (CLS)** that could become a data-collection platform, enabling greater energy savings in buildings and cities. Connected lighting is a catch-all term, a marketing buzzword used to describe any kind of lighting equipment that has an element of intelligence or connectivity to it. Each fixture or bulb in a connected lighting system has its own unique hardware address, though most will need a separate "bridge" to connect the bulbs to the internet. There's a variety of features that would come under the blanket term of connected lighting, so let's take a look at some of the features to look out for. At the most basic level, lighting systems combine luminaires and controls. [BRU-13]

Recent advancements in solid-state lighting, the **"LEDification of lighting"**, have led to breakthroughs in light source efficiency and lifetime. However, the real revolution, the digitization of lighting is yet to come and will involve a paradigm shift from a lighting component approach to an application centric approach. [KLA-13]

In fact, LED technology affords opportunities for integrating controls directly into luminaires. Intelligent or connected luminaires can, in turn, integrate with Information Technology (IT) networks in cities and facilities, and with lighting management software systems that offer new capabilities for monitoring, control, optimization, and autonomy.

Such connected lighting systems can not only drastically improve the energy performance of lighting and other technical systems, but also enable a wide array of services, benefits, and revenue streams that would enhance the value of lighting systems. For a long time, the lighting industry has designed products to fulfil our visual needs with a special focus on energy savings. This model is now obsolete, because of modern trends of people migrating to cities, spending more time in interior rooms, and living longer have amplified efforts to provide a healthier indoor environment. **Human Centric Lighting** (HCL) is becoming the next big step in lighting. Within the range of human centric lighting systems, two major distinctions can be made: on one hand, biologically effective lighting represents lighting systems that are appropriate to stimulate the biological organism, thus improving cognitive performance; on the other hand, emotionally effective lighting systems are designed to create emotionally stimulating environments and appealing atmospheres. [LEU-13] Thus, human centric lighting simultaneously considers our requirements for good vision as well as our emotional and biological needs. Human Centric Lighting coupled with smart lighting is of course the best option.

In a smart lighting configuration, luminaires are uniquely identified and seamlessly integrated into the IT network in a building or city, and share information about their status and operations. Outfitted with integrated sensors, each luminaire becomes a point of intelligence that can share information on occupancy, activity patterns, changes in temperature or humidity, daylight levels…

Furthermore, by integrating wireless communications into the lighting system, location-based services and in-context information can be delivered via mobile apps to people in illuminated spaces. **Thanks to mesh functionality, the wireless network finds the best communication path. The system can include self-healing and re-routing features.** Even in the worst-case scenarios, the data transmission rate remains 10 times higher compared to a powerline communication without interference.

With integrated wireless communications, connected lighting systems can deliver completely new experiences. **Visual light communications (VLC)** use the LED beam itself to send a data signal to the camera of a smartphone running a mobile app. Coded light provides highly accurate positioning, with high precision in the space. In tandem with VLC, systems can use Wi-Fi, Bluetooth low energy, or other wireless communications to deliver in-context information and location-based services. [HUN-15].

Silvair experts believe that smart technologies will fundamentally change the business model of the lighting industry and force all serious market participants to join the revolution or be left on the side-lines. However, this **collision of the worlds of Internet of Things (IoT) and lighting is still in its infancy, making it difficult to predict which of the current trends or standards will come to dominate**. [SLV-15] In fact, as Kirk Bloede, Woodside Capital Partners, expects **smart technologies have the potential to bring a massive breath of fresh air to the lighting sector, which has recently been dealing with a number of challenges**. The integration of digital technologies to create “smart” lighting systems out of previously “dumb” systems has led to the idea of **“Lighting 2.0”**, the idea that lighting can now communicate and interact with its environment and the people or things in it. **The opportunities that these offer are only beginning to emerge, and are expected to increase in range and scope as the LED revolution progresses**. [BLO-15]

Additionally, the deployment of smart lighting systems will inevitably push to an economic model transformation, leasing-type models and ‘pay-as-you-use’ services are expected to grow. The **Light-as-a-service** (LaaS) is one among them. This LaaS concept is expected by most market participants to pick up as a service offering in the future. Key advantages for the end-customer is the ability to use new technology, increase comfort levels and bringing related energy savings, whilst taking away the up-front weight on the balance sheet of customers. [FRS-15] Of course, this model would apply first in smart buildings, then to smart home and smart street lighting.

2 Technological advances

Last years' technological advances concern both components and lighting systems. All these advances serve at least one of the following objectives:

- Objective 1: Increasing the efficiency and reliability in all levels from the component to the global system.
- Objective 2: Reducing the cost of the components and single lamps and using more sustainable materials.
- Objective 3: Enhancing the quality of light associated to the comfort and more focusing on lighting application efficiency (LAE).
- Objective 4: Implementing new functionalities and services beyond basic illumination for vision and visibility.

Since mid-2010 we have been observing a net increase of proposed technological advances at systems level, whereas innovations at component/device-level[4] rarefy. Today, we can identify a number of areas where potential enhancement at component/device level still exists, as shown in Table 1.

Table 1: Potential advances in R&D at component/device level, the objective's number refers to the list given in the previous paragraph.

Domain	R&D efforts and Improvement domains	Concerned Objective
White-light Light Emitting Diodes	Improving basic understanding of LED material-device-synthesis relationships [DOE-20]	Objective 1, Objective 2
	Understanding and Improving quantum dot down converters for on-chip LED usage [DOE-20]	Objective 1, Objective 3
	High Luminance Emitters: Improving efficiency at high luminance to enhance optical control, including device structures and phosphors. [DOE-20]	Objective 1, Objective 3
White-light Large Area Diffuse emitters	Advancing the efficiency and lifetime of emitter materials and device architectures for low profile, diffuse, and direct emitters [DOE-20]	Objective 1
	Improve light extraction efficiency and optical control for low profile, diffuse direct emitters [DOE-20]	Objective 1
White-light Laser Systems emitters	Developing phosphors that converts the laser light to eye-safe, broad-spectrum, incoherent white light [OVE-17]	Objective 3
	Developing phosphors that can support temperature elevation due to Stokes shift losses [TRI-18] and support better long-term effects of intense radiation exposures [CZE-18]	Objective 1
	Developing efficient supercontinuum white laser sources coupled with optical fibres [GRA-19]	Objective 1

There are much more progress to achieve in the domain of global lighting systems as shown by Table 2.

[4] In this text we consider as "component" a single encapsulated small size electronic component whereas "device" corresponds to a larger encapsulated emitting element; both are drive-less but can include some reverse-current protection elements. "Component" applies better to LEDs and LDs when "device" is more appropriated for OLEDs and laser-systems.

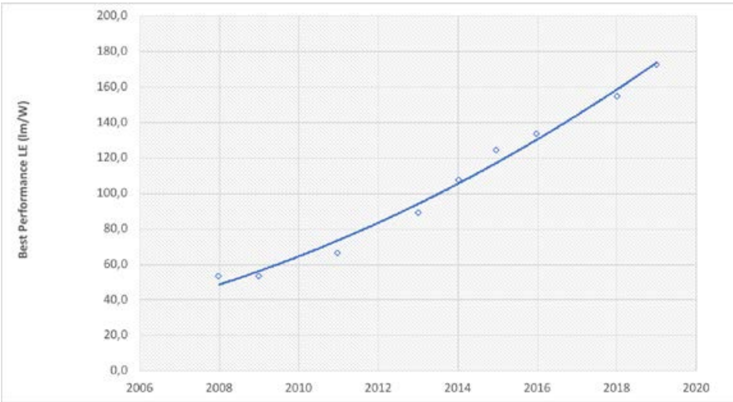
Table 2: Potential advances in R&D at system level, the objective's number refers to the list given in the previous paragraph

Domain	R&D efforts and Improvement domains	Concerned Objective
Lighting System	Developing the Lighting Application Efficiency (LAE) Framework: Understanding relationships between and energy impacts of light source efficiency, optical delivery efficiency, spectral efficiency, and intensity effectiveness. [DOE-20]	Objective 3
	Improve power supply efficiency, functionality, and/or form factors. [DOE-2Ø] Reduce light flicker	Objective 1, Objective 3
Human-centric lighting	Understanding and Demonstrating Human Physiological Impacts of Light: Translate lab-scale human physiological responses to light understanding to practical guidance and understanding of impacts in realistic lighting situations. [DOE-20]	Objective 3, Objective 4
Smart Lighting systems	Develop Connected lighting systems and LiFi communication	Objective 4
	Develop LaaS Concept	Objective 4

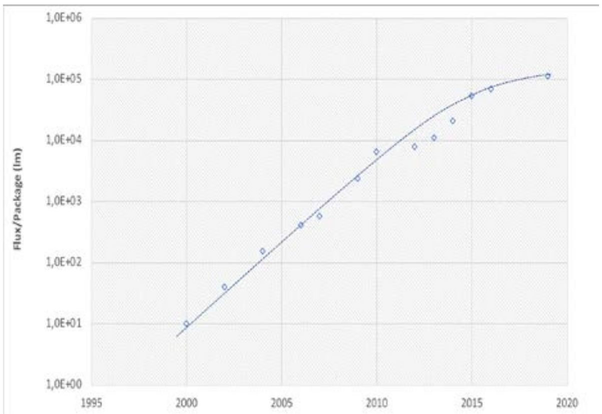
2.1 White-light Light Emitting Diodes (W-LEDs) and LED lamps/luminaires

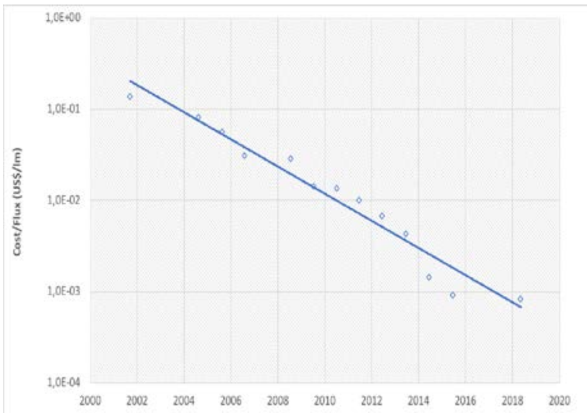
Performances of packaged W-LEDs are still enhancing every single year, even if some signs of saturation start to appear. The enhancements concern several characteristics like luminous flux and luminous efficacy (LE), white colour quality and CRI. Furthermore, cost per generated lm by packaged LEDs is still decreasing, according to IEA's analysis. As LED efficacy is already the highest on the market, and as gains in this area began to decelerate very recently, the question is whether LED manufacturers will be interested in fostering innovation to reach even higher efficacy levels. [IEA-19] Figure 6 illustrates clearly the above-mentioned enhancements. Further, Figure 6(b) shows that Haitz-law will remain applicable at least for a few years from now. Hung and Tsao calculated the theoretical upper-limits for LE for different CRIs and CCTs. [HUN-13] Figure 7 shows that, even if some energy losses linked to inevitable physical phenomena can't be discarded, there is still some place for improvement. The same figure also illustrates two well-known facts: (a) LE decrease with increasing CRI and (b) above CCTs of 2 500 K, LE decreases with increasing CCT. This last fact can appear, at a first glance, contradictory with the adage "cool-white LEDs are more efficient than warm-white ones". This contradiction can be explained by the fact of energy losses, which aren't included in the previous model and are higher in warm-white LEDs. Concerning luminous flux, we should notice the very recent announcement in LpR journal, claiming that Luxeon HL2X delivers more than 318 lm at 700 mA and 85°C junction temperature, a record value. [LPR-20]

Figure 6: (a) Best performing LED announcements for Luminous Efficacy; (b) Luminous flux par package; (c) cost per emitted lumen by the package.



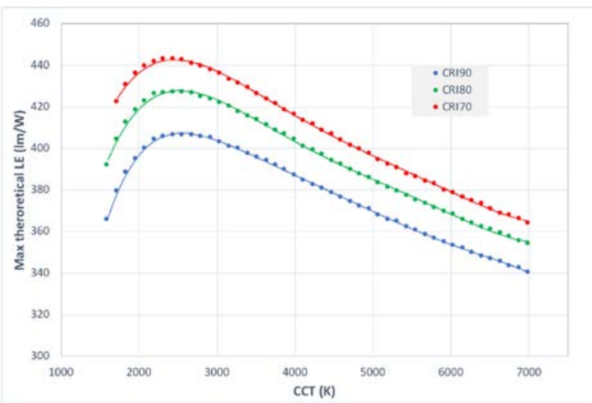
(a)

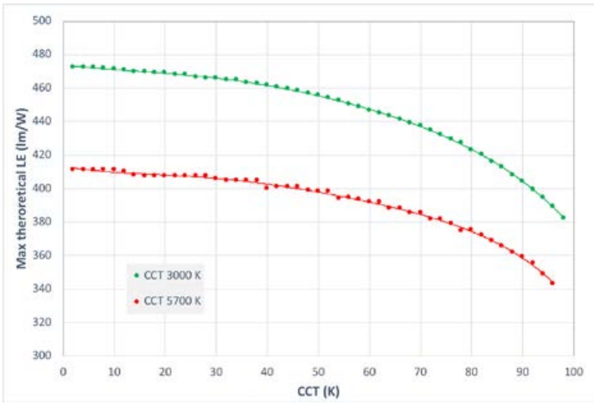




(b) (c)

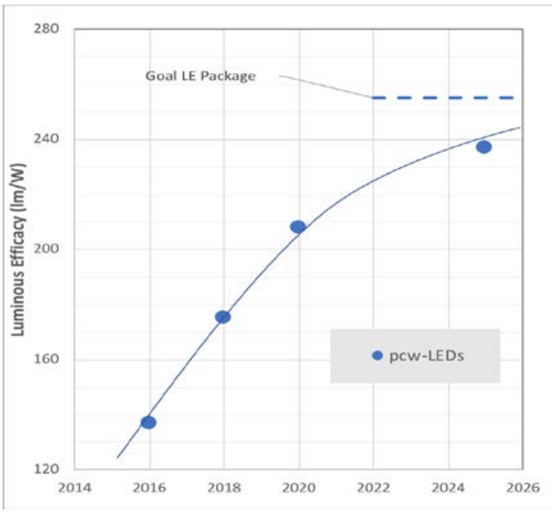
Figure 7: (a) Maximum theoretical efficacy for W-LEDs as function of (a) Correlated Colour Temperature and (b) Colour rendering index. Data from [DOE-17]





Today's production of white light from **phosphor converted LEDs** (pcw-LEDs) is a fully mature technology, while package's LE is still improving, as shown in Figure 8, and there is room for improvement. The DOE based projections established on historical LE observed values until 2016, fixed the ultimate goal to be attained by packaged pcw-LEDs to 255 lm/W. [DOE-17]

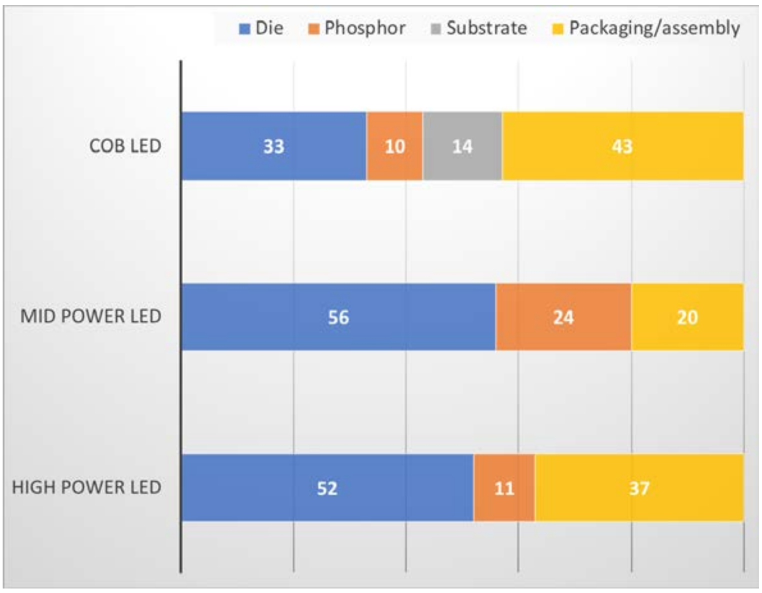
Figure 8: Luminous efficacy evolution projections and DOE Goal. Drive current density (35 A/cm^2) and junction temperature 25°C and 3 000 K CCT. Data from [DOE-17]



According to [DOE-17], the efficiency of blue LED has improved enormously, but it is still highest at low current densities. The current "best" research has seen LED packages exceed 80% efficiency, but only at relatively low current densities. At higher current densities, desirable for low-cost light to drive higher market penetration, the LED efficiencies decrease. This so-called "efficiency droop" from about 10 A/cm^2 to 35 A/cm^2 is about 10%, and to 100 A/cm^2 is about 15%. The challenge will be to circumvent the key physical mechanism responsible for efficiency droop, Auger recombination. Auger recombination is a non-radiative carrier recombination process, which increases non-linearly with carrier density and hence current density. For more information, refer to the presentation by Nelson et al. [NEL-16]

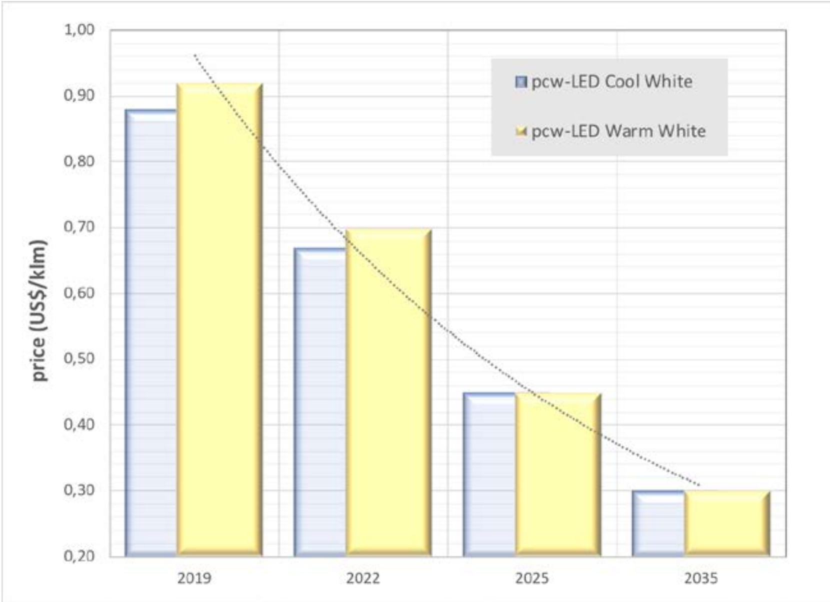
Looking closer at the global production cost of 3 product's segments that pcw-LED technology englobes, namely: High-Power, Mid-Power and COB LEDs, DOE identified the typical costs inside the component. [DOE-20] Figure 9 illustrates that cost breakdown. Assembly represents the higher expense for COB-LEDs when the price affects seriously the High-Power LED components.

Figure 9: Cause of energy losses inside pcw-LED technologies. Data from [DOE-20]



Based on such a type of cost analysis, DOE projected the cost evolution path for the next five years (Figure 10).

Figure 10: Pathway to the cost reduction for pcw-LED components forecasted by DOE. Data from [DOE-20]



Even if pcw-LEDs are today the dominant technology, two other architectures have made their proof-of-concept in the past few years and are starting to be considered as potential substitutes of the dominant technology:

The **hybrid LED** (Hy-LED) architecture is the combination of a blue LED, a yellow-green phosphor and a red LED to produce white light. This is a non-standard but emerging white light architecture. For example, in the Cree TrueWhite and OSRAM Brilliant Mix technologies, greenish-white light (deliberately shifted off the black body curve toward the green) from a pc-LED is mixed with a pure red component from a red LED. Initially that technology had the objective to increase the red content in the spectrum and thus enhance the R9 value. This architecture has a significant efficiency advantage over the more standard pc-LED architecture because the red LED incurs no Stokes deficit in generating red light. Following DOE's projections, a luminous efficacy of about 280 lm/W, or an efficiency of around 68%, is considered to be the Hy-LED upper potential. [DOE-17] while the efficiencies and CRIs can be higher, the main drawback of this architecture is that the package contains two distinct technology chips: AlInGaP for the red and AlInGaN for the blue. This implies to accommodate different thermal and electrical behaviours, more complex drivers and different ageing mechanisms and light emission drifts. Other way round it, would be to use Hy-LEDs to obtain **CCT tuneable light sources** that are fully in line with the needs of Human-Centric Lighting concept.

Another way to obtain white light is to mix colours (at least Red, Green and Blue). This is an old idea but until a few years ago it was difficult to implement due to several limitations linked to the colour-LED technologies[5]. The idea is very attractive because it allows to obtain fully colour tuneable light sources and of course CCT tuneable white light without using phosphors (this discards all Stokes losses that suffer pcw-LED and Hy-LED). Today, with the arrival of μ-LED technology, the dream may be transformed into reality. This emerging technology is known under the term of **Colour Mixing White LEDs** (cmw-LED). Overcoming the limitations imposed by phosphor down-conversion losses, DOE expects that the upper potential of the technology would be ~330 lm/W. The main drawbacks are (a) poor CRI, but this can be solved by increasing the number of mixed colours adding, for example, an amber chip; (b) colour stability control and generally speaking complex drivers; (c) as in the past, lack of efficient green and amber LEDs. R&D efforts have to concentrate in that direction to achieve the ambitious DOE goal fixed to 327 lm/W (this includes optical and driver losses) as shown by Figure 11.[DOE-17]

[5] This was especially true for the green LED.

Figure 11: Projections for LE evolution of cmw-LED vs pcw-LEDs. The dot-points represent measured LE for cmw-LEDs. Drive current density (35 A/cm²) and junction temperature 25°C and 3 000 K CCT. Data from [DOE-20]

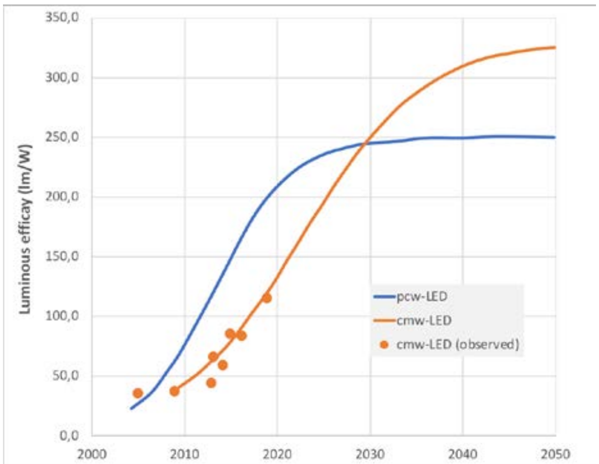
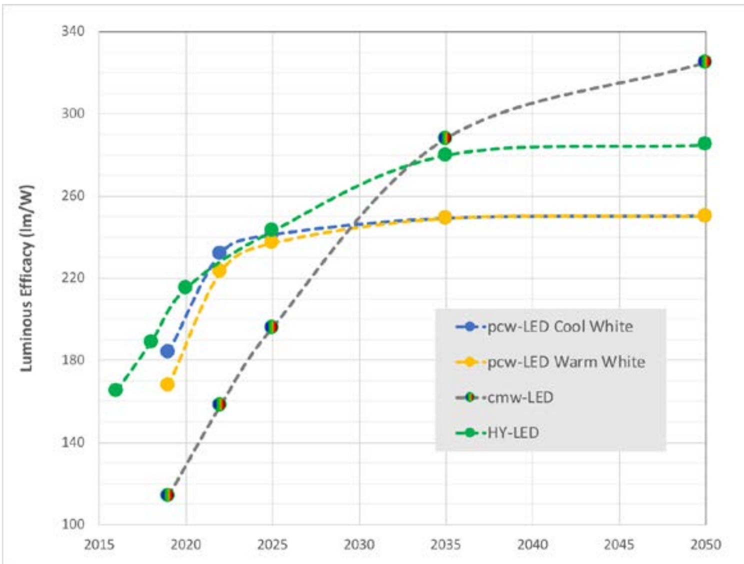


Figure 12 summarises the DOE projections and goals for the luminous efficacy of the 3 technologies discussed previously.

Figure 12: Projection for the evolution of Les for pcw-LEDs (cool and warm white), Hy-LEDs and cmw-LEDs and goals fixed by DOE by 2050. Drive current density (35 A/cm²) and junction temperature 25°C. Data from [DOE-17], [DOE-20]



GaN-based nanowire heterostructures have been sought out in recent times for their potential to generate emission wavelengths, varying from ultraviolet to near-infrared regions, which in turn, gives the lighting industry additional flexibility to develop **phosphor-free white-LEDs**. Nanowire LED technology is progressing. III-nitride based nanowire light-emitting diodes (LEDs) have received a staggering response as a future candidate for solid-state lighting[6] for creating cmw-LEDs, due to their unique and exceptional features, including drastically reduced polarization fields, dislocation densities as well as the associated quantum confined Stark effect on

[6] This technology is also applicable to displays

account of their effective strain relaxation. More specifically, AlGaN shell in InGaN/(Al)GaN core–shell LEDs leads to an enhancement in the carrier confinement and reduced nonradiative surface recombination that suffered axial or radially aligned bottom-up nanowire heterostructures including dot/disk/well-in-a-wire or core–shell structures. III-nitride nanowire LEDs are normally grown on Si substrates, but as it has been recently demonstrated, nanowire LEDs on copper (Cu) are possible. They exhibit several advantages, including more efficient thermal management and enhanced light extraction efficiency due to the usage of metal-reflector and highly thermally conductive metal substrates. These exceptional properties are paving the way for a whole new generation of optoelectronic devices for the future solid-state lighting, flexible displays and wearable electronic applications. [LPR-18]

Further, Flexible LEDs are currently a topic of intense research, as they are desirable for use in many applications. The use on nano-wires pave the way to that. Guan et al demonstrated that polymer-embedded nitride Nano-Wires offer an elegant solution to create flexible optoelectronic devices in which we combine the high efficiency and long lifetimes of inorganic semiconductor materials with the high flexibility of polymers. In these prototype devices, the NW arrays, which are embedded in a flexible film and can be lifted-off from their native substrate, can sustain large deformations because of the high flexibility of the individual NWs. Furthermore, the footprints of individual NWs are much smaller than the typical curvature radius of LEDs (i.e., on the order of a few millimetres or more). [GUA-17]

Quantum dot LEDs (QLEDs) are based on the emission of Quantum Dots (QD) to obtain bright pure colours. QDs are semi-conductor nanocrystals that are able to absorb higher-energy light and convert it to lower-energy light. The light wavelength that quantum dots emit varies depending on their size. For example, the smallest dots, with a diameter of just 2nm, emit blue light. The largest particles, with a diameter of around 6nm, emit red light. This technology targets at a first displays' applications, but it can be extended to lighting sectors.

In 2017, researchers have developed a process to make light-emitting diodes by spraying a substrate with QDs a low-cost route to bright, flexible displays and with potential extension to lighting. They obtained quantum-dot LEDs are 100 times brighter than similar classic devices. The QLEDs are demonstrated by using NiO and ZnO as the charge transport layers fabricated via ultrasonic spray processes. The 5 mm^2 QLEDs prototype is created by spraying a series of three nanoparticle solutions onto a glass substrate, depositing one layer at a time. Excellent device performance is achieved thanks to the introduction of an Al_2O_3 interlayer between QDs and an amorphous NiO layer. Compared to that of a device without an Al_2O_3 layer, the efficiency of an Al_2O_3-containing device is enhanced by a factor of 539%, increasing from 3,8 cd/A to 20,5 cd/A, and it exhibits colour-saturated green emission (peak at 530 nm) and high luminescence (>20 000 cd/m^2). [JIW-17]

2.1.1 Lamps & luminaires

Since 2010, the average efficacy of LED components has improved by 6-8 lm/W each year. [IEA-19] , which according to DOE, busted the WPE off lighting products. As a result, LED lighting products registered in the LED Lighting Facts database continued to grow each year reaching a mean efficacy of 102 lm/W in 2018. [DOE-20]

Especially LED lamps, which are typically available in the residential market, have an efficacy of over 100 lm/W, depending on the model (e.g. directional, non-directional, tubular). As DOE reported in the Lighting Facts database, at the end of 2017 there were roughly 50 products with efficacy values greater than 177 lm/W. All of these products are industrial luminaires and one showed a listed efficacy of 210 lm/W. [DOE-20]

In many developed countries, the efficacies of LED lamps available for residential use are already 110 lm/W to 130 lm/W, and they need to increase to an average of 160 lm/W by 2030 to meet DOE's SDS ambitions. In fact, some products for commercial uses such as office and street lighting have already reached or exceeded these efficacies. [IEA-19]

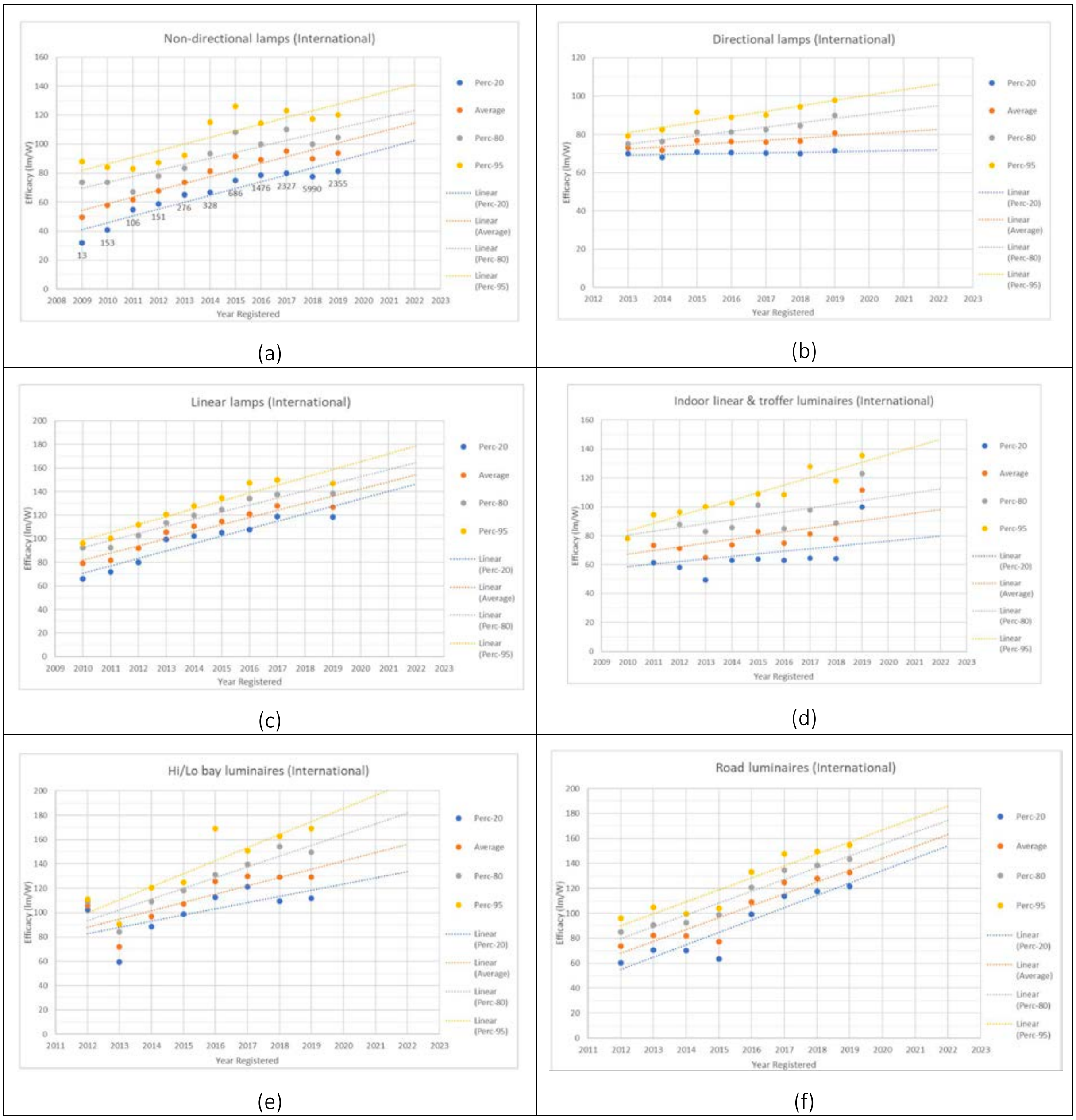
To track the LE evolution of different LED-lamps and LED-fixtures, IEA 4E-SSL Annex collected data from various international databases, totalling almost 90 000 lamps and 150 000 luminaires covering the period between 2009 and 2019, as shown in Table 3. [SSL-19]

Table 3: Luminous efficacy data collected by IEA 4E-SSL Annex to track the evolution during the last decade.

	Dataset Source	Number of lamps	Entry Years	Number of luminaires	Entry Years
Market Data	US Lighting Facts database	63 691	2009 -2016	73 814	2010 -2019
	Australian Market Survey	3 196	2017 -2018		
Register data	Energy Star database	9 671	2009 -2019	19 200	2009 -2020
	Japan energy-saving product database	433	2017		
	Thailand Label No. 5 product database	95	2019		
	Korea high-efficiency certification system database	3 487	2017 -2019	29 255	2017 -2019
	Design Lights Consortium (DLC) Quality Product Listing	9 204	2016 -2020	27 578	2016 -2020
	Total listing	**89 777**	**2009 -2019**	**149 847**	**2009 -2019**

This impressive database enabled experts to deduce trends by looking at the average LE values as well as the number of products lying in the 20, 80 and 95-percentile. Figure 13 shows the findings. It can be seen that higher percentile products in all categories achieved remarkable progress in the past decade.

Figure 13: LE efficacy evolution observed using international databases.(a) non-directional LED lamps (A-shape); (b) directional LED-lamps (spots); (c) Linear LED tubes; (d) Indoor linear and troffer LED luminaires; (e) Low- and High-bay luminaires; (f) Street lighting LED-luminaires. Courtesy of IEA 4E-SSL annex.



While the development can be considered spectacular, there is still room for improvement. According to DOE, WPE efficacy (including thermal droop, driver's efficacy and light extraction from the luminaire) could achieve an 86% level by 2035, a much higher level compared to the values attained in 2019: 75% for LED luminaires and 64% for A-shape LED lamps, as depicted in Figure 14. If this happen, the WPE will follow the path shown in Figure 15.

Figure 14: Average WPE value in 2019 for 3 types of LED lighting devices and DOE targets for 2035. Data from [DOE-20]

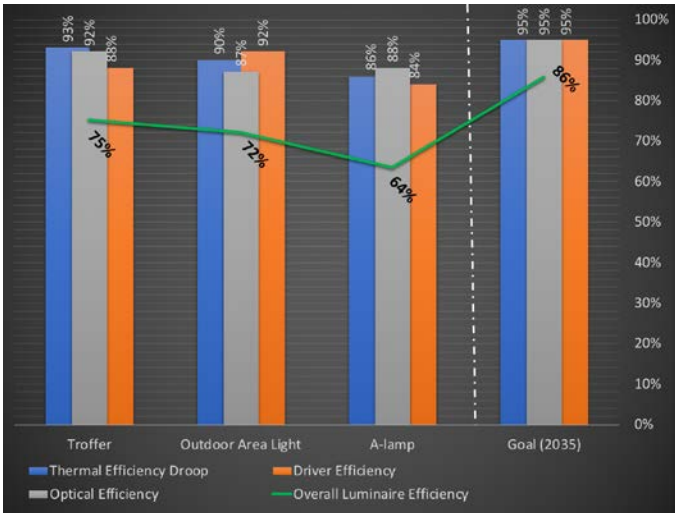
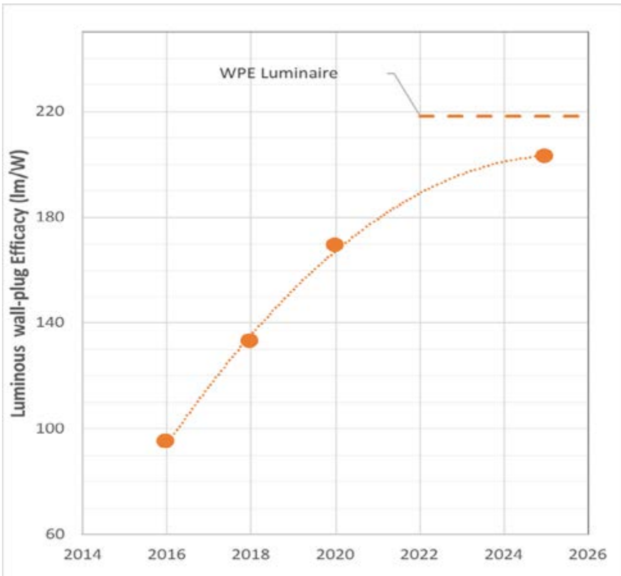


Figure 15: Average WPE of LED luminaire (any type) evolution and DOE target by 2035. Data from [DOE-17]



While the improvement in LED lighting product luminous efficacy has been impressive, it is only one of the beneficial features of SSL. Lighting attributes, such as spectral (colour) quality, optical distribution, intensity level and system reliability can be prioritised along with efficacy to provide the best lighting for the application and the occupants in the space. [DOE-20]

To include all these aspects, DOE and other analysts/scientists/engineers think that Luminous Efficacy is no longer the best metrics to account for quality. A proposal consists to replace (or to supplement) LE and WPE by a new metrics called “Lighting Appliance Efficacy” (LAE). This LAE metric should include at least the following aspects: (a) Light source efficiency of the luminaire; (b) Optical delivery efficiency; (c) Spectral efficiency; (d) Intensity effectiveness. [DOE-20] Precise modelling is also necessary to understand the impacts of the space on the light as it is supplied from the luminaire and travels to the ultimate receptor (typically a human eye). LEA should be the new frontier in improving the next generation of lighting systems. LEA can enable optimization of the various factors of lighting application efficiency according to understood trade-offs between colour quality and source efficiency, for example, or optical control and source efficiency. It clearly opens the way to the characterisation of smart human-centric systems (see paragraph 3.4 of this report).

2.2 White-light Large Area Diffuse emitters (W-LAD)

Organic light-emitting diodes (OLEDs) have for long been considered a promising technology for solid-state lighting sources, thanks to their healthy, high-quality white light. In fact, OLEDs, are larger in size and can be viewed directly, without using the diffusers required to temper the intense brightness of LEDs[7]: OLEDs are by definition diffuse "Lambertian" type emitters. Furthermore, OLEDs have excellent mechanical properties, are flexible/bendable and also transparent, thus they can be added to any suitable surface, including glass, plastic or metal foil, and can be cost-effective to manufacture in high volume, especially using roll-to-roll (R2R) techniques. In addition, consumers now have higher aesthetic requirements of lighting that combines life and art. Table 4 summarises some key features supporting the statement that OLED lighting is likely to become the star of next generation lighting. However, to fully penetrate the lighting sector, OLEDs need to overcome the challenges in reducing cost and commercialising the high-efficacy performance that has been demonstrated in the lab [DOE-17].

Table 4: What are the advantages of OLED technology for lighting that can drive the market

Requirements	Advantages of OLED technology
Energy efficiency – environmentally friendly	• Long lifetime • High luminous efficacy and WPE • Recyclable • Increased RoHS compliance
Light controllability	• Easy to control • Instant "ON" full-light • Dimmable, no noise
Highly desirable light and colour quality	• Wide range of CCT • High CRI possible • Colour tuneable • No flicker • No glare • Lambertian/diffuse character
Form factor	• Thin and lightweight • Transparent • Non-breakable, conformable, flexible, bendable • Large emitting area
Easy to drive and safe	• Low drive voltage • Cool to touch • Low operating temperatures • Low blue light hazard • Low UV content
Lowering costs	• Scaling advantage • Roll-to-roll process

Organic light-emitting diodes are now viewed as an established mainstream technology for display applications in everyday consumer electronic devices. The penetration in the domain of lighting is more complex but still possible. Niche market segments are addressed first: Currently, automotive lighting is reported to be the most promising and most mature application market for OLED lighting (see 4.1 in this report).

In fact, since Ching Tang and Steven Van Slyke's pioneering work in Eastman-Kodak [8] which three decades ago demonstrated the first white OLED (W-OLED), OLED technology has continued to evolve. The luminous efficacy of both laboratory prototypes and lighting systems demonstrators is constantly increasing. Figure 16 shows the progress by tracking "record" efficacy announcements, published by specialised press and academic literature since 2004.

Between 2004 and 2020, the year-on-year (YoY) luminous efficacy yield is impressive: 28% increase per year for laboratory prototypes (all technologies inclusive) and 33% increase per year for lighting producers (commercial or demonstrators). However, on the one hand, the absolute record value of 156 lm/W obtained independently, within 7-year interval, by NEC Corporation (Japan) and Jiangsu (China) [MER-13], [HUA-20] is

[7] LED components are, by nature, small and bright

[8] C.W. Tang and S. A. Van Slyke, Appl. Phys. Lett. 51, 913 (1987); doi: 10.1063/1.98799 1987.

65% lower of the theoretical upper limit luminous efficacy for white OLEDs is around 240 lm/W for a device without any out-coupling enhancements [TYA-11]. On the other hand, current commercial OLED panels provide an efficacy of approximately 90 lm/W lagging behind LED panels [DOE-20]. However, US DOE estimates that, by 2035, devices' luminous efficacy must increase by a factor of 2 and lifespan must increase by a factor of 3, compared to 2018 values, in order to consider OLEDs as competitive and give them the best chance to conquer part of the lighting market. At the same time the OLED luminaire wall plug efficacy (WPE) must attain more than 150 lm/W; this calculation is based on the assumption of 180 lm/W device efficacy and 88% total Efficiency from device to luminaire.

Figure 16: Record luminous efficacies announced since the demonstration of the 1st White OLED (Eastman-Kodak, 1987). The green dots correspond to lighting panels and lamps (commercially available).

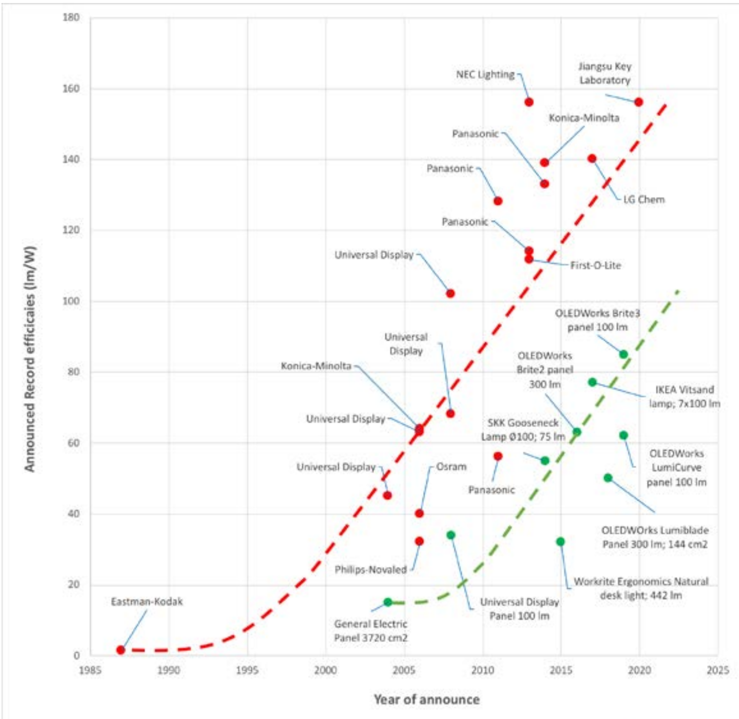
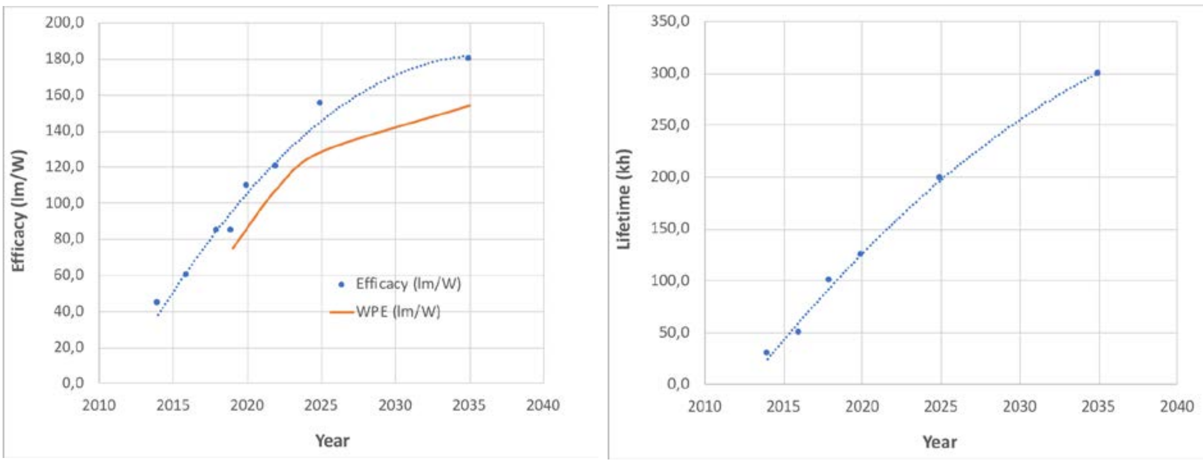


Figure 17: US-DOE roadmap towards OLED enhancement in order to hope lighting market penetration (a) luminous efficacy for devices (blue) and luminaire WPE (orange); (b) Device lifespan L70B50. Data from [DOE-20]



(a) (b)

An important difference from LED concurrent systems is the possibility to obtain flexible panels. Bendable panels have been commercialised recently by OLEDWorks (USA): The characteristics of the "LumiCurve Wave" product are given as an example in Table 5 and they are compared to a similar rigid OLED panel commercialised by the same manufacturer.

It is clear that flexible white organic light-emitting diodes (FW-OLEDs) have considerable potential to meet the rapidly growing requirements for lighting applications. To achieve high-performance FWOLEDs the main challenges to address are [LUO-19]:

- the selection of effective flexible substrates
- the use of transparent conducting electrodes
- the introduction of efficient device architectures
- the exploitation of advanced outcoupling techniques for enhancing radiation output

Table 5: (a) Characteristics of OLEDWorks LumiCurve Wave bendable panel. Data from [OLW-20]; (b) Comparison between a rigid and a bendable OLED panels data from [DOE-20]

(a)		L = 3 000 cd/m^2	Higher luminance*
Warm White CCT: 3 000 K CRI >90; R9 >50	Luminous Flux (lm)	100	300
	Luminous Efficacy (lm/W)	62	55
	Life span L70B50 (h)	50 000	10 000
Neutral White CCT: 4 000 K CRI >90; R9 >75	Luminous Flux (lm)	100	250
	Luminous Efficacy (lm/W)	47	43
	Life span L70B50 (h)	50 000	10 000

*Higher luminance means respectively 8 500 cd/m2 and 7 000 cd/m2 for the warm and neutral white products

(b)		Bendable OLEDWorks LumiCurve	Rigid OLEDWorks Brite 3
Photometric characteristics Flux: 100 lm L: 3 000 cd/m^2 CCT: 3 000 K	Thickness (mm)	0,4	1,4
	Weight (g)	15	38
	Lit area size (mm x mm)	221 x 46	102 x 102
	Input power @17 V (W)	1,615	1,19
	Efficacy (lm/W)	62	85
	Life span L70B50 (h)	50 000	100 000

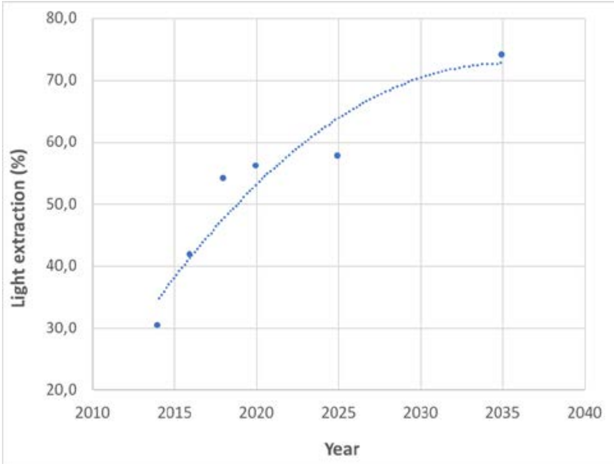
Furthermoreongoing improvements to OLED devices will require continued scientific advancements in the areas of emitter materials and device architectures [DOE-20]. The key R&D challenges identified by DOE in OLED lighting that affect the cost and performance of OLEDs include:

- Performance materials for stable, efficient devices
- Light extraction
- Advanced fabrication technology
- Luminaire design – including optical control and driver's efficiency

For instance, for bottom-emitting and transparent FWOLEDs, the transparent electrode should have outstanding optical transparency (e.g., a transmittance of >90% in the visible regime), good electrical conductivity (e.g., a sheet resistance of <20 Ω/sq), and mechanical flexibility. Figure 18 shows the DOE fixed target (x1,4 compared to 2018) for light extraction efficiency from a competitive OLED device by 2035. The quest for better and cheaper flexible electrodes[9] pushed the DOE to award Prof. Paul Leu from the University of Pittsburgh and Texas-based Electroninks US$ 1 million to develop silver inks to replace ITO in OLED lighting panels. This can be achieved by using a new metal patterning technique that prints the metal grid directly on glass or plastic, thus creating micro-grids that can outperform ITO at a lower manufacturing cost [MER-19].

[9] The cost of inorganic materials in OLED panel fabrication is very high (see section 3.1 in this report)

Figure 18: DOE target for light extraction from the OLED devices. Data from [DOE-20]



Another way to enhance light extraction from the device is the incorporation of micro-lens arrays (MLA). The paper by JH. Han et al gives an excellent paradigm of the efforts in that direction using MLA on thin film: The luminance enhancement observed with a 2500 mm^2-large OLED was dependent on the viewing angle, and the largest enhancement (64%) was observed in the normal direction, while 60 and 18% enhancements were observed at 60 and 30°, which led to lower enhancement (38%) of the total luminous flux compared with the luminance enhancement (64%) in the normal direction [HAN-18].

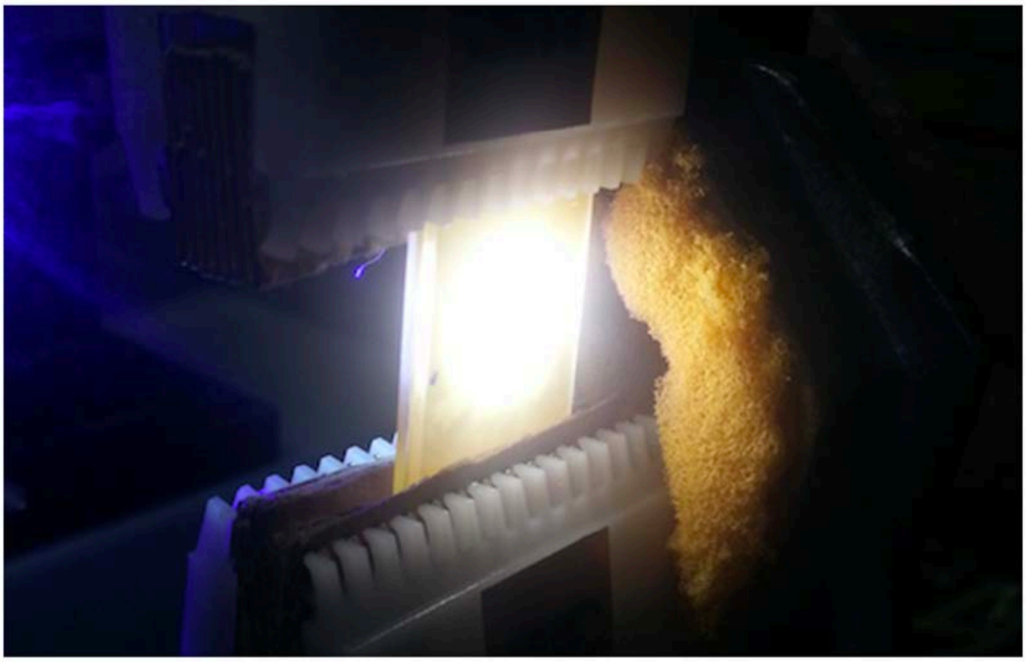
Other diffuse direct emitter materials, such as hybrid structures of OLEDs with QDs and perovskites, can also provide this low-illuminance lighting and can be compatible with elements of the OLED architecture and manufacturing process. As an example, Che-Yu Chang et al demonstrated the possibility to realise Perovskite native-white LEDs with CIE chromaticity coordinates of (0.3, 0.49), which are approaching the ideal pure white emission coordinates (0.33, 0.33). In this work, a device structure was developed for perovskite white LEDs with only one emissive layer. As explained by the authors, an emissive material with emission in the orange-near infrared range was introduced into the sky-blue perovskite layer to realise a perovskite white LED. The light from the emissive material and the perovskite material in different wavelength ranges is mixed to generate the white light emission [CHA-19]. This may open the way to native white SSL.

2.3 White-light Laser Systems emitters (W-LS)

2.3.1 Laser Activated Remote Phosphor systems

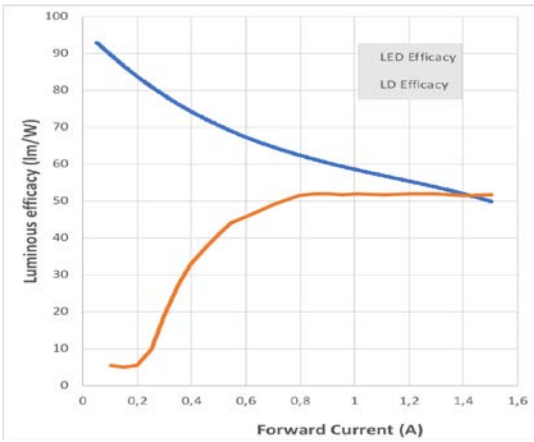
The idea to replace blue LEDs by blue laser diodes (LDs) emerged in early 2000s as demonstrated by Narukawa et al [NAR-02]. Car manufacturer BMW has been working at least since 2011 on combining blue-emitting laser-diode light with a phosphor to create efficient white light for car headlights [OVE-11]. The automotive world was the first commercial target of this technology. Since then several academic laboratories and industry development departments across the world have been interested in the technology and its potential extension to lighting. That way from 26 lm/W demonstrated by Narukawa et al [NAR-02] for a flux of 5 lm and a CCT of 5800 K (CRI 85), Ledru et al in 2014 achieved a Laser Activated Remote Phosphor (LARP) white source, shown in Figure 19, 40 lm/W for a CCT of 4000 K (CRI 94) [LDR-14]. Since then the possibility of using violet lasers has been examined and by using semi-polar gallium nitride (GaN) laser diodes and phosphors, SoraaLaser manufactured white-light surface-mount devices (SMDs) that produce up to 500 lm of output from a 300 μm^2 emitting area [OVE-17].

Figure 19: White light obtained by exciting remote phosphor by blue light from laser Diode (40 lm/W; 4000 K; CRI: 94). Photo Credits: LAPLACE Laboratory [LDR-14]



It is known that LED technology suffers from efficiency droop, which causes a gradual decrease of light emission efficiency as the operating current density of the device increases. This undesirable effect has two drawbacks: (1) the maximum achievable efficiency at higher currents is limited, (2) the maximum light density that can be emitted from an LED chip is strongly affected. In a solid-state Laser Diode, the stimulated emission allows the immediate recombination of injected charges into the emission region, thus eliminating the droop effect. In fact, even though the Wall Plug Efficiency (WPE) of laser diodes (30% when electrical power density tops 10 kW/cm^2) is less than that of LEDs (70% of the electrical power passing through them into light at a power density of 3 W/cm^2) [WIE-13], due to the suppression of the droop effect, the LDs can be more efficient than LEDs at higher currents (Figure 20).

Figure 20: Comparison of luminous of LDs vs. LEDs as function of forward current. Original data from [TRI-17]



Using blue, violet or even near-UV lasers for generating white light may be hazardous to the human eye due to the important blue light component in the spectrum, as shown in Figure 21. It is however possible to reduce the blue light component by shaping the phosphor [CAT-20] as shown in Figure 22

Figure 21: Spectrum obtained from an experimental high CRI LARP in LAPLACE laboratory [CZE-18b]

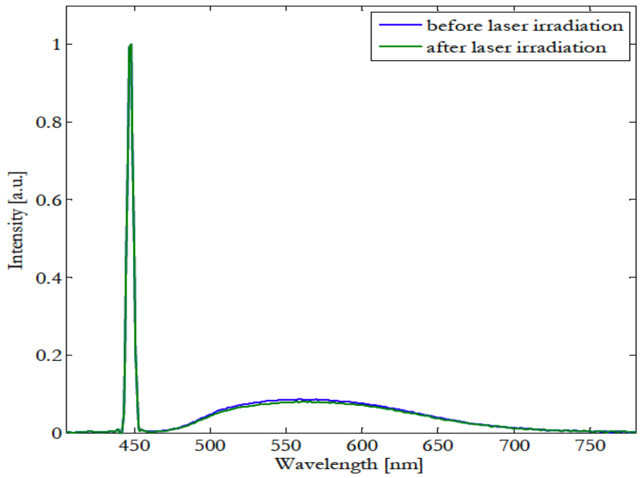
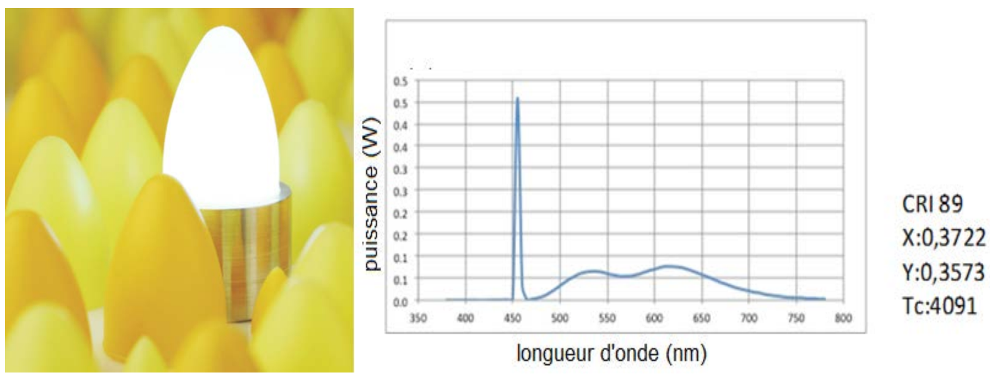


Figure 22: It is possible to reduce the blue light component by shaping the phosphor [CAT-20] (Credits: LAPLACE Laboratory)



WhileLARPs can (1) reach high CRIs using custom phosphors, (2) reduce the harmful blue-component of the spectrum by optimising its shape and (3) reduce the ageing effects due to the long-term exposure in intense radiation by choosing the right ligands and substrates, researchers expect to achieve, in the mid-term, efficacies as high as 200 lm/W, as reported by Laser Focus World [OVE-13], and even higher, at high currents corresponding to high luminous fluxes. **LARPs is certainly a technology with huge market potential in areas where high fluxes are necessary**.

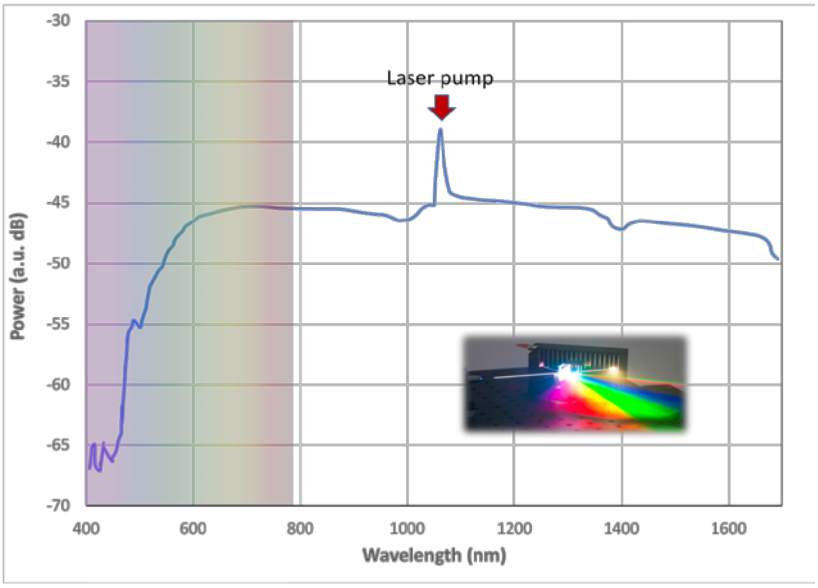
Furthermore, the use of **LDs paves the way to communicating lighting systems thanks to LiFi**. Accordiing to Chao Shen (as reported by [HAL-20]]) 'There are many advantages to using lasers. One can have 100 times higher speed and 100 times longer transmission distance when using laser LiFi in comparison with LED LiFi'. In addition, LD LiFi systems can go an order of magnitude faster than LED based systems: they can achieve 100 Gbits/s in the next year or two. To illustrate this, we can cite the paper published in 2020 by Changmin Lee et al that demonstrates a 20 Gbits/s. The demonstrator was equipped with high power blue laser diodes that offer over 3.5 GHz of 3 dB bandwidth, the laser-based white light SMD modules exhibited a signal-to-noise ratio above 15 dB up to 1 GHz. [CHA-20]

2.3.2 Supercontinuum lasers

LARPs technology produce composite white light (blue/violet + yellow/red) it is however possible to obtain native white light from lasers.

As it has been said by Granzow [GRA-19], Supercontinuum lasers are a technology that combines some of the properties of conventional broadband light sources (like Halogen lamps, Xenon lamps, laser-driven light sources, super-luminescent light emitting diodes etc.) with the unique properties of single-mode lasers: an extremely broad spectral coverage from ~400 nm to 2400 nm emitted as a continuum with an integrated power of up to several W (even tens of W). Besides well-known applications within bio and medical imaging, more and more new applications areas have come up over the past decade, including steady-state or time resolved measurement techniques within plasmonics, metamaterials, 2D-layered materials, carbon nanotubes, quantum dots, nano-optics, physical chemistry or spectroscopy, along with a wide range of applications within industrial metrology and inline process monitoring.

Figure 23: Supercontinuum laser emission coveting the full visible spectrum from propagation of IR laser pulse (λ_{ex}=1,604 µm) in a fibre (original data are public domain from Creative Commons)



Supercontinuum is formed when a collection of nonlinear processes acts together upon a pump beam in order to cause severe spectral broadening of the original pump beam, there is no consensus on how much broadening constitutes a supercontinuum. It can be obtained by propagation of high-power pulses through nonlinear media. The phenomenon was first observed in 1970. Figure 23 shows the emitted supercontinuum spectrum covering the full visible region.

This technology could be used for niche applications in lighting (projectors, high-bay luminaires...) in the next decade provide that numerous technical challenges solved.

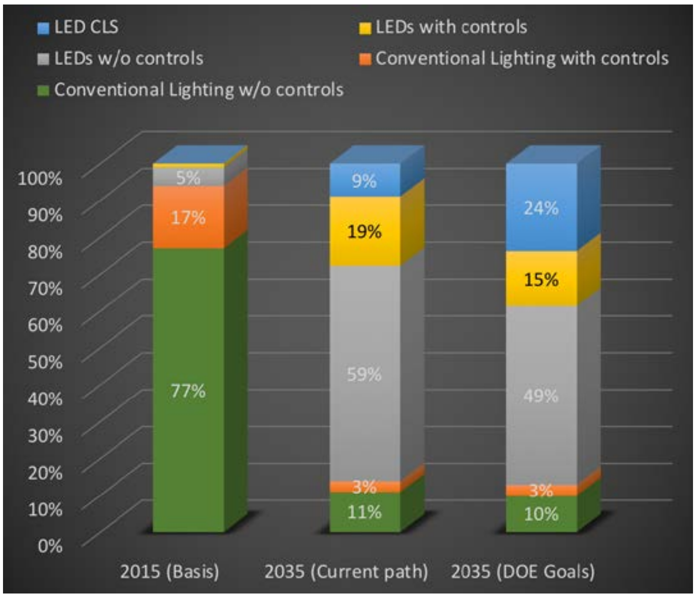
2.4 Lighting systems

For several years now, **sensor technology** has been coupled to lighting to reduce wasted light. For example, occupancy sensors monitor room occupancy and turn on lighting when needed and turn it off when space is empty, which can achieve savings as high as 30-41% of lighting energy use in a household [FRA-16]. This technology can be enhanced by making of IT as the era of **Smart/Intelligent lighting** is knocking on the door.

In a system, we can define "**Intelligent Efficiency**" (IE) as the Operation of a system of devices so that they respond to changing conditions of the external environment, in order to maximise energy savings. [BEL-20] For example, smart lighting in households adjusts in accordance to occupancy and/or light levels, thus demonstrating an additional IE ranging from 1 to 10% of the whole home energy use. [NEE-15] Figure 24 shows the road to 2035 for energy savings following the current market path and the impact of the fixed DOE goals. [NAV-17]

In the domain of **public street lighting**, switching to LED lighting alone will not be enough to meet cities' energy consumption and reduction targets. Adaptive, interoperable lighting solutions are needed to bring savings to the next level, facilitated by connecting LED lamps with a central management system (CMS) over the internet. These networked street lighting systems allow operators to monitor and regulate light levels in unprecedented ways, resulting in increased energy savings and lower operational costs. The 50% energy savings that are realised by switching to LEDs increase to 80% when connectivity and a central management system are added. [GRF-19]

Figure 24: Energy savings linked to the system intelligence degree. 2015 is the basis for the comparison and the forecasted savings for 2035 are calculated following the current market path as well as the target values following DOE. Data from [NAV-17]



Additionally, both traditional lighting poles and more advanced smart lighting installations have the potential to act as a smart city platform, enabling a range of other smart city applications through the integration of data collection devices such as sensors and cameras. Lighting infrastructure can be used, among others, as a basis for (a) Environment monitoring; (b) Transport optimisation (traffic management and parking); (c) Public and traffic safety; (d) Electric vehicle charging; (d) Wi-Fi or Li-Fi and internet provision; (e) Digital signage and public communication; (f) Communication with smart/autonomous cars; (g) Localisation services; (h) Remote meter reading; (i) Analytics at the edge. Moreover, anectodical, smart lighting poles can be used to fight against urban crimes: GE Lighting signed an agreement with STT to incorporate the gunfire sensors developed by that company into their LED street lighting systems. This integration is expected to differentiate GE in the market, while significantly reducing cost of deployment for the gunfire sensors. That way, the system can broadcast in real-time alerts to emergency and dispatch centres, patrol cars etc. [GRF-19]

Lighting control systems can be wired, wireless or a combination of the two (hybrid). The system architecture refers to how control signals are communicated and not how a control device receives power. Although wired devices might be less expensive to purchase, the installation of wired solutions, particularly in retrofit scenarios, entail considerably more labour and materials than wireless solutions. Wireless technology offers a natural grid for connectivity, enhances operational efficiency and assists in developing new business avenues. The wireless technology also offers multiple benefits compared to the traditional wired technology, including flexibility, cost-effective, easy installation and security, augmenting its demand in the commercial and residential market space. The following [OSR-18] factors Influence System Architecture Decision:

- Building Status - Is the building already built or in the process of being built? If it is in the construction phase or under development, it is the most opportune time to integrate a wired lighting control system. For a pre-existing building, a wireless lighting control solution will probably be the best option.
- System Reliability - Although wireless technology has come a long way, there are some situations where a wired solution is still the most reliable. In some applications, building materials and technology interference can cause wireless systems to be less reliable. To mitigate this issue, a wireless mesh network topology can be used. In this case, each network node (connection point on the network that can send, receive or store data) can communicate with every other device, and can relay messages for its neighbours. Mesh networks are self-healing, in that if any disruption occurs, data is automatically re-routed helping provide better coverage and reliability.
- Scalability - A wireless system requires more nodes/repeaters (hardware) in a given radius to keep the signal strong in comparison to a wired system. The range, or maximum transmission distance of a signal, is dependent on a number of factors, including the wireless communications protocol used, building

structure and line-of-site obstructions. A wired system uses less hardware because it can support long cable runs (for example, 2500 ft.). Both are scalable, however as building size increases, the cost of wiring can exceed the cost of a wireless installation.

- Budget - Equipment and installation costs are generally higher for wired systems.

As related by [ENO-11], innovative and cost-effective wireless strategies, when viewed from a life cycle cost standpoint, present an attractive solution for achieving energy savings, flexibility, productivity, reduced maintenance costs and personal control. In new constructions, the ability to run wire to enable hard-wired controls is often considered a more cost-effective solution, particularly when a building owner is only considering these “first” costs. A wireless solution, in a new construction environment, can make for a difficult sell, unless total costs to the building owner are considered. If the project developer and the building owner are not on the same page, the person in charge of the building’s construction is predominantly going to care about first costs. When it comes to building retrofits, wireless technology provides clear advantages, since no new wires are required, thereby reducing labour costs.

Today, the lighting manufacturers are shifting from traditional lighting controls and associated protocols to sophisticated wireless lighting control systems and associated flexible and deep-learning algorithms. On the other side, wire-less network control proprietary or open protocols are deployed in the market. Proprietary protocols are usually robust and difficult to hack, but they offer a very limited interoperability. Open protocols mitigate the previous interoperability issues but their development needs significant effort and resources. Furthermore, open source systems are more subject to security failures that can compromise (intentionally or not) the system integrity and data privacy. The lighting industry is quickly moving in the direction of standard open protocols developed by a collaborative effort of experts from different organisations.

Today, **colour tuneable lighting systems** are seen as fashion “must have” products, and demand is strongly increasing, at least for a population category. According the US Office of Energy Efficiency & Renewable Energy (EERE), understanding all the variations in colour tuneable products can be challenging, so it may be helpful to consider each product type in terms of its most common applications, control options and potential issues or complications. There are three basic categories of colour tuneable products [EER-20]:

- Dim-to-warm: These products, also referred to as warm dim, blackbody dimming or incandescent-like dimming, mimic incandescent or halogen dimming performance, usually designed for 2 700-3 000K at full output with a decrease in CCT as the output is reduced to as low as 1 800 K (the colour of candlelight). As with incandescent lamps, the light colour becomes increasingly warm in appearance (i.e., more yellow and red) as the product dims. The light colour and dimming quality of incandescent/halogen products are prized in such settings as restaurants, hotel lobbies and guestrooms, ballrooms, theatres and residential spaces.
- White-tuneable: Some white-tuneable products, also called tuneable white or Kelvin changing, have two sets of controllable pcw-LEDs: one with a warm-white colour (usually around 2 700 K) and the second with a cool-white colour (usually 5 000 K to 6500 K). By individually raising and lowering the output of the two coloured “LED primaries”, white colours between the two-colour points can be created along the straight line that connects them on a chromaticity diagram (this is called linear white tuning). When only two white PC LEDs are selected, the manufacturer must choose where the mixed colours of white will lie, relative to the blackbody curve. As the blackbody line is curved, two colours of white cannot track along the blackbody and, the wider the range of CCTs, the greater the maximum deviation from the blackbody. However, recently Tomokazu Nada announced in LpR journal that his company, ZIGEN, proposes a new solution for obtaining full BBL-tuneable white LEDs using a 2-channel control process. [NAD-20] There are also white-tuneable products that use three or more LED primaries, in which case they may have the capability to produce a wider range of colours than just different CCTs of white. White tuning allows for changing the colour of light from warm to neutral to cool in appearance, which may be desirable for a range of reasons, from aesthetic to medical.
- Full-colour-tuneable: These products, also referred to as RGB, RGBA, RGBW, spectrally tuneable, or colour changing, usually have three or more different LED primaries that can be individually varied in output to create a mixture of light that is white, a tint of white or a saturated hue. The individual LEDs used in a full-colour-tuning mixture can be very narrow band LEDs (producing a narrow range of blue or red, for example), or monochromatic too but with phosphor coatings that produce a slightly wider spread of colour; however these can be augmented with amber or whiter pcw-LEDs, and other monochromatic colours. The minimum number of LED colours is three for full-colour tuning, but four-, five-, and seven-colour systems are also on the architectural lighting market, and some sophisticated colour systems use

even more unique colours of individual LEDs. Full-colour-tuneable products are well-suited for application in theatres, theme parks and restaurants.

In addition to "intelligence", **larger-system** has other attributes: The development of smart micro-grids at building level pushes the deployment of **DC distribution low-voltage grid** inside the buildings. This is rather a revolution in the construction domain, and the first industrial scale demonstrators tend to validate the idea and put forward a series of advantages. SSLs (and more especially LEDs) pledges also to this direction. Lux Review [LXR-18] published a teaser entitled "10 reasons the future of lighting is DC grids" as follows:

- Lighting has effectively gone DC thanks to LEDs. Why have the expense of local drivers for each luminaire when they can all be run off the same local DC network?
- The power industry is moving to distributed power generation, thanks to a switch to renewables such as solar panels and the advent of energy storage.
- It's much easier to integrate battery packs such as those produced by Siemens and Tesla into DC systems and grids. DC to DC converters are up to 20 times smaller than AC/DC equivalents.
- There's a significant energy loss every time power is converted from AC to DC at each device. Removing a stage can improve system efficiency by 5 to 10%.
- System reliability will be improved. By removing AC/DC converters, especially those with electrolytic capacitors, we can dramatically improve the mean time between failures.
- By using a relatively higher voltage such 380V DC rather than 48V DC, we can solve the challenges of direct current such as voltage drop and increased cabling sizes, while maintaining safety.
- There's less local heat at the luminaires when there is no power conversion electronics built into the housing, leading to cooler-running, more efficient and longer life LEDs and cooler ceiling voids and interiors.
- A local DC grid opens up opportunities to connect other DC devices, such as sensors and cameras, to the lighting to create a network that can use data to deliver new services.
- The technology is field proven and is used by blue-chip clients such as Carrefour and MaxMara.
- Louis Vuitton, for instance, is using DC microgrids for lighting 40 of its newer stores in both Europe and China.

3 Market Evolution

Fortune Business Inside analysts estimated that the global lighting market size reached US$ 118,33 billion in 2019 and is projected to reach US$ 163,72 billion by 2027, exhibiting a CAGR of 4,3% during the forecast period. General lighting represented in 2019 79% of the above figure. [FBI-20] Further, the demand has risen in developing countries owing to the increasing population, climate change and resource scarcity. Governments in developing countries such as India and China are focused on developing new houses for homeless people, which, in turn, is driving the lighting market growth in the region. Moreover, companies in this sector are more inclined towards producing and selling lights at minimum rates, so that people can afford and use them for a long period. [FBI-20]

According to [PSI-20], **COVID-19 pandemic has impacted, and for sure, will impact the lighting market across the globe**. The stringent lockdown measures implemented by governments have led to the postponement of residential projects in countries including India and China. Additionally, the disruption in the supply of electrical components from China is another consequence of the pandemic on the LED lighting market. Further, lack of availability of raw materials for manufacturing light casings, chips and other factors has affected the supply and demand for the lighting industry. The growth of the market is expected to remain constant during the lockdown period. Additionally, the pandemic has affected the growth owing to the immediate shutdowns in the commercial sector and industries such as automotive and retail. According to a survey conducted by the Lighting Industry Association (LIA) during the lockdown period 89% of LIA's members reported that their business remained open and have recovered 95% of their sales. [FBI-20]

3.1 Light Emitting Diodes (LEDs) and lamps/luminaires

3.1.1 Market by segments

3.1.1.1 General Illumination (indoor and outdoor)

As the International Energy Agency reports [IEA-19], in 2019, LED sales reached a critical milestone, achieving a record number of sales of more than 10 billion units, including both light sources (bulbs, tubes, modules) and luminaires.

Figure 25: LED penetration rate, by sales, in rapidly increasing. Based on IEA data from the [IEA-19]. (All rights reserved; as modified by G. Zissis)

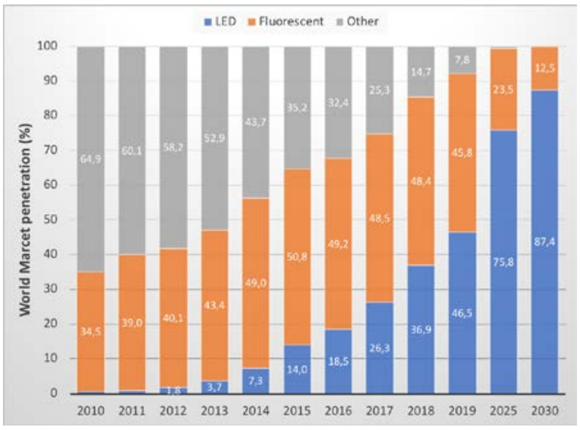
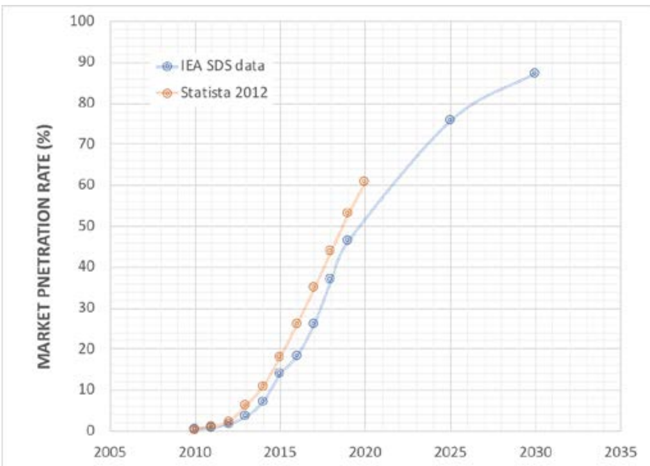


Figure 25 shows that indoor LED deployment is advancing, and LED sales now exceed fluorescent lamps, as LED costs continue to fall. In fact, global LED use has increased substantially in recent years, rising from a market share of 5% in 2013 to nearly half of global lighting sales in 2019, with integrated LED luminaires making up an increasing share. To remain in line with the Sustainable Development Scenario (SDS), LEDs need to make up more than 90% of lighting product sales by 2030. [IEA-19].

Figure 25 and Figure 26 clearly show that since 2015 LED technology has been taking over large parts of the illumination market. However, it is interesting to underline the deviations between Statista and IEA data [IEA-19] [STA-12]. In fact, even if Statista published its data in 2019, only 2010 and 2011 values are from surveys, the values for 2012 through to 2020 are just projections. As a result, Statista projections aren't able to predict the revisable saturation of the market segment.

Figure 26: LED penetration rate projected by Statista (data from [IEA-19] and [STA-12])



Bodo Ischebeck claims that old-fashion illumination is seen by industry as a mature and stable, ~€5 billion, core market for the lighting industry [ISC-18]. Osram forecasts an average 4% growth in the segment from 2017 to 2023 and softness of General Lighting market (outdoor/industrial) expected to continue for the next years. [DIE-18]

Generally speaking, the Illumination market is segmented into Professional and Consumer as well as High Power and Mid Power. Professional and Consumer markets differ along four key dimensions as given in Table 6.

Table 6: Professional vs Consumer illumination markets

	Consumer	Professional
Key success factors	1. Price 2. Performance	1. Performance 2. Lifetime and Product Quality 3. Service/Price
Lifetime (h)	15 000	75 000
Manifacturers	Mostly Chinese	Predominantly Western
Competition	Aggressive and cost driven Mostly Chinese competitors	Strong Both Western and Asian competitors

As stated by Semiconductor Today 2017 publication relating Yole's findings, LED lighting module market is growing at 22,6% CAGR from US$ 4 billion in 2016 to US$ 13,8 billion in 2022, driven by mid-power modules. [SMT-17] The global lighting market that concerns lamps and luminaires has a much higher size (~US$ 120 billion). Navigant roughly estimated that 75% of the global lighting market comes from luminaires/fixtures and 25% from lamps. The share of LED technology is 10% of the unit's sales for 36% of the global revenues. This average value grows to 36% in 2022, but the range and variability in estimates increases (ranging from 19% up to 53%). [NAV-17] Concerning the LED lighting market, Statista forecasted that global LED lighting market will rise from US$ 69,7 billion to US$ 98,5 billion by 2023. [STA-2019]

According to Markets and Markets report[10] [MAM-17], the global LED lighting market is expected to be valued at US$ 92,4 billion by 2022 and to witness a shipment of 14,01 billion units by 2022, at a CAGR of 13,66% and 21,23%, respectively, between 2016 and 2022. The same source related that in the market by end-use application, indoor lighting is expected to have a higher growth rate than outdoor lighting. The reason for the large market size and high growth rate of indoor lighting is increasing infrastructural activities across the world, mainly focused on residential lighting.

Another analyst at Prescient & Strategic Intelligence reported in 2018 that the global light-emitting diode (LED) market was valued at UD$ 30,50 billion in 2016, and is projected to advance at a CAGR of 12,6% during the forecast period (2017–2023)[11] [PSI-18]. This figure was US$ 67,60 billion in 2019, and it is projected to witness a CAGR of 12,9% during the forecast period (2020–2030). [PSI-20]

Further, the report from Grand View Research published in 2019 and based on historical data from 2015 to 2017, estimated the global LED lighting market size was valued at US$ 45,57 billion in 2018 and forecast an expansion at a CAGR of 11,8% over the 2019-25 period. The same report relates that the indoor segment was valued at over US$ 31,70 billion in 2018 and is expected to witness stable growth throughout the forecast period. [GVR-19]

According to the market research report published by P&S Market Research in 2018, the global LED lighting market size is projected to cross US$ 70,2 billion by 2023, growing at a CAGR of 12,6% between 2017-2023. [PSM-18]

Figure 27 summarises the various forecasts and a good agreement among all of them is visible. The same observation concerns the CAGR values, thus we can adopt an average value of 12% for the period 2016-23.

LED prices continue to fall as the estimated 38 billion cumulative sales of LED lighting products in the past five years have generated economies of scale. Not only is competition among manufacturers making standard LED products more affordable, but further innovation is presenting customers with a wider choice of prices and products. [IE-19] China has taken the lead in manufacturing, benefitting from considerable government subsidies and incentives, and prices have fallen substantially to US$ 3-5 per LED light bulb. Prices are similar in many European markets and in North America.

[10] The base year considered for this report is 2015, and the market size forecast is provided for the period between 2016 and 2022.

[11] The market for retrofit LEDs is projected to register higher CAGR, of 16,3%, during the forecast period (2017-23) [PSI-18].

Figure 27: Global LED Lighting market forecasts by various analysts. Data origins are marked on the plot, data with red dots are data projections from [STA-19]

As claimed by CSIL analysts [CSI-19d], in 2018, the world trade of lighting fixtures among the 70 countries representing the whole global production and 97% of global consumption has expanded both in terms of imports (US$ 42 billion; +4,3% YoY) and exports (US$ 42 billion; +5,1% YoY). The expansion of the sector was driven by an increase in lighting fixtures production (+4,6%) and consumption (+4,3%) over 2018.

Even if LED penetration remains uneven across many markets, and sales are typically lower in relative terms for lamp replacements than for newly built buildings, many companies and governments are enacting measures to enlarge the share of LEDs in existing residential, public and commercial buildings. [IEA-19]

The worldwide market for lighting fixtures is expected to reach more than US$ 107 billion by 2023. China is the largest producer and exporter of lighting fixtures, when, United States is the main consumer and importer (the value of its lighting fixtures imports has risen by 6,5% in 2017). During 2018 the world trade of lamps offered a mixed picture: exports fell by 5,4%, while imports increased by 3,7%. Overall, it was worth US$ 16 billion. [CSI-19d].

The retrofit category, based on installation type, is projected to experience faster growth in the LED lighting market untill 2030. The growth is attributed to the increasing replacement of sodium-vapor and incandescent lamps with LED lights, in countries such as India, Japan, China, the U.A.E., the US, and South Korea. The strong demand for retrofit LED lamps in these countries, due to the phasing out of incandescent bulbs, is expected to further boost the LED lighting market. [PSI-20]

Public street lighting is an essential element of urban environment and is responsible for typically ~40% of a city's overall electricity costs. There are currently 317 million total streetlights in the world. This number will grow to 363 million total streetlights by 2027. [NEG-17] In 2012, 10% of new public streetlights were LED based, and this figure is expected to rise to 80% by 2020. [GRF-19] Based on more recent data, Statista reported in 2019 the value of the global outdoor lighting market amounted to about US$ 10,7 billion and forecasted to rise to US$ 23,8 billion dollars by 2030. [STA-20d]

The Northeast Group estimates that Across 125 countries, 264 million LED streetlights will be added over the next ten years, reaching a penetration rate of 89% by 2027. [NEG-17] Replacing legacy SHP lighting by modern LEDs, that offers longer lifetimes, lower energy consumption and reduced maintenance expenses, represent a typical payback periods range from 4 to 12 years for a city [SCC-15]. As of 2016, the Northeast Group has identified more than 1 000 unique LED streetlight projects in over 90 countries. [NEG-16] Global investment, from 2017 to 2027, in public LED street lighting will be US $53,6 billion. [NEG-17]

Globally [SCC-15] forecasted an investment of US$ 57 billion in LED lighting. Similar estimations come from Northeast Group, forecasting a US$ 64,2 billion market opportunity over the next decade (2017-27). The largest market segment will be cobra-head LED streetlights, which will be worth US$ 36,1 billion over the next ten years. Decorative LED streetlights will have a value of US$ 14,1 billion and high wattage LED streetlights will have a value of US$ 3,3 billion over the forecast period (2017-27). [NEG-17]

In the near term, the largest markets will be North America, Europe and South Asia, with adoption being driven by cities looking to reduce high energy and labour costs.

In any case, all analysts agreed, on the one hand, that decreasing cost of LED lights is one of the major factors driving their adoption across several applications, including residential, commercial and architectural lighting. On the other hand, they observed that lack of awareness regarding new installations of LED lighting solutions and large payback period of the installation have led to the slow adoption of LED lighting solutions, globally. Awareness level of the total installation cost, payback period of LED lights, return on investment (ROI) and energy savings among consumers is low, mainly in countries such as India, Saudi Arabia, the U.A.E., Indonesia and Canada. Due to this, the consumers use either traditional lighting solutions or other low-cost energy efficient lighting sources, such as CFLs and LFT lamps. This is likely to hinder the growth of the LED lighting market.

3.1.1.2 Automotive lighting

Initially, LED technology use had been limited to high-end vehicles and has had to compete with traditional light sources, namely halogen and HID lamps. Improved LED performance, lower power consumption and flexible design were the first enablers. Then, cost reductions helped LED technology spread to all vehicle categories [YOL-17]. However, automotive lighting is a very stringent segment that requires (1) highest quality standards across value chain; (2) sustained commitment due to long time to market; (3) Availability of production capacity subject to the potential for volume growth. Of course, OEMs and suppliers are continuously faced with price pressure. [LEX-18]

During the few past years, many progresses also have been achieved in the automotive lighting segment. Glare-free adaptive headlamps were made possible by the development of LED matrix systems splitting the front beam into up to 25 vertical segments. Today, the highest matrix resolution commercially available has 84 pixels per headlamp, making it possible for the system to create sharp masking zones. Car manufacturers and Tier-1 equipment suppliers are now developing new technologies like very small and/or μ-LEDs, laser or Liquid Crystal Display (LCD) light sources with resolutions ranging from 2 000 pixels to more than 500 000 pixels per headlamp. [YOL-17] Suji Nakamura, reported that phosphor converted-violet LD technology developed by his spin-off company[12] car illuminate the road to a distance between 600 m and potentially up to 1 km ahead when LED head-lights can go up to 300 m. This is a very important breakthrough for traffic security. [NAK-18]

Yole analysts report that the automotive lighting market totalled UD$ 25,7 billion in 2016 and close to US$ 27,7 billion in 2017. They estimate to reach UD$ 35,9 billion in 2022 at a 57% CAGR within the forecasted period 2016-22.

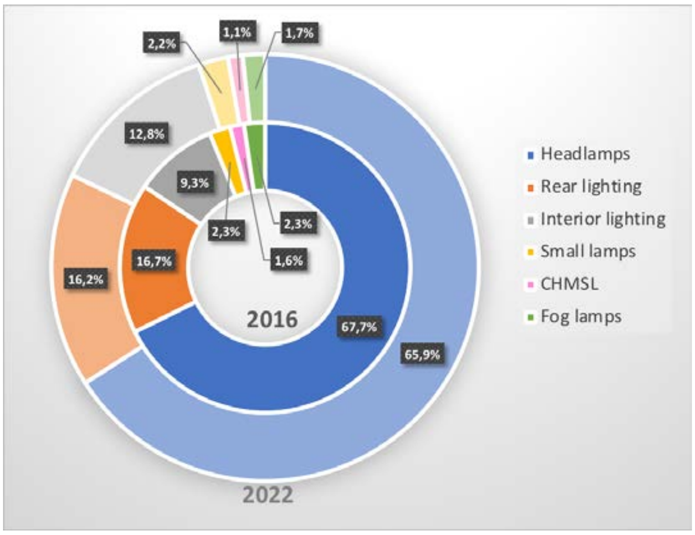
Figure 28: Number of automotive headlamps per technology (data from [LEX-18])

[12] SLD Laser : www.sldlaser.com

If today a modern car has a number of LEDs valued to €25/vehicle it is expected to increase to €35/vehicle by 2023. The global segment growth is forecasted to 7-9% per annum; thus, it is expected passing from €2 billion in 2017 to €3 billion in 2023. The new generation of LEDs, the μ-LED, will have a major role to play in this market segment. Headlamp will drive the market growth with ~60-70% of the surplus [LEX-18]. Figure 28 shows the number of headlamp units produced in 2017 and the projections for 2023.

Yole also confirmed that automotive lighting is driven by exterior lighting and especially headlamps, generating more than two-thirds of the total market revenue of the segment as it can be seen in Figure 29. Further, rear lighting 17% of total market revenue is the second largest area (this segment is also targeted by OLED technology, see paragraph 4.2.1). Interior lighting represents almost 10% of revenue but growth is expected to be linked to the development of autonomous vehicles and the creation of vehicles as “living homes”. Other types of lighting, such as fog lamps, Centre High Mounted Signal Light (CHMSL) or small lamps, comprised the remaining 7% altogether of revenue in 2016. [YOL-17]

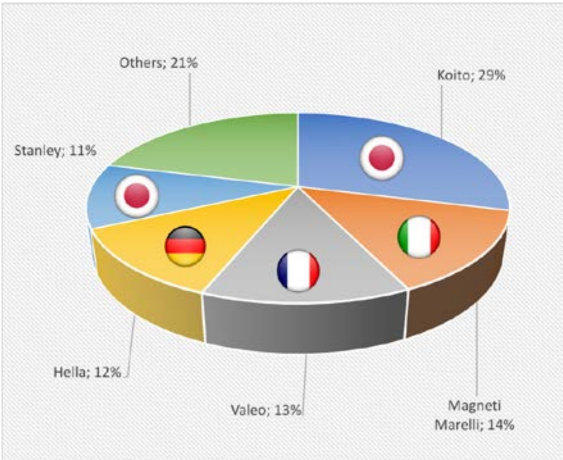
Figure 29: Evolution of market size for various sectors in automotive lighting between 2016 and 2022. Data from [YOL-17]



Among 20 competing companies, the automotive lighting industry is in the hands of five players: Japan’s Koito and Stanley, Italy’s Magneti Marelli, France’s Valeo, and Germany’s Hella. They received 80% of the total automotive lighting revenue in 2016. [YOL-17] Figure 30 illustrates the market parts of the industrial ecosystem in 2017; it can be seen that Japan, with 2 major companies, covers more than 40% followed very closely by the EU with more than 39% of market shares (3 major companies).

Asia, and mostly China, represents the next main opportunity in the automotive market, with nearly 65% of vehicles to be sold in the region between 2017 and 2022. Osram OS has a leading position in Chinese marker. [LEX-18]

Figure 30: Automotive lighting industrial ecosystem in 2017. Data from [YOL-17]



Osram Opto Semiconductors (Germany), with close connection to more than 100 automotive OEMs, is also a very important and ambitious player. [LEX-18]. Osram OS reported, that the OSRAM-Continental GmbH joint venture, set up by the two technology companies Continental AG and Osram, is up and running. For the joint venture, based to a large extend in Toulouse (France), Continental and Osram are combining their strengths to develop state-of-the-art and intelligent solutions for headlamps, tail and interior lighting. OSRAM Continental is planning growth rates of up to double digits annually for the next five years. This is based on strong growth in the market for LED as well as laser-based lighting modules and solutions and associated electronics.

3.1.1.3 Stage lighting

The global stage lighting market is anticipated, by ResearchAndMarkets, to reach revenues of approximately US$3 billion by 2023, growing at a CAGR of around 4% during 2017-2023 [RAM-18]. This market segment is driven by the introduction of upgrades and expansion of product portfolios by leading vendors. The development of products with features such as ease of usage, connectivity, design, sensor technology, signal transmission and brightness level will revolutionise the global stage lighting market.

3.1.1.4 Decorative lighting

Decorative lighting is the fourth layer of interior illumination; it helps the space sparkle and shine. It accessorizes the house and brings out its best features by adding decorative lighting fixtures. The decorative lighting segment includes: (1) Atmosphere and mood lighting; (2) Nostalgic style lighting; (3) Playful and festive lighting.

The European market for decorative lighting is expected to continue to offer interesting opportunities. The rising popularity of LED lighting as an energy efficient and green solution drives the demand for new lighting concepts and lamp designs.

The European market for lighting is significant and growing and in the home sector, the lion's share consists of decorative lighting. Between 2014 and 2018, total imports of lighting into the European Union increased from €12 billion to €14 billion. The average annual growth between 2014 and 2018 was 5,1%. By comparison, global imports of lighting grew at an average rate of 6% between 2014 and 2018, reaching almost €37 billion in 2018. In 2018, 44% of the total European import value came from developing countries. Imports from developing countries grew significantly between 2014 and 2017, after which they remained relatively stable in 2018, reaching €6.3 billion. The average yearly growth rate stood at 6,4% between 2014 and 2018. [CBI-20]

3.1.1.5 Emergency Lighting

According to Prescient & Strategic Intelligence report [PSI-18b], the global emergency lighting market is expected to reach US$ 7,4 billion by 2024, registering a CAGR of 7,6% during 2019-2024. The growing number of construction projects and technological advancements in lighting industry are the key factors contributing to the growth of the emergency lighting market.

Based on application, the emergency lighting market is categorised into residential, commercial, industrial and others, wherein 'others' include railway station, airports and ship yards. Among these, residential emergency lighting is expected to be the fastest growing category in the forecast period. This would be due to increasing construction of residential homes predominately in APAC and MEA region. Further, several countries such as U.A.E, Qatar, and Brazil, are making it mandatory to install emergency lighting systems in buildings, which in turns is fuelling the demand for emergency lighting. [PSI-18b]

Globally, North America with a share of 30% is estimated to be the largest emergency lighting market, in 2018 (when MENA were at 20%, Europe ~20% and APAC in ~30%). This is attributed to increasing construction of commercial and residential buildings in the US, increasing the focus of the US government on energy efficient lighting in buildings, and strict safety norms pertaining to installation of emergency lights in commercial buildings in the country. However, the emergency lighting market in APAC is expected to witness fastest CAGR in the forecast period. This would be owing to growing smart home market in the region, development of smart cities especially in India, and increasing government initiatives supporting adoption of LED lights in India, and Japan. [PSI-18b]

In Europe, in 2017, the average growth rate per year of the emergency lighting market has been approximately 3,5% in Euros. EBITDA margin for the considered products runs around 10% along the considered period. Fifty (50) manufacturers hold over 90% of the European market for emergency lighting. The production is made by around 15% of centralised systems, 40% stand-alone systems, 45% signage/ordinary products. The incidence of LED on sales of emergency lighting fixtures was estimated around 20% in 2012. In 2017 it is expected to reach 70%. [CSI-17b]

3.1.1.6 Off-grid lighting

Following a report from International Finance Corporation (IFC) the global off-grid solar sector is providing improved electricity access to an estimated 73 million households, or over 360 million people lack access to an electricity connection to the national grid [IFC-18]. As example, in Nepal, 18,28 % of household uses kerosene as the source of lighting (4.04 % in urban and 21.68 % in rural environments). [BIS-19]

The sector encountered for sales of over 130 million devices since 2010, penetrating approximately 17% of the global potential market (60% CAGR), and generating US$ 3,9 billion in cumulative revenue. Based on GOOGLA data, IFC reports that (1) ~US$ 5,2 billion in economic savings to households as they switch from kerosene and/or other conventional fuels[13] to solar lighting devices; (2) 28,6 Mt of greenhouse gas emissions have been avoided that way and (3) an estimated 1,9 million people have used solar lighting devices to support income generating activities. [IFC-18]

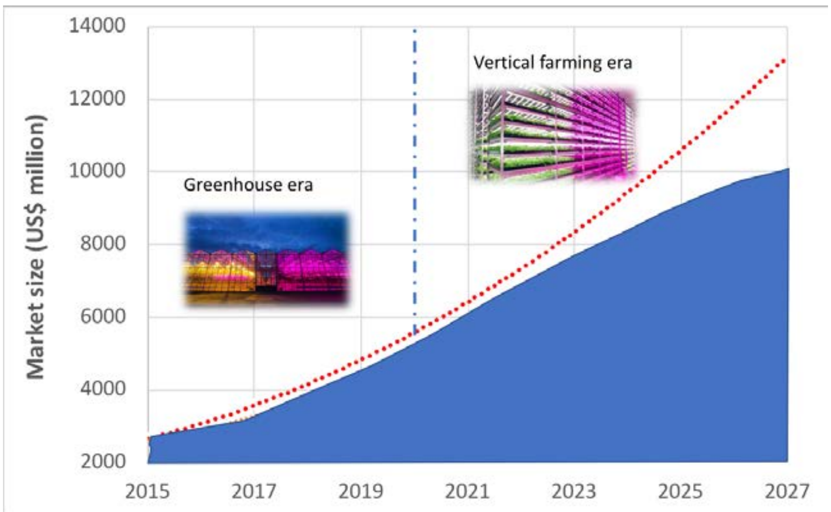
IFC experts pointed out also the emergence of multiple product categories sold via cash and Pay-As-You-Go (PAYGO) business models, and expanding beyond lighting to increasingly include off-grid appliances. In parallel, the same source observed an increasing interest and commitments from investors, including commercial debt and equity players, since 2014. More than USD 500 million has been raised within a 2-year period (2016-17). Further, more than 25 countries are now engaged in partnerships with the World Bank Group (mostly in Sub-Saharan Area) to build capacity and deploy funding to the sector. [IFC-18]

3.1.1.7 Horticultural lighting

Urban farming and greenhouses are underlying drivers for the strong market growth in horticulture lighting. Indeed, this is a rapidly merging segment. Until 2020 the sector has been dominated by greenhouse non-stacked inter-lighting. Here, LEDs have strong advantages because of better spectral match and low radiative heat damage of the crops. In the next few years however top-lighting in greenhouses will be dominant[14]. In that case cost reduction and strong performance are critical. LEDs expected to catch-up in 2-3 years. [DIE-18]

The management of photosynthesis using artificial lighting is the most effective way of influencing the productivity and yield of plants. As Leonid Yuferev et al recently published, the most favourable factors for growing "light-loving" plants are intensity, within the range of 150-220 W/m^2, and optimum composition of radiation, with the following ratio of energies over the spectrum: 30% in the blue region (380-490 nm), 20% in the green (490-590 nm) and 50% in the red region (600-700 nm). [YUF-18] However, as plants also need UV-A and UV-B radiation during the growth period, in fact UV-A and B play an important role to plant's secondary metabolism, phototropism, shade avoidance and photomorphogenesis, [ASH-20] LEDs have a structural disadvantage due to their low UV emission.

Figure 31: Horticultural lighting market for greenhouse applications (blue area) and surplus revenue linked to vertical farming (red dotted line). Data from [YOL-18]



[13] 670 million is the number of fuel lamps used in the world according to UNEP producing 74 million tons of greenhouse emissions per year.

[14] This is similar to traditional lighting configuration which is currently cost beneficial

Currently the market is driven mainly by greenhouse applications and many LED producers have entered the market of horticulture lighting to share the expanding opportunities when the demands in the general lighting market are relatively weak. In 2020 the era of vertical and indoor farming has begun, as shown in Figure 26. It should be noticed that today, greenhouse lighting requires a power density of ~1,2MW/ha. [WAT-18]

According to the research conducted by LEDinside [AIC-18], the market scale of LED plant lighting will reach US$ 224 million in 2018 and is estimated to grow to US$ 633 million by 2022, with a CAGR of 30% during 2018-2022. However, Yole reported that horticultural LED lighting market reached almost US$ $3,8 billion in 2017. Yole considers that emerging applications, including urban farming, are likely to make the horticultural lighting market boom with a 16,4% CAGR between 2018 and 2023. [YOL-18]

Europe, APAC region and North America are, and will remain at least until 2025, the main drivers of this market with equivalent shares oscillating from 37% for Europe to ~30% for the two other regions. In this context, it is not surprising to discover Jeff Bezos' support for a vertical farms project in China. In a recent article, a journalist announced a 300 vertical farms project in China, supported by Amazon. A start-up named Plenty has raised more than US$ 200 million, thanks to the Softbank Group and investment funds. Entering the Chinese market, Plenty hopes to tap into the country's growing demand for organic foods. [YOL-18]

In 2017 the USA totalised a 4 million square meters of lit surfaces for horticulture. Only 1% among them where dedicated to vertical farming.

Osram Opto Semiconductors (Germany) is today number one in this segment. Even if the size of the segment for Osram OS is estimated to reach approximately € 500 millions in 2023, it can be considered modest. Emmanuel Dieppedalle predicts a CAGR higher than 30% in the domain for the period 2017-23 and the volume can go up by approximately 4 times in next five years. [DIE-18]

In February 2019, Cree, Inc. introduced a next-generation 'XLamp,' called XP-E2 Photo Red (660nm) and Far Red (730nm). The newly launched product has especially been developed to provide enhanced services in the horticulture sector. These horticulture LEDs increase the efficiency of LED luminaires and also shorten the payback period. [FBI-20]

3.1.2 Market by world regions

3.1.2.1 European Union & UK

The European Union (EU) lighting market is expected to grow from € 16,3 billion in 2012 to € 19,8 billion in 2020 [CBI-14] and it will surpass a remuneration of US$ 30 billion by 2024 [GMI-19b]. Following [MAM-17] Europe is expected to be the second largest LED lighting market by 2022. LEDs lighting is increasing its market share from 15% in 2012 (or even 9% in 2011) to 72% in 2020. However, more recent data show that Europe's overall LED penetration rates are estimated in 2016 to be 8% of lamps and 9% of luminaires [NAV-17], lagging behind previous predictions. This can be partially explained by the fact that Europe has a population with a relatively high standard of living. A key factor driving the demand of LED products in Europe has been the European Union's policy measures banning the sale of inefficient lighting technologies. In fact, phasing out traditional lighting technologies will prevent over 15,2 million tons of carbon emission by 2025. [GMI-19b] That way, the European Union announced new regulations to phase out the tungsten halogen and compact fluorescent lamps by 2020. The new regulations under the new Ecodesign Law state a maximum standby power of 0,5 W and a minimum efficacy requirement of 85 lm/W. The national governments are also providing subsidies and incentives to increase the adoption of LED products among consumers, phasing out older and less efficient technologies to enhance the overall efficiency of lighting sector. According to Imarc analysis, other key factors driving the demand of LED products in Europe include infrastructure growth, upcoming smart building projects and a decline in the average prices of LEDs. Looking forward, the same analyst expects the market to exhibit moderate growth during 2020-2025. [IMA-20b]

CSIL analysts estimated the total Lighting fixtures sold in the European market at around € 21 billion for the year 2019 (+1,6% compared to 2018). LED lamps registered a 14% growth (additionally € 1,9 billion) while legacy lamps registered a -17% (now around € 450 million). To be added also, to reach a grand total for the Lighting market (not considering only lighting fixtures), an estimate of European market for Lighting controls of about € 550 million (+4,8%). The slight increase of consumption of lighting fixtures comes from a +2% for professional luminaires and around -1% for consumer lighting. [CSI-20b]

In 2019, the volume of lighting fixtures exports reached € 13,4 billion, registering an increase of +0,6% compared to the previous year. Imports of lighting fixtures in Europe reached € 17,1 billion in 2019, with an increase of 2,6% compared to 2018. [CSI-20b] In 2019, the European trade balance recorded a deficit of € 3,7 billion, (€ 3,6 billion the previous year). As the internal EU market accounted for € 21 billion revenue, that the difference of € 4 billion is covered by European production.

According to [CSI-20b], among the companies growing in the European market during 2019 (not ranked): Zumtobel, Ikea, Fagerhult, Yankon, Glamox, SLV, Flos, Xal. More European leaders include Signify (on all the market segments), Ledvance (mainly on lamps), Eglo (consumer lighting), Flos (design), Trilux (industrial lighting), Glamox (office), Fagerhult (retail), Molto Luce (hospitality), Schréder, AEC (street lighting), to mention some.

Table 7: Situation some EU countries

France	in France, AFE compiled data from different national sources (ADEME, Recylum, OpusLight, Syndicat de l'éclairage) and published them in their web site [AFE-19]. The size of the French lighting market (excluding smart lighting) represents roughly €2,3 billion per annum. The fixtures/luminaire market represents a turnover ~€800 million. Residential lighting LED lamp sales rose sharply to exceed 127 million units in 2017, i.e. three quarters of the lamps sold during the year (169 million units in total). Between 2016 and 2017, the number of LED lamps sold jumped by almost 46%, from 87 million to 127 million. The market share of LED lamps for building lighting of buildings will increase from 35% in 2017 to 61% in 2020. The penetration rate of LEDs in France for street lighting is estimated at 15% in 2017. Lighting absorbs in France: 56 TWh of electricity per annum, i.e. 12% of French electricity consumption. Street lighting uses 5,6 TWh/yr and indoor lighting is responsible for additional 37 TWh. The major contribution in this last figure are (a) 9,5 TWh for commercial spaces; (b) 6,6 TWh for office spaces; (c) 4 TWh for health care establishments; (d) 4 TWh for education premises. The electricity consumption of a French household, excluding heating and hot water, is on average 2700 kWh/yr. Households devote 12,8% of their specific electricity consumption to lighting, i.e. between 325 and 450 kWh/yr.[15] The average household lighting time is 2 464 h/yr, or 6,7 hours per day. Each household has an average of 25 light points and buys 3 lamps per year. Around 7 million households buy an indoor luminaire each year with a median annual budget of 106 €. 28% of sales are made by DIY specialists and the place of the house which is equipped first and foremost is the living room with 26% of the purchased equipment intended for it. Smart Lighting in residential is growing: Household penetration will be 7,8% in 2020 and is expected to hit 18,7% by 2025. The interior market revenue in the Comfort and Lighting segment is projected to reach US$ 202 million in 2020 and it is expected to show an annual growth rate (CAGR 2020-2025) of 23,5%, resulting in a projected market volume of US$579 million by 2025. The penetration for Smart bulbs in households will be at 5,6% in 2020. [STA-19c] In the sector of tertiary-building sector, 80% of lighting installations are obsolete, often dating back more than 20 years. For instance, 50 million LFLs should be replaced by end of 2020. This obsolescent lighting systems are responsible for the 4 Mt of greenhouse gas per annum[16]. Further, 5,1 billion euros is spent unnecessarily each year to run those same obsolete facilities. It should be noticed that more than 70% of the lighting consumption of buildings is done during the daytime… Concerning street/urban lighting it exists in France 9,5 million light points for an annual consumption of around 5,6 TWh. In 2019, 60% of the French urban lighting parc is made up of sodium lamps, 30% of mercury vapor lamps and 10% of LEDs. Operating for average 3 200 hours per year (-24% since 1990). Urban lighting expenditure totalled nearly €2 billion per year, including: €1 billion devoted to maintenance, €400 to €500 million euros invested in the renewal of the park and more than €450 million attributable to energy consumption. This corresponds to average annual cost of €24-30 per inhabitant. For an average city council, public lighting, despite a 6% drop in consumption over the past seven years, represents 17% of their total energy consumption and 41% of their electricity bill. In 2020, 75% of installed

[15] For comparison, devices left on standby represent between 7 and 18% of electricity consumption
[16] 3 % of the total emissions of tertiary sector buildings

	lighting poles are more than 15-year-old and 43% of municipalities with more than 500 inhabitants plan to invest in improving their public lighting in the next two or three years. This corresponds to investments of €1 billion. Since 2017, more than 95% of renovations or new street lighting projects are using LEDs. To power Christmas festive lights, the electrical power required is 1,300 MW; 75% of this overconsumption is due to lighting in private homes. This represents the equivalent of the annual consumption of 600 000 recent refrigerators. For this reason, the city councils adopted massively LEDs to reduce festive lighting consumption. That way, the City of Paris has considerably reduced the consumption and budget of its lighting, by switching to LEDs: the 800 000 light points on the famous Clamps Elysées avenue absorb no more than a family of 4 in one year, i.e. 10 990 kWh (consumption divided by 4 compared to 2013 and 50 times less than in 2006). Accounting for 11% the total European imports of decorative lighting, France is the number two importer. Although imports in this specific sector increased at an average rate of 6,7% between 2014 and 2018, reaching €1,6 billion in 2018. Some 48% of the imported lighting comes directly from developing countries. Between 2014 and 2018, imports from developing countries grew at an average rate of 9% per year. [CBI-20]
Italy	Italy is one of the largest markets for lighting in Europe. Following BusinesScoot analysts, the Italian lighting sector is in turn divided into products for indoor or outdoor, decorative or technical. In Italy, lighting is a driving segment of the national economy and accounts for a considerable part of exports (estimated to more than €1,5 billion per year). The value of production in fact shows positive signs in recent years but will have to reckon with a rapid change in the needs of consumers increasingly attentive to the environment and cost efficiency, and a regulation in continuous change. The offer of Italian companies must therefore be able to anticipate and manage these transformations and adapt both production and marketing towards a growing focus on smart lighting and LEDs. [BSC-19] Following ASSIL, the National Association of Lighting Manufacturers who brings together manufacturers of appliances, electrical components for lighting, light sources and LEDs, operating on the Italian market, its member companies represented in 2020 a global industry turnover of € 2,9 billion and employ over 8 000 persons [ASS-20]. ASSIL It includes around 80 manufacturers of luminaires, electrical components for lighting, light sources and LED. Assuming that the revenue given by ASSIL represents over 65% of the total Italian lighting industry turnover in the sector, we can estimate the global national lighting revenue in 2020 at € 4,46 billion. It should be noted that the global revenue of Italian Lighting industry was estimated at € 4,17 billion in 2014. [ITA-15] This corresponds to a CAGR in the period 2014-20 of 1,13% and indicates a relative stability concerning industry turnover. Looking at the national interior market, Statista estimated the global revenue from OEM sales to US$ 2 576 million in 2020 and forecasts an increase of national demand to a CAGR of 4,9% for the period 2020-25. Figure 32 shows the evolution of the national lamp and fixture revenue.

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Figure 32: Evolution of Italian lamp and fixture revenue interior market revenue data from [STA-20h]

The average per capita investment is estimated at US$ 42,60 with a decline with a YoY rate of -8,8% from 2019 to 2020. However, an increase is foreseen till 2025. [STA-20h]

Italy saw steady growth in its imports of decorative lighting between 2014 and 2018, which averaged almost 7% per year. In 2018, the total import value of lighting was €888 million. Italy obtains over 60% of its imported lighting from developing countries. [CBI-20]

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Germany

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Following Statista, the revenue in the Lamps and Lighting segment in Germany reached US$7,815 billion in 2020 and the market is expected to grow annually by 2,0% CAGR for the period 2020-25. [STA-20e]. Global Market Insides reports that in 2017 the German market size was US$ 2,37 billion and forecasted to reach US$ 8,5 billion by 2024. [GMI-19b] Figure 33 shows the revenue evolution split among end-use sectors.

Figure 33: German Market size evolution by end-use sector; original data from [GMI-19b]

The average revenue per person in the segment for Lamps and Lighting amounts to US$93.27 in 2020. [STA-20e]

Germany, for its part, is seeing its public lighting stock being renovated at a rate twice as fast as France, supported by an electricity price double the French price. By 2020, the latest studies show that LEDs will represent 80% of the German market. [AFE-19]

In 2019, Germany had 9% of all smart home users in Europe. [STA-20b] It should be noticed also that in Germany the Elder Care lighting sector generates an annual revenue of approximately US$ 24 million. [GMI-19b]

More especially for decorative lighting, Germany is Europe's largest market for lighting. representing 20% of European imports. German imports of lighting reached almost €3 billion in 2018. Between 2014 and 2018, German imports of lighting grew moderately at an average rate of 3% per year. It is noteworthy that the German lighting market is well integrated with developing country supply chains, as over 60% of its imports of lighting come from developing countries. At the same time, Germany is one of the leading producers and suppliers to the

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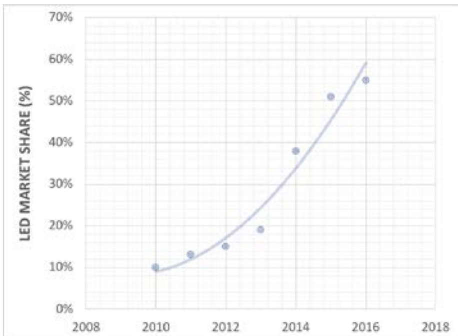
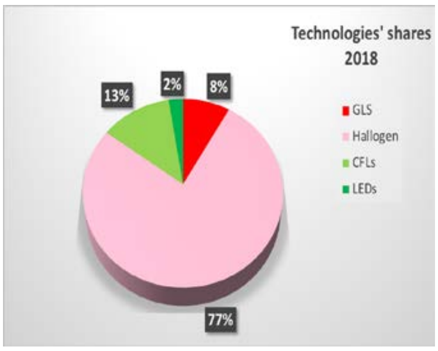
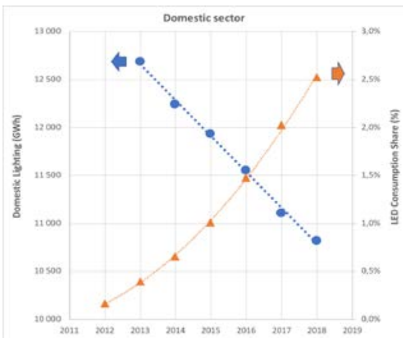
	European Union. That means that German production does compete with developing country suppliers. [CBI-20]
Greece	The electricity consumed by lighting is 21% of the national annual consumption [GRI-20]. Lighting represents 14% of final electricity consumption in households while increases to 43% in public sector office buildings. Smart home and smart lighting markets are lagging back in Greece: Household penetration will be 1,8% in 2020 and is expected to hit 7,1% by 2025. The penetration for Smart bulbs is at 1,2% level in 2020. This can be explained partially by the recent financial crisis that experienced the country. The interior market revenue in the Comfort and Lighting segment is projected to reach US$ 4 million in 2020, it is expected to show an annual growth rate (CAGR 2020-2025) of 30,9%, resulting in a projected market volume of US$15m by 2025. [STA-19c]
Netherlands	Netherlands is a small country with long tradition in lighting. Smart lighting and smart homes are for sure very trendy here: Smart Housing penetration will be 16,4%-level in 2020 and is expected to hit 34,6% by 2025. Further, Smart bulbs will be at 12,8% in 2020. The national revenue in the Comfort and Lighting segment is projected to reach US$ 119 million in 2020. It is expected to show an annual growth rate (CAGR 2020-2025) of 25,2%, resulting in a projected market volume of US$366m by 2025. [STA-19c] In 2018, following CSIL analysts, the Dutch fixture market has exhibited an 8,4% expansion and it is among the top importing countries. [CSI-19d] Private consumption expenditure growth for decorative lighting in the Netherlands is forecast to drop from 2,5% in 2018 to 1,1% in 2019. The Brexit as well as the international trade disputes between the United States and China, have a big impact on the Netherlands. The country relies heavily on international trade and negative developments in that respect area have an amplified effect on the economic performance of the country. This will likely have an effect on economic growth, consumer confidence and resulting consumption of decorative lighting in the country. [CBI-20]
Spain	As reported by ANFALUM, Spanish market is on rapid transformation path towards LED technology. Figure 34 shows that path. **Figure 34:** Market shares of LED technology in Spanish lighting market. Data from [ANF-16]  The turnover of Spanish lighting industry has been evaluated in 2016 to be €1,26 billion. Technical interior lights with €577 million lead, followed by street lights with €262 million. Further, looking at exports of lighting products from Spanish industry, LED technology share were established at 35%. [ANF-16] Between 2014 and 2018, Spain saw an average growth rate of 7% in the sector of decorative lighting, reaching a total import value of €819 million in 2018. The country is responsible for almost 6% of the total European imports of lighting. Spain sources over 65% of its lighting from developing countries and imported €457 million worth of lighting in 2018. On average, imports from developing countries grew by almost 12% between 2014 and 2018. Spain is therefore an interesting country to target. [CBI-20]
Portugal	Following BusinesScoot analysts, in recent years, companies in the lighting sector in Portugal have invested heavily in the internationalisation of their products. As a result, since 2009, exports from the Portuguese market have more than doubled, according to data from the

	Agência para o Investimento e Comércio Externo de Portuga (AICEP). Currently, approximately 70% of the total turnover of the Portuguese lighting industry comes from exports. [BSC-20] The Portuguese market stands out internationally for its differentiated production of unique pieces made to measure for each customer, as well as for its limited and innovative productions. This emphasis on personalised follow-up with a higher market value benefits the many players involved. However, the country suffers from the lack of economies of scale of enterprises (most of which are micro and small enterprises) that sometimes fail to meet a large demand. [BSC-20]
Denmark	European leader in terms of LEDs, Denmark has already converted between 25 and 30% of its lighting parc (1 million luminaires) to LEDs. [AFE-19] In 2019, Denmark with 23% of all smart home users in Europe occupies the 1st place of the top-10 EU countries (smart household penetration will be 18,4% in 2020 and is expected to hit 35,8% by 2025). [STA-20b] [STA-19c] The national revenue in the Comfort and Lighting segment is projected to reach US$ 59 million in 2020. The revenue is expected to show an annual growth rate (CAGR 2020-2025) of 18,3%, resulting in a projected market volume of US$ 137 million by 2025. The penetration for Smart bulbs will be at 13,1% level in 2020. Further, the average expenditure per installed Smart Home for Comfort and Lighting currently is US$ 118.31, one of the highest in EU. [STA-19c]
Sweden	Following Statista, the revenue in the Lamps and Lighting segment in Sweden is estimated to be US$375 million in 2020. The market is expected to grow annually by 1,7% CAGR for the period 2020-25. The average revenue per person in the segment for Lamps and Lighting amounts to US$214,55 in 2020. [STA-20f]
Finland	Following Statista, the revenue in the Lamps and Lighting segment in Finland is estimated to be US$2,167 million in 2020. The market is expected to grow annually by 1,7% CAGR for the period 2020-25. The average revenue per person in the segment for Lamps & Lighting amounts to US$67,75 in 2020. [STA-20g]
UK	Following the last statistics of the UK Department for Business, Energy & Industrial Strategy, lighting consumed in 2018, 22,5 TWh corresponding to ~9% of the electricity consumption of the kingdom [BEI-19]. Domestic sector uses ~48% of the above quantity when tertiary building's and street lighting and consumed 41% and 11% respectively. The exceptionally high domestic lighting consumption can be partially understood by the fact that still in 2018 the dominant technology is Halogen lamps (Figure 35a). For sure there is a huge potential for energy savings in that sector. Further, UK is today in the midst of a LED transition. Figure 35)b illustrates the evolution of electricity use for lighting by households as well as the part of that energy used by LED systems: it can be seen that since 2013 the electricity consumption of the sector decreases constantly and the shares of LED technology increases sharply. Further, using effective lighting controls & energy efficient lighting could drop by 4 to 6%. In 2019, UK had 16% of all smart home users in Europe. [STA-20b]. **Figure 35:** (a) Shares of different technologies used for domestic lighting in 2018. (b) Evolution of the electricity use for lighting in the Domestic sector (orange) and share of LEDs in that consumption (blue). Data from [BEI-19]



(a)



(b)

With 80% of new street lighting installations using LED the ongoing market transformation seems to be solidly engaged. [AFE-19] In fact, Within the UK, the Green Investment Bank has created the Green Loan for Local Authorities, a value for money financing product which can finance all LEDs and CMS capital expenditure including the poles. [GRF-19]

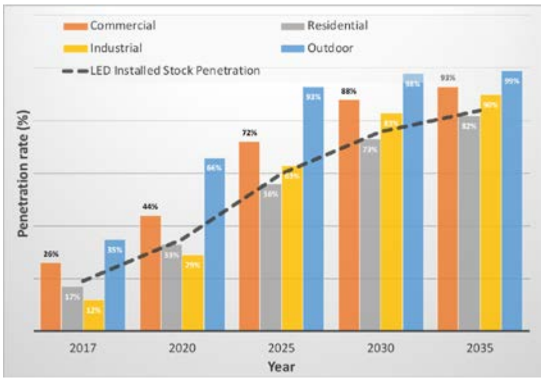
A downward trend in imports of decorative lighting in the United Kingdom was seen starting from 2015 (€1,6 billion), with the import value falling to €1,4 billion in 2018. Of the top six leading importers in Europe, UK ranks highest in terms of imports from developing countries, accounting for with 78% of these imports. However, decorative lighting segment saw a decline over the 2015 to 2018 period. The main reason for the decrease is the economic fallout, depreciation of the British Pound and loss of consumer confidence due to the Brexit. This trend is not expected to be reversed anytime soon. [CBI-20]

3.1.2.2 United States (USA) and Canada

United States

United States has 874 million cumulative LED unit installations as of 2016, this translates to an installed penetration of 12,6%. [NAV-17] USA-DOE estimated the installed stock penetration in 2017 to be 19%, and in 2035 the penetration was forecasted to reach 84% [DOE-19]. Figure 36 shows the current path for the installed stock penetration of LED technology in major USA lighting market segments as projected by DOE. It can be seen that outdoor lighting is the shows the highest penetration due to the application of public procurement politics, whereas the residential sector, subject of purchase price and eventual incentives, is lagging back.

Figure 36: Shows LED-technology penetration in various USA market segments as the projected by DOE (data from DOE-20])



Based on those forecasts DOE estimated that, if DOE SSL program goals for LED efficiency and controls/connected lighting are achieved, a total cumulative, from 2017 to 2035, energy savings of 78 quads is possible. This is equivalent to approximately, US$ 890 billion in avoided energy costs over that period [DOE-19]. However, one year later, based on market evidences DOE had to correct the current path for LED penetration in all the above segments. As can be seen in Figure 37a the relative estimation error based on the past year's data can reach 45% in the case of commercial buildings, when Figure 37b shows that energy savings were initially overestimated by 25%! This is a clear illustration that forecasts are volatile and that in rather short term; the only reliable way to proceed is using real marked data and limit forecast periods to less than 10-year periods. However, other way round, if DOE proposed measures are adopted then 25% additional energy savings could be achieved.

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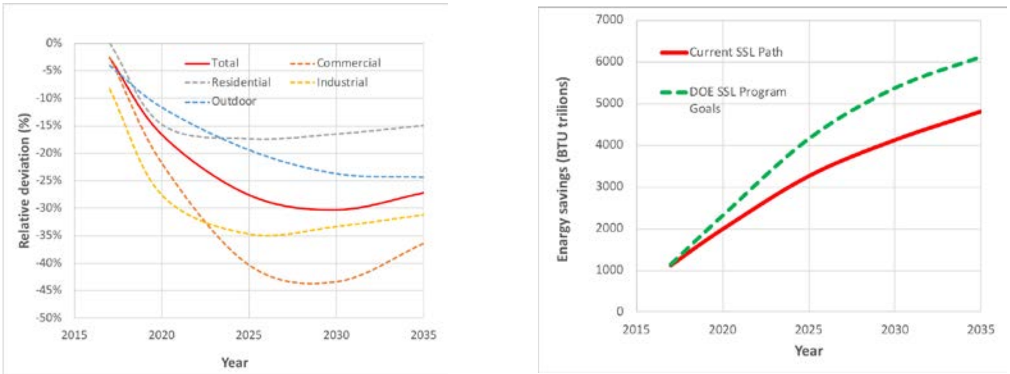
Figure 37: (a) Relative errors between 2019 and 2020 forecasts and their propagation till 2035. (b) Estimation error in the expected cumulative energy savings by 2035 using different market penetration forecast models (data from [DOE-20])

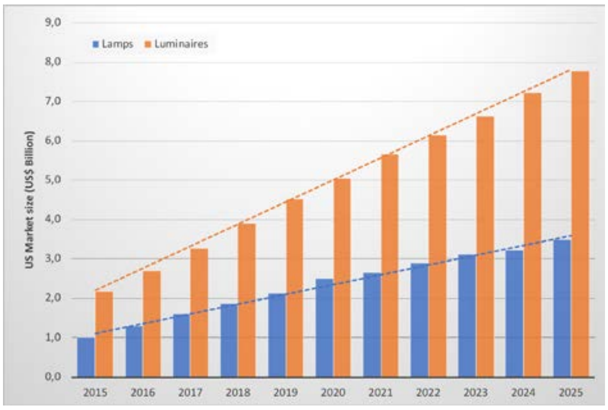


(a) (b)

It should however, noticed that in 2016 only 18% of the lamps and 16% of the luminaires (all technologies inclusive) where compliant with Energy Star standards for energy savings. [NAD-17]

Grand Vision Research [GVR-19] reported that US LED lamp and luminaire market size was US$ 4,0 billion and as can be seen in Figure 38 the analysts applied a linear progression model to estimate that the market size will attain in 2025 US$ 4,5 billion for LED lamps and US$ 4,5 billion for LED luminaires respectively.

Figure 38: Estimation of LED lamp and Luminaire market size in USA [GVR-19]



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<td>Canada</td>
<td>In Canada, Statista reports that the revenue in the Comfort and Lighting segment for residential sector is projected to reach US$ 197 million in 2020. This is lagging seriously back compared to US market. In fact, the number of smart households is expected to amount to 5,9 million by 2025. However, Smart bulbs penetration is rather high: 13,3% in 2020 and the average expenditure for Comfort and Lighting segment is evaluated to US$ 72,31 per household. [STA-19c]</td>
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3.1.2.3 Latin America region

Furthermore, Latin America is expected to grow moderately owing to the slow adoption of technologies in the region. Moreover, there are less light manufacturing companies present in Latin America, which is also affecting the market growth in the region. [FBI-20]

Following P&S Marker research, the Latin American market for LED lighting is expected to witness the fastest growth between 2017-2023. The LED lighting market in Latin America is projected to grow at a CAGR of 14,5% during the forecast period. [PSM-18]

The lighting fixtures market in Latin America has been evaluated by [CSI-18c] in US$ 4,3 billion in 2017, to reach over US$ 5,0 billion in 2022. LED share represents around 35% of overall consumption today, to double in around five years. Among the most promising segments for international players: all the Contract market (around US$ 700 million in the five countries as a whole), as well as solutions for hospitality, retail and office spaces (around US$ 1,2 billion as a total).

The top 50 players in Latin America account for 40% of the entire market. Among them: Acuity, Blumenau, Celsa, Construlita, Elec, Intral, Inesa Feilo, Kingsun, Ledvance, Lumicenter, Philips, Schreder, Taschibra, Tospo, Yankon. [CSI-18c]

Table 8: Some examples from various country's markets in Latin America Area

Brazil	Among all the countries in the Latin American region, **Brazil** is estimated to contribute the largest revenue to the Latin American market for LED lighting between 2017-2023. The growth of market in the country can be attributed to the declining manufacturing cost of LEDs and increasing demand for energy efficient and sustainable lighting. [PSM-18] Brazil has phased out incandescent bulbs through government regulations and the growth in residential and retail are expected to cause massive increases in LED lighting adoption. [NAV-17] Smart housing is growing in Brazil: smart technologies for houses penetration is ~2,6% in 2020 and is expected to hit 8,7% by 2025. The national market revenue in the Comfort and Lighting segment is projected to reach US$ 78 million in 2020 (Smart bulb penetration ~1,9%) and it is expected to show an annual growth rate (CAGR 2020-2025) of 30.1%, resulting in a projected market volume of US$292m by 2025. The average expenditure per installed Smart Home for Comfort and Lighting currently is estimated to US$ 43,57 per household, which is high in regard to country's GDP. Following BusinesScoot analysts, the Brazilian market has more than 600 companies in activity, representing a significant part of the economy, as it generates more than 37 000 jobs. In this segment, revenues are distributed in 61% for luminaries, 28% for lamps. The vast majority of industries are concentrated in Greater São Paulo, representing 58% of the total. 25% are in Rio Grande do Sul, Santa Catarina, Rio de Janeiro, Paraná, Minas Gerais, Bahia and Pernambuco. The remaining 17% are in the interior of the State of São Paulo. A growth of 10% per year is expected only for the LED lighting market, until 2022. [BSC-20b]
Argentina	In Argentina the smart home technology penetration is established at 2,4% in 2020 and is expected to hit 6,9% by 2025. The national market revenue in the Comfort and Lighting segment in residential sector is estimated to US$ 14 million in 2020 and it is expected to show an annual growth rate (CAGR 2020-2025) of 27,2%, resulting in a projected market volume of US$ 47 million by 2025. Smart bulb's penetration is estimated be at 1,7%-level in 2020, while the average expenditure per installed Smart Home currently is expected to amount to US$ 40,95. [STA-19c] These values are much lower that Brazil who is the leading market in South America, this lag can be partially explained by the current financial crisis that faces the country.

3.1.2.4 Middle East and Africa regions (MEA)

When it comes to lighting, Middle East users have been concerned about telling the hype from the reality, and when it comes to modern lighting technology, they still demand value for money.

Frost & Sullivan relates Gulf Cooperation Council (GCC) lighting market forecasts. They envisioned that market will witness a CAGR of 16,8% between 2015 and 2020 to reach revenues of US$ 1,98 billion. [FRS-17]

Various countries in the Middle East region are dedicated towards deploying energy efficient lighting solutions across residential, commercial, industrial and other sectors, to reduce carbon footprints and emissions as well as to provide a sustainable environment across the region. The demand of EEL light systems is anticipated to grow from 2017 to 2020. Demand for fluorescent lamps and HID lamps is anticipated to decline in the Middle East in coming years [TSR-18]. Table 9 indicates the evolution of market shares (in sales) for different light sources technologies, it can be seen that LEDs are the leading market technology since 2017.

Table 9: Shares of various light sources technologies evolution in Middle East region (data from [TSR-18])

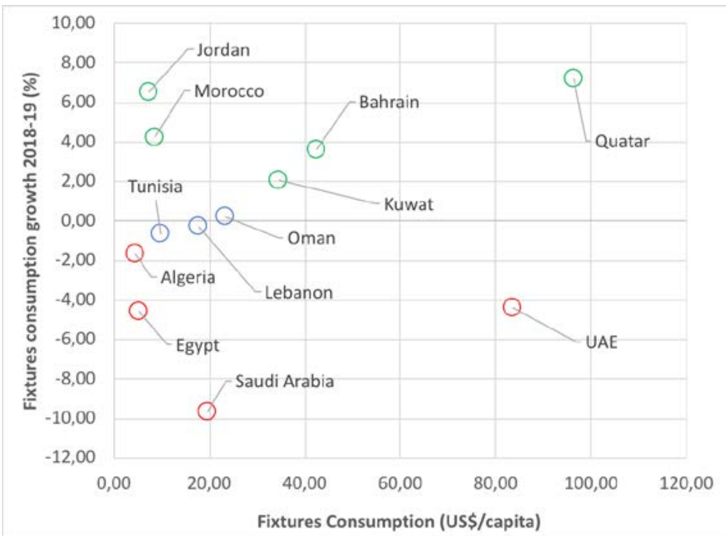
Type of light source	2017	2020
CFLs and LFLs	19,09%	18,16%
HID	4,19%	2,79%
LED	73,26%	75,44%
Others	3,46%	3,61%

As Frost & Sullivan reports [FRS-17], GCC is committed to reducing its carbon footprint and electricity demand through 2025, with clearly established targets in place. One of the easiest demand-side measures that can achieve this goal is to overhaul the lighting within buildings and at a city level, presenting robust market potential for LED in the region. GCC would also facilitate the evolution of OLEDs in the region that are considered the future solution for sustainable and energy-efficient lighting. [FRS-17]

To achieve EEL targets, GCC governments push to phase out inefficient lighting, such as incandescent bulbs or high-intensity discharge street lamps. Further, many ME governments are adopting since 2015 energy efficient lighting policies, directives, standards, regulations. The Middle East Lighting Association (MELA), is working with national governments on a more uniform Lighting System Legislation (LSL) approach that focuses on lighting systems put into service. [TSR-18]

The lighting fixtures market in the Middle East and North Africa regions (MENA) is estimated by CSIL to be worth US$ 3,3 billion in 2018, to reach 3,4-3,5 billion in 2020. After a stable 2019, a new growth is expected in most of the countries in the coming year. The Region is a net importer of lighting fixtures (around US$ 2,5 billion, equal to 77% of the total consumption). In 2017 and 2018, exports have decreased and currently amount to US$ 344 million. Since 2011 consumption of lighting fixtures registered a robust increase. However, due to the oil price implications, the market showed a negative performance in 2015 and 2016. Starting from 2017, the annual variation has returned positive. Most of the growth during 2018 comes from Saudi Arabia and Egypt. Lighting market in 2019 is growing especially in North Africa. Sales in the Gulf countries in 2020 are estimated growing by 3,4% on average. [CSI-20] Figure 39 shows fixtures revenue growth correlated to the actual sector's revenue by country.

Figure 39: Situation of lighting fixtures market in 2018-19. Green points correspond to progression, red t regression and blue to stable YoY rate. Data from [CSI-20]



Top 50 brands hold around 50% of the market. LED consumption has grown steeply over the last years. While in 2013 LED lighting incidence on the total was just 16%, in 2018 it was over 50 %. This trend is expected to continue in the next years: LED-based consumption will account for 70% of the total by the end of 2022. [CSI-20] Further, Middle East region fixture manufacturers will benefit from the increased business that will come their way from global LED light source manufacturers and can leverage their strengths to reach local customers and businesses.

Table 10: Situation some MEA region countries

United Arab Emirates	In U.A.E. the sales ban on inefficient incandescent lamps came into effect on 1 July 2014 move expected to save the country US$ 182 million a year on energy bills and the equivalent of 165000 cars in carbon emissions. [HAS-14] Dubai's outdoor lighting programme for demand side management (DSM) aims to retrofit 75% cent of lighting systems with LED fixtures across the country's roads, streets, and parks, with an aim to achieve savings of up to 300 gigawatt hours (GWh) in energy consumption by 2030. [FRS-17] Further, Dubai has reached an agreement with Philips to provide what has been dubbed the "Dubai Lamp" for all newly constructed buildings ~2 million units in 2017. [NAV-17].
Saudi Arabia	Saudi Arabia ambitions to increase rapidly both, smart home and smart lighting (smart bulb's share at home is estimated to ~3,0% in 2020) segments: Smart Household technology penetration will be 4,4% in 2020 and is expected to hit 10,4% by 2025. That way, the national market revenue in the Comfort and Lighting segment in households is projected to reach US$ 32million in 2020. And it is expected to show an annual growth rate (CAGR 2020-2025) of 19.5%, resulting in a projected market volume of US$77m by 2025. The average expenditure per installed Smart Home for Comfort and Lighting is currently estimated to US$ 125,39 per household. This the highest worldwide. [STA-19c] Following CSIL analysts, and Saudi Arabia with a fixture import growth of 16,3% occupied the 2nd rank I the top-10 importing countries [CSI-19d]
Turkey	In Turkey, the number of enterprises related to lighting equipment OEMs grown from 1 849 in 2010 to ~4 375 in 2018; 61,5% of the firms in manufacturing industry of electrical Lighting equipment have gathered in Istanbul. Share of Ankara is 10,6%, while Izmir ranks as the third with its share of 6,7%. Istanbul has production activity in each field of general Lighting. However, decorative lighting is common in Ankara and Izmir mostly. Automotive and industrial Lighting are common in Bursa and Kocaeli mainly. And mostly interior and exterior Lighting have been carried out in other cities. Production value in the manufacturing industry of electrical Lighting equipment was 1,46 billion TL in 2010; but it is estimated to reach 6,45 billion TKL in 2018. The total number of employees increased from 13 474 up to 25 500 in the 2010-18 period. [ICC-19] Turkish Domestic market size of Lighting equipment was US$ 2,45 billion in 2013; and it reached to US$ 2,59 billion. While the domestic market grew in real terms during 2015 and 2016, it contracted in dollar terms. The domestic market experienced a fast growth in 2017 in real terms and despite the depreciation of the Turkish lira, it expanded to US$ 2,31 billion. Domestic market contracted in 2018 in real terms and it shrank to US$ 1,94 billion dollars [ICC-19] Smart housing and smart lighting are lagging back compared to other countries. Penetration of smart technologies for houses is ~3,7% in 2020 and is expected to hit 11,7% by 2025. Smart bulbs penetration is established at 2,6%-level in 2020. The national market revenue in the Comfort and Lighting segment is projected to reach US$36m in 2020 and it is expected to show an annual growth rate (CAGR 2020-2025) of 26,0%, resulting in a projected market volume of US$ 116m by 2025. [STA-19c]
Iran	More surprising, LEDInside, based on information from Trend News Agency (Azerbaijan), related in 2018 that Iran plans to build a LED lamps plant with the cooperation of Chinese investors in Ardabil Province. The new plant will provide employment opportunities for local people and it is expected to produce nearly 12,500 LED lamps per day once it starts to run. The construction of the LED lamp plant aimed to reduce LED lamps imported to Iran. This project is on hold due to embargo conditions imposed to Iran. In FY2017, more than 2,000 tons of LED lamps worth US$19 million were imported by Iran from China, Germany, the UAE, Turkey and South Korea [LDI-18].
Kenya	Following Lighting Global Market Research Report [LGO-15], there has been massive growth in off-grid lighting sector. From 2012 to 2014, the number of off-grid lighting products sold in the three towns almost doubled (77% increase from 2012 to 2014), and the estimated monthly revenue from off-grid lighting products more than quadrupled (from US$ 32 000 in

	2012 to over US$ 180 000 in 2014). All three towns saw growth in product revenue, and Kericho accounted for the vast majority of product sales and revenue growth from 2012 to 2014. This perhaps indicates a key shift in consumer (and re-seller) purchasing preferences toward urban and peri-urban centres where there are established markets for other high-value electronic goods. Solar lighting products were the main drivers of growth in the off-grid lighting sector over the study period. In 2009 less than 2% of available products were solar in a retail market dominated by very inexpensive (and low quality) torches, and sales were sparse. By 2012, solar products represented ~1% of all products sold with 31% of the revenue in the market. In the most recent survey, solar products captured 24% of product sales and 85% of product revenue. It remarkable to see that Kenya is doing important efforts to implement smart housing and smart lighting technologies. Smart Households penetration in 2020 is just 0,9% but is expected to hit 2,6% by 2025. The national market revenue in the Comfort and Lighting segment in houses is projected to reach US$ 3 million in 2020 but it is expected to show an annual growth rate (CAGR 2020-2025) of 33,4%, resulting in a projected market volume of US$12m by 2025. In parallel, smart bulb's share is established at 0,4% level. In fact, the average expenditure per installed smart home for comfort and lighting segment currently is estimated to US$ 25,20 per household. This a very high investment in regard to the country's GDP. [STA-19b]
South Africa	In South Africa the smart home technology penetration is yet established at 3,4% in 2020 and is expected to hit 9,0% by 2025. The national market revenue in the Comfort and Lighting segment in residential sector is estimated to US$ 51 million in 2020 and it is expected to show an annual growth rate (CAGR 2020-2025) of 25,7%, resulting in a projected market volume of US$ 158 million by 2025. Smart bulb's penetration is estimated be at 2,3%-level in 2020, while the average expenditure per installed Smart Home currently is expected to amount to US$ 86,48. [STA-19c]

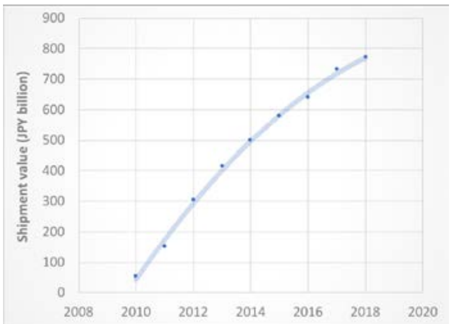
3.1.2.5 Asia pacific region and Indian subcontinent (APAC)

Following [MAM-17] and [PSI-20] Asia-Pacific region held the largest share of the LED lighting market since 2015. It reached US$ 55,84 billion in 2019 and expected to dominate in the coming years. [FBI-20] Grand View Research estimated the APAC market share as high as 41,3% in 2018 [GVR-19], when [TMR-17] reports 40% in 2016. This is mainly attributed to the growing demand for LED lighting from the residential sector, especially in China, India, and South Korea. The people in this region have the required financial means to invest in smart homes which are fitted with several innovative LED lights. The high growth of the market in APAC can be attributed to the ongoing infrastructure modernization projects in the developing economies such as China and India, where the governments have approved the construction of several smart cities. Further to the increasing government initiatives to support the usage of EEL sources and the surging focus on the electrification in rural areas. Further, the growth in construction and infrastructural development in the region is due to the booming population, which, in turn, is fuelling the demand for LED lighting solutions. Further, the growing consumer awareness for energy-efficient lighting, due to the rise in power tariff and environmental concerns, is another factor driving the demand in the APAC region.

The retrofit category, based on installation type, is projected to experience faster growth in the LED lighting market during the decade 2020-30. The growth is attributed to the increasing replacement of sodium-vapor and incandescent lamps with LED lights, in countries such as India, Japan, China, the U.A.E., and South Korea. The strong demand for retrofit LED lamps in these countries, due to the phasing out of incandescent bulbs, is expected to further boost the LED lighting market in the same period. [PSI-20]

Government initiatives for the deployment of smart lighting products, along with toughening regulations for energy efficiency, are being implemented, especially in countries such as China, India and South Korea. The increasing adoption of smart lighting products, coupled with the strong government focus on developing smart cities, is further propelling the LED lighting market growth.

Table 11: Some examples from country markets in APAC area

Japan	Japan, one of the pioneers of LEDs who started promoting SSLs since 1998,[17] is among of world 's largest LED lighting market. In 2014, Japan, had a global LED market share of 25,6%. [ENE-14] An iMarc study shown that Japan LED market reached a value of US$ 5,8 billion in 2019. [IMA-20] **Figure 40:** Shipment value of the LED lighting fixture market in Japan from 2010 to 2018. Data from [STA-20c]  In 2019 LED penetration has already reached 60% [AFE-19] The value of the LED lamp market in Japan grown from JP¥ 26 billion in 2010 u to approximately JP¥ 81 billion in 2018, [STA-19b]. At the same year, the LED lighting equipment market size was forecasted to reach approximately JP¥ 770 billion, up from about 53 billion yen in 2010. [STA-20c]Figure 40 illustrates the LED fixture market growth in the country in the last decade. According [CSI-19], the lighting fixtures market in Japan grew by 1% (-0,5% in JP¥) in 2018 to a market value of JP¥ 710 billion. In the middle run (2013-2018), the market registered a CAGR of 2,7% (in JP¥). The LED-base lighting fixtures segment has almost reached 97% of the market. The LED-base lighting fixtures segment has almost reached 97% of the market. The demand is going to soften in the coming years, especially in the consumer segment, as new constructions is expected to decline due to a reduction in the population and a contraction in the number of new housing started. In 2018, in Japan less than 10% of the local fixture consumption was satisfied by imports (US$ 704 million); China remains the top importing country (71% of the total import value). Exports only amounted to US$ 89 million (less than 2% of the production). [CSI-19] As LED fixtures is almost saturated market, the industry has identified Connected Smart Lighting (CSL) and Human Centric Lighting (HCL) as the next propelling force that will guide the market in the next future. [CSI-19] Japan, is among the top-5 countries in the domain smart lighting for residential sector. The national revenue in the Comfort and Lighting segment Revenue in the Comfort and Lighting segment is projected to reach US$ 389 million in 2020. It is expected to show an annual growth rate (CAGR 2020-2025) of 23,0%, resulting in a projected market volume of US$ 1,1 billion by 2025. [STA-19c]
China	The LED lighting market is projected to show a CAGR of 14,4% for the period from 2020 to 2030 [PSI-20] Navigant, reported following information from CSA, that China sold 8 billion lighting units in 2016, half of which were sold domestically. [NAV-17] Following [RAM-19], China's LED lighting market is going to cross the US$ 29 billion mark by the year-end of 2025. Interior market and demand for LED lighting are growing rapidly due to supportive government policies that help out LED manufacturer and distributor to a great extent Further, people are

[17] Japanese government created in 1998 the "21st Century Lighting Project" to promote LED lighting

	adopting LED lighting at a rapid pace because of the gradual reduction of LED lighting price. In [CSI-19b] analysts estimated that in 2018 the LED consumption still grew by 12,3%. On the other hand, traditional-source lighting fixtures sales dropped by 4,1% compared to 2017. China is a major producer and consumer of LED lighting products. Many Chinese LED light manufacturers increase their production capacity because they are getting an optimal subsidy from both central and local government. [RAM-19] Concerning LED fixture manufacturing, [CSI-19b] considered that during 2018, the overall Chinese production of lighting fixtures registered an annual increase of 7,7% (in US$), reaching a value of RMB 281,7 billion. This growth rate is even higher the growth rate for the top 60 players (+18%), with high performances for companies like MLS, NVC, Yankon, Opple, FSL, Inesa Feilo. A steady growth path means also an interesting profitability ratio: an average EBITDA by around 15% among a representative sample of companies. [CSI-19b] Fast growth has been registered for emergency lighting, urban landscape lighting, lighting for infrastructures. [CSI-19b] In 2018, the output value of outdoor lighting products reached RMB 95 billion and that of landscape lighting exceeded RMB 93,6 billion. Decorative lights for public areas, such as streets and squares, are the leading products in this area. [HKT-19] The National Semiconductor Lighting Project has helped to create seven national semiconductor lighting industrial bases (Shanghai, Dalian, Nanchang, Xiamen, Shenzhen, Yangzhou and Shijiazhuang, Guzhen). [HKT-19] Today, Guzhen (Guzhen town is located in Zhongshan City, Guangdong Province) is famous as “Lighting capital in China”. Guzhen is not only the biggest wholesale lighting market in China but also the biggest LED light production base and the biggest manufacturing base in China. China’s LED enterprises are actively expanding into overseas markets. For example, Mulinsenhas merged with Germany’s Ledvance, while Opple is continually establishing subsidiary companies overseas. Meanwhile, mainland lighting enterprises are also strengthening their presence in China by setting up display centres and more specialty stores. Mainland enterprises are expected to devote more resources in future into technological development and innovation so as to add more value to their products and boost their competitiveness. [HKT-19] Despite the trade friction between China and the USA, exports went up by 8,2% compared to 2017 (in US$) and accounted for 57% of its value. Moreover, the United States confirmed as the main destination market for Chinese export, with a stable share of 28%. Imports account for only 2% of the domestic consumption as in 2018 they were worth about RMB 2,5 billion. Imports of lighting fixtures mainly come from Germany and Japan (both growing in term of market share in the middle run between 20183 and 2018), the USA (declining), Taiwan and Italy (both increasing). [CSI-19b] National standards on LEDs are being formulated and improved following the industry’s rapid growth. Foreign companies looking to enter the Chinese market should be aware of the mainland’s relevant standards. Under the Standardisation Law of the People’s Republic of China (Revised Draft 2017), there are five sets of standards - national standards, industry standards, local standards, organisation standards and enterprise standards. [HKT-19] China’s interior market is ranked in 2020 top-2 in the residential smart lighting worldwide. Revenue in the Comfort and Lighting segment in households is projected to reach US$ 1,87 billion in 2020. Revenue is expected to show an annual growth rate (CAGR 2020-2025) of 23,6%, resulting in a projected market volume of US$ 5,39 billion by 2025. [STA-19c]
South Korea	Following Jurgen Yeh, Korea’s LED industry took off at a much later date than Japan or Taiwan, in fact it developed at around the same time as China, but has advanced at an accelerated rate. However, the country’s LED industry plummeted much sharply compared to Japan, China and Taiwan. The Korean LED industry development occurred in three phases the first was started by upstream LED manufacturers coined the “double E era” (EE), followed by Samsung and LG’s entry during the peak of the Solid-State Lighting phase, followed by large scale withdraw from the market, in response to emerging Chinese LED industry. Nowadays, in Korea, LEDs are barely getting any attention. Instead, OLEDs and quantum dots have come under Korea’s industry spotlight. Korea’s advantages are its large electronic export market, and a comprehensive electronic product supply chain. However, few of its products are innovative or original. Moreover, Korea lacks natural resources making it difficult to support a supply chain

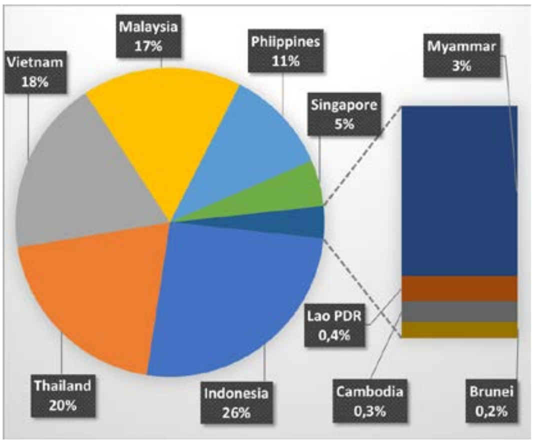
model that aims to incorporate everything. Hence, manufacturers could end up accidentally making deadly products. Since most Korean manufacturers are large enterprises, and if the group subsidiaries follow Asian culture's hierarchical order, mismanagement within the group can be a huge issue. [YEH-16]

In Korea, smart lighting is serious trend. The national revenue in the Comfort and Lighting segment is projected to reach US$ 270 million in 2020. Revenue is expected to show an annual growth rate (CAGR 2020-2025) of 18,8%, resulting in a projected market volume of US$ 637million by 2025. [STA-19c]

ASEAN countries

ASEAN area countries used globally in 2015 ~98 TWh of electricity for lighting. Figure 41 shows how this amount of energy is distributed among the ASEAN area countries. [IIE-16]

Figure 41: Share of annual electricity use for lighting of each ASEAN country member in the global area consumption. Data from [IIE-16]



In this geographic area residential sector absorbs 40% of the energy, tertiary buildings and street lighting are responsible for 50% and 10% respectively. However, there are important variations among the different countries. [IIE-16] In 2015, the LED penetration in the area was 11%.

Following [CSI-18], the lighting fixtures market in ASEAN area is estimated worth US$ 3,6 billion at factory prices, for the year 2017. In 2018, market value will be in excess of US$ 3,8 billion, and in 2019 in excess of US$ 4,2 billion. Over one billion US$ is made by LED based lighting fixtures, while approximately USD 2,5 billion worth is the market for Conventional powered lighting fixtures.

Beyond fixtures, lamps (Conventional and LED lamps), LED modules, lighting equipment (drivers), lighting controls, for an estimated additional US$ 860 million (approximately US$ 620 million lamps, US$ 240 million between modules, drivers, automotive lamps, controls). [CSI-18]

Commercial lighting market in Asia Pacific (6 Countries) is estimated worth around US$ 1,17 billion in 2017. Expected growth rate is around 5% yearly for 2018 and 2019. Outdoor lighting market is estimated worth around US$ 790 million.

Approximately one fourth of the Asia Pacific market for lighting fixtures is handled on a Project basis. Almost 50% of the market is handled by wholesalers. Top 50 players hold around 35% of the lighting fixtures market in Asia Pacific and around 50% of the total lighting market (fixtures, lamps, equipment). Vietnam and Indonesia are today the major markets in the Region. Malaysia, Vietnam and Singapore are the main exporters. Figure 42 illustrated the market situation in 2018.

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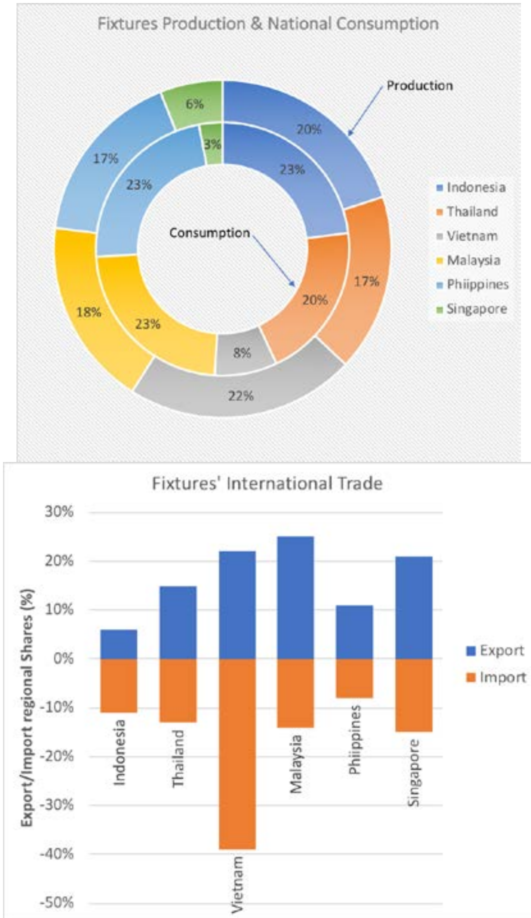
Figure 42: Fixture's market situation in main ASEAN countries (2018). (a) Production and interior market consumption shares; (b) International trade (Import & export). Data from [CSI-18]



(a) (b)

The countries with the highest import growth rates over the last year include Vietnam (+18%) [CSI-19d]

</td></tr>
<tr><td>India</td><td>

India's UJALA programme especially has helped deploy more than 360 million units since 2015, out of an intended 770 million. [IEA-19] India has demonstrated that it is possible to deploy million LED lamps rapidly on a large scale when the right financing and market mechanisms are in place: it has one of the largest LED markets in the world thanks to its national UJALA programme, which uses bulk procurement to offer bulbs that are 50% more efficient than other lamps typically available. Using bulk procurement and energy service providers, can help reduce LED costs even further while increasing uptake.

In India, one city leases its street lighting poles to a company that equips them with digital LED signs and smart cells, collecting advertising and subscriber revenue [DEL-15]

India set up the Energy Efficiency Services Limited which has installed over 237 million LED replacements in 2016 [NAV-17]

Earlier, in 2015, the government of India announced to develop 100 smart cities in the country over the next five years. Hence, with increasing construction of smart cities and increasing number of construction projects, globally, the demand for lighting is expected to increase in the forecast period. [PSI-18b]

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<tr><td>Nepal</td><td>

As per the data provided by Nepalese Central Bureau of Statistics (CBS), in 2011, 67,26 % (94.11 % in urban[18] and 60,84 % in rural) of household uses electricity as the source of lighting. [BIS-19]

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[18] Only 3,1 % of the Nepalese urban population is unreached to the electricity supply.

	A study showed that about 60% energy used in Kathmandu can be saved by using LED lamps [TIM-13]. It should be noticed that majority of Nepalese electricity is consumed due to residential loads. That way, in 2018, 43,5% of electrical energy was consumed by domestic sector, 37,53% by industry, 10,49% by buildings (3,11% by tertiary non-commercial and 7.38% by commercial destination), 8.43% by other sectors[19] [NEA-18]. Developing EEL for residential sector should be seen as a priority for Nepal. In Nepal, there is no clear policies on lighting technologies directly, although some incentives on clean energy associated with lighting existed. Standalone solar photovoltaic street lighting utilising LEDs has become a wide spread practice. Alternative Energy Promotion Centre (AEPC) in collaboration with different municipalities has been installing Solar Power LED Street Light with specific purpose. AEPC provides subsidy to renewable energy- based technologies to secure the socio-economic development of communities by utilising the available natural resources with best technology. That way, it is expected AEPC to provide 40% of subsidy in total cost of the solar based energy system in metro and sub-metro municipalities, where 30% cost should be covered by the beneficiaries and 30% coming from credit [AEP-16]. As per the data provided by AEPC, in the fiscal year of 2016/17, 2017/18 and 2018/19, a total of 1622, 1 357 and 1 060 solar street light systems have been implemented. On the other hand, Nepal Electricity Authority (NEA) had installed 1 600 street light with lamp power of 30, 40 and 60 W within Kathmandu Valley at various locations. Some innovative concepts that links business and lighting just implementing, in which private company owned street lighting system with advertisement display as source of revenue. In past few years more than 2000 lamps of 30 and 40 watt had been installed in such business-oriented concept. [BIS-19]
Australia	Following CSIL, with a value of almost US$ 1,3 billion in 2016, Australia is estimated to account for 1,4% of the worldwide lighting fixtures consumption. Approximately 74% of its consumption is satisfied by imported lighting fixtures. This share has been progressively increasing, especially in the residential segment, where Chinese imports have been substituting the local production. Overall, Australia is a net importer, with a trade deficit of USD 861 million. In 2016, the share of LED-base lighting fixtures was approximately 45% of the market; it is forecasted to reach 65% of the total market by 2021. In the country, the top 50 players hold more than 75%, the professional segment emerged to be more concentrated than the consumer one. [CSI-17] In Australia, smart lighting is also advancing. The smart home technologies reached a penetration rate of 17,5% in 2020 and is expected to hit 35,2% by 2025. The national revenue in the Comfort and Lighting segment is projected to reach US$ 139 million in 2020. Revenue is expected to show an annual growth rate (CAGR 2020-2025) of 17,5%, resulting in a projected market volume of US$ 420million by 2025. The Smart bulbs penetration is estimated to be at 12,6% in 2020, while the average expenditure per installed Smart Home currently is expected to amount to US$ 77,43. [STA-19c]
New Zealand	As reported by CSIL, in 2016, the market for lighting fixtures in New Zealand was worth less than one-fifth of the Australian one, approximately US$ 241 million with an increase of 8% compared to 2015. Approximately 82% of its consumption is satisfied by imported lighting fixtures. Over the last five years, it has shown an average annual growth of almost +13%. In New Zealand, the lighting fixtures market is even more open to foreign players than the Australian one, as 80% of its consumption is satisfied by imported lighting fixtures. In 2016, the LED-base lighting fixtures segment amounted to US$ 110 million and the top 50 players hold more than 75% of the total market. [CSIL-17]

3.1.2.6 Other countries - Russian Federation

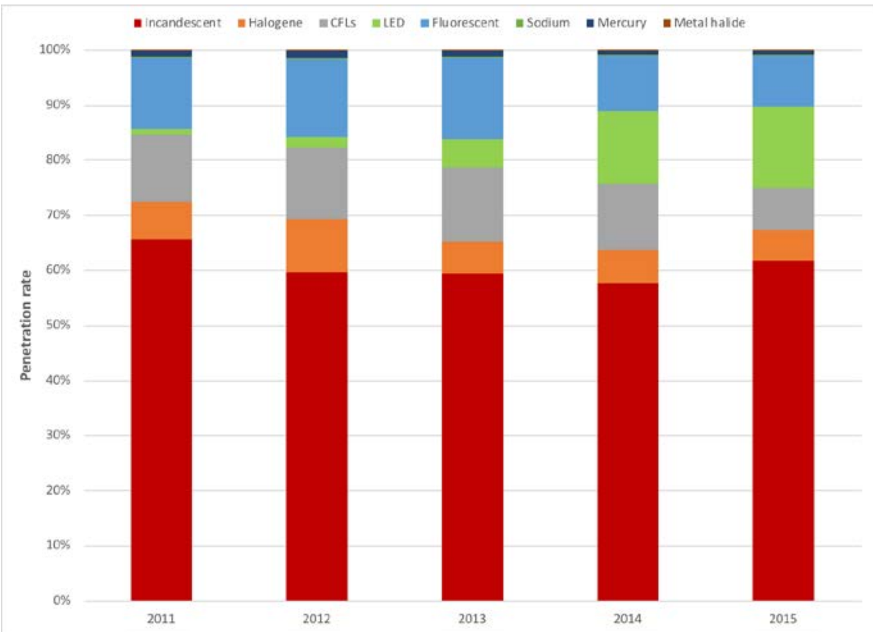
Russia is one of the world's coldest countries, lying mostly above 55° latitude north, with permafrost on two-thirds of its territory. Compared with Central Europe, its cold climate increases the cost of energy used in lighting and heating buildings by 20%. [ERI-14] In 2009, Russian Federation who was rather lagging behind from other countries in adopting an Energy Efficient Lighting (EEL) program, inaugurated the TRAMEL joint UNDP/GEF Project[20]. According to TRAMEL Project Document, 14% of Russian's Federation electricity consumption could

[19] The remaining 0,05% was exported to India in 2018.
[20] The TRAMEL Project was approved by the GEF CEO on April 7, 2010.

be attributed to lighting, in the order of 137,5 TWh at that time for powering approximately 0,8 billion electric lamps, this can be reduced by 57 TWh/yr just by replacing Incandescent lamps by more efficient technologies (CFLs mainly ate that time). [TRA-09] As basis, the Federal Law n° 261 (November 2009) on "Saving Energy and Increasing Energy Efficiency, and Amendments to Certain Legislative Acts of the Russian Federation" was adopted introducing a number of concrete measures, incentives and mechanisms to promote energy and ecological efficiency in all sectors of the economy. The law for lighting entered in action in 2011. TRAMEL project estimated that under BAU assumptions with the restrictions imposed by this new law only 5% of the annual potential savings could be achieved. The initial project duration was fixed to 5 years but it was extended twice until April 30, 2017. Because of these extensions, LED technology was included in the project (2015). A direct outcome linked to the project was the promulgation by the Government of decree #898 (on July 1, 2016) specifying MEPS for EEL devices for public procurement. According to the Final Project Evaluation report, at the end of the project in 2017 a reduction 5,55 Mt/yr of CO_2 emissions is effective (initial target: 2 Mt/yr) corresponding to 10,1 TWh/yr Indirect energy savings, thanks to the market transformation and incandescent lamps' phase out (initial target 4 TWh/yr) [TRA-17]

In March 2017, a Draft Governmental Decree listing the MEPS of lighting products for the Russian market was developed and agreed by relevant ministries. The MEPS on this Decree also impose the phase-out of inefficient lighting devices similar to those listed in Decree #898. The phase-out is to be implemented in 2 stages and concerns (1) a phase-out of all CFLs with E14 and E27 base (2) a ban on all mercury vapour HID lamps regardless of their installed capacity (3) a ban on all inefficient sodium HID lamps (with luminous efficacy < 75-85 lm/W – depending on whether these are for indoor or outdoor use) (4) a total ban on all halo-phosphate LFL lamps (5) a ban on all electro-magnetic drivers. As it can be seen in Figure 43 the project led to an observable increase of LED penetration in the national market, of course, this trend is expected to continue and amplify thanks to the adopted national policies.

Figure 43: Evolution of penetration rate of different lighting technologies in Russian federation during the execution of TRAMEL project (data from [TRA-17])



Russia is actively trying to catch-up with the technology (only 1% of smart bulb penetration in 2020). Statista estimated that the revenue in the Comfort and Lighting segment in households to be US$ 52 million in 2020. This national market revenue is points to an annual growth rate (CAGR 2020-2025) of 27,0%, resulting in a projected market volume of US$ 173 million by 2025.

According to [CSI-18b], in 2018, the Russian market for lighting fixtures is projected to reach RUB 107 billion, registering an increase of 6,2% (-4.8% if measured in EUR due to a strong depreciation of the rouble) compared to 2017. It should be underlined that fixtures sales are not uniform across the Federation territory: the Moscow Region totalises more than € 250 million sales while the far eastern region accounts for less than € 50 million. During the year the top 50 players, which account for almost 50% of the market, performed slightly better than the total market -(-3,8% compared to 2017, in EUR). [CSI-18b]

NB. Considering the local currency, between 2013 and 2018, the Russian market for lighting fixtures has grown by an average rate of 11,8% per year. Several factors concurred to explain such a positive result. Firstly, despite currency instabilities and political uncertainties, the Russian economic growth has remained robust. Private consumption has benefited from rising wages, household credit and employment; large infrastructure projects have boosted both public and private investment. Second, the recent years have witnessed the rapid rise of LED lighting technology. Due to the sharp drop in their cost and their remarkable performance in energy saving and emission reduction, LED lighting products have been generally accepted by consumers, resulting in a higher and higher penetration rate as well as a fast-shrinking market for conventional lighting products. CSIL estimates that in 2018, LED lighting reached a share of 52% of the market and it is projected to reach 69% of the market by 2022. [CSI-18b]

3.1.3 Update from the LED industrial ecosystem

The LED lighting ecosystem comprises hardware component manufacturers, prototype designers, and original equipment manufacturers (OEMs) such as Phillips Lighting Holding B.V. (Netherlands), General Electric Company (U.S.), OSRAM Licht AG (Germany), Cree, Inc. (U.S.), Cooper Industries, Inc. (Ireland), Virtual Extension (Israel), Dialight plc (U.K.), Zumtobel Group AG (Austria), Samsung (South Korea), and Sharp Corporation (Japan). The objective of this section is not to provide an exhaustive list, but to highlight the most striking effect in the reference period.

Table 12: Ranking of the top 10 packaged LED manufacturers

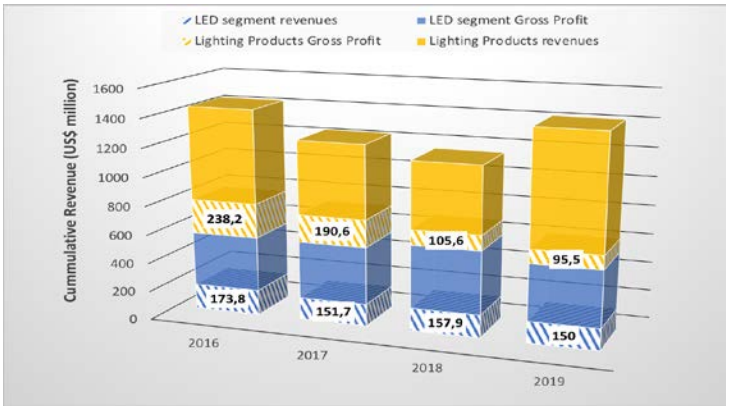
Rank	2016	2017	Change
1	Nichia	MLS	↑
2	MLS	Nichia	↓
3	Lumileds	Lumileds	stable
4	Everlight	OSRAM OS	↑
5	OSRAM OS	Everlight	↓
6	Nationstar	Nationstar	stable
7	LiteOn	LiteOn	stable
8	Honglitronic	Seoul Semiconductors	↑
9	Cree	Honglitronic	↓
10	Seoul Semiconductors	Jufei	New

According to [AIC-18], based on LEDInside information, Chinese LED package market scale was US$ 10 billion in 2017, representing an increase of 12% YoY. Among the top ten manufacturers, illustrated in Table 12, four are international firms, two are Taiwan companies and four are Chinese enterprises. Noticeably, it was the first time that Jufei appeared on the rank list. In addition, the top ten manufacturers represented a market share of 48%. MLS surpassed Nichia for the first time, ranking No.1 in Chinese market, and its market share reached 8,5%. Moreover, MLS possessed number-one market share in both light decoration market and lighting market. Table 12 indicates the top-10 of packaged LED manufacturers.

Acuity Brands (USA), funded in 2001, is one of the leading LED lighting manufacturers in the world, specialising in lighting, controls and daylighting systems. It offers a wide range of indoor and outdoor lighting solutions suitable for every application and environment. The company's diverse portfolio of lighting products caters to several industries including education, commercial offices, healthcare, hospitality, government, industrial, retail, residential, transportation, roadway, bridges, tunnels, sewer and dams. The company is focusing on developing new technologically advanced products such as solid-state LED lighting integrated with digital controls, organic LED lighting (OLED) and variety of LED-based lamps. The digital lighting systems manufactured by this company comes equipped with eldoLED driver technology, which provides superior system performance, innovative features and a wide range of power levels. Lighting revenue: US$ 3,29 billion (FY 2016)

CREE Inc. (USA) is one of the world leaders in the domain of Light Emitting Diodes. Indeed, CREE's LED Products segment's consist of LED chips and LED components. Those LED products enable our customers to develop and market LED-based products for lighting, video screens, automotive and specialty lighting applications. CREE's Lighting Products segment consists primarily of LED lighting systems and lamps. The company designs, manufactures and sells lighting fixtures and lamps for the commercial, industrial and consumer markets. Figure 44 shows CREE's revenue and gross profit from those two product segments for the period 2016-19. It can be seen that LED segment's gross profit is almost stable (~27% of the revenues in average) while it decreases for Lighting Products.

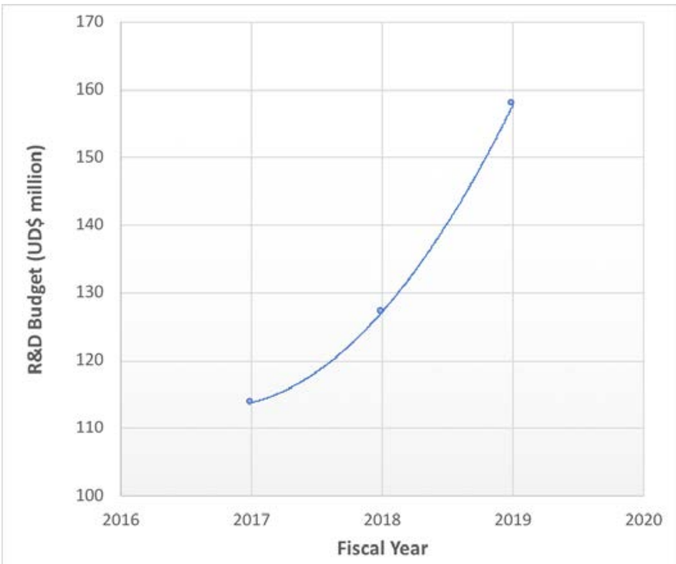
Figure 44: CREE's revenue and gross profits for the LED and Lighting product segments (data from [CRE-18], [CRE-19])



On May 13, 2019, CREE sold its Lighting Products business unit to IDEAL Industries, Inc. The aggregate net proceeds from the sale of the Lighting Products business unit was US$ 219 million in cash; Further, a LED Supply Agreement has been signed to supply IDEAL with certain CREE LED chip and component products for three years. [CRE-19]

To maintain its position in the LED market CREE invested massively to R&D: on average, the R&D budget represents every year 15% of the revenues, this is leading to a rapid increase of the amounts invested.

Figure 45: CREE's R&D budget evolution (data from [CRE-19])



Eaton lighting division (Ireland) delivers a broad range of innovative and reliable indoor and outdoor lighting and control solutions. These lighting systems find use in several applications including commercial, industrial, retail, institutional, utility and residential applications. The company is leveraging the latest technologies to help businesses and communities improve efficiency, reduce costs as well as protect the environment. The company offers a diverse line of connected systems such as ConnectWorks Connected Lighting System, DALI Lighting Control, Halo Home, ILumin Plus, LumaWatt Pro Wireless Connected Lighting System and WaveLinx Wireless Connected Lighting System. [TEC-19]

Everlight Electronics is known as one of the world's largest LED lighting manufacturers. Initially positioned as a light source supplier, Everlight now develops COB technology and is seeking to enter the automotive lighting business, positioning itself as an advanced module supplier. It offers a wide range of products portfolio including high power LEDs, SMD LEDs, lamps, lighting components, LED lighting modules, digital displays, opto-couplers and infrared components for various applications. The street lighting products produced by this company have high brightness and over 80 CRI, thereby creating a comfortable environment. Everlight LED bulbs, tubes and candles act as omni-directional lighting sources and are mostly used in indoor applications. The company's horticulture LEDs can replicate sunlight and can be fine-tuned according to the specific needs of the customer. [TEC-19]

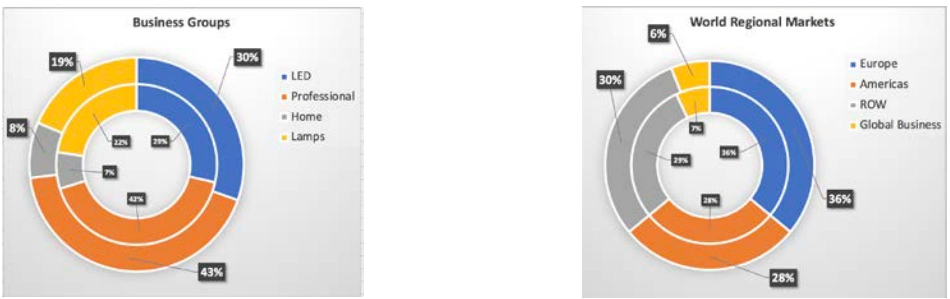
GE Lighting (USA) one of the former “Big-three” in the domain of lighting, specialises in creating optimal lighting solutions for homes. GE LED light bulbs are known for their high-energy savings and durability. C by GE is a line of smart lighting products, having the functions, features and voice control of Amazon Alexa. These range of smart lamps have features such as visual timers and sleep/wake cycle support and can be controlled by voice. Lighting revenue: US$ 1,99 billion (FY 2017). [TEC-19]

With subsidiaries in more than 50 countries and business activities in over 140 countries, **Ledvance** is one of the world's leading general lighting companies for professional customers and end-consumers. Originating from Osram's general lighting division, Ledvance's portfolio includes a wide range of LED luminaires for a variety of applications, intelligent lighting products for smart homes and smart buildings, one of the most comprehensive offerings of advanced LED lamps in the lighting industry and traditional lamps. Based on an agreement with Osram, Ledvance will continue to use the Osram brand name for many of its products (Sylvania in the USA and Canada). - www.ledvance.co.uk

Nichia Corporation (Japan) is one of the world’s top LED lighting manufacturers in terms of revenue generated from the sales of LED packages. It designs and manufactures LEDs for displays, LCD backlighting, automotive and general lighting purposes. The world’s first white LED was developed by this company by combining yellow phosphor and blue LED. The company also produces UV-LED which is used in applications that require rigorous quality checks such as high precision curing, ink curing, bill checking, counterfeit detection and lithography. Nichia LED packages are characterised by high efficiency, flexible cluster configurations, and high luminous flux density. Nichia standard LED, which has uniform spatial distribution, excellent temperature stability and lighting reproducibility, is developed in collaboration with Advanced Industrial Science and Technology (AIST). Lighting revenue: US$ 2,42 billion (FY 2016). [TEC-19] As reported by [AIC-18] Nichia released in 2018 the news that the company decided to expand LED production capacity by building a new plant in response to the increasing demands of lighting and backlight LEDs as well as the applications for automotive use and others. The new plant is scheduled to start running in October 2020 and with the new capacity added, Nichia plans to double the production of Naruto factory in 2021. The major revenue of Nichia depends on white LED. However, Nichia has strategically intensified its momentum in high margin LED products including automotive lighting.

Philips Lighting (Netherlands), the pioneer of the lighting industry. It has been officially known as **Signify** since May 2018. However, it can use the brand name “Philips” for its products until 2030. When Philips was founded in 1891, its plan was to provide cost-effective and reliable electric incandescent light bulbs for everyone. For over 120 years, Philips lighting has been making people’s lives more comfortable and productive by offering high quality lighting solutions for public places, professional spaces and homes. By using a combination of patented technologies, Philips lighting systems can connect seamlessly with other digital devices, thereby benefitting the customer and the environment.

Figure 46: 2018 and 2019 Signify’s (a) Business Groups and (b) world-regional market distribution. Inner ring is 2018 and outer ring 2019. Data from [SIG-19] and [SIG-19]



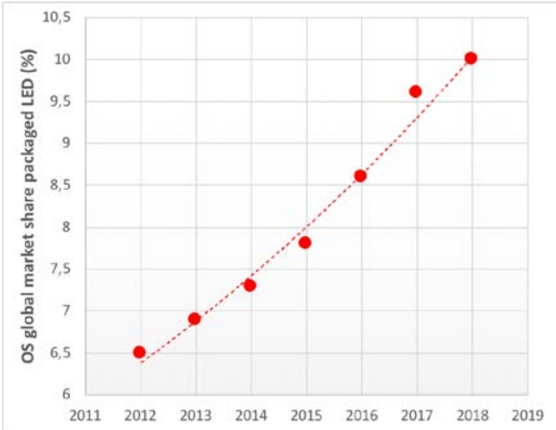
(a) (b)

Philips Hue is a wireless lighting system by which one can control the lights and create the right ambience for any moment. This line of connected lighting system works with a range of different smart devices and can connect with Amazon Echo, Google Home and Apple Homekit. [TEC-19]. Signify employs ~29 000 people worldwide and its global lighting revenue is € 6,38 billion (FY 2018) and € 6,22 billion (FY2019). The LED based sales of Signify passed from 65% in 2017 to 71% in 2018 and 78% in 2019, however the net income reduced from € 281 million to € 267 million within the 2017-19 period. [SIG-18], [SIG-19] Figure 46 gives some additional information about Signify’s market shares in 2019.

Germany-based **Osram**, with ~12 000 employees worldwide, is number 2 in the lighting industry worldwide and number 3 in the high-power LED components. In 2017 Osram earned US$ 4,9 billion in revenues. The

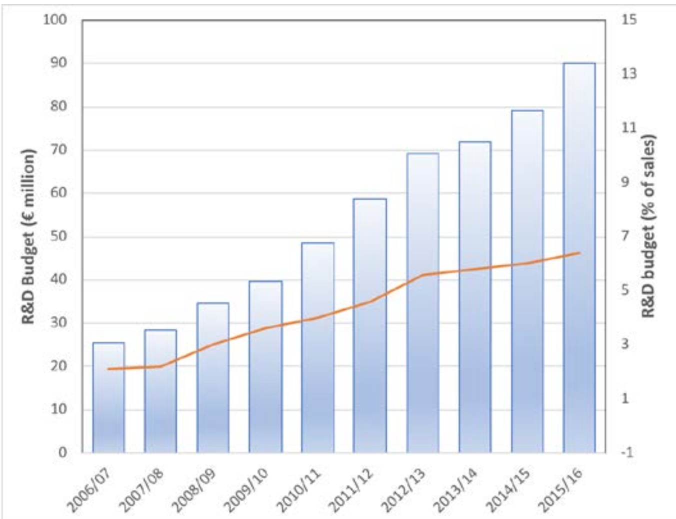
General Lighting segment accounts for 15% of the global revenues while the automotive segment accounts for 50%; the remaining 35% is gathered by the segment Industry and Mobile Devices. The company also offers digital lighting systems that helps customers deliver smart building and IoT projects. Since 2007 Osram has tripled its revenues at high profitability through the cycle. In the same decade the average annual EBITDA of the company was ~28% and the CAGR of 10%. [KAM-18] Figure 47 shows the evolution of Osram's global market share for packaged LED. With ~10% share in 2018 the company positions itself in 2nd position, close to the leader Nichia (Japan) who cover ~12% of the market.

Figure 47: Osram's shares in the packaged LED market (data from [KAM-18]



Zumtobel Group (Austria) offers innovative, high-quality lighting solutions and components as well as associated services for customers worldwide. In 2019, the group had 6 000 employees and cumulated €1,14 billion of revenues[21]. The group invested massively in innovation at least until 2016. In 2019 the group dedicated €65,9 million in R&D. Figure 48 shows the efforts in increasing R&D budget by dedicating every year a higher percentage of the sales revenue in the decade 2005-16.

Figure 48: R&D budget evolution in Zumtobel group (data from [VAM-16])



Seoul Semiconductor (South Korea) has more than 12 000 patents related to LED lightings in its name, including EPI, packaging, optics and modules. The company has invested in research and development for the last two decades to develop package free LED technology, "WICOP" and AC driven LED technology, "Acrich". The company's SunLike LED technology replicates sunlight by replacing blue LED light source with a purple light LED chip. The company strives to provide its customers with safe and environment friendly products by strictly inspecting and managing all parts and raw materials used in their products. Seoul expects the FY 2020 third quarter revenues to be between KRW 290 billion and 310 billion, increasing 8% - 16% on a quarter-on-quarter and 2% - 9% on a YoY basis exceeding market consensus of KRW 284 billion and operating profit of KRW 14 billion. [SEO-20]

[21] Data from Zumtobel's web page: https://z.lighting/en/group/company/

3.2 Organic LEDs

3.2.1 Market size & segments

Today, the automotive lighting is the most promising and most mature application market for OLED lighting. Indeed, lighting became a significant feature of cars with potential value rather than its basic functions consisting “on see and be seen”. OLEDs have the real potential to differentiate themselves from LEDs and can provide new added values for the automotive sector [EVA-18]. Such way, since 2016, automotive segment is accessed by proposing commercial OLED tail lights for cars (BMW M4 GTS), but also, they can be found as signal lights in other sectors as the aerospace industry.

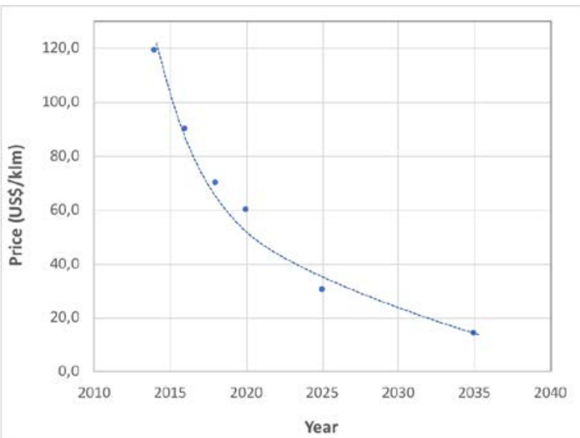
Important resources are invested in R&D to achieve some stringent requirements linked to such applications. As an example, in 2020, OLEDWorks and Acuity Brands were awarded with US$ 150 000 a 12-month project in the frame of US-National Shipbuilding Research Program (NSRP) to perform research on marine OLED lighting. This project is the continuation of the earlier Low-Voltage Shipboard Lighting Feasibility Study, it is assumed refining shipboard configuration, optimizing size & weight to maximize the inherent advantages of the OLED technology [MER-20].

According to LEDinside, the size of global OLED lighting panel market has reached about US$ 153 million in 2017. The size of OLED lighting market is expected to reach more than US$ 1,1 billion by 2020 [EVA-18]. The value of China’s OLED market grew from US$ 530 million in 2011 to US$ 10,35 billion in 2017, a compound annual growth rate of 64,2%. [HKT-19]

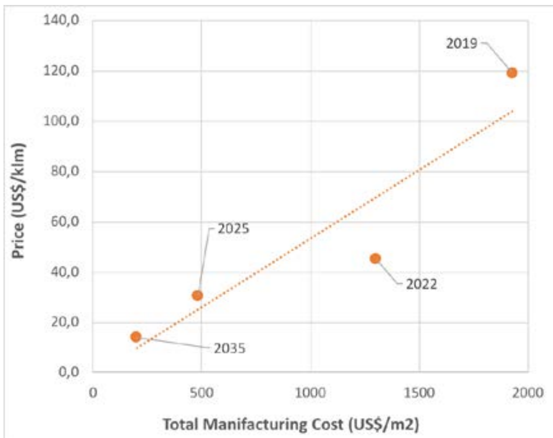
3.2.2 Pricing and manufacturing costs

According to [EVA-18], OLED lighting products have no longer opportunities for a “price war” with LEDs. The only breakthrough will be high-end designs such as diffuse area light source (no glare), no blue light hazard, and flexible/bendable products, which help OLED avoid direct pricing and performance competition with LED products. In addition, OLED technology must also combine several niche markets, including medical lighting and embedded lighting, in order to realize economies of scale and to reduce costs. Therefore, OLED lighting will also have the chance to improve the performance-cost ratio due to the entire market’s *status quo*. As a paradigm, China’s OLED display industry capacity expansion can substantially improve the yield rate in OLED industry and lowering the costs that can be echo to the lighting segment. However, today the cost of displays for OLED TV is around US$ 800/m^2, which still stays high for general lighting applications. DOE estimates that the manufacturing cost of OLED lighting panels needs to be reduced to about US$ 200/m^2. This will allow luminaires to be sold in the range of US$ 400/m^2 to US$ 600/m^2 [DOE-20]. Figure 49 illustrates the DOE’s price target per kilo-lumen and the correlation with the total yielded manufacturing cost per square meter.

Figure 49: (a) DOE’s target price for OLED panels in US$/klm. Data from [DOE-20]



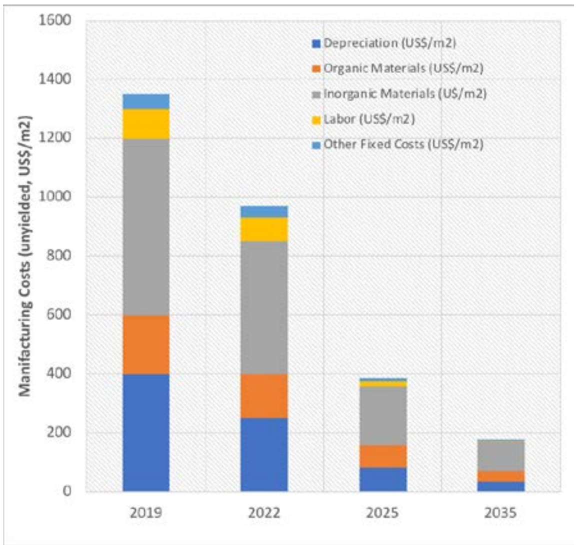
(a)



(b)

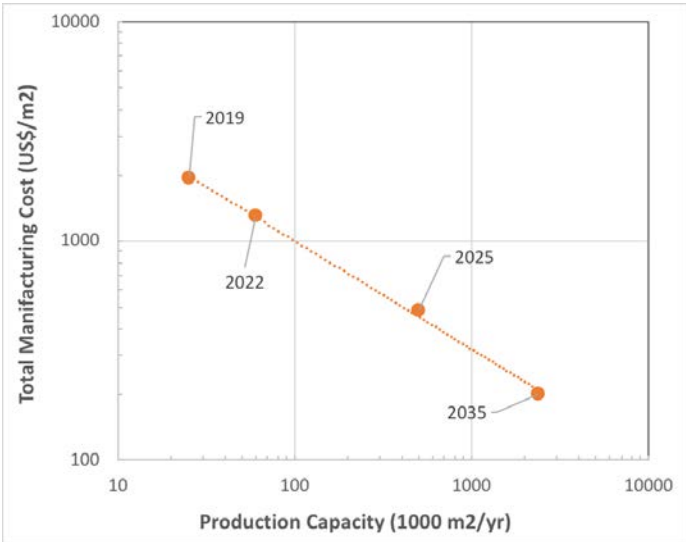
To achieve this drastic cost reduction, it is necessary to (1) understand how the panel manufacturing cost split and (2) increase drastically the production capacity. Figure 50 shows the split into major cost sectors incurring in OLED panel produced by traditional methods.

Figure 50: Split of major cost inuring in OLED panel manufacturing. Data from [DOE-20]



Further, as shown clearly in Figure 51 the manufacturing cost reduces rapidly with the increase of production capacity.

Figure 51: Correlation between total unyielded manufacturing costs and production capacity. Data from [DOE-20]



Back to the existing reality, it was possible to find in the early market OLED panel task lights (~400 lm) at a price in the order of US$ 250 corresponding roughly to US$ 600 per kilo-lumen [MER-15]. More recently a desk Lamp features a single OLEDWorks Lumiblade Brite FL300 OLED panel, which is 46x222 mm^2 in size and features 300 lm at 3 000K CCT/ 80 CRI and a lifetime of 10 000 hours for less than US$90 (~US$ 300/klm or US$ 8 715/mm^2) [MER-17b]. Further a well-known Swedish store chain commercialise a 9 W OLED luminaire, composed by 7 OLED panels to provide 700 lm at 2 700K for €199 (~US$ 340/klm) [MER-17]. As can be seen, match the DOE predictions by 2035 is a major challenge for industry and as DOE projects a cumulative investment of US$ 725 millions would be necessary for the next 15 years [DOE-20].

3.2.3 Industrial ecosystem

The ambition of this paragraph is not to establish an exhaustive list of the companies involved to OLED lighting business. In any case, as OLED lighting is an emerging technology, industrial ecosystem is rapidly evolving and volatile. The information contained in this paragraph is mainly based on data from OLED-info web last updated on Jun 23rd, 2019 [OLE-19]. Table 13 gives a rapid summary of the latest activities of the main OLED manufacturers and shows the geographical distribution of the main industrial actors.

Figure 52: Geographical distribution of the main industrial actors in the OLED Lighting ecosystem

Table 13: Rapid summary of the main's industrial actors in OLED Lighting arena

Acuity Brands		Acuity Brands is one of the world's largest lighting solution providers. Acuity Brands is involved with OLED based lighting fixtures and installations for many years, using panels by both LG and OLEDWorks. In April 2019 Acuity Brands announced it has decided to exclusively rely on OLEDWorks panels. [OLE-19] http://www.acuitybrands.com
ALKILU		ALKILU was founded in 2013 by Alex Khayat, a technology expert with over a decade of experience in OLED industry research and development. Alkilu has a diverse range of products - from night lights, to bike lights and music conductor stands. They develop a portable OLED lamp with rechargeable battery that offers 30 hours of light and it can be fully recharged using a USB power adapter or solar charger in just four hours. A partnership with Visionox (Chinese company) will significantly speed up the process – enabling us to get new and existing OLED products into the hands of consumers at an extremely low price point. http://www.alkilu.com/
Blackbody		Blackbody is a brand devoted to OLED lighting applications. Blackbody covers all the aspects from design study to mass production. The company offers OLED lamps and installations (it does not offer stand-alone panels), and sometimes use 3rd-party panels in its OLED lamps. Blackbody has a unique, global expertise offering OLED solutions for aeronautics, medicine and the automobile industry, notably for Airbus and BMW. It also offers ready to install lighting products for residential use, conceived by the biggest names in design. http://www.blackbody.fr/en
Fisrt-O-Lite		First-O-Lite was established in 2010 in Nanjing, China. The company is developing OLED lighting panels (based on a hybrid tandem architecture) and has a 2-Gen OLED lighting production fab that is currently producing 70 lm/W OLED lighting panels. First-O-Lite focuses on finding niche OLED applications, mostly the health market, and it has released 29 products into the Chinese market aimed for babies and kids lighting. In March 2017 we posted an article detailing the company's current product offering and its strategy and roadmaps. In November 2013 the company announced it has developed the world's most efficient OLED lighting module at 111,7 lm/W. [OLE-19] http://www.first-o-lite.cn
General Electric		GE had an active OLED lighting program, collaborating with Tokki and Konica-Minolta on roll-to-roll printing of OLEDsGE started the OLED project since 2010, and its global R&D Center claimed to make a "major breakthrough" in white OLED during the joint development with Konica Minolta. It is reported that their white OLED products achieved a luminous efficacy of 56 lm/W, using solution-based coating materials, which is an important condition for making OLEDs to lower the costs. GE did not update on their OLED Program since 2010, though, but GE and Konika-Minolta

		launched the first flexible OLED lighting product in 2011. [OLE-19] [EVA-18] http://www.ge.com
Kaneka		Kaneka is a Japanese materials company that active with plastics, PVC and caustic soda, foodstuffs, pharmaceuticals and other markets. Kaneka have been working on OLED Lighting since 2008, producing panels in low volume mainly for large installations. In 2015 Kaneka announced new 50,000 hours OLED panels, and in June 2017 Kaneka unveiled its latest lighting fixture. The Kumiko is a fully-customizable modular tile system that can be vertically-mounted on a surface or built into complex architectural designs. The Kumiko panels offer diffused light that looks like stanned-glass windows. The panels have a mirror surface when not in use. Kaneka did not disclose the technical specification of these Kumiko panels. Kaneka's current annual OLED lighting production capacity is about 20,000 panels. Kaneka aims to accelerate OLED lighting development and reach sales of ¥50 billion (~€400 million) by 2020. [OLE-19] http://www.kaneka.co.jp/kaneka-e/
Konica Minolta		Konica Minolta (KM) is based in Japan and is involved in copiers, printers, medical equipment, optical devices and thin films used to enhance picture quality in LCD. KM is developing and producing OLED for lighting, and in March 2014 the company announced that it is starting to construct a R2R flexible OLED lighting fab with plans to start production in the fall of 2014. The fab is not in mass production stage yet, although KM does produce samples and in February 2015 the company shipped 15000 flexible OLEDs to a Tulip Festival installation in Japan. In 2017 Konica Minolta and Pioneer announced that the two companies will setup a joint venture, which will be called Konica Minolta Pioneer OLED (KMPO) and will focus on OLED lighting for automotive applications. In 2019 KMPO was dissolved following Pioneer's withdrawal from the OLED lighting market and the operations moved back into Konica Minolta. [OLE-19], [EVA-18] http://www.konicaminolta.com
LG-Display		LG-Display (LGD) based in Korea, is one of the world's largest display makers. LGD produces screens for TVs, laptops and mobile devices. LGD continued to deploy in OLED segment in 2017 and initiated large-scale investment in the field of display. At the same time, LGD also actively approached BMW regarding the sales of OLED lighting products. It is reported that LGD will supply products including taillights and interior lighting components to BMW. In addition, LGD also unveiled its new OLED brand Luflex at the end of 2017 and announced that Luflex will sell its OLED lighting products in the future with automotive application as its top priority, followed by commercial lighting and lighting manufacturers. Towards the end of 2015 LGD acquired LG Chem's OLED lighting business unit for US$ 135 million, and is now in charge of LG's OLED lighting too. As for the future, LGD aims to be the largest OLED lighting brand worldwide [EVA-18], [OLE-19]. http://www.lgdisplay.com
Lumiotec		Lumiotec, located at Yonezawa City, Japan, was formed in May 2008 by Mitsubishi Heavy Industries, ROHM, Toppan Printing and Mitsui to check the viability of OLED panels for lighting, and to manufacture and sell the panels. In March 2009 Lumiotec showed their first OLED lighting prototype, and the company is now offering panels online - making about 60,000 panels a year. Here's our hands-on review with their Version 1 development kit and square OLED panel and here is some details on Lumitec's technology. In early 2018 V-Technology announced it is set to acquire Lumiotec. [OLE-19] http://www.lumiotec.com
OLEDWorks		OLEDWorks was established in July 2010 by former Kodak OLED business experts and has become one of the OLED lighting leaders. OLEDWorks acquired Philips' OLED light source components business and associated intellectual property rights in April 2015. OLEDWorks produces panels in both Rochester, New York and Aachen, Germany (the former Philips' site). The company offers a wide range of OLED panels and related products, and in November 2018 OLEDWorks started to ship its first flexible OLED lighting panels. [EVA-18], [OLE-19] http://www.oledworks.com

OSRAM Opto Semiconductors		Osram Opto Semiconductors GmbH, Regensburg, is a wholly owned subsidiary of OSRAM, a leading supplier and manufacturer of lighting solutions who employs more than 35 000 people throughout the world. OSRAM announced the closure of its OLED display factory in Malaysia in July 2007, shifting its focus to OLED lighting applications. OSRAM released the world's first OLED lamp back in 2008, but this was more of a prototype than a commercial product. In November 2009 they have started to ship their first OLED lighting panel, the ORBEOS, and here's our hands-on review of those panels. In the past 10 years, OSRAM not only released OLED lamps, but also became the industry pioneer of automotive OLED lighting. In 2014 or so OSRAM shifted its OLED lighting focus to the automotive market. OSRAM was the first company to supply OLED lighting panels for serially produced cars as it supplies the OLEDs for BMW's M4 GTS taillights and also the OLED lighting in Audi's TT RS Coupe 2016. Companies, including BMW and Audi, released cars embedding OLED lighting in taillights during 2015 and 2016, and many of the OLED lighting components are supplied by OSRAM. In 2018 OSRAM decided to pull out of the OLED lighting market. The company will continue to provide product support for both automakers until 2020, and will continue to monitor the market. [EVA-18], [OLE-19] http://www.osram-os.com/osram_os/en
Universal Display Corporation		Universal Display Corporation (UDC) founded in 1994, by Sherwin Seligsohn It is US based with 311 employees and international offices in China, Hong Kong, Ireland, Japan, South Korea and Taiwan. Universal Display Corporation is a leader in the research, development and commercialization of organic light emitting diode technologies and materials for use in display and solid-state lighting applications. UDC's mission is to be a key enabler in the OLED ecosystem and help grow the OLED industry with our broad and deep experience and know-how, proprietary OLED technologies and PHOLED (phosphorescent OLED) emissive materials' systems. Universal W-OLED™ OLED lighting has the potential to reach more than 150 lm/W. UDC has a 5 000+ world class patent portfolio. Based on UDC proprietary Universal PHOLED® technology and materials, OLEDs have the potential to offer power efficiencies that are superior to those for today's incandescent bulbs and fluorescent tubes. UDC is a Nasdaq company and the CY2019 revenue was ~US$ 405 million. Information from: https://oled.com/
Yeolight Technology		Yeolight technology is a company separated from Visionox in May 2015 with a focus on OLED lighting manufacturing. Visionox was initially an OLED project group in Tsinghua University, and was established as an OLED company later. Visionox is now one of the leading OLED manufacturers in China as part of Kunshan Govisionox Optoelectronics Co., Ltd. It mainly focuses on lighting products, including automotive and general lighting. The company's hybrid encapsulation technology enables OLED devices to be built on ultrathin, flexible plastic substrates while effectively offsetting the permeation of oxygen and moisture that may decay the light panels. In September 2016 Yeolight's 2.5-Gen OLED production line went into trial operation. The initial investment for this project was RMB 400 million. In November 2016 Yeolight introduced its first OLED lamp, using panels acquired from LG Display. The company's 0,1 mm flexible OLED panel was specifically designed for automotive rear lighting applications. With improved external quantum efficiency (EQE), reduced roll-off properties, and features like dynamic lighting, Yeolight's OLED taillights offer superior efficacy and design flexibility without sacrificing color quality. [EVA-18], [OLE-19] http://www.yeolight.com/

3.3 Smart & Human-centric Lighting

Smart lighting has emerged as one of the most disruptive technologies over the past five years. Advanced LED lights are offering a significant bottom-line saving in terms of energy costs. These units are being offered by companies as a part of IoT systems for enabling highly connected infrastructure. This provides users with extra control to effectively manage smart lighting systems. With cheaper & smarter lights rapidly replacing CFLs and incandescent bulbs, smart and connected digital lighting using IoT is expected to bring an excellent intelligence and functionality into lighting systems. [GMI-19]

According to a recently released research report from Global Market Insights, Smart Lighting Market is estimated in 2018 ~US$ 7,5 billion and to grow at CAGR between 15% (from 2019 to 2025) and 20% (from 2018 to 2024). [GMI-19], [AIC-18] Thus, it is expected to reach US$ 23-24 billion in the 2025 horizon. Other analysts from Market and Markets report that the smart lighting market is estimated to grow from US$ 13,4 billion in 2020 and are projected to reach US$ 30,6 billion by 2025, at a CAGR of 18%. [MAM-19]

The smart lighting market growth is attributed to worldwide initiatives for smart city development and the growing popularity of home and building automation systems in residential, commercial, and industrial sectors. As the modernised smart city infrastructure offers intelligent connectivity among different components of the administrative framework such as transport, healthcare, and law & order, further initiatives for developing smart cities are likely to be undertaken aggressively around the world over the next decade. [AIC-18] For instance, according to Statista, US households "becoming smarter": in 2020, 28,4 million among them gather a smart/connected comfort/lighting control and it is expected to increase to 45,8 million smart household by 2024 (Smart home technology penetration is ~22,1% in 2020 and is expected to hit 40,5% by 2025);. [STA-20] [STA-20b] The national market revenue in the Comfort and Lighting segment for residential sector is projected by Statista to reach US$ 3,05 billion in 2020. The segment's revenue is expected to show an annual growth rate (CAGR 2020-2025) of 20,7%, resulting in a projected market volume of US$7,82 billion by 2025. [STA-19c] To compare, ~10% in average of European households affirming to possess smart systems[22].

Even if today **connected lighting systems** (CLS) relies on wired communication technologies, i.e. DALI (this represents 70% of the market in 2018) [GMI-19], the rising adoption of Li-Fi technology and the integration of advanced technologies, such as Bluetooth, ZigBee, and Wi-Fi, into lighting solutions are powerful market development drivers. In addition, the adoption of such technologies that allow the smart bulb to be controlled through mobile apps or home/building automation hubs will transform fundamentally the market, dominated today by hardware[23], towards to the IoTs and digital lighting era. It is forecasted that wireless technology segment will grow at a CAGR of more than 21% for the period 2019-25.

Further, the rapid surge in the number of smart city development initiatives and investments has further accelerated the adoption of the market. Taking into account that today more than 60% of the world energy is consumed in cities, it is crystal-clear that smart lighting constitutes a huge potential for rational use of energy.

Looking closer, [GMI-19] reports that, even if in 2018 Europe with 35% market shares is leading the market, APAC world region with a 19% CAGR (2019-25) will take definitively the lead in the next couple of years. This growth can be attributed to the large-scale adoption of LED lamps in the APAC Region.

Outdoor lighting is expected to grow at a CAGR of approximately 20% for the period 2019-25 [GIM-19]. TrendForce's latest 2020 Global LED Lighting Market Report by analyst Christine Liu shows that, by 2024, the global LED smart street light market scale will expect to reach US$ 1,1 billion with CAGR of 8,2% during 2019-2024. [LDI-20]. Navigant Research estimates the global market for smart street lighting to be worth US$ 837,4 million in 2018 and forecasted that it will grow to nearly US$ 8,3 billion globally by 2027, representing a CAGR of 28,9%. [NAV-18] It seems rather difficult to compare the forecasts…

The Smart City Council claims that a total of US$ 12,6 billion is expected to be invested in smart networked streetlights from 2016-2026 [SCC-15], when Northeast Group predicts US$ 10,6 billion in the period 2017-27 [NEG-17], in addition to the amount to be invested for the transformation into LED lighting (see above paragraphs in this report). Cities and utilities will network 94,8 million streetlights over the next ten years, reaching a 29% penetration rate.

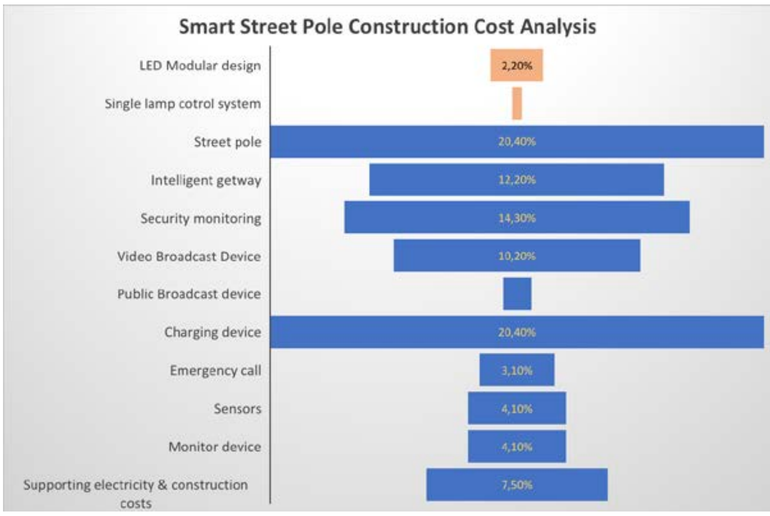
The per-endpoint costs of networking streetlights are falling rapidly. Currently, the costs outweigh the benefits in some countries, but with falling prices, cities that can dim lights at least 20-30% of the time will see positive benefits and by 2027. [NEG-17]

Looking closer at smart public street lighting, among its functional accessories, lighting equipment itself, including LED modular design lamp head and single light controller, is a 100% standard product. According to TrendForce's investigation, the average market price of the highest equipped (selective assembly) smart light poles is US$ 6998 per unit, of which lighting equipment is US$ 182,5, accounting for 2,6%. [LDI-20]

[22] Smart systems of any kind, not only lighting. The study has been based on 5 800 respondents via internet questionnaire and telephone interviews

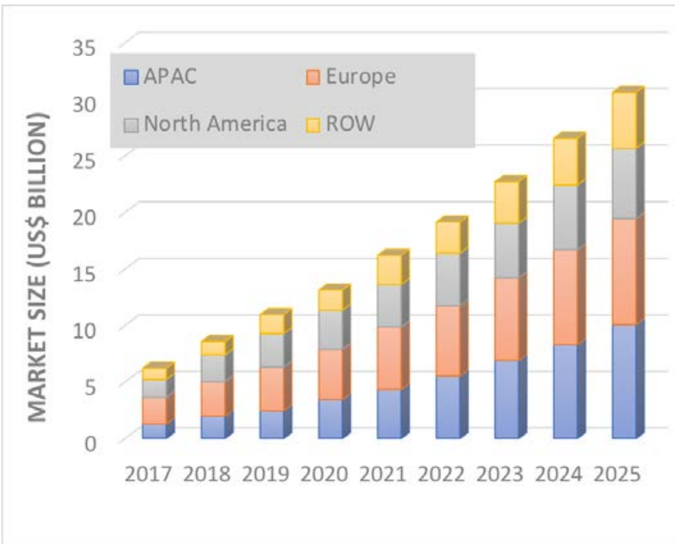
[23] Today, hardware is leading the component landscape with more than 80% share in the smart lighting market in 2018, but the software market will grow at a CAGR of more than 22% (2019-25) [GMI-19]

Figure 53: Smart Street Pole Construction Cost Analysis. The lighting module (orange boxes) counts for 2,6% only. Data from [LDI-20]



In the near term, the largest markets will be North America (US), Europe (Germany, France, UK, and Italy), and East Asia (China, Japan, and South Korea), particularly for networked streetlights. Indeed, China is today the main driver of the global smart street light development around the world. TrendForce believes that the further the smart street light goes to the downstream industrial chain, the greater its added value will be. [LDI-20]. However, ME region markets will witness higher growth in coming years due (1) to the decision of GCC to Invest in R&D of smart and green technology lighting systems to reduce carbon emissions (2) to mega projects planned in the region, such as Qatar's hosting of FIFA World Cup 2022. [FRS-17]Figure 54 shows the market size forecasted by [MAM-19] distributed among the major world regions.

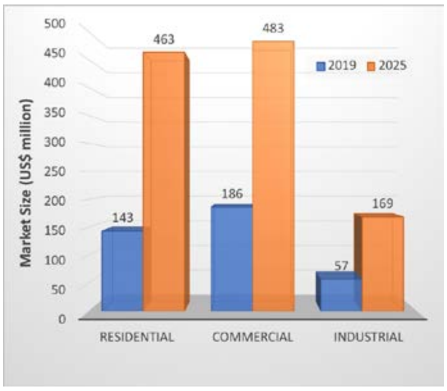
Figure 54: Smart lighting market size evolution till 2025 per world region. Data from [MAM-19]



Even if all indicators for smart street lighting deployment are in "green", to achieve the forecasted, albeit ambitious, market targets there are still some barriers that can jam the market transformation. The most important are identified by [GRF-19] as follows: (a) Siloed nature of many city governments (b) Cooperation of multiple stakeholders and complex financial arrangements; (b) Cyber-attacks and data privacy issues; (c) Infrastructure complexity; (d) Lifespan of Lighting Infrastructure; (e) High cost combined with lack of proven business case.

An increasing number of customers are looking to integrate smart home functions in their residential area. **Indoor lighting** accounts today for over 78% share in the smart lighting world market. [AIC-18] APAC region is leading the market. As example, Figure 55 shows the growth of the market size for smart indoor lighting in Japan.

Figure 55: Japanese Smart lighting market size, by major sectors, in 2019 and 2025 forecast. Data from [GMI-19]



Digitalisation of light in the ME region is foreseen by GCC as a mega trend that will see a surge in adoption in the short term. For example, connected lighting indoor positioning systems are being used to enhance the shopping experience in supermarkets, and light as a service (LaaS) is being offered to reduce electricity consumption. [FRS-17]

Within smart home lighting we can distinguish the segment **Comfort and Lighting** that includes devices for the improvement of the living atmosphere. These are devices such as sensors and actuators (e.g. door and window sensors, shutters) as well as connected and remote controllable light sources (smart bulbs) or garage door controls. Today, in almost all countries worldwide individual consumers (especially people in the segment of 25-45-year old) are more and more attracted by smart technologies and invests significant amounts of money to equip their homes with such trendy technologies. Figure 56 shows the 2020 penetration rate of smart bulbs in private houses. USA is leading with 17,1% followed by Scandinavian countries (especially Norway). China is still behind but its market is growing exponentially.

Figure 56: Penetration of smart light bulbs in residential sector across the world in 2020. Data aggregated from [STA-19c]

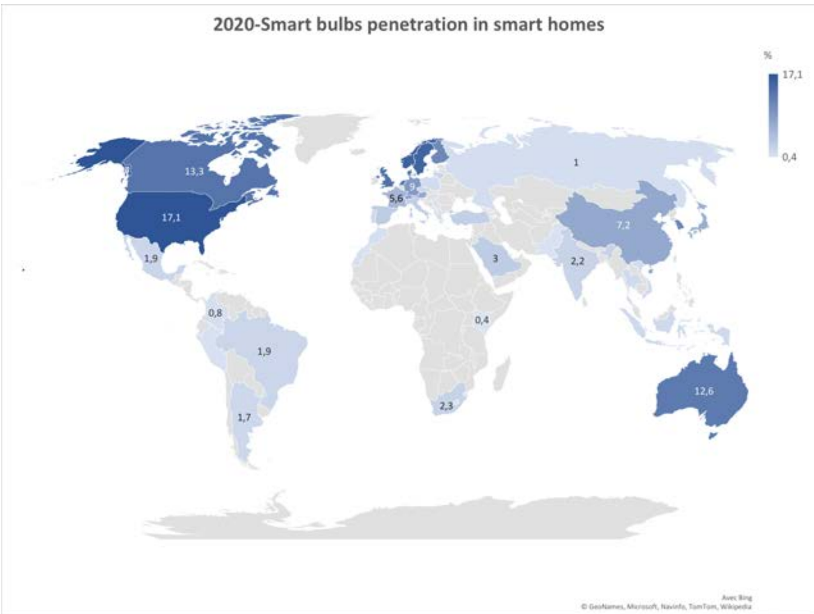
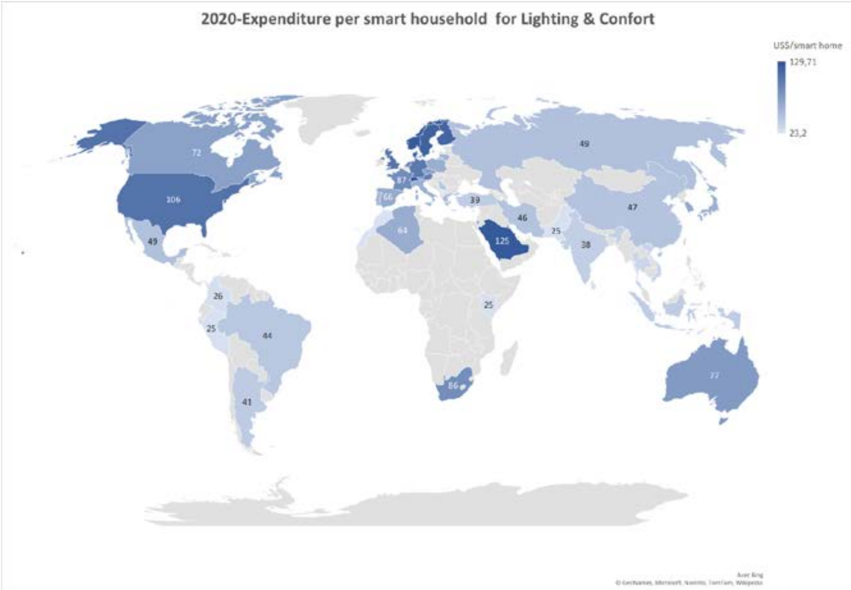


Figure 57 shows the financial efforts by private sector to equip smart households with Comfort and Lighting related systems. Switzerland is leafing with an effort of ~US$ 130 per smart house, followed by Saudi Arabia and Norway where smart households invested per year, in average, ~US$ 125 each in this segment.

Figure 57: Expenditures per "smart household" in the segment of Comfort and Lighting across the world in 2020. Data aggregated from [STA-19c]



In this segment, the quality of light is fundamental. This pushed Lighting Industry to develop the Human Centric Lighting (HCL) concept. **Human Centric Lighting** is a lighting solution intended to improve a person's well-being, mood, and health by varying the Correlated Colour Temperature and offering the best light quality according to a task and/or end-user's preference.

An example of this type of products is the Ledvance PARATHOM® product series for residential and garden areas, which can be controlled optionally by voice command or app and offers a suitable solution for a wide range of features such as colour and colour temperature change or dimming capabilities. The portfolio includes smart lamps in a wide variety of shapes, smart luminaires, products for indoor and outdoor use or plugs for integrating conventional light sources. A professional version is also available with either ZigBee or Bluetooth technology and allows convenient voice control with digital assistants such as Alexa from Amazon, Siri from Apple or Google Assistant. It enables the easy creation of different light scenarios – dimmed, from warm to cool white and multi-colour for choosing from 16 million colours. [NES-20]

According to information released by [AIC-18], HCL market was estimated US$ 445,9 million in 2017 and it is anticipated to reach US$ 3,91 billion by 2024 growing at a CAGR of 35,2% during the forecast period.

According to a market intelligence report by BIS Research, the demand for HCL solutions vary according to geographical regions. Europe led the global HCL market in 2017 in terms of volume and value and is expected to witness the highest growth during the forecast period (2018-2024). This is mainly due to the increased adoption rate of HCL solutions across the region. The U.K. and Germany together held approximately 65% of the total Europe HCL market. Europe has been on the forefront of HCL in the global scenario and the market in Europe is expected to grow at the highest rate during the forecast period (2018-2024). The early adoption of HCL solution in this region is primarily driven by the regulatory bodies providing enough research to showcase the benefits of HCL across various applications. [BSR-18]

3.3.1 Industrial ecosystem

Some of the major players in the **smart lighting** market are Signify (Philips Lighting) (Netherlands), Legrand S.A. (France), Acuity Brands, Inc. (US), Eaton Corporation (Ireland), General Electric Company (US), and OSRAM Licht (Germany), Lutron Electronics (US), Zumtobel Group (Austria), Honeywell International Inc. (US), Hubbell Incorporated (US), and Leviton Manufacturing Company, Inc. (US). Other players operating in the smart lighting market include Dialight PLC (UK), Helvar (Finland), Ideal Industries, Inc. (Cree Lighting) (US), Adesto Technologies (Echelon Corporation) (US), Panasonic (Japan), LightwaveRF PLC (UK), RAB Lighting (US), Synapse Wireless (US), Syska LED (India), Wipro Enterprise Ltd (India), LG Electronics (South Korea), ABB (Switzerland), and Enlighted Inc (a Siemens company) (US). [MAM-19]

The market leaders for smart street lighting are Telensa (19% share), Silver Spring Networks, Signify/Philips, and Echelon. [NEG-17] Navigant [NAV-18] ranked the principal companies in the sector according to their go-to-market strategy and execution of this strategy. As it can be seen in Figure 58, Signify can be seen as leader in the domain, because its background as a lighting company that offers end-to-end systems gives it an advantage over most of its competitors.

Figure 58: Ranking of companies with stake in smart street lighting segment. Green area corresponds to “Leaders”, orange to “Co-tenders” and the remain are the “Challengers”. Data from [NAV-18]

Further, Signify was ranked first in the smart lighting market in 2019 in market shares. The company has a huge advantage over its competitors in the smart lighting market due to is its extensive product portfolio, with lighting systems compatible with various connecting technologies ranging from DALI, KNX, and BACnet to ZigBee and EnOcean. For instance, in October 2019, Signify acquired Cooper Lighting Solutions from Eaton. This acquisition would strengthen its position in the North American lighting market. Also, in April 2019, it acquired WiZ Connected—a developer of the WiZ Wi-Fi-based connected lighting ecosystem. This acquisition will allow Signify to extend its leadership position in the Wi-Fi-based smart lighting market. [MAM-19]

Legrand S.A. (France) was ranked second in the smart lighting market in 2019. Legrand S.A. is a global specialist in electrical and digital building infrastructures. The company has a strong product portfolio pertaining to the smart lighting market. This enables the company to maintain its leading position in this market. Legrand focuses on growth strategies such as acquisitions, partnerships and product launches. For instance, in May 2019, the company launched wireless DLM systems, which are designed for easy installation, which, in turn, saves cost and time and thereby benefits engineers, electrical contractors, and facility managers needing reliable, code-compliant lighting controls. Moreover, in December 2018, the company acquired Kenall, a leading manufacturer of innovative, energy-efficient, and sustainable specification-grade lighting and control solutions. The company also focuses on geographic expansion to increase its footprint. For instance, in December 2018, the company acquired Trical (New Zealand), which provides switchboards for residential and commercial buildings. This acquisition would strengthen its position in New Zealand. [MAM-19]

The key market players in the **global HCL market** are Acuity Brands, Inc., OSRAM GmbH, Hubbell Incorporated, Legrand, Philips Lighting, Glamox, Digital Lumens, Inc., Zumtobel Group AG, Seoul Semiconductors, Cree, Inc., Waldmann Lighting, Lutron Electronics Co., Inc., and Hevlar, among others.

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5 List of abbreviations and definitions

AC: Alternative Current (50 or 60 Hz)
ADEME: Agence de la transition écologique (France)
AFE: Association Française de l'Éclairage (France)
AIST: Advanced Industrial Science and Technology (Japan)
APAC: Asia Pacific region
ASEAN: Association of Southeast Asian Nations
ASSIL: Associazione Nazionale Produttori Illuminazione (IT)
AICEP: Agência Investimento Comércio Externo de Portugal
BAT: Best Available Technology
BAU: Business-as-usual
CAGR: Compound Annual Growth Rate
CBS: Central Bureau of Statistics (Nepal)
CCT: Correlated Colour Temperature
CFL: Compact Fluorescent Lamp
CHMSL: Centre High Mounted Signal Light
CLI: Connected Lighting System
CMS: Central Management System
cmw-LED: Colour Mixing White LEDs
COB: Chip-on-Board
CRI: Colour Rendering Index
CSA: Chinese Solid-State Alliance's (China)
CISL: Center of Industrial Studies in Lighting
CY: Current Year financials
DALI: Digital Addressable Lighting Interface
DC: Direct Current
DIY: Do It Yourself stores
DOE: Department of Energy (USA)
DSM: Demand Side Management
EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization
EEL: Energy Efficient Lighting
EERE: Office of Energy Efficiency & Renewable Energy (USA)
EU: European Union
FW-OLED: Flexible White OLED
FY: Fiscal Year
GE: General Electric
GCC: Gulf Cooperation Council (Middle East)
HCL: Human-Centric Lighting
HID: High Intensity Discharge lamp
IEA: International Energy Agency
IFC: International Finance Corporation
IoT: Internet of Things
IT: Information Technology
JRC: Join Research Centre (European Commission)
KM: Konica Minolta (Japan)
KMPO: Konica Minolta Pioneer OLED (Japan)
LaaS: Lighting as a service
LAE: Lighting Application Efficiency
LARP: Laser Activated Remote Phosphor system
LCD: Liquid Crystal Display
LD: Laser Diode powered light source
LED: Light Emitting Diode
LFT: Linear Fluorescent Tube
LIA: Lighting Industry Association
LiFI: Light Fidelity
LGD: LG-Display (S. Korea)
LSL: Lighting System Legislation
μ-LED: micro-LEDs
ME: Middle East world region
MEA: Middle East and Africa world region
MELA: Middle East Lighting Association
MENA: Middle East and North Africa region
MEPS: Minimum Energy Performance Standards
MLA: Micro-lens arrays
NEA: Nepal Electricity Authority
NSRP: National Shipbuilding Research Program (US)
OEM: Original Equipment Manufacturer
OLED: Organic Light Emitting Diode
Osram OS: Osram Opto-Semiconductors (Germany)
PAYGO: Pay-As-You-Go business models
pcw-LED: Phosphor Converted white LEDS
PHOLED: Phosphorescent OLEDs
QD: Quantum Dots
QLED: Quantum Dot LED
R2R: Roll-to-roll technique
R&D: Research & Development
RF: Russian Federation
ROI: Return on Investment
ROW: Rest of the World
SDS: Sustainable Development Scenario
SMD: Surface-Mount Devices
SSL: Solid State Lighting
TRAMEL: Transforming the Market for Efficient Lighting (Russian Federation - UNDP/GEF EEL joint program)
UAE: United Arab Emirates
UJALA: Affordable LEDs for All programme (India)
UK: United Kingdom
UDC: Universal Display Corporation (USA)
UNEP: United Nations Environment Programme
US/USA: United States of America
UV: Ultraviolet
VLC: Visual Light Communications
W-LAD: White-light Large Area Diffuse emitters
W-LED: White-light Emitting Diodes
W-LS: White-light Laser Systems emitters
W-OLED: White OLEDs
WPE: Wall Plug Efficiency
YoY: Year-on-Year

5.1 Currency conversion rates (as in August 2020)

1 US$ = 0,84 €
1 000 JP¥ = 7,95 €
1 000 KRW = 0,71 €
1 RMB = 0,12 €
1 RUB = 0,011 €
1 TKL = 0,11 €

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