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Update on Status of Solid-State Lighting & Smart Lighting Systems

Assessment of latest energy efficiency progresses and world market in solid state and smart lighting

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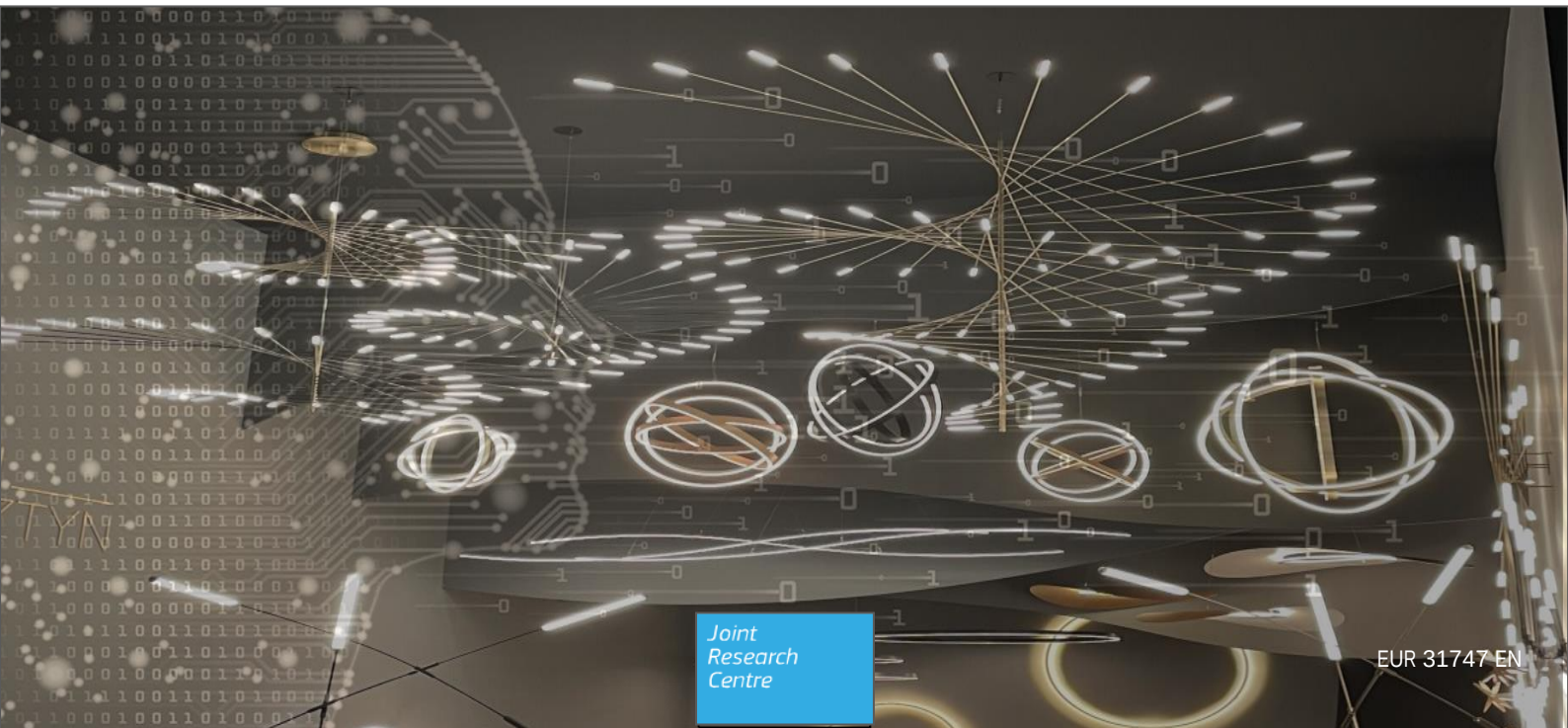
2023



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Contents

Abstract

Today, lighting is responsible for 5% of worldwide CO_2 emissions. Electricity demand for lighting attained 2900 TWh for a global light production of 215 Plmh. It is foreseen that in 2040 the needs for artificial lighting will increase by 25%. The challenge for the next decade will be to harness the increase of electricity demand. The only light source technology evolutions are not sufficient to stem uncontrollable growth. Today the best commercialised LED lamps are almost 2 times more efficient than fluorescent tubes. This is not sufficient to inhibit the well-known rebound effect. Only a transition from the conventional analogue lighting technologies to digital lighting can help. Smart lighting will become the heart of the Internet of Things in smart cities and buildings. However, only the Sustainable Smart Lighting SSL^2 concept introduced in this report solve the above-mentioned issues. Global lighting market revenue reached €130 billion and it is growing steadily with a 10% CAGR till 2025. Today, LED technology share is higher that 50% and it expected to reach 85% by 2035. Smart Lighting is on the way to become the 4^{th} revolution in the domain. It can achieve more than 40% additional energy savings and the market size can exceed €90 billion by 2030. Finally, the report illustrates the effect of some regulations and policies have as objective to harness uncontrollable increase of lighting and protect the ecosystem from some collateral damages.

Executive summary

This report brings an update of previous analysis on solid state lighting market published in 2013, 2015, 2018 and 2020. This includes elements on (1) energy consumption in various lighting segments and across world geographical area; (2) the latest Solid-State Lighting technology performances and market evolutions. A special focus is done on the smart lighting technology.

Policy context

Due to the high energy savings, numerous government incentives, as well as, utility rebate programs are now supporting the smart lighting technologies. We are witnessing the transition from simple demonstrators (TRL-5-6) to large installations (TRL 8-9) and transnational and national policies and regulations shell support this transition.

Europe implemented energy efficient lighting regulations (like Ecodesign) well before USA. However, European regulations are less "aggressive" than in USA. This allows a smother but slower market adaptation.

Many countries engaged energy efficien lighting programs and initiatives, our analysis based on harvested data targeting 120 countries worldwide (7,25 billion people), but Europe, shown that in 2030 these countries, in the case of BAU scenario, will use 3 666 TWh of electricity of indoor illumination (residential and no residential buildings) and outdoor areas. This amount can shrink to 2 274 TWh in case of Minimum Ambition Scenario and that correspond to a 37,9% reduction. We show also that projected efforts are correlated to the population size of each country and also on the country's GDP.

Key conclusions

Artificial light needs are foreseen to attain, by 2040, almost 285 Plmh corresponding to an increase of 25% in lighting service demand compared to 2020. Further, beyond the implication of lighting in energy, greenhouse gas emissions and depletion of abiotic resources of our planet, artificial lighting, has some additional important side-effects like the light pollution of the skies and the associated erosion of the biotopes.

The challenge for the next decade will be to harness the increase of electricity demand, limit the associated greenhouse gas emissions and avoid undesirable effects on the biotope. The only light source technology evolutions, even supported by ambitious policies, are not sufficient to stem uncontrollable growth. This report illustrates the effect of some regulations and policies to harness uncontrollable increase of lighting demand and to the promotion of innovative technologies.

Smart lighting will become the 4th revolution and it will be the heart of the "Internet of Things" in smart cities and smart buildings. However, only the "Sustainable Smart Lighting" SSL^2 concept introduced in this report could solve the above-mentioned issues.

Main findings

Today, lighting is responsible for a worldwide emission of CO_2 1,38 billion metric tons per annum. Electricity demand for lighting is estimated to be in the order of 2 900 TWh (which 13,7% of world's net electricity production) for a global light production of 215 Plmh. It is foreseen that in 2040 the needs for artificial light shall attain almost 285 Plmh corresponding to an increase of 25% in lighting service demand.

From the market side, the global lighting revenue reached EUR 130 billion in 2021 and it is growing steadily, at least till 2025, with a consolidated annual rate higher than 10%. Today, LED technology, is already a mass-market technology considered as full mature since 2015, has turned into a game changer beating the conventional technologies in all aspects. In lighting market, LED technology share is higher that 50% of the global revenue and it expected to reach at more than 85% by 2035. LED prices are expected to strongly decrease in the medium to long term (up to 70% by 2050 in USA) and high-quality products which are able to provide different light temperatures and new services have been placed on the market.

Geo-political situation has strong impact on lighting market. However, since the end of pandemic restrictions the market is healing rapidly. Even if, the ongoing war in Ukraine is impacting trades and businesses worldwide by constraining traditional energy sources leading to high costs, lighting industry can change that to an argument to strengthen and accelerate the transformation from legacy lighting technologies to SSLs.

Commercialisation channels are evolving. For instance, eCommerce of lighting products is rapidly rising a CAGR of 11,2% for the period 2022-32 is forecasted. eCommerce distribution segment is used today by

954,2 million users worldwide (roughly 12% of world's population). The total revenue of this distribution channel is estimated for 2023 to reach USD 25,2 billion. This is roughly 33% of the full LED Lighting market size and it will rapidly increase.

As has been shown by patent and lighting technology shipments evolution, Smart Lighting is on the way to take more and more shares. Smart Lighting can achieve more than 40% additional energy savings in the next decade and the market size can exceed EUR 90 billion by 2030.

The legacy lighting industry is healthy and generates benefits. However, the numerical transformation of lighting is changing dramatically the lighting industry world. New challengers coming from IT world appear (and disappear) in the industrial ecosystem. Business models for lighting are also evolving very fast from traditional trade product-oriented models to non-traditional service-oriented cases; the Light as a Service is the perfect example.

Quick guide

This report is divided into two major parts. The first concerns the energy consumption, industry and market evolution of solid-state lighting. The second part is dedicated to smart lighting system technology.

The work is based on analysis of more than 175 recent (2018 and after) free accessible documents and data harvested by open access databases for more than 150 countries. All data have been confronted and assessed in order to draw conclusions and tendencies.

1 Introduction

Artificial light sources play an indispensable role in the daily life of any human being. As indication, in beginning of the 2nd decade of 21st century, it was estimated every day approximately 30 to 35 billion electric light sources operate and about 1,0 to 1,5 billion people without access to electricity still use candles, oil or kerosene lamps [ZIS-09].

Since 2000's, the rise of Solid-State Lighting (SSL) has been considered as the 3rd revolution in the domain of lighting. SSL systems that are, today, based on components like LEDs (Light Emitting Diodes), OLEDs (Organic Light Emitting Diodes) and Phosphor Converted White Laser Diodes (PC-WLDs), challenge conventional lighting technologies (discharge and incandescent lamps). More especially, LED technology, is already a mass-market technology considered as full mature since 2015, has turned into a game changer beating the conventional technologies in all aspects. As expected, SSLs are on the way replacing a large part of legacy technologies in all application segments ranging from traditional indoor and outdoor to automotive or horticultural lighting; this replacement is expected to be accomplished within in the next years, this is also a major change in the lighting market and associated industrial ecosystem. SSL is already shaping current market dynamics in developed economies and is gaining a growing share in many emerging and developing countries. Further, following K. Lane, "the competition among manufacturers is driving further innovation, wider product choices and lower prices."

Taking 2009 as starting point[1], electrical lighting consumed 2 650 TWh of electricity, at that moment, this represented 19% of world electrical production[2] [ZIS-09], since then thanks to various actions from governments and industry a deflation has been confirmed. For instance, in 2019, we estimated the electricity used for lighting with around 2 900 TWh stabilized (less than 1% annual growth rate), or 13,5% of the world's yearly electricity generation. [ZIS-23] Even if the absolute value slightly increased in the last years, the relative part of lighting reduced drastically (~4% annual decrease rate). Increasing building space and population is driving additional demand for lighting. The observed decrease is the effect of combined effort of technological developments and worldwide energy policies. For instance,

- LED technology has evolved so quickly that in 2022 best LEDs lumens per watt (lm/W) offer efficacies over 200 lm/W – double the efficacy of the fluorescent technology – with high colour rendering and stability. The best commercialised non-directional LED lamps are 210 lm/W over 15 times more efficient than incandescent and four times more efficient than compact fluorescent lamps (CFLs). [SCO-22] Following K. Lane, since 2010, the average efficacy of LEDs has improved by around 4 lm/W each year. [LAN-23]
- minimum energy performance standards are widely employed as the key driver for efficiency improvements, incandescent lamps are almost banned worldwide, and many countries are now beginning to eliminate fluorescent lighting.

However, following K. Lane, electricity consumption for lighting increased in 2022, with greater efficiency not offsetting increased use of lighting. Despite the falling carbon intensity of electricity, CO_2 emissions from lighting rose slightly in 2022. The emissions intensity of electricity, an important factor for CO_2 emissions, fell too little to offset increased lighting demand [LAN-23]. This can be a concrete expression of the well-known "Jevons paradox" (or rebound effect"). This tendency, if confirmed, shall be considered with the highest attention because may be the sign of reaching some limits of "SSL beneficial effect" and that even if we expect some further technology efficacy increase during the next 5 years.

Beyond the implication of lighting in energy, greenhouse gas emissions and abiotic resources of our planet, to evaluate the full impact of artificial lighting, we shall take into account some additional side-effects like the light pollution of the skies and the associated erosion of the biotopes. Sánchez de Miguel et al., shown that the power of global satellite observable light emissions increased from 1992 to 2017 by at least 49%[3]. [SAN-21] The same authors conclude that, even if "these dynamics vary by region, but there is limited evidence that

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1 This year has been chosen as reference because it considered to be the starting point for incandescent lamp technology ban

2 The percentage includes approximatively 7% losses related to the electricity transport and distribution, when the absolute value is allocated to light generation only. [WRB-18]

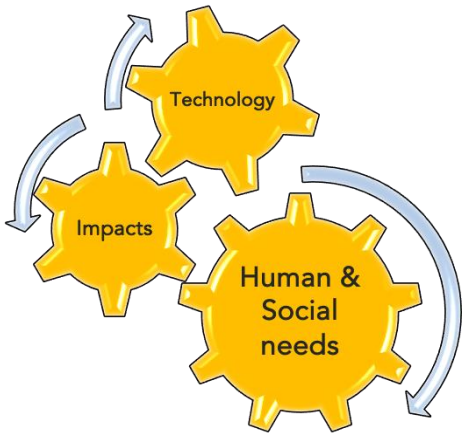
3 The quantity of artificial light detected from satellites includes a mixed signal of direct emissions from outdoor lighting that is not vertically shielded, as well as reflected light from the ground, buildings and vegetation, and light scattered within the atmosphere. [SAN-21]

advances in lighting technology have led to decreased emissions." [SAN-21] This shows the absolute need to intensify and coordinate world policy efforts to harness this problem.

Consequently, we knowingly are still not serving society as effectively as we could. To encompass this lack efforts shall, not only intensify, but they shall explore new technological horizons, include new concepts like circular economic, sustainability and affordability; more important, to be more efficient, efforts shall be coordinated at supra-national level. This shall lead to the "Sustainable Smart Lighting" that is Lighting-up smart, to a sustainable and affordable way, where it is needed, when it is necessary and as best as possible!

As SSL technology offer new control opportunities, encompassing rebound effect and maximizing the energy savings using connected/smart SSL systems, will become a challenge to address all these unforeseen, or just neglected till recently, issues. In fact, today, we are witnessing a transition from the conventional "analogue" lighting technologies to "digital" lighting. Smart lighting will become the backbone for smart homes and smart cities. This way, lighting will become the heart of the "Internet of Things". This will constitute the 4th technological revolution in the domain of lighting. To achieve such ambitious objectives to a sustainable mane, Zissis, introduced in 2023, the SSL^2 concept, that defines a "Sustainable Smart Lighting (the 1st SSL in SSL^2) system uses and optimizes to an intelligent way the best existing technology (Solid State Lighting, the 2nd SSL in SSL^2) to best fulfil present needs for artificial light of humans and reduce undesirable side-effects, without compromising the ability of future generations to innovate." [ZIS-23] Figure 1, illustrates the SSL^2 concept.

Figure 1: Illustrating the SSL^2 concept for lighting



Source: G. Zissis

This report, based on the compilation of more than 175 recent documents, has two objectives:

— It brings an update of previous analysis on solid state lighting market published in 2020, 2018, 2014 and 2013. This includes elements on (1) energy consumption in various lighting segments and across world geographical area; (2) the latest Solid-State Lighting technology performances and market evolutions.

— It introduces the Smart Lighting System (SLS) revolution and its potential benefits to energy savings. This part is including (1) assessment of existing technology and roadmap to the future, and (2) market evaluation and forecast for this kind of systems.

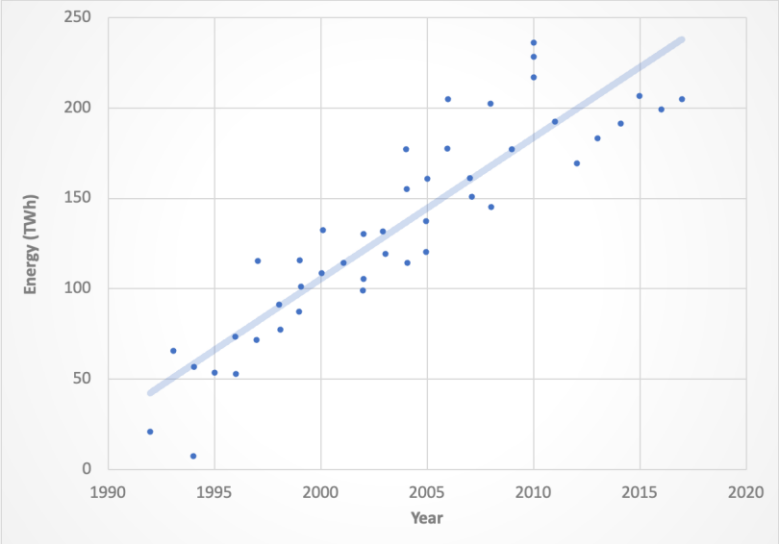
2 Part I – Energy Consumption, Industry & Market Evolution of Solid-State Lighting

This part of the report brings an update of previous analysis on solid state lighting market published in 2020, 2018, 2014 and 2013. This includes elements on (1) energy consumption in various lighting segments and across world geographical area; (2) the latest Solid-State Lighting technology performances and market evolutions.

2.1 Electrical lighting, Energy Consumption and Greenhouse gas emissions

It shall be noticed that world electricity consumption for lighting is rather difficult to estimate. Such estimations are based on calculations using (1) the annual sold lamp quantities coupled with import/export data that allows to obtain the power distribution of the devices and (2) national statistics on the number of operating hours by application segment. Many authors, using different accessible data, agreed that, in 2017-19 electricity used for lighting was in the order of 2 900 TWh, when it was around 2 650 TWh in 2009-10. In reality, it is rather difficult to validate such data. As an example, the Spectaris report [SPE-19] based on a Thematys data shows much higher values: 4 050 TWh in 2012 and 3 000 TWh for year 2019, these values are judged as rather unrealistic. However, unexpectedly, another study based on light pollution of the skies thanks to satellite radiance measurements shown (Figure 2) that street lighting consumed in 2018 roughly 215 TWh of electricity [SAN-23], considering the street light is representing 8% of the total lighting consumption [ALM-14], we can find the figure of 2 690 TWh. This is an excellent independent confirmation of common agreed values.

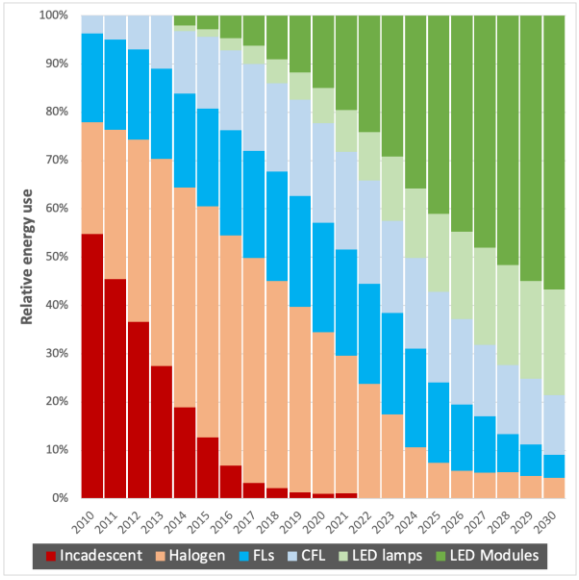
Figure 2: Estimation of world's street lighting electricity use from satellite radiance measurements (dots) and linear regression tendency. Original Data are courtesy A. Sánchez de Miguel



Source: G. Zissis

Figure 3 shows the relative energy used by the most common lighting technologies from 2010 extended to 2030. This graphics use data from [SPE-19] with corrections to avoid the total energy demand overestimation. The effects of incandescent lamp ban are obvious. However, as the study has been published in 2019, the fluorescent lamp ban, effective from 2023, has not been included. The graphics shows also clearly that LED-modules technology will be dominant in the next years.

Figure 3: Evolution and forecast of relative energy use for producing light by the most common technologies.

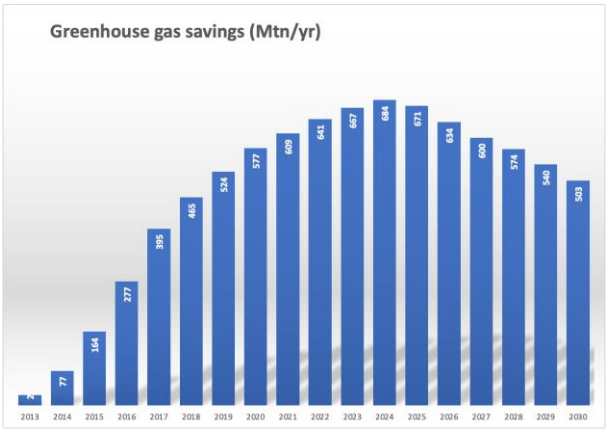


Source: G. Zissis

As has been told in the introduction in 2009 the world's electricity consumption for lighting were 2 650 TWh [ZIS-09]. Ten years later, in 2019, the world demand of light rose and the total electricity consumption attained of 2 900 TWh [ZIS-23] for a global light production of 133,5 peta-lumen-hours (in 2018). [U4E-22b] This corresponds to an average luminous efficacy of 46 lm/W. Following the analysis of United for Efficiency (U4E), in 2040 the needs for artificial lighting shall attain 285 Plmh corresponding to an increase of 25% in lighting service demand. [U4E-22b]

Applying a world average carbon intensity of electricity generated of 475 g eq.CO_2/kWh [IEA-19], lighting is responsible for a worldwide emission of CO_2 1,38 Gt per annum, corresponding to 4,16% of the world's annual greenhouse-gas emissions. Following Spectaris report [SPE-19] translated by Photonics21, transition to energy-efficient lighting will result in the avoidance of 503 of CO_2 per year in 2030. Figure 4, shows the estimated, by the same authors CO_2 annual avoidance thanks to energy-efficient lighting. The GHG avoidance related to only LED lighting is given in Table 1.

Figure 4: CO_2 avoidance thanks to energy-efficient lighting. Data from [SPE-19]



Source: G. Zissis

Table 1: CO_2 avoidance thanks to LED lighting in CO_2 metric tons. Data from [SPE-19]

2019	2025	2030
526	671	503

Source: G. Zissis

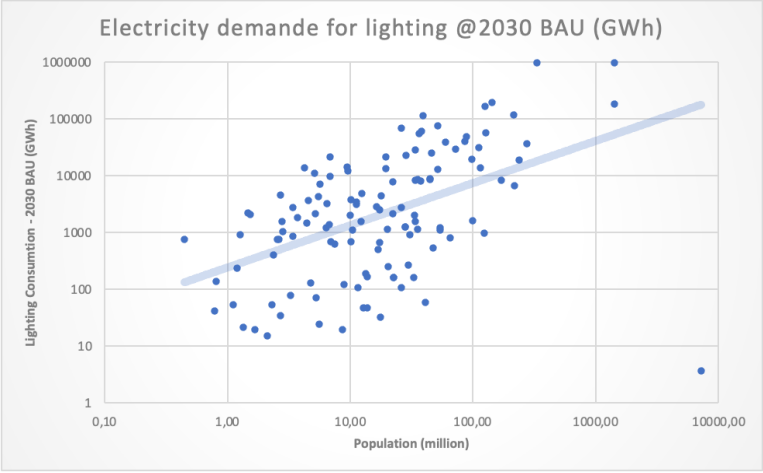
Of course, beyond the big-picture, the situation is different from country to country as well as the various lighting application segments.

2.1.1.1 Electricity demand for lighting and energy savings potential by country

United Nations Environment Programme's (UNEP) "United of Efficiency" (U4E) published in 2022 on-line an excellent analysis of energy savings potential for 156 countries with special focus on developing economies. This assessment pays a special attention to energy efficient lighting. [U4E-22] The following analysis is based on data harvested from U4E Efficient Lighting Savings Forecasting Model (v.1.0.4) coupled with geopolitical data from World Bank and United Nations databases. Our analysis is based on the forecasted electricity demand for lighting in 2030 under 2 assumptions: (1) Business as Usual (BAU) and (2) the Minimum Ambition Scenario: Based on MEPS levels defined in the United for Efficiency Model Regulation Guidelines. [U4E-22]

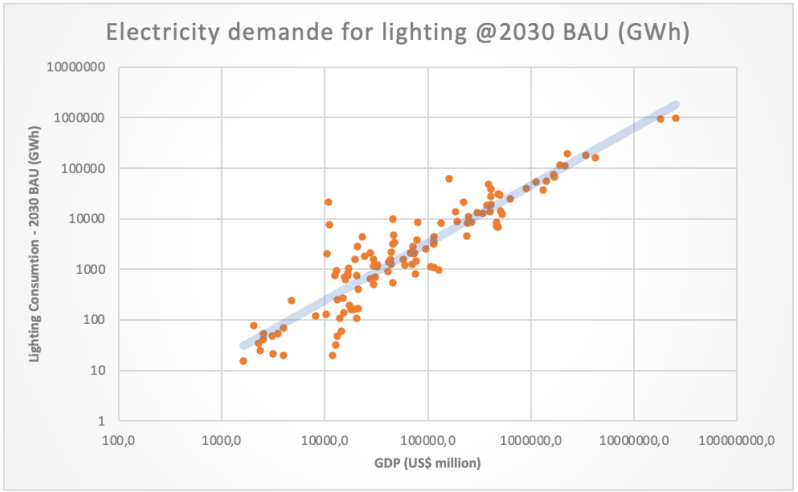
Our analysis based on the previous data targeting 120 countries worldwide (7,25 billion people), but Europe, shown that in 2030 these countries, in the case of BAU scenario, will use 3 666 TWh of electricity of indoor illumination (residential and no residential buildings) and outdoor areas. This amount can shrink to 2 274 TWh in case of Minimum Ambition Scenario and that correspond to a 37,9% reduction. Figure 5, shows that the projected savings are correlated to the population size of each country and also on the country's GDP (Figure 6).

Figure 5: 2030 Electricity demand under BAU Scenario vs country population. Energy data from [U4E-22]



Source: G. Zissis

Figure 6: 2030 Electricity demand under BAU Scenario vs country's GDP. Energy data from [U4E-22]

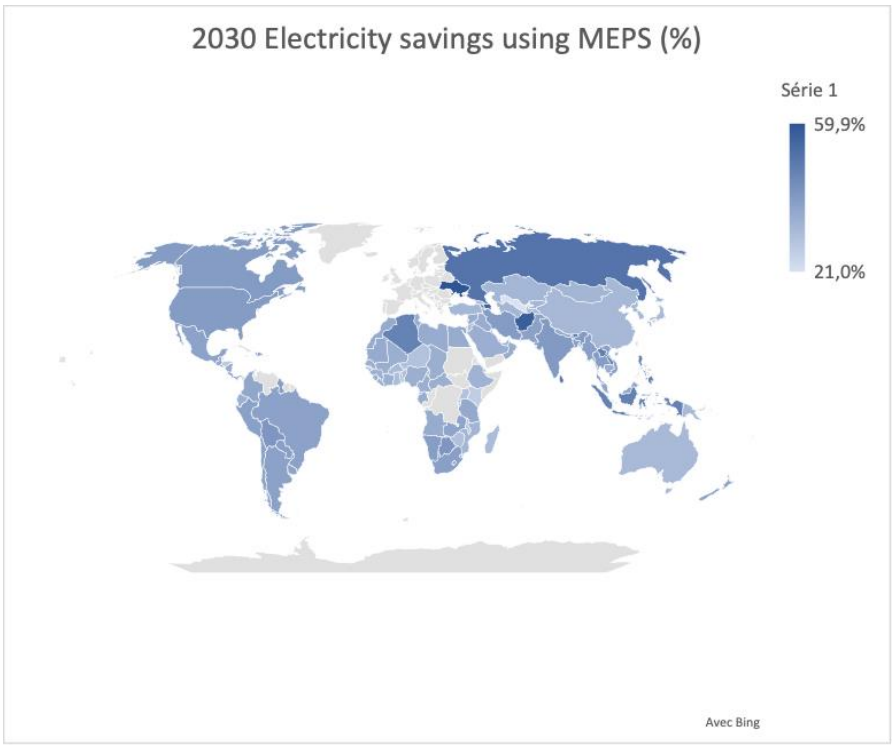


Source: G. Zissis

In this scenario each country is engaged to reduce the electricity demand thanks to applying MEPS between 21% and 50,9%, The average engagement is 36,9%.

Figure 7 shows that engagement for the concerned countries.

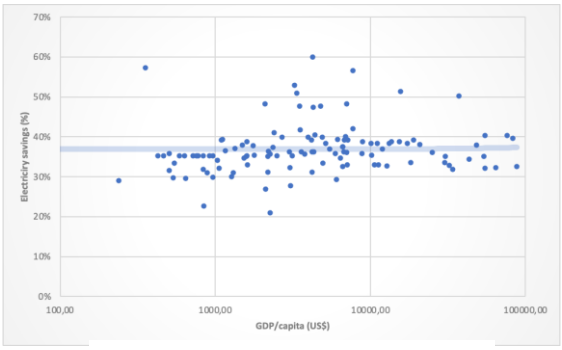
Figure 7: Targeted 2030 Electricity demand reduction (%). Data from [U4E-22]



Source: G. Zissis

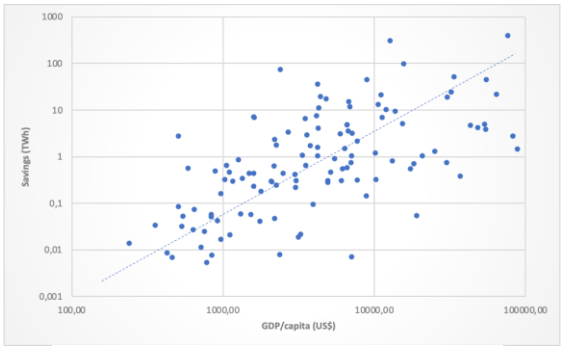
Even if absolute value of electricity demand reduction is correlated to county's GDP per capita (Figure 8), Figure 9 shows that the county's effort, measured in percent savings, is completely independent from the GDP per capita.

Figure 8: Targeted 2030 Electricity demand reduction (%) as function of country's GDP per capita. Energy data from [U4E-22]



Source: G. Zissis

Figure 9: Targeted 2030 Electricity savings (GWh/year) as function of country's GDP per capita. Energy data from [U4E-22]

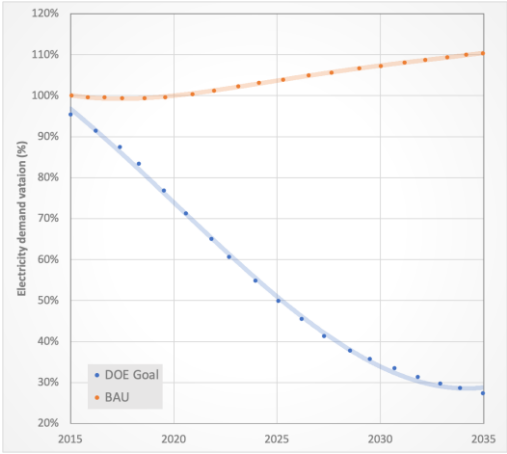


Source: G. Zissis

2.1.1.1.1 USA and European Union

USA: The Department of Energy (DOE) Solid-State Lighting (SSL) Program estimated that in 2017, lighting consumed approximately 1 758 TWh of electricity and accounted for 16% of the total electricity consumed in the U.S. in 2017. [DOE-19] Among that quantity, 15% of the electricity consumed by the residential and commercial sectors of the economy and if nine major residential and commercial lighting applications switched to LED sources "overnight," the immediate annual savings would be about USD 37 billion. [NAS-23].

Figure 10: Relative variation of electricity demand for lighting in the case of Business as Usual (BAU-orange) and following the DOE goals scenario (blue). Data from [PAT-19]

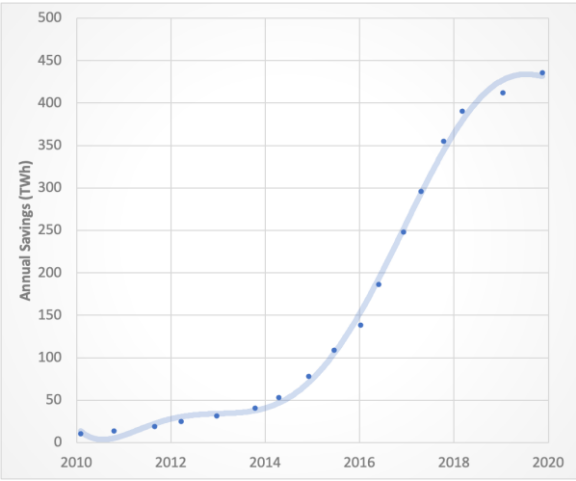


Source: G. Zissis

In fact, since several years the DOE lighting electricity savings scenario related to SSL adoption, meets relatively aggressive goals for efficacy and cost, and gradually displaces conventional lighting at a rate that depends on the degree of its improvement in efficacy and cost over conventional lighting. In 2018 Pattison et al., predicted that lighting electricity demand is expected to increase by 15%, which without massive SSL adoption would require a 15% increase in primary energy consumption. To avoid such catastrophic scenario, DOE engaged an ambitious program for supporting energy efficient lighting based on SSLs. This project has the ambitious target is to reduce electricity demand by 72% by 2030 (Figure 10). [PAT-18] A PNNL report published in 2021 shows, that by 2030 DOE projects supporting the technological research would be associated with 48,8 TWh in electricity savings or a 4,5% reduction in electricity usage for lighting in the US; And by 2035 these savings will extend to 97,9 TWh corresponding to 10% reduction in electricity demand. [PNN-21]. To compare, the VHK Inc. MELISA Model (Model for European Light Sources Analysis) predicted that, in 2020, USA will achieve 438 TWh of savings, when DOE expected 402 TWh. Figure 11, shows the MELISA Predictions till 2020.

In November 2019, the California Energy Commission voted to ban the sales of inefficient lighting bulbs with effect from 01 January 2020. China has also banned the production of incandescent lights for domestic use to encourage the replacement of traditional lighting with LED lights. [GVR-21]

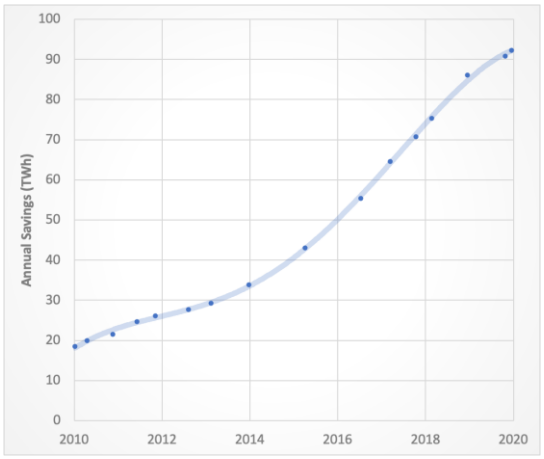
Figure 11: USA Electricity annual savings predicted by MELISA model. Data from [VHK-22]



Source: G. Zissis

European Union: Figure 12 shows MELISA Predictions for energy savings in lighting for the European Union.

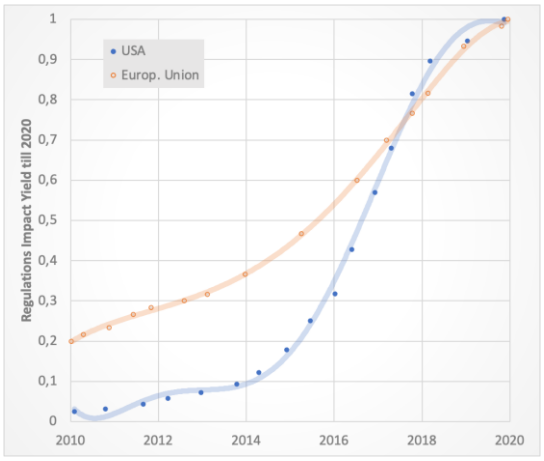
Figure 12: European Union Electricity annual savings predicted by MELISA model. Data from [VHK-22]



Source: G. Zissis

Europe implemented energy efficient lighting regulations well before USA. As can be seen European regulations are less "aggressive" the DOE strategy and allows a smother but slower market adaptation. Figure 13 shows the impact of energy efficient lighting regulations between European Union and USA expressed as the annual relative yield of energy savings calculated by MELISA from 2010 to 2020.

Figure 13: Impact of EU vs USA regulations to reach a relative saving's target value. Data from [VHK-22]



Source: G. Zissis

2.1.2 Lighting by end-use segments

Let consider that global general lighting can split into the following end-use oriented segments: (1) residential, (2) tertiary building indoor and (3) outdoor lighting.

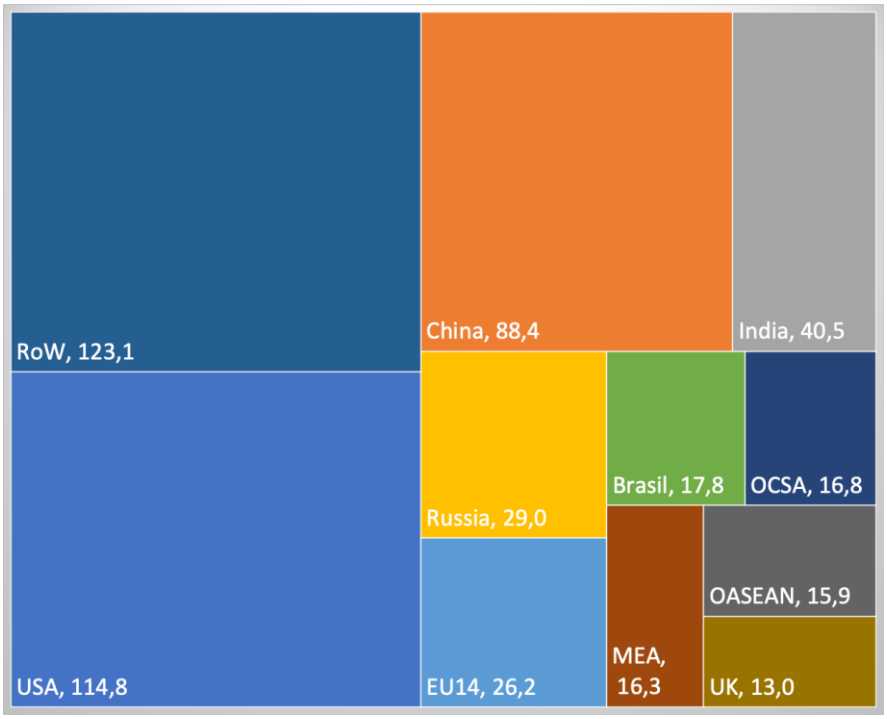
2.1.2.1 Residential segment

In the frame of COP26 initiative the UK Department for Business, Energy & Industrial Strategy (BEIS) estimated that in 2017, the world electricity consumption for residential lighting was 501,9 TWh, corresponding to 17,3% of the total electricity used to generate artificial light [BEI-20]. K. Lane gave a value of 550,2 TWh for the same year. [LAN-23] In fact, residential lighting consumption is similar to electricity use for refrigerators at homes. Nair predicts that global lighting demand in the residential segment is expected to grow at a CAGR of 6,12% in 2018-22. [NAI-21]

The BEIS study indicates that in 2017, USA residential segment weights 23% of the total followed by China (18%) and India (8%). In, 5th position, EU14 countries' residential lighting represents 26 TWh (5% of the world

segment's consumption). Figure 14 gives more information about the residential electricity consumption for lighting in various geographical areas.

Figure 14: Annual electricity consumption (in TWh) by residential segment in 2017. Data from [BEI-20]



Source: G. Zissis

Thanks to massive adoption of LED technology the energy consumption is drastically reducing (Figure 15). Globally, in the global residential segment the electricity demand for lighting fell from 655 TWh to 512 TWh Following [LAN-23] today about 50% of global residential lighting sales use LED technology (when the penetration was only 5% in 2013).

Following BEIS, substantial energy savings can be achieved in the residential lighting segment (Figure 16). However, US Department of Energy Solid-State Lighting (SSL) Program is much more optimistic as can be seen in the same figure. [DOE-19].

Figure 15: Annual energy consumption of residential lighting segment. Data from [LAN-23]

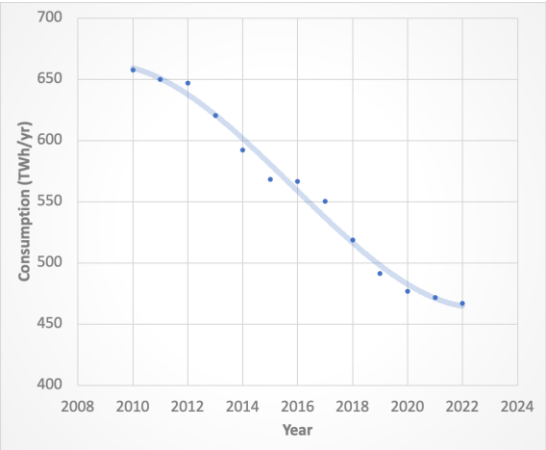
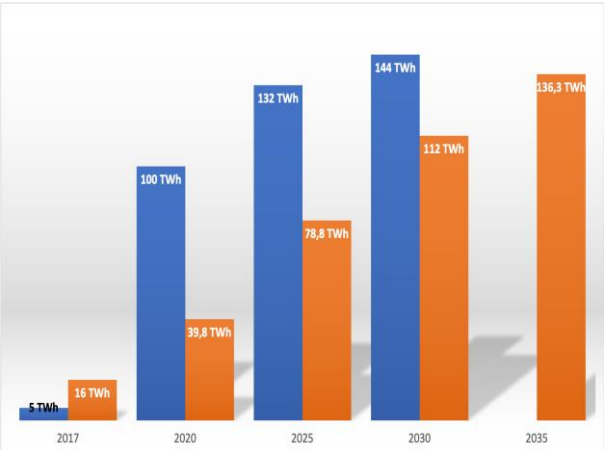


Figure 16: World (blue bars) and USA (orange bars) forecasted energy saving by the residential segment. Data from [BEI-20] and [DOE-19]



Source: G. Zissis *Source: G. Zissis*

K. Lane, predicts worldwide residential segment will save up to 141 TWh from 2022 to 2030. [LAN-23] This is more optimistic than BEIS forecast because it assumes that to keep Net Zero Scenario for 2050, the average luminous efficacy in the residential segment shall achieve 100% LED technology by 2025 and that a 140 lm/W average segment's luminous efficacy must attained by 2030.

In Europe (EU27) the average annual consumption for residential lighting reduced within 10 years by 27,2%: from 521 kWh per household in 2005 to 379 kWh in 2015 and is expected to fall to 132 kWh in 2030. [EUC-22] As shown in Figure 17, EC analysts believe that these savings have been, and will be, accelerated by regulations enforced in the European Union.

Figure 17: History of EU27 Residential segment electricity demand for lighting (forecasts from 2020)

Source: G. Zissis

In USA, the latest Residential Energy Consumption Survey (2015) shown that 25% of households own 40 or more bulbs. The average household electricity demand for lighting is 1,105 MWh/year for lighting; this is about 10% of electricity consumption in homes. The values can range from 1,333 MWh/yr in West North Central states of the Midwest to 0,911 MWh/yr in Pacific west-coast states. [EIA-19] This is roughly twice the EU27 individual household electricity demand for lighting. All-in-all, in 2022 the residential lighting segment weighted for 67 TWh, corresponding to 2% of the global USA electricity use. [EIA-23] Taking into account that in 2017 the total electricity demand of the segment was 114,8 TWh [BEI-20], the accomplished energy savings attained 46,8 TWh within 4 years. This figure is agreement with the DOE's projections related in the above lines. [DOE-19]

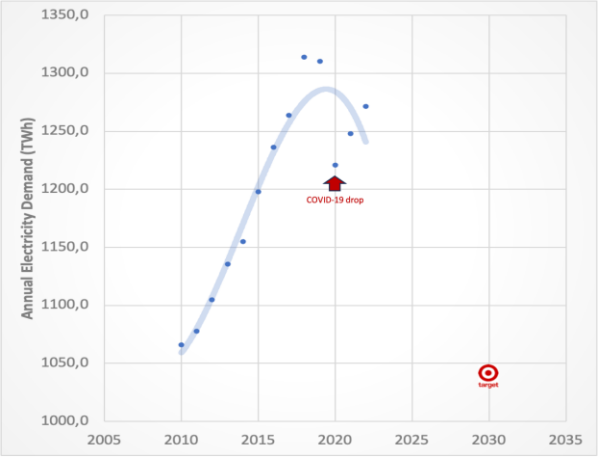
In Indonesia, an average household located in Jakarta area use 500 kWh/yr for lighting (releasing 0,94 t/yr CO_2), while the electricity demand if an average household located in Bandung is 531 kWh/yr releasing 1,0 t/yr CO_2). [KUB-14]

In Australia low voltage dichroic halogen lamps (50W MR16), which are being phased out as a result of a government import ban in 2012, are still in use in many residential situations in 2016. They should be replaced as they are highly inefficient, with each light costing up to AUD 50 per annum to operate. In New South Wels, thanks to Government package supporting low-income household over 20 000 rental homes enabling low-income tenants benefited, among others from energy-efficient lighting systems. [SOE-23] The Office of Environment and Heritage of New South Wells propose to the household keepers replace them with new 16W LED fittings, the expected energy savings will attain 75% at the same service level. [OEH-16] In Victoria, it is estimated that a household uses 4% of the total electricity just for lighting. [SUV-23]

2.1.2.2 Non-residential building segment

Following K. Lane, Non-residential service building sector used 1 271 TWh of electricity for lighting (this is 43,8% of the full lighting consumption) [LAN-23]. Figure 18 shows the evolution of electricity demand of the segment since 2010 and the target to reach by 2030 in order to fulfil Net Zero Energy (NZE) building scenario. The 2020 observed drop is clearly a consequence of COVID-19 pandemic and associated lock-downs. Building floor area has grown by about 60% in the past two decades and is set to increase by another 20% this decade, adding a total floor surface area of nearly 45 billion m^2, equivalent to about five times the floor area in Indonesia today. [LAN-23]

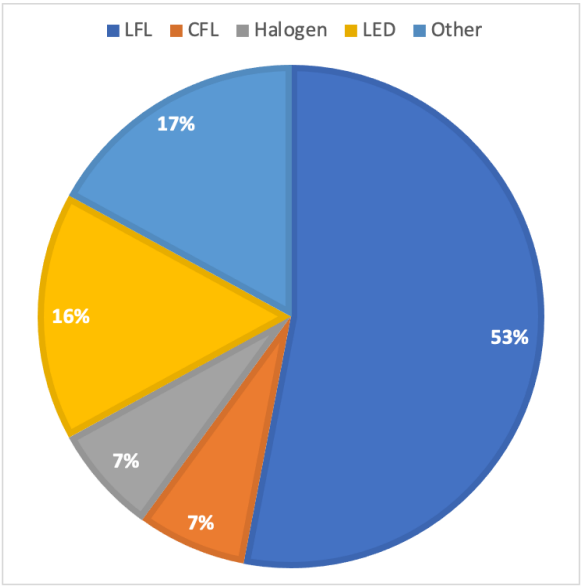
Figure 18: World Annual electricity demand of service buildings. The red point is the fixed target in the frame of NZE ambition and the arrow indicates the COVID-19 drop. Data from [LAN-23]



Source: G. Zissis

In Europe around 71% of electricity demand for lighting was consumed in the non-residential sector in 2020, the typology of the top consumers include offices (20%), shops (15%), manufacturing areas (15%) and circulation areas in buildings (10%). [ISA-23] Figure 19 shows in the energy demand for the various lamp technologies present in European buildings. [ISA-23]

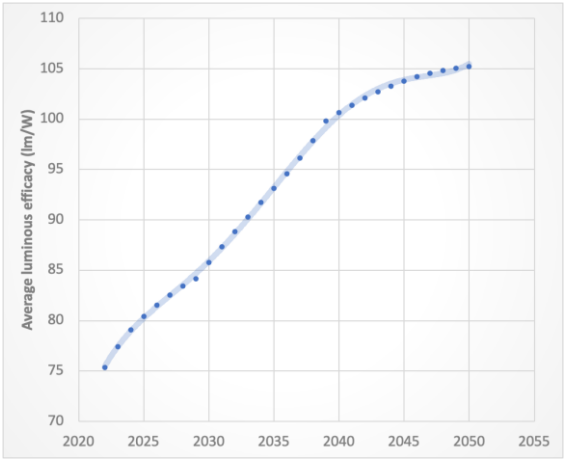
Figure 19: Energy demand for the various lamp technologies present in European buildings in 2020. Data from [ISA-23]



Source: G. Zissis

The data from US Energy Information Administration concerning energy the equipment efficiency of Commercial Sector buildings forecast an increase of the average luminous efficacy of the segment and that at least till 2050. The value found for 2022 is 75,4 lm/W. [EIA-23b] Figure 20 shows the EIA projections for the period from 2022 to 2050, the value shall stabilize at term around 105-106 lm/W.

Figure 20: EIA projections for the evolution of average luminous efficacy in the commercial building segment. Data from [EIA-23b]



Source: G. Zissis

In USA, in 2020 office buildings used 237 TWh, retail and service counted for 181 TWh, schools for 156 and hotel lodging buildings 47 TWh. [EIA-21b] Further, in 2018, about 48 TWh were consumed for facility lighting in manufacturing facilities. [EIA-21] However, the DOE expects the commercial sector to yield far more significant energy savings 39% of total savings, in the next years. [PLU-23] It shall be noted that following and DNV recent report, in Massachusetts 4% of lamps in commercial and industrial (C&I) spaces is never switched off in 2020… [NDV-21]

For instance, Alabama's Local Government Energy Loan Program offers zero-interest loans to public schools and universities for energy efficiency improvement projects that will pay back in utility savings. Upgrades eligible for funding include heating and cooling equipment, insulation improvements, water-saving efficiency measures, and energy-efficient lighting installations. [IBI-23]

In Greece, Doulos et al. estimated that their annual lighting electrical energy annual consumption in school buildings can be reduced from 31,2 kWh/m^2 (1980–2000 buildings equipped with T8 fluorescent lamps) to 9,15 kWh/m^2 and 4,94 kWh/m^2 with the installation of T5 fluorescent and LEDs lamps, respectively. [DOU-19]

In Italy, Statista forecasted that the volume of electricity used by the industrial sector for lighting purposes is expected to reach 11,1 TWh [STA-16]

In France, a study realized by In Numeri for ADEME in 2019, shown that since 2012 at least 75% of municipalities engaged actions for installing in public buildings energy efficient lighting systems obtained at least 51% of enhancements. [ADE-19]

In UK a significant step toward making homes more efficient is the estimated at 14% thanks to LED lighting products installed by household occupants. [EMG-23]

Wan Yun Hong estimated the electricity demand of commercial buildings in 4 Southeast Asia countries: Brunei Darussalam, Malaysia, Singapore and Thailand. They found that the annual average electricity consumption of lighting is 46,94 kWh/m^2 (values ranging from 9,74 to 105,50 kWh/m^2). This amount corresponds to 16,6% of the global building's electricity demand. Table 2 and Source: *G. Zissis*

Table 3 give some more details by country and by building destination. In all four countries the top consumers are buildings for retail activities followed by hospitals. [HON-21]

Table 2: Building annual electricity demand & CO_2 emissions for lighting in 4 Southeast Asian countries, by country. Data from [HON-21]

Country	Building annual electricity demand for lighting (kWh/m^2)	Annual CO_2 emissions due to lighting ($kgCO_2/m^2$)
Brunei Darussalam	33,94	6,41
Malaysia	46,84	10,46
Singapore	61,77	4,97
Thailand	60,56	12,80

Source: G. Zissis

Table 3: Building annual electricity demand & CO_2 emissions for lighting in 4 Southeast Asian countries, by destination. Data from [HON-21]

Building destination	Building annual electricity demand for lighting (kWh/m^2)	Annual CO_2 emissions due to lighting ($kgCO_2/m^2$)
Hospital	59,39	9,19
Hotel	53,60	8,94
Library	38,63	7,67
Temple	29,96	5,66
Office	34,70	6,22
Retail	81,54	15,53
University	10,66	2,25

Source: G. Zissis

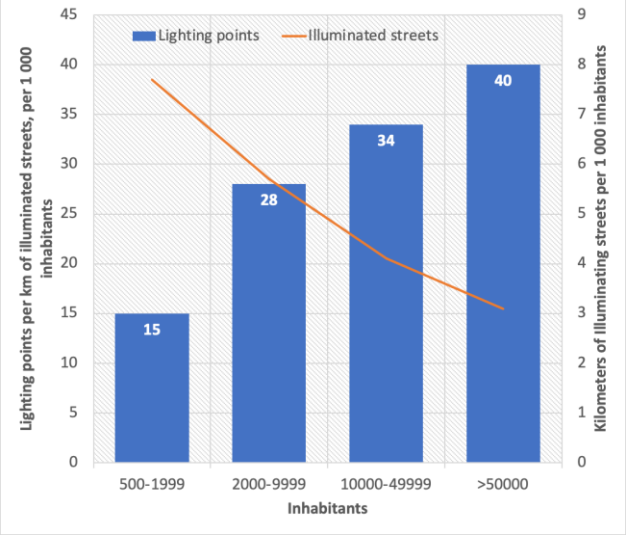
In the domain of stage lighting LEDs and light controllers are expected to save 70% energy in the domain. These types of innovations are likely to help vendors overcome the challenge associated with traditional light systems such as high cost, low intelligence, and high installation and deployment cost. [ARI-20]

2.1.2.3 Outdoor Public Lighting segment

Graham Colclough, chair of EU Action Cluster on Smart Cities, estimates that European cities spend mora than 20% of their energy bills on lighting, while 75% of public lighting assets in the EU are more than 25 years old and mostly use inefficient lamps. [COL-22]

In France, in 2017 public lighting expenditure represented the amount of EUR 9,70 per inhabitant per year. [ADE-19] But this cost is very rapidly increasing since then. Sixty-nine percent (69%) of French municipalities are managing their public lighting systems and 19% transferred that responsibility to public syndicates. [ADE-19] Since 2012 and thanks to the effort of replacing legacy lighting systems by LEDs and controls the annual electricity demand of the segment reduced from 85 kWh/inhabitant in 2012 to 56 kWh/inhabitant in 2017. Figure 21 gives the average number of lighting points per kilo-meter of illuminated streets and the number of kilo-meters of illuminated steers per 1 000 inhabitants. [ADE-19]

Figure 21: Average number of lighting points per kilo-meter of illuminated streets (per 1 000 inhabitants) and the number of kilo-meters of illuminated streets per 1 000 inhabitants. Data from [ADE-19]



Source: G. Zissis

In Italy, the electricity deployed for public lighting is estimated to achieve 4,13 TWh in 2020. [STA-16]

In Poland, Sedziwy et al. [SED-18], estimated in 2018, that replacing all legacy sodium lamps in a city (80 000 lighting poles) by LEDs can achieve substantial savings that can be amplified by the adjunction of dimming and controls. Indeed, in that case the energy use will reduce from 28,4 GWh (sodium) up to 10,5 GWh (LED with dimming and controls) for the same service level. Table 4 gives some more detains including environmental impacts[4]. The suggested also that for road/street lighting the annual CO_2 avoidance is related to the road class according CEN/TR 13201-1:2004 (*Source: G. Zissis*

Figure 22). It is obvious that motorway M2 class lighting systems shall be retrofitted in priority. [SED-18]

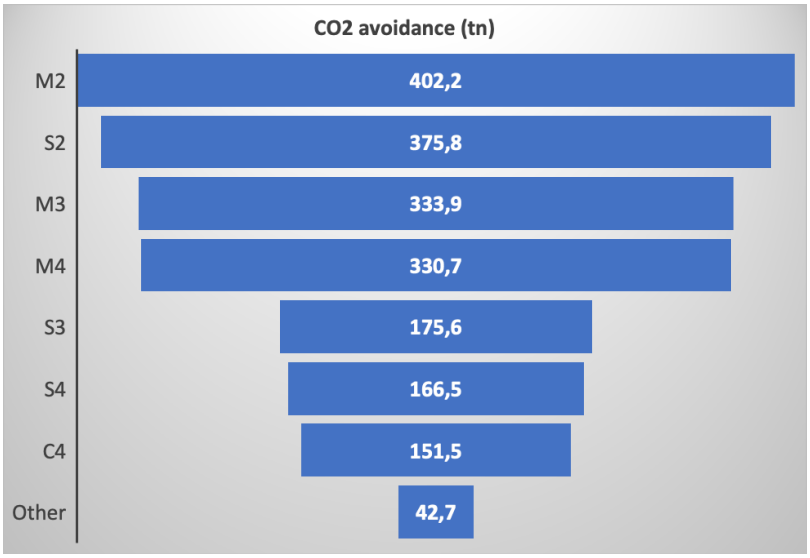
Table 4: Estimated energy savings and reduction of environmental impacts in a Polish city that replaces 80 000 legacy lighting points with LED technology. Data from [SED-18]

	Legacy (Sodium)	LED	LED + dimming	LED + Dimming & Control
Power usage (MW)	6,6	3,9	3,4	2,4
Annual Energy consumption (GWh)	28,4	16,7	14,4	10,5
CO_2 emission (t)	22,908	13,455	11,59	8461
SO_2 emission (t)	23,99	14,09	12,14	8,86
NOx emission (t)	24,16	14,19	12,22	8,92
CO emission (t)	7,39	4,34	3,74	2,73
Particulate matter (kg)	1535	901	776	567

Source: G. Zissis

[4] Emission factors in Poland in kg/MWh (2017): CO_2: 806, SO_2: 0,844, NO_x: 0,850, CO: 0,260, particulates: 0,054. Data from [NCE-17]

Figure 22: CO_2 avoidance per 1 000 lighting points in Poland as function of road class. Data from [SED-18]

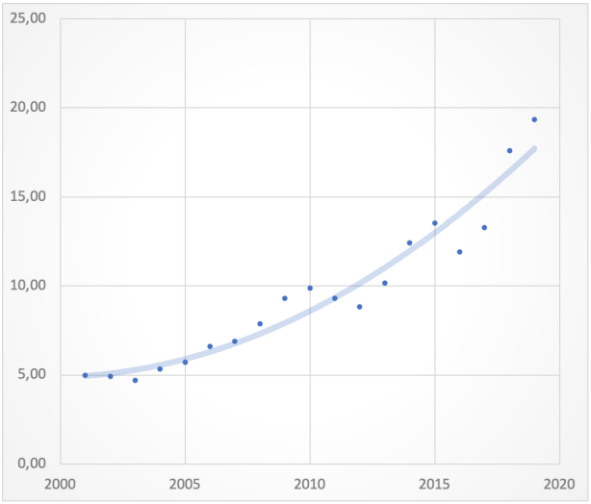


Source: G. Zissis

Polish municipalities spendings for operating street lighting is increasing exponentially since 2000's. Figure 23 shows the annual global expenditure for street lighting. [BAC-21]

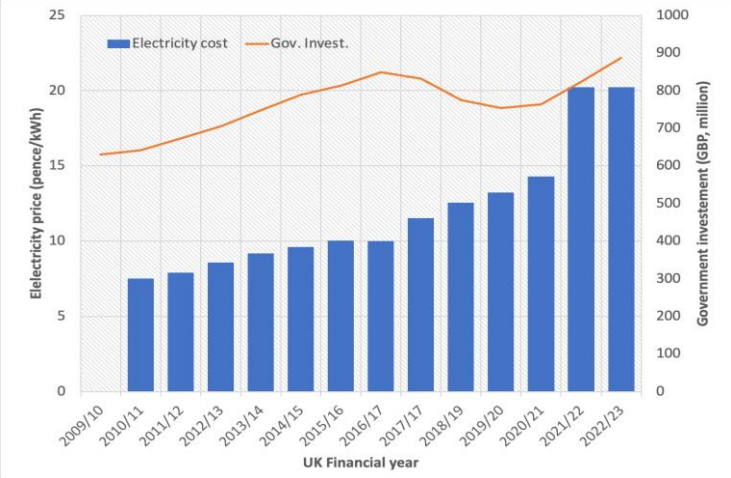
D. Clark said that UK Government spending on street lighting was GBP 884 million in 2022/23, compared with GBP821 million pounds in the previous financial year. [CLA-23] In parallel, as Figure 24 shows, the average net selling value of electricity increased nearly threefold, from 7,51 pence/kWh of electricity sold in 2010 over 20 pence/kWh in 2022. [STA-23f]

Figure 23: Evolution of Polish municipal expenditure for street lighting operation. Data from [BAC-21]



Source: G. Zissis

Figure 24: Evolution of electricity price and governmental investments in UK for street lighting. Data from [STA-23f] [CLA-23]



Source: G. Zissis

In India, since 2015, the Street Lighting National Program has installed more than 12,7 million LED streetlights. of this is leading to expected annual reductions in customer electricity bills of INR 193,33 billion, peak demand avoidance of 9,789 TW, emission reduction of 39,30 Mt CO_2, and energy savings of 48,42 TWh [EMG-23]

Another important source for overspending energy for lighting is directly linked to Christmas festive illuminations of the major cities. Following, Gallizzi's, Uswitch comparison of the luminous pollution generated by a city at night analyzing night time satellite data from NASA, during Christmas time compared to a regular month, obtained the energy overspent between October and December. [GAL-21] The top-10 of Christmas illumination overconsumption by European cities is given in Table 5.

Table 5: Relative increasing of city brightness seen from space in December 2021 compared to October 2021. Data from [GAL-21].

	City	Increase		City	Increase
1	Milan	69,25%	6	Frankfurt	42,37%
2	Istanbul	69,14%	7	Dublin	41,76%
3	Ljubljana	67,57%	8	Amsterdam	40,73%
4	Stockholm	49,33%	9	Athens	33,65%
5	Oslo	48,53%	10	Andorra	32,52%

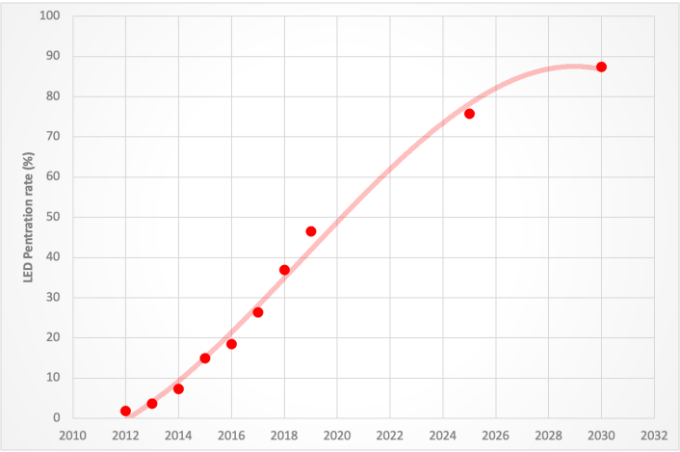
Source: G. Zissis

2.2 Market update

Historically, IHS Markit analysts evaluated the LED penetration in the global lighting market, in 2014, at only 7%, but they attributed to that technology 1/3 of the global revenue. Considering that in 2017 the global lighting market revenue was USD 130 billion[5] the LED share elevated at USD 43,3 billion. [HIS-17] DOE predicts that in 2035 86% of the global lighting marker revenue will be attributable to LED technology. [MAM-21] Figure 25 gives the historic evolution of LED technology penetration in the global Lighting Market.

[5] Nair, in 2021 said that the global lighting market was estimated at USD 133,94 billion growing steadily, with a CAGR of more than 10,4% at least till 2025. [NAI-21]

Figure 25: Historic evolution of LED technology penetration in the global Lighting Market. Data from [MOR-22]

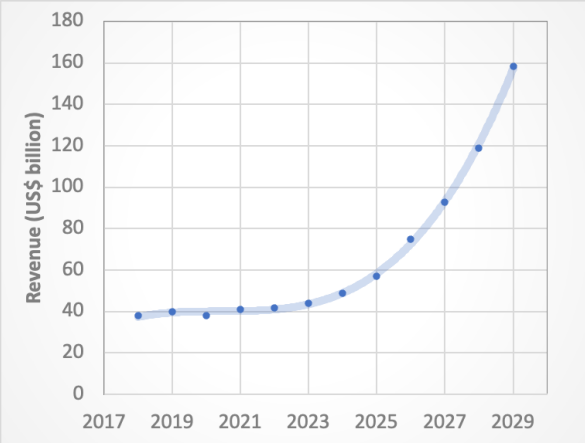


Source: G. Zissis

In 2022 Market and Markets analysts estimated the LED lighting market revenue to be worth USD 75,3 billion and expected to attain USD 124,7 billion by 2027. The associated CAGR for 2022-27 5-year period is estimated at 10,6%. [MAM-22] However, Technavio analysts stipulate that the global LED lighting market will grow by USD 34,82 billion from 2017 to 2027. In that period, the market is expected to grow at a CAGR of 7,35% and the year-over-year (YoY) between 2022 and 2023 is 6,8%. [TCA-23] Spherical Insight analysts reported in January 2023 that the global lighting market count for USD 80 billion and they expect a CAGR of 10% from 2022 to 2030 to reach at the end USD 160 billion. [SPH-23] Research-And-Markets, predicted a CAGR of 10,7% for the decade 2020-30 and a revenue growth from USD 55,2 billion up to USD 152,44 billion at the term of the period. [MAR-22] Prescient & Strategic Intelligence estimated the 2022 revenue of the segment to USD 88,95 billion and expected a CAGR of 10,5/ for the period 2022-30 to reach USD 152,84 billion. [PSI-22] Fortune Business Insight predicts à CAGR of 17,6% for the period 2018-29. [FBI-22] Even if the given value of segment's revenue (USD 77,79 billion) in 2021 is coherent, the proposed CAGR is very large to be credible. Emergen Research, reported more recently, a global revenue of 73,8 billion in 2022 associated with a 10,6% CAGR for the decade 2022-32. [EMG-23]

Following [MAM-22] APAC world region is expected to witness the highest CAGR during the next 5-year period and [TEC-23] estimated that the region will generate 43% of the growth. Figure 26 gives the predictions of APAC region LED lighting revenue growth. [FBI-22] The major factor contributing to the LED lighting market's growth in the region includes the rising demand for LED lighting solutions from major economies such as China, India, Japan, Australia, and South Korea. Similarly, the increasing number of construction activities in residential, commercial, and industrial sectors of developing economies of Asia Pacific, including Southeast Asian countries, also drives the growth of the market in the region. [MAM-22] China is the major revenue-contributing country in the market owing to the presence of many LED lighting manufacturing units and industries. [TCA-34]

Figure 26: APAC region revenue evolution and forecast for the period 2018-29. Data from [FBI-22]

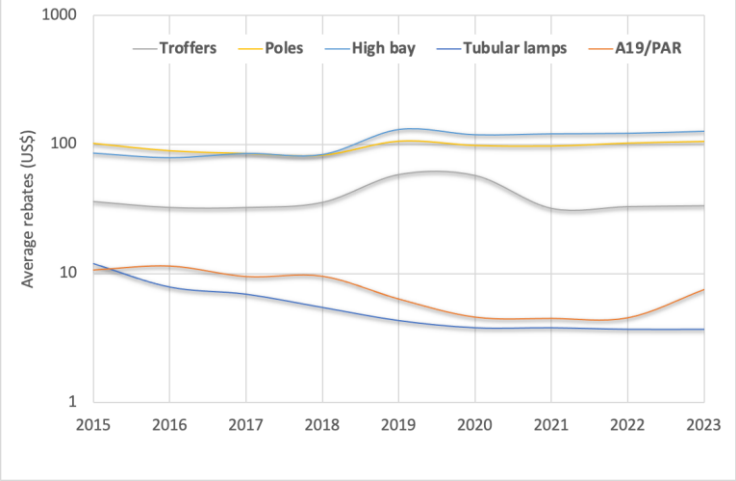


Source: G. Zissis

Following [EMG-23] 31% of the global revenue was accounted in North America.

In USA, rebates have been a staple in the commercial lighting marketplace for decades, helping millions of customers transition to more efficient lighting at a reduced cost. The most significant change for rebate programs in 2023 is in response to the Energy Independence and Security Act (EISA). EISA Phase 2 will go into full effect in July 2023 and will increase the minimum efficacy requirement of many general service lamps (GLS). At the start of 2023, 78% of the USA states has a commercial lighting rebate program available. That's consistent with the past few years and just shy of the record of 79% we saw back in 2017. The most robust programs are still in the Northeast and Northwest, while states like Ohio, Kansas, and North Dakota offer no rebates. California, Florida, and Texas, also have some of the lowest rebate potential, the programs there are so restrictive that they offer little value for most national average. [YOU-23] Usually, rebate programs are offering bonuses or increased dollar amounts in an effort to capture the savings while they still can. Figure 27 shows average rebate amounts for the retrofit of various technologies by LEDs. [YOU-23]

Figure 27: Rebates for retrofit to LED technology in USA. Data from [YOU-23]



Source: G. Zissis

2.2.1 Components

2.2.1.1 LEDs and LED light Engines

Growth drivers for LED lighting market are (1) less energy requirement, (2) financial savings, (3) mercury free (4) high life-span and (5) turnability.

Asavari and Vineet in an Allied Market Research report published in 2022 stated that the global LED market was valued at USD 78,69 billion in 2020, and is projected to reach USD 192,68 billion by 2030, growing at a CAGR of 8,2% in the 10-year period from 2021 to 2030. [ASA-22] Asia Pacific region is expected to have the largest CAGR (9,4% in 2021-30). [ASA-22]

In parallel, LED prices are expected to strongly decrease in the medium to long term (up to 70% by 2050 for USA as reported by DOE) and high-quality products (e.g., RGB White) which are able to provide different light temperatures and new services have been placed on the market. [CAL-21]

In fact, LED Technology is deeply changing the lighting market, making it into a new booster/enabler for smart city development. However, as a consequence, complexity of the sector's value chain is increasing and new players are entering the market. [CAL-21]

Table 6 and *Source: G. Zissis*

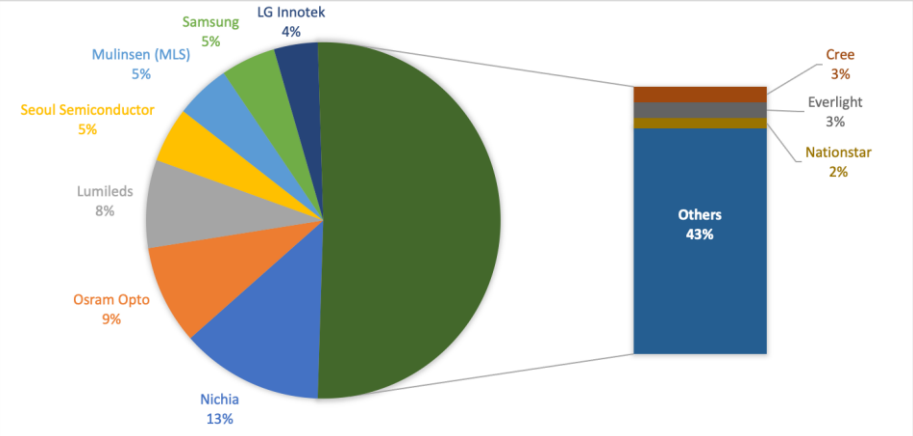
Figure 28 give the top-10 ranking of worldwide LED manufacturing companies in 2019. The top-10 corresponds to 47% of the world total. [SHI-21]

Table 6: 2019 Ranking of worldwide LED manufacturing companies. Data from [SHI-21]

#	Company	Country	Revenue (USD billion)	Market Share (%)
1	Nichia	Japan	2,132	13%
2	Osram Opto	Germany	1,411	9%
3	Lumileds	USA	1,202	8%
4	Seoul Semiconductor	South Korea	0,867	5%
5	Mulinsen (MLS)	China	0,860	5%
6	Samsung	South Korea	0,749	5%
7	LG Innotek	South Korea	0,572	4%
8	Cree	USA	0,502	3%
9	Everlight	Taiwan	0,441	3%
10	Nationstar	China	0,353	2%

Source: G. Zissis

Figure 28: LED production Market shares in 2019. Data from [SHI-21]



Source: G. Zissis

Following Strategies Unlimited analysts [SHI-20]:

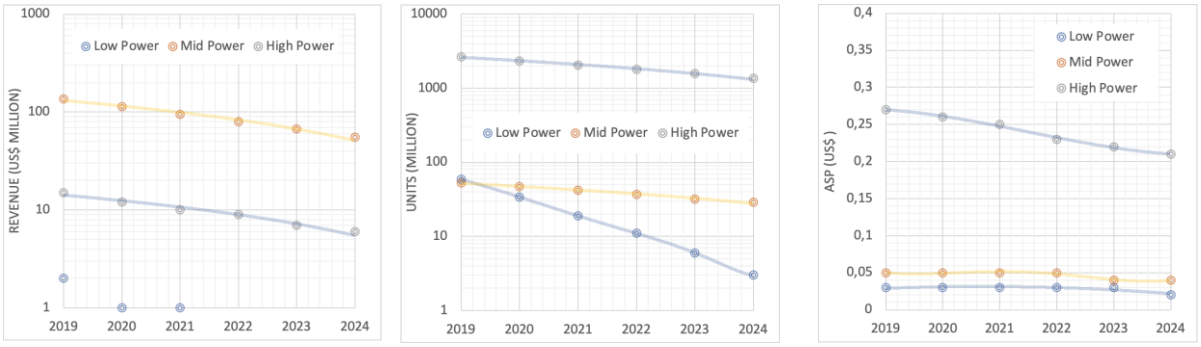
— Osram Opto stayed at the number two position from 2015 through 2019.

— Lumileds retained its third position from 2016 through 2019.

— Mulinsen (MLS) from China, who made the top ten in 2014, continues to be in the top at number 5 with US $860 million in revenue and close to Seoul Semiconductor at number 4.

Strategies Unlimited's report gives more insight on the various traditional phosphor converted white LED sub-segments; Figure 29 shows these projections. [SHI-21]

Figure 29: Market evolution of LEDs for lighting (a) revenue, (b) number of manufactured units, (c) average selling price



(a) (b) (c)

Source: G. Zissis

TrendForce analysts, reported that for some high-power lighting LED products (above 1W) such as ceramic substrate and surface mounted LEDs an average annual market price growth was as much as 3-6%. More especially, in 2022 the forecasted YoY growth was 9,2% to USD 8,11 billion. [TRE-22] This may indicate a technology switch to more modern LED technologies.

The global market for Chip-On-Board Light Emitting Diodes (COB LEDs) estimated in 2022 at USD$ 3 billion, and following [GIR-23] it is projected to reach USD 6,4 billion by 2030, growing at a CAGR of 10% over the 8-year period (2022-30).

The same report, indicates that The COB LED's market in USA is estimated at USD 811,3 million in the year 2022. China, market is forecasted to reach USD 1,4 billion by 2030 corresponding to a CAGR of 14% for the 8-year period from 2022 to 2030. Japan and Canada markets, are expected to grow at 7,2% and 8,1% during the same period. Within Europe, German market CAGR is forecasted at 7,8%. Asia region market, led by countries Australia, India, and South Korea, is forecasted to reach USD 933,2 million by 2030. [GIR-23]

An integrated assembly known as the LED light engine (LLE) is made up of one or more LED arrays (modules) or light-emitting diodes (LEDs). The global LED light engine market size was valued at USD 29,708 billion in 2021, presumed to reach USD 80,728 billion, expanding at a CAGR of 13,31% during the forecast period. The market for LED light engines is expanding due to the rise in demand for high-class residential communities and luxurious homes. Additionally, urbanization has facilitated a significant increase in infrastructure construction, which is expected to increase demand for lighting systems further and propel the market for LED light engines. [STR-22] North America and the Asia Pacific will Dominate the Regional Market. It is expected to grow at a CAGR of 11,41% from 2021 to 2030. However, APAC is the largest market for LEDs, accounting for around 50% revenue share in 2022. [PSI-22] The regional market will expand at a CAGR of 16,21% and hold USD 26,508 billion by 2030. [STR-22]

2.2.1.2 Lighting equipment, LED Lamps and Fixtures/Luminaires

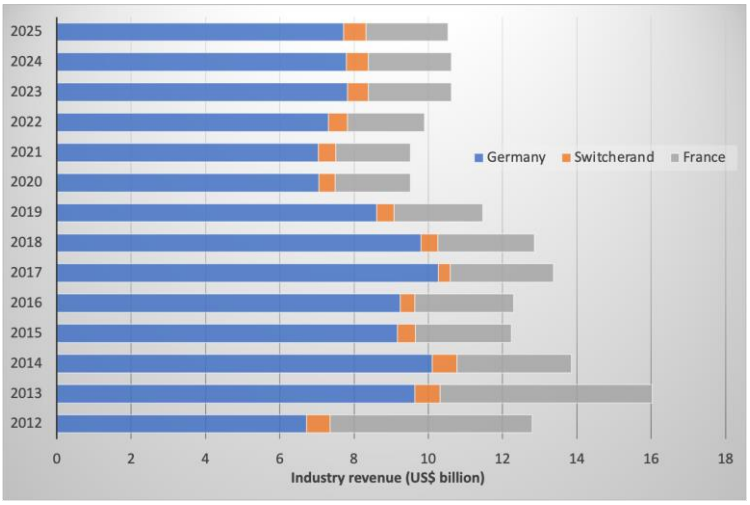
According to an analysis related by [MKL-21], the LED lighting market penetration rate will increase to 57% in 2021.

LED lamps segment dominates the overall LED lighting market in 2022 and similar trend is expected to continue at least till 2027. A-type and T-type lamps are highly adopted in residential applications, which, in turn, leads to a larger market size of the lamps segment compared to luminaires. [MAM-22]

Technavio reported that the size of the LED lighting market in North America is projected to grow by USD 5,81 billion with a CAGR of 9,1% during the 2021 to 2026 5-year period. [TCA-23]

Europe is also a market driver region, Figure 30 shows the revenues of manufactured of electric lighting equipment in France, Germany and Switzerland. It is projected that the revenue of manufacture of electric lighting equipment in France will amount to approximately USD 2,24 billion by 2025. [STA-21]. In Switzerland, it is projected that the revenue of manufactured of electric lighting equipment will amount to approximately USD 591 million by 2025 [STA-21]. the industry "manufacture of electric lighting equipment" is projected that will generate a revenue of approximately USD 7,74 billion by 2025 [STA-21]. It is interesting to notice that since several years Germany's income is almost 3,5 higher than for France, but this ratio was 1,24 in 2009. This corresponds to several factories shut-down in France during of 2010's (i.e., Philips closed its last French factory in 2016).

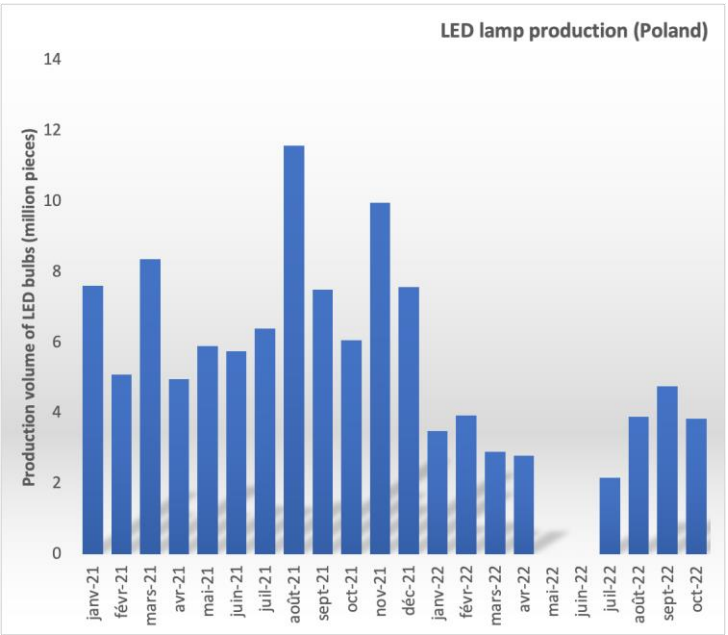
Figure 30: Industry revenue for companies under NACE C247 activity



Source: G. Zissis

As shown in Figure 31, October 2022, the production of LED bulbs in Poland halved compared to the same period last year and amounted to more than 3,9 million units. The record production occurred in August 2021, at nearly 11,6 million units. [SAS-23]

Figure 31: LED bulb production in Poland



Source: G. Zissis

In Russia, LED lamps constituted in 2021 the largest share of electric lamp sales volume. In total, 440 million LED lamps were sold nationwide in that year, up nearly 8% from the previous year. Further, the number of standard incandescent lamps sold amounted to 227 million units in 2021. [STA-22b]

Following IMARC report, East Africa[6] LED lighting market is currently being driven by several factors such as strong government support, declining prices of LED products, infrastructure growth, rising consumer awareness The market reached a value of USD 538 million in 2019 when its size was valued to USD 482,4 million in 2018. Kenya is currently the largest market for LED products in the region linked to the fact that 75% of the population has access to electricity. The Imarc analysts expect the market to reach a value of USD 968,1 million by 2024, with a CAGR of around 12% corresponding to a moderate growth for the 5-year period from 2019 to 2024 [IMA-19]

In Malaysia, in 2022, the sales value of manufactured electric lighting equipment was worth approximately MYR 1,64 billion. This indicates an increase from around MYR 1,29 billion in the previous year. [STA-23h]

Technavio analysts believe that the size of the LED lighting market in South Korea will grow at a CAGR of 6,99%, with the market growing by USD 1,16 billion during period 2021 to 2026. [TCA-23]

LED luminaires became the largest segment and accounted for 56% of the global revenue in 2019. The luminaires are widely used in the commercial and industrial lighting segments. [MDF-23] Lighting designers, specifiers, architects, and engineers are becoming more comfortable recommending LED luminaires for new construction, but they do look for products where manufacturers can offer a product warranty. [STU-20]

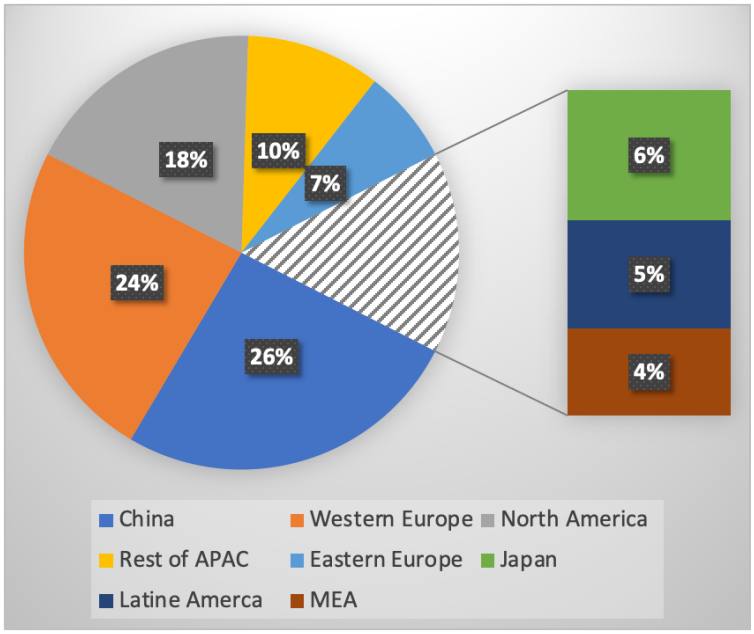
Strategies Unlimited estimated that in 2019 the LED luminaire market size was valued at USD 87,9 billion. Following [PSI-22], luminaire segment generated USD 40 billion, in 2022, but this sems underestimated even if the pandemic effect is taken into account. Another analyst reports that in 2021 LED luminaires accounts for 55% of the global LED lighting market revenue. [SPH-23] The two predictions are coherent.

Figure 32 gives the distribution of the 2019's market to the various regional sub-segments. China and Western Europe (more than 4 billion units installed) are the major contributors. Figure 33 shows the distribution among end-use sub-segments for the same year. Residential segment is dominating. And Figure 34 gives the same's year revenue distribution among the luminaire forms. Troffers is the largest sub-

[6] This market covers mainly Kenya, Tanzania, Uganda, Ethiopia (as well as, the test of east African countries with significatively lower shares)

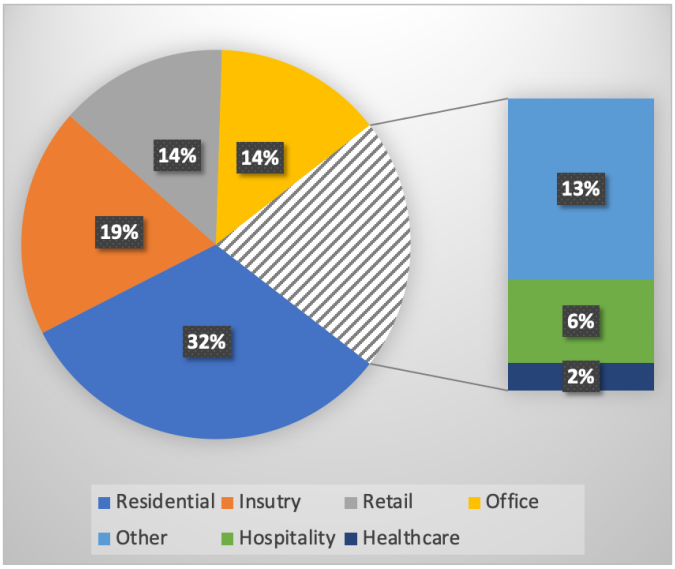
segment. Total revenue shipments for high bay luminaires were calculated to be USD 1 billion for 2019. [STU-20]

Figure 32: Luminaire market revenue (2019) distributed among world regions. Data from [STU-20]



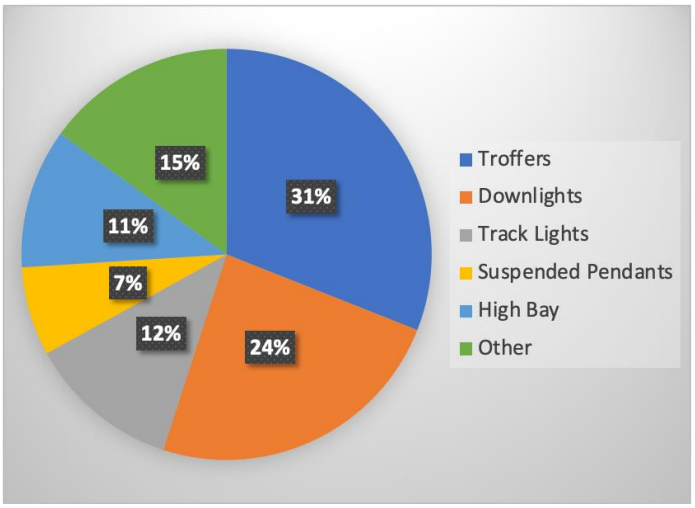
Source: G. Zissis

Figure 33: Luminaire market revenue (2019) distributed among end-use sub-segments. Data from [STU-20]



Source: G. Zissis

Figure 34: Luminaire market revenue (2019) distributed among various fixture's forms. Data from [STU-20]



Source: G. Zissis

As A. Pluemer reported, in the USA LED luminaires share was about 19% of total installed lighting units in 2017, but that number would grow to 84% by 2035. The DOE expects nearly 80% of the total LED lighting stock in 2035 to be in the residential sector, and 17% to be in the commercial sector. [PLU-23] A DNV report shows the in C&I buildings in Massachusetts in 2020, 85% of the linear lighting fixtures and 77% of the high bay luminaires are using LED technology. [DNV-21]

In 2022, consumption of lighting fixtures in the European countries registered an 8,3% increase, reaching a value of EUR 15,5 billion. Germany is the first European exporter of lighting fixtures, but also the first importing country. Italy is the second largest exporter and ranks first as net exporter. However, following CSIL Lighting, in 2022 European trade in the domain of fixtures recorded a deficit of EUR 5,9 billion. [CSI-23]

When, LED High Bay unit shipments using LED technology is expected to increase with a CAGR of 34% from 2020 to 2024, respectively, the legacy technologies recorded serious decrease in the same period (CAGR of -23% and -7% for fluorescent and HID luminaires respectively). Figure 35 shows the evolution of shipments for the forementioned 5-year period.

Figure 35: Evolution of High Bay luminaire shipments in number of units from 2019 to 2024 for various technologies Data from [STU-20]

Source: G. Zissis

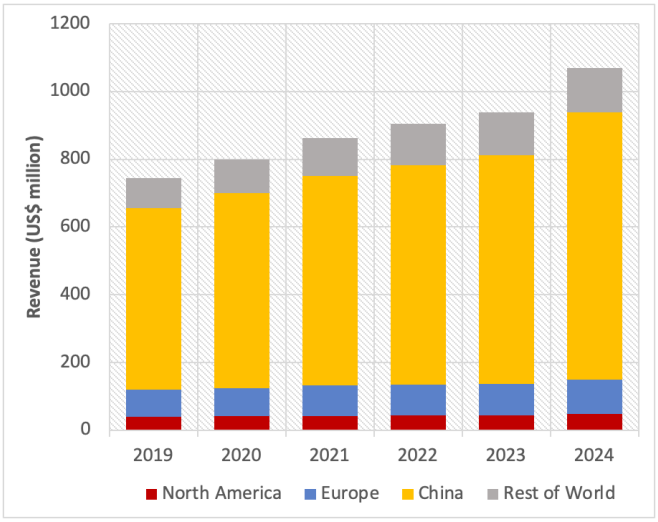
In 2019, the ASP of LED high bay luminaires was evaluated by Strategies Unlimited at USD 313 which is dramatically lower than 2015 (USD 385). [STU-20] However, the cost of manufacturing electric lighting fixtures in USA increased by approximately 9% for both residential and commercial buildings in 2022. [STA-23e] In the opposite side, Syska launched new LED T5-LED lights under the "T5 LED Batten" brand in India for INR 449 and INR 549 in June 2021. [TMR-21]

2.2.2 Application segments

2.2.2.1 Residential lighting

Market and Markets analysts believe that residential buildings are expected to have a huge potential for LED lighting market in the next 5-year period. The residential segment is likely to capture most of the market share throughout the that period. [MAM-22] Following a Strategies Unlimited report, Figure 36 gives the evolution of expected market from 2019 to 2024 around the world. [SHI-22]

Figure 36: Residential segment LED lighting revenue evolution around the world. Data from [SHI-22]



Source: G. Zissis

The forecasted average market's CAGR for that 5-year period from 2019 to 2024 is 6,23% but it is strongly depended on the geographical area: when for Europe and North America the CAGR is 4,9% and 4,0% respectively, it is expected to attain 8,1% China and 7,9% for the rest-of-the-world. [SHI-21] The low average value can be explained partially by the pandemic. In a Global Industry report, it is projected that due to ongoing post pandemic recovery, the growth in the residential segment will reach 11,3% CAGR in the period 2023-30. [GIR-23] With rapid industrialization, infrastructure development, and continuous improvement in the citizens' standard of living, China is expected to lead the market in APAC Region. [MAM-22]

The growth of this segment is attributed to increasing urbanization and rising energy efficiency requirements. Many consumers prefer personalized home decoration, including LED lights. In addition, governments of several countries offer support for LED lighting. [TCA-23]

Figure 37 shows the distribution of different LED components used in residential light sources [CHI-21]

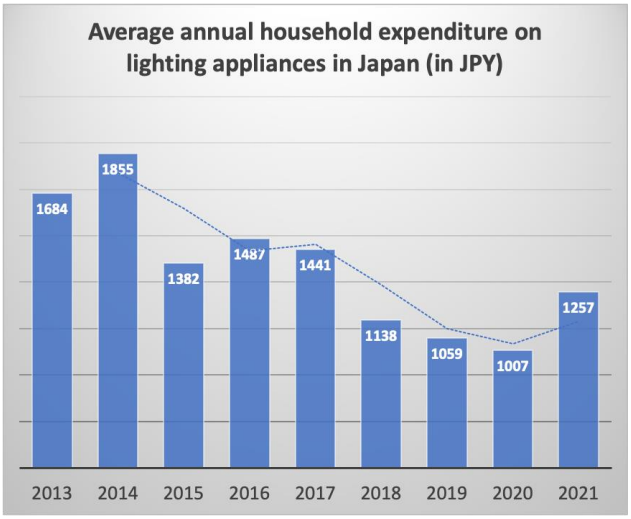
Figure 37: Evolution of LED component types integrated in light sources for residential use. Data from [CHI-21]

Source: G. Zissis

USA households are increasingly switching to light-emitting diode (LED) bulbs; 47% report using LEDs for most or all of their indoor lighting in 2020 while only 4% used that technology in 2015. Use of LED bulbs in homes varies across key household characteristics, such as household income and ownership status. Among households earning less than USD 20 000 a year, 39% reported that LED bulbs were their main indoor lighting choice, while 54% of households earning USD 100 000 or more per year used mostly LED bulbs in 2020. [EIA-22]

In Japan, in 2021, the average annual household expenditure on lighting appliances accounted for JPY 1 270. The expense increased by JPY 259 compared to 2020. [STA-22] Figure 38 shows the evolution of the average household expenditure.

Figure 38: Average household expenditure for lighting equipment in Japan. Data from [STA-22]



Source: G. Zissis

However, following [IBI-23] the lack of general consumer awareness combined with low quality of LED lighting, especially in emerging regions such as MEA and APAC, is expected to restrict growth of this market segment. There is still a massive unawareness among consumers in India and China where they prefer incandescent bulbs and CFLs over LED lights. Moreover, there are major issues regarding low quality of LED lightings MEA region, which is hindering adoption of the same manner. [IBI-23]

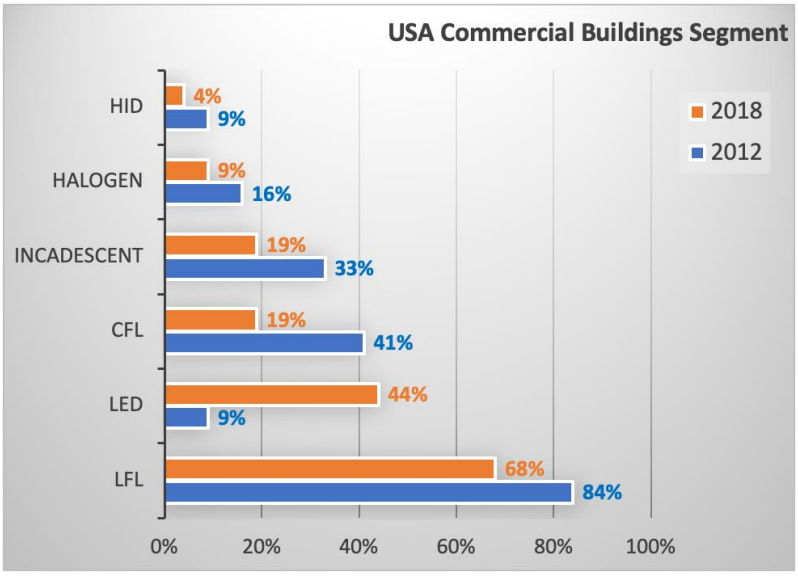
2.2.2.2 Non-residential lighting

According The Europe and Middle East industrial & commercial LED lighting market size was valued at valued at USD 6,03 billion in 2018, and is projected to reach USD 21,96 billion by 2026, registering a CAGR of 17,2%

from 2019 to 2026. [MAR-20] In 2021, retail segment was dominating the market with the largest market share. [SPH-23]

In USA, according to Energy Information Administration's (EIA) 2018-Commercial Buildings Energy Consumption Survey, LED technology is the 2nd most common type of light source in commercial buildings. LED bulbs were reported in 9% of commercial buildings in 2012, but this figure rose up to 44% in 2018. The shares of all other lighting technologies decreased between 2012 and 2018 (Figure 39). It is expected that LED lighting to continue growing and to provide up to 95% of commercial lighting needs by 2050. [EIA-21].

Figure 39: Percentiles of US commercial buildings using different lighting technologies. Data from [EIA-21]



Source: G. Zissis

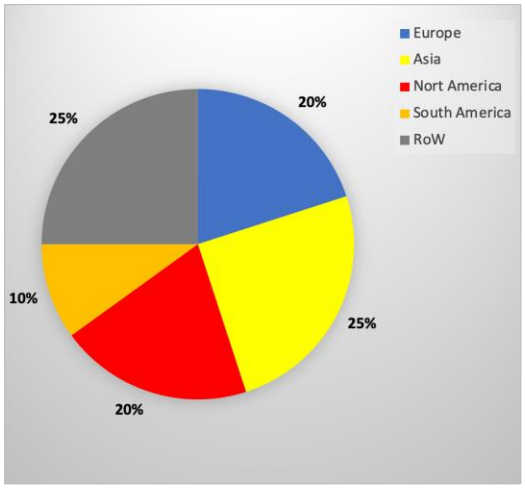
In China the constant increase in commercial and industrial building construction projects is likely to power the growth of the LED market. [MAM-22]

2.2.2.3 Outdoor lighting

The outdoor lighting category held a larger share, around 60%, in the LED lighting market, in 2022. [PSI-22] Following a Global Industry report, the segment is projected to reach USD 1,8 billion by 2030 corresponding to a CAGR of 10,5% between 2023 and 2030. [GIR-23]

According Caldani et al., worldwide, there are around 320 million street lighting poles. As can be seen in Figure 40, Asia has the largest number of lighting poles followed by Europe and North America. [CAL-19] Graham Colclough estimates that 360 million street lights are projected to exist on the globe by 2029, and that only a quarter of uses LED lamps. [COL-22]

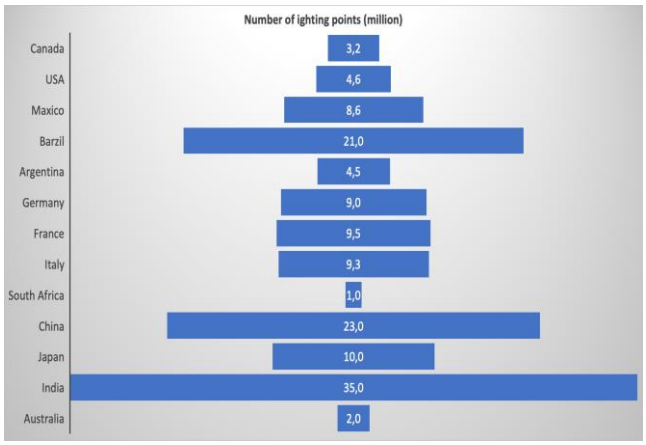
Figure 40: Geographical distribution of 320 million lighting poles around the world. Data from [CAL-19]



Source: G. Zissis

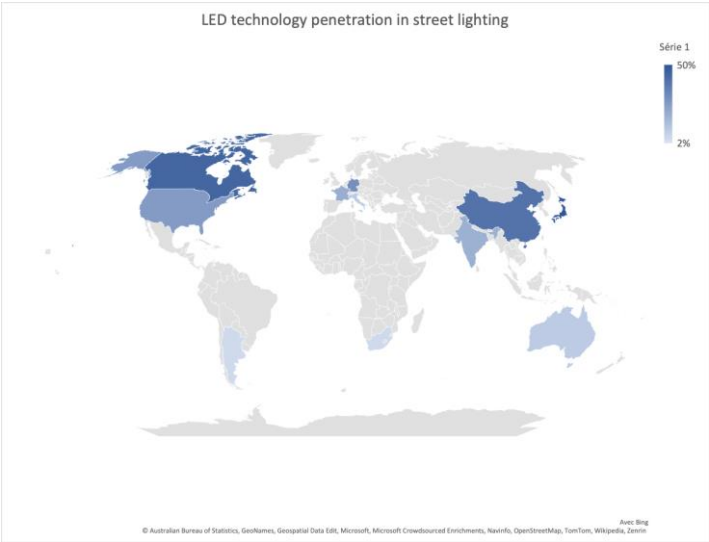
Figure 41 shows the number of lighting points in some countries and Figure 42 indicates the penetration of LED technologies in the same countries at 2018. Japan is leading with 50% penetration. [CAL-19]

Figure 41: Number of lighting points for street lighting. Data from [CAL-19]



Source: G. Zissis

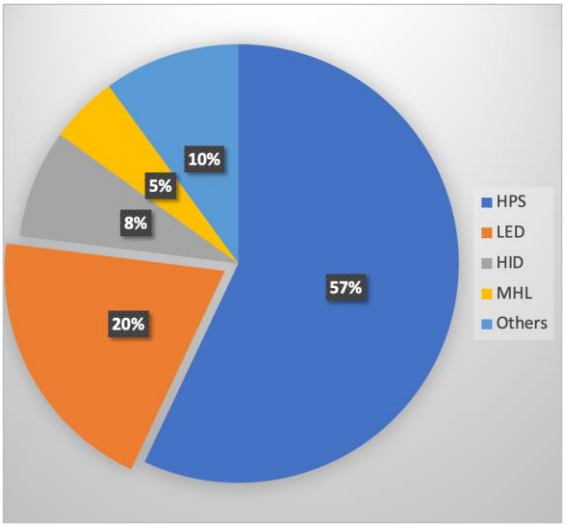
Figure 42: LED technology penetration in street lighting segment (2018). Data from [CAL-19]



Source: G. Zissis

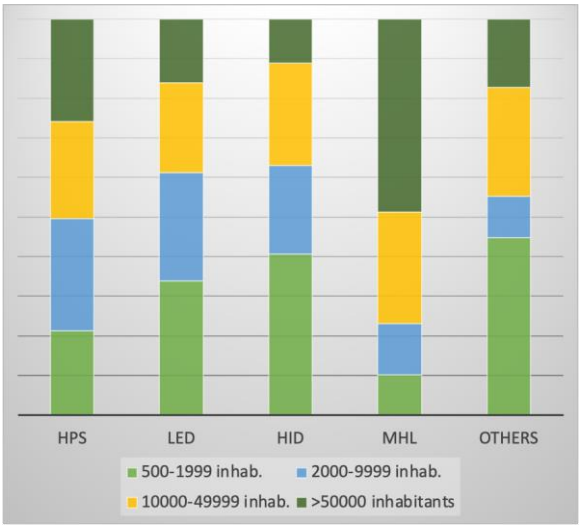
In France, following ADEME the penetration of LED technology is rapidly growing. Even if since 2019, 100% of new installations and replacements are using LEDs, still in 2017 the majority lamp technology with 57% shares was high pressure sodium (it was 66% in 2012). [ADE-19] Figure 43 gives the distribution of various lamp technologies present in 2017 in public lighting in France (LED penetration was 20% in 2017 and virtually zero in 2012), while Figure 44 illustrates the same distribution taking into account the size of the municipality. LED technology has less shares in large cities lighting parcs. [ADE-19]

Figure 43: Lamp technologies used for public lighting in France (2017). Data from [ADE-19]



Source: G. Zissis

Figure 44: Lamp technologies used for public lighting in France (2017) as function of city population. Data from [ADE-19]



Source: G. Zissis

In USA, New York planned to replace 250 000 streetlights, followed by the replacement of decorative lights in urban areas, by LED technology. [MFD-23] [TMR-21] in February 2022, the Washington D.C. Council announced an investment of USD 309 million to be spent over the next two years on bulbs. It will help replace 75 000 streetlights throughout Washington. [PSI-22]

In China, increasing government expenditure on public infrastructure, during the next 5-year period, is expected to boost the LED lighting market in the segment. [MAM-22]

In India, as part of the national program to replace lighting with greener and more efficient, government has planned to change 35 million streetlights and 770 million light bulbs to LED by the end of 2020, saving EUR 4,9 billion a year by reducing electricity consumption. In fact, the installation of 1 million LED streetlights has resulted in annual energy savings of 6,71 TWh and avoided 1,119 GW of peak energy demand, resulting in a reduction of 4,63 million tons of CO_2 emissions per year. [BAC-21] Indeed, since 2015, the Street Lighting National Program has installed more than 12,7 million LED streetlights. [EMG-23] As example, 2,1 million LED lighting poles were erected in 2017 as part of the program. [STR-22]

2.2.2.4 Other segments

Table 7 gives some information about the market shares in other segments

Table 7: Information about other LED lighting segments

Grow Lights, Horticultural lighting	MKLights related in 2021, that LED plant grow light market will grow 49% annually in 2020 to reach 1,3 billion U.S. dollars. It is estimated to be 4,7 billion U.S. dollars in 2025 and from 2020 to 2025 with an associated CAGR of 30%. [MKL-21] Market and Markets analysts estimated a global grow lights market from USD 1,5 billion in 2022 to reach USD 7,2 billion by 2028, registering a CAGR of 30,7% from 2022 to 2028. [MAM-23] The two projections are coherent. Globally, the Americas and EMEA are the areas with the largest demand for plant grow Lighting and they accounted for 81% of the segment in 2021. [MKL-21] The Netherlands, the United Kingdom, and other European countries actively advocate the establishment of plant factories and propose relevant subsidy policies to boost the willingness of agricultural growers. In response to COVID-19 and the needs of the localized agricultural market, Japanese plant factories have received renewed interest, developing high-value crops such as leafy vegetables, strawberries, and grapes. in China and South Korea continues to shift to the cultivation of high-economic crops such as Chinese medicinal materials and ginseng to improve the economic benefits of their products. [MKL-21] On 2 September 2020, a collaborative agreement between Helsinki, Finland based

	Valoya Oy, and Citizen Electronics Co., Ltd. will advance the creation and distribution of LED solutions for horticultural lighting. Valoya Oy has extensive expertise and knowledge in the horticultural lighting industry. [EMG-23]
Emergency Lighting	An emergency light is a battery-backed lighting device that self-powers and switches on automatically when the main power supply is cut and normal light falls. The death of the main power supply can be due to fire or a power cut and failure of normal lighting supplies. The global emergency lighting market size was valued at USD 7,05 billion in 2022. It is projected to reach USD 17,03 billion by 2031, growing with a CAGR of 10,3% during the forecast period (2023–2031). [STR-22b] Following Mordor analysts, the projected CAGR is 7,22%, during the forecast period (2021 - 2026). The largest market is North America, but APAC is the fastest growing segment. [MOR-23c] LED Penetration in 2018 was estimated at 44% of the market. [MOR-23c]. Europe is one of the prominent regions in the global emergency lighting and exit sign market Due to the rising demand in the residential market while, APAC region's market expansion is attributable to the region's growing construction projects. [STR-22b] Further, Allied Marker Research reports that the emergency lighting market size was valued at USD 5,48 billion in 2020, and is projected to reach USD 10,73 billion by 2030, registering a CAGR of 6,9% from 2021 to 2030. [ALM-22] LED technology is dominating that market. Competitive analysis and profiles of the major emergency lighting market players in the report include Acuity Brands, Syska, Daisalux, Eaton Corporation, Hubbel Lighting Inc, Legrand, Osram Licht Ag, Philips Lighitng Holding B.V, Schneider Electric SE and Zumtobel Group. These key players have adopted strategies, such as product portfolio expansion, mergers & acquisitions, agreements, geographical expansion, and collaborations to enhance their market penetration. [ALM-22]
LED Work Light	Work light refers to high-intensity light fixtures that are used to illuminate the stage for the benefit of technicians. These fixtures use LED technology as a main source of illumination and are termed as LED work light. There are three types of LED work light namely battery-operated rechargeable LED work lights, battery-operated non-rechargeable LED work lights, and plug-in LED work lights. LED work lights to have a significantly high service life of around 30 000 to 50 000 hours. [MAR-20] Following, Persistence analysts, the segment counts for USD 10,67 billion for 2022, and it is expected to reach USD 15,63 billion by 2033, with a CAGR of 3,5% from 2023 to 2033. USA is one of the most lucrative markets for the segment, and it holds around 82,2% value share in the North America region. One of the most attractive markets in the East Asia region is Japan, which accounts for a 45,1% value share in the region. Indian market is anticipated to expand at a CAGR of 5,1% from 2023 to 2033. The battery-operated devices represent a value share of 78,3% of the global segment [PER-23]
Stage lighting	The stage lighting market is expected to witness rapid growth on account of the continuous increase in demand for live entertainment across the world. The global stage lighting market was valued at USD 1,775 billion in 2019 and is expected to grow with a CAGR of 9,1% during the period 2020–29. [STR-23] These figures are compatible with [MAI-23] which indicates a reached a value of USD 2,621 billion in 2022 and expects that the market will achieve USD 5,593 billion by 2028, exhibiting a CAGR of 13,46% during the forecast period. Following Aritzon, the size will cross USD 3,2 billion in 2025 and it is growing at a CAGR of over 4% from 2020 to 2025 [ARI-20]. This market segment has been particularly impacted by lockdowns during the pandemic period. North America accounted for the largest market share in 2019 and is expected to dominate the market at least till 2030. This is because of the increased replacement and upgrading of legacy systems in the region [ARI-20]. The regional market growth by 12% in 2021 compared to 2020. Asia-Pacific to Exhibit the Highest CAGR among all regions. The EU regulations on energy-efficiency on conventional light sources are likely to generate demand for new installation as well as upgrades. [ARI-20] Globally, the segment is fragmented and the competition is intense. [ARI-20] The main industrial stakeholders in the segment are focussing in their countries or regions and their international activity is rather limited. [STR-23] The demand for stage illumination fixtures and control solutions from countries such as China, Germany, Japan, and India have also grown due to the flourishing commercial real estate, hospitality, corporate, and music markets. [ARI-20] Controllers operating with LED lights contributed over USD 360 million to the market in

	2019. [ARI-20]
Decorative Lighting	Increasing recognition of the role of the illuminating medium in setting up the ambiance of the room is expected to promote the utility of various decorative lighting fixtures. [GRV-19] The Decorative Lighting Market size is estimated at USD 105,93 billion in 2023, and is expected to reach USD 146,83 billion by 2028, growing at a CAGR 6,75% from 2023 to 2030. LED Source of Lights Dominated the Decorative Lighting Market (44,75% of shares). It shall be noticed that in 2023 incandescent technology has a 20% of market share. [MOR-23b] Following Technavio report, The Decorative Lighting Market size is estimated to grow at a CAGR of 5,34% between 2022 and 2027. The size of the market is forecast to increase by USD 9,99 billion. [TCA-22] Grand View Researcher analysts reported that decorative lighting market size to be valued at USD 42,9 billion by 2025 and is expected to grow at a compound annual growth rate (CAGR) of 3,1% during the considered forecast period. [GRV-19] Decorative Lighting Market size was valued at by SkyQuest at USD 38.65 billion in 2021 and is poised to grow from USD 40 billion in 2022 to USD 54,52 billion by 2030, growing at a CAGR of 3,5% in the forecast period (2023-2030). [SQM-23b] The market size is huge but the growth rate is very limited. The perceived value gap of customers is a major factor hindering the market growth. Further, as it is not a brand-driven market, the knowledge of established brands is low in the market. [TCA-22] It shall be noted that the offline commercialisation segment was valued at USD 26,95 billion in 2017 and continued to grow at least until 2021. This almost 55% of the global volume. [GVR-22] The flush mount products are expected to expand at the fastest CAGR of 3,8% from 2019 to 2025 [GVR-19] The largest geographical segment is North America (USA represents roughly 60%). [SQM-23b] APAC is estimated to contribute 49% to the growth by 2027. [GVR-19]
Architectural lighting	Global Architectural Lighting Market size was valued at USD 7,33 billion in 2021 and is poised to grow from USD 7,70 billion in 2022 and up to USD 12,52 billion by 2030, corresponding to a CAGR of 5,5% in the forecast 2023-30. [SQM-23] LED has emerged as the largest segment in the global architectural lighting market; LED technology represented roughly 55-60% of the market in 2021 (the remain was attributed to HID lamps). North America stands as the largest and most dominating in the global architectural lighting industry (USA represents 60% of the shares). However, the various world regions have similar shares. [SQM-23]
Landscape lighting	The growing demand for landscape lights in public spaces, parks, and university campuses is one of the market factors for this product. Additionally, more and more locations these days, including highways, public parks, business sites, and outdoor parking lots, are utilizing landscape lights. The global arcade for landscape lights is valued at USD 15,03 billion in 2022. The market is further expected to grow with a CAGR of 15,68% in the forecast period. Moreover, this market is anticipated to gain a size of USD 64,50 billion by end of 2032. [FMR-22] The North American market is expected as one of the leading markets owing to the high adoption of lighting solutions in almost all areas in the region. The presence of modern electronic technologies related to sensors is expected to give potential growth in the Europe. APAC (44% share [TCA-22b]) market is also expected to witness significant growth as it is a major hub for the manufacturing and distribution of LED-based lighting systems and a major exporter of energy-efficient lighting solutions. China and Japan are the key markets for outdoor landscape lighting in APAC [TCA-22b]. Middle East and Africa are expected to have considerable growth in the landscape lighting market due increasing number of constructions of buildings and malls. The landscape lighting arcade is expected to grow at a substantial rate in Australia and New Zealand due to government initiatives toward the installation of smart landscape lighting in smart cities. [FMR-22] The poor performance of LED lighting at high temperatures will be a major challenge for the outdoor landscape lighting market [TCA-22] Further, there is a sever issue with light pollution generation by such kind of lighting.
Stadium lighting	Global Stadium Lighting Market is estimated at USD 0,59 billion in 2021 (in 2017 it was valued at USD 392.0 million [MAM-18]) and it is expected to reach USD 1,07 billion by 2029, at a CAGR of 7,57% from 2022 till 2029. [MMR-21] StraitsResearch, evaluated the size at USD 535 million in 2021 and estimated to reach an expected value of USD

	1,415 billion by 2030 at a CAGR of 8,7% during the forecast period (2022-2030). Stadium Lighting include indoor and outdoor subsegments. Indoor segment is usually dominating. A RationalStat report stated that the global Indoor Stadium Lighting Market is expected to reach USD 800 million by 2030, registering a CAGR of over 5,1%. The market was is valued at USD 514 million in 2022. [RST-23] The outdoor stadium segment accounted for the largest market share and is estimated to grow at a CAGR of 7,5% [STR-22c] Nort America is the leading region with more than 55% of the market share in 2022 (Europe was leading in 2018). [MMR-21] Further, 60% of the revenue is coming from retrofit actions. [MMR-21] Light-emitting diode segment accounted for the largest market share and is estimated to grow at a CAGR of 8,1% during the 2022-30 period. [STR-22c]
Underwater and pool lighting	Underwater lighting refers to submersible lights to illuminate areas with poor visibility under the water. [MOR-23c] The underwater lighting is used for the decoration purpose in the pools or recreational ponds. The underwater lights are also installed for aesthetic water-featured landscaping. Because of its energy economy, extended lifespan, and colour-changing capabilities, LED lights are becoming increasingly popular for swimming pool lighting. In general, LEDs are increasingly gaining traction for underwater lighting, and they are taking over as the industry standard. The global Underwater Lighting Market in terms of revenue was estimated to be worth USD 279 million in 2019 and is poised to reach USD 348 million by 2024, growing at a CAGR of 4,5% from 2019 to 2024. The new research study consists of an industry trend analysis of the market. [MAM-23] Following Mordor analysts, the underwater lighting market is expected to record a CAGR of 3,7% over the forecast period (2021 - 2026). [MOR-23c] The LED Pool Light market has grown significantly in recent years, owing to rising demand for energy-efficient and visually attractive lighting solutions in swimming pools and aquatic settings. From 2023 to 2030, the worldwide LED Pool Light market is expected to develop at a CAGR of 10,5%, reaching a market value of USD 1,2 billion. [OPR-23] The Asia Pacific region is projected to lead the underwater lighting market from 2019 to 2024. More especially, countries such as China, Japan, South Korea, India, Taiwan, Australia, and Singapore are expected to be the major contributors to the market development [MAM-23]
Hazardous location lighting	The oil and gas industries are ones of the primary end-users of hazardous location LED lighting. Rigs used for offshore drilling require hazardous location LED lighting systems. In various locations such as offshore platforms, processing facilities, and petroleum refineries, these systems are in high demand. [EMR-22] The global hazardous location LED lighting market stood at a value of around USD 417,1 million in 2020 and USD 493,2 million in 2022. This market is further expected to grow to USD 689,5 million by 2026 and up to USD 815,29 million by 2028. [EMR-22] North America secured the largest market share and is anticipated to retain its dominance in the hazardous location LED lighting Industry. [EMR-22]
Marine and Airfield Lighting	The global marine lighting market is estimated to be USD 328 million in 2019 and is projected to reach USD 495 million by 2027. This corresponds to a CAGR of 5% for the period. LEDs are estimated to hold a significant share in this market. [MAM-19b] APAC is projected to hold the largest market share, by value, during the forecast period. Some of the key players in the marine lighting market are Signify (Netherlands), Hella (Germany), Koito (Japan), Osram (Germany), West Marine (US), Lumishore (UK), Foresti & Saurdi (Italy). Hella is identified as the leading player in this market. [MAM-19b] Airfield lighting helps pilot in locating and understanding the runway. It is helpful during low vision and adverse weather. Airfield Lighting Market is estimated in 2022 at USD 660,4 million expected to reach USD 976,8 million by 2029, at a CAGR of 7,2% during the forecast period. [MMR-22] Following Starview Research, the market was estimated at USD 555,71 million in 2022 and is likely to grow at a CAGR of 7,3% during 2023-2028 to reach USD 852,45 million in 2028. [STV-22] Nikhil Kaitwade, reports that market is expected to witness a market value of US$ 778,31 million in 2023 and is expected to accumulate a market value of USD 1,604 billion by registering a CAGR of 7,5% in the forecast period 2023 to 2033. [KAI-23] Globaly, Airport Smart Lighting

	Market size is projected to experience a healthy growth during 2023 to 2032, as a result of the significant recovery in air travel from the COVID-19-induced crises. [GMI-23] North America is the larger geographical segment in the market and it is expected to remain. [MMR-22] [SVT-22] Solar powered LED lights are on the way to be adopted by the airport authorities as these are cheaper than their counterpart. [KAI-23]
Navigation lights (marine and aircrafts)	The navigation lighting is mainly used for marine or aerospace transportation, to avoid collision at night. The primary function of any navigation lighting system is to prevent vehicles' accident. The market segment size was USD 34,826 million in 2021 and is predicted to grow with a CAGR of 4,2%, to USD 51,277 million by 2030. [RED-22] In 2021, the marine navigation sub-segment represented 54,2% of the global segment revenue. [RED-22] The PAC navigation lighting market is predicted to be dominant and will continue to do so in the next fifteen years. [RED-22]
Off-grid lighting	Solar lighting system market share is projected to reach USD 10,8 billion by 2024 at a CAGR of 15,6% during the 5-year forecast (2019-24). [MAM-19] he outdoor solar LED market size to in USA is expected to reach USD 24,75 billion by 2028 and corresponding to a CAGR of 24,6% from 2018 to 2028. In terms of application, the solar LED street lights segment dominated the market in 2020, capturing a revenue share exceeding 50,0%. The trend is expected to continue over 2030. The 40 W to 149 W sub-segment dominated the market in 2020, accounting for more than 39,0% of the global revenue. APAC region dominated the market accounting for more than 40,0% revenue share in 2020. China is the major regional market growth driver. [GVR-20] Global Off-Grid Solar Lighting Market is projected to reach USD 4,54 billion by 2024 and Africa to expand at highest CAGR estimated at of 17,56% from 2016 to 2024. [TMR-17]
LED Services Market	This market segment includes lighting services such as installation, design, maintenance provided by commercial electrical/lighting contractors/integrated solution providers. The segment was valued by [CMI-19] USD 11,8 million in 2019 and expected to grow at CAGR of 11,1% over the forecasted period 2019-27. Another analyst [IBI-23] expect a CAGR of 15,9% for the period 2020-30, the difference is most probably due to the inclusion of post-pandemic recovery.

Source: G. Zissis

2.2.2.5 Automotive lighting

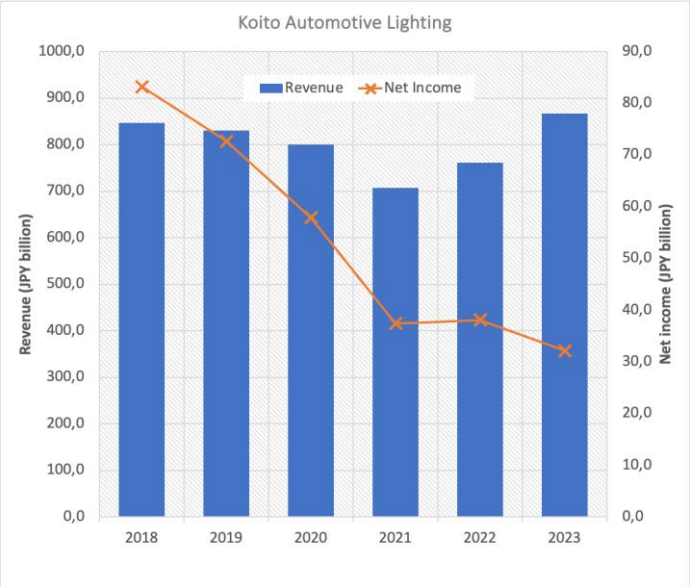
Following [ISA-23], the automotive lighting market in 2022 ranges from $US 20 billion to USD 35 billion, with growth rates predicted between 3,2% and 9,5%. However, it's unclear how much market share LED suppliers have captured (somewhere between USD 6 billion and USD 20 billion). [ISA-23]

Following CSA group estimates automotive lamps represent only 2% of the revenues from all lighting applications in China, which is among the largest markets. [ISA-23]

There is even more uncertainty about the LED share, with guesses USD 6 - 20 billion. Lumileds inherited the automotive business of Philips and supplies traditional lights as well as LEDs. Approximately 40% of the revenues of AMS/Osram come from automotive applications. Chinese chip manufacturers such as Sanan, HC Semitek and Jucan Optoelectronics are all paying more attention to automotive applications. [ISA-23]

Looking at the market leader of the segment (Koito, Japan), the projected revenue for fiscal year 2023 are estimated at around JPY 900 billion. Although revenues have recovered (Figure 45), net income has fallen by more than 50% in the same period (2018-23). [ISA-23]

Figure 45: Koito (Japan) revenue and net income in automotive segment. Data from [ISA-23]



Source: G. Zissis

The Visibility Systems Business Group of Valeo (France) also reported higher sales in the first 9 months of fiscal year 2023, with revenues rising to EUR 1,32 billion from EUR 1,13 billion in the corresponding period of the previous year. [ISA-23]

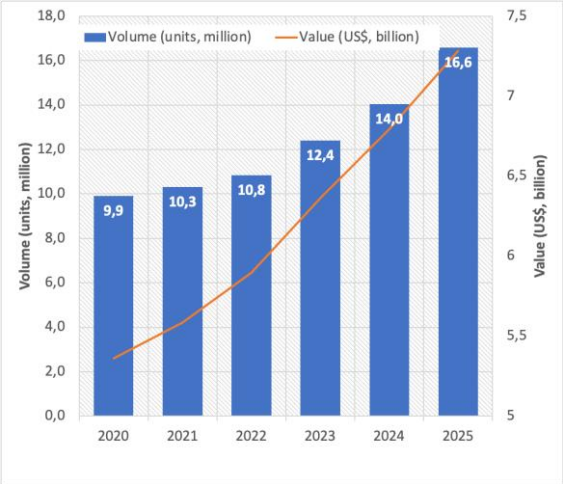
Hella (Germany) reported revenues from lighting of EUR 2,9 billion in the fiscal year 2022. Due to the particularly strong demand for innovative body lighting in the Chinese market, HELLA has joined hands with BHA to set up a third lighting factory in China, that will be called the Beijing BHA Hella Lighting Changzhou Factory. [ISA-23]

2.2.2.5.1 Laser lights for automotive use

Laser-light headlights is a rather new rising technology, however, is very difficult to estimate the laser market light sub-segment. Contradictory information is circulating: Following [DAT-22] the Automobile Laser Lights market sub-segment is expected to grow from USD 2,5 billion in 2019 at a CAGR of 18,2% till 2030. A report from Transparency Market Research the automotive laser headlight market is predicted to cross the USD 18,9 billion by 2030. [TMR-20] and valued at USD 28 billion. Maximize Market Research reports that the sub-segment represented USD 28 billion in 2021, and it is expected to reach USD 42,43 billion by 2029, exhibiting a CAGR of 5,4 % during the forecast period (2022-2029). [MMR-20] Following [YAN-21], the lobal laser lighting market size for 2021 represented 10,304 million units[7] for a value of USD 5,586 billion. This is more compatible with [DAT-22] and more realistic in comparison for the global automotive lighting market. Figure 46 shows the projections for the marker size from the same analysts till 2025. [YAN-21]

[7] This figure may include home projectors using laser technology

Figure 46: Automotive Laser lighting sub-segment volume and value. Data from [YAN-21]



Source: G. Zissis

The growth of the market is attributed to the increasing demand for luxury and safety features in automobiles and the rising adoption of advanced technologies, such as LED. Europe followed by APAC are the driving regions. Passenger cars dominate the marker sub-segment. [DAT-22], However, following [MMR-20] the dominant market is North America followed by Europe.

2.2.3 Lighting products Distribution Channels

Market and Markets analysts indicated that retail and wholesale distribution channels are the most popular in the LED lighting market. This distribution channel is likely to hold the largest market share during 2022-27 as it is likely to be the most preferred choice among consumers. [MAM-22]

However, eCommerce of lighting products is rapidly rising: following [EMG-23] eCommerce displays a CAGR of 11,2% for the period 2022-32. The eCommerce Lamps and Lighting market is a segment of online retail that specializes in selling various types of lighting products for indoor and outdoor use, including lamps, chandeliers, pendant lights, sconces, ceiling fans, and other lighting fixtures. The purpose of eCommerce is to provide consumers with a convenient and accessible way to purchase lighting products from the comfort of their homes. This market allows consumers to easily browse a range of products, compare prices and styles, and make informed purchasing decisions. The relevance of the eCommerce in Lighting market lies in its ability to offer consumers a wide variety of lighting options for different spaces and purposes. With the increasing importance of interior design, lighting has become a crucial element in creating the desired ambiance and mood in a room or outdoor space. [STA-23g]

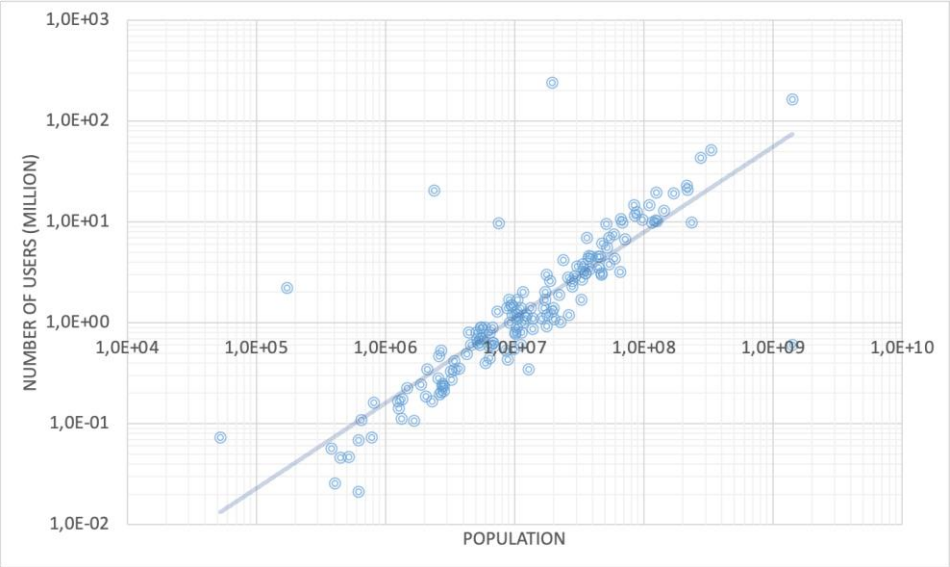
Following data from 152 countries worldwide, updated August 2023, harvested from [STA-23g][8] eCommerce distribution segment[9] is used by 954,2 million users worldwide (roughly 12% of world's population). The total revenue[10] of this distribution channel is estimated for 2023 to reach USD 25,2 billion. This is roughly 33% of the full LED Lighting market revenue and it is growing rapidly to attain USD 38,6 billion by 2027. The number of eCommerce users is directly correlated to the country's population (Figure 47). The average penetration rate of eCommerce channel for lamps and lighting products in 2023 is 7,48% (ranging from 0,7% to 14,5%) but with internet democratisation, it is expected to reach 10,28% in 2027.

[8] Statista derived data from annual filings, national statistical offices, Google- and Alibaba-Trends and industry knowledge

[9] The market only displays B2C revenues and users for the above-mentioned markets, hence C2C, B2B and reCommerce is not included

[10] Revenues are including VAT

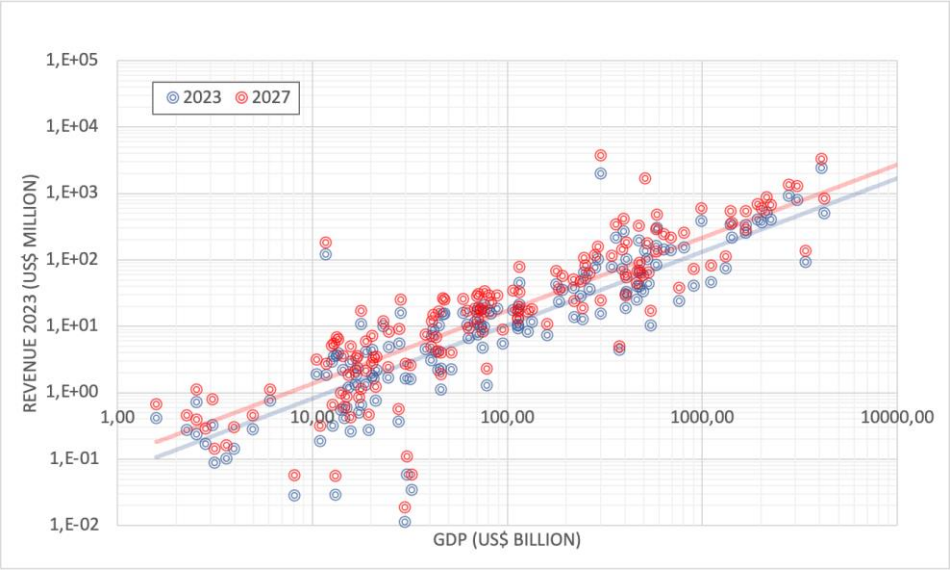
Figure 47: Number of lamps and lighting products eCommerce users vs country's population. Data from [STA-23g]



Source: G. Zissis

By analysing the [STA-23g] data, the average projected annual revenue of this channel for 2023 is projected to be USD 165,7 million per country and will reach USD 253,7 million per country in 2027. However, the spread of this revenue per country is very large and ranges from USD 11,2 thousand (Zambia) to USD 11 billion (USA). In fact, as shown in Figure 48, the channel revenue is related to the country's GDP.

Figure 48: Correlation between GDP and eCommerce lamp and lighting product revenues in 2023 and 2027. Data from [STA-23g]



Source: G. Zissis

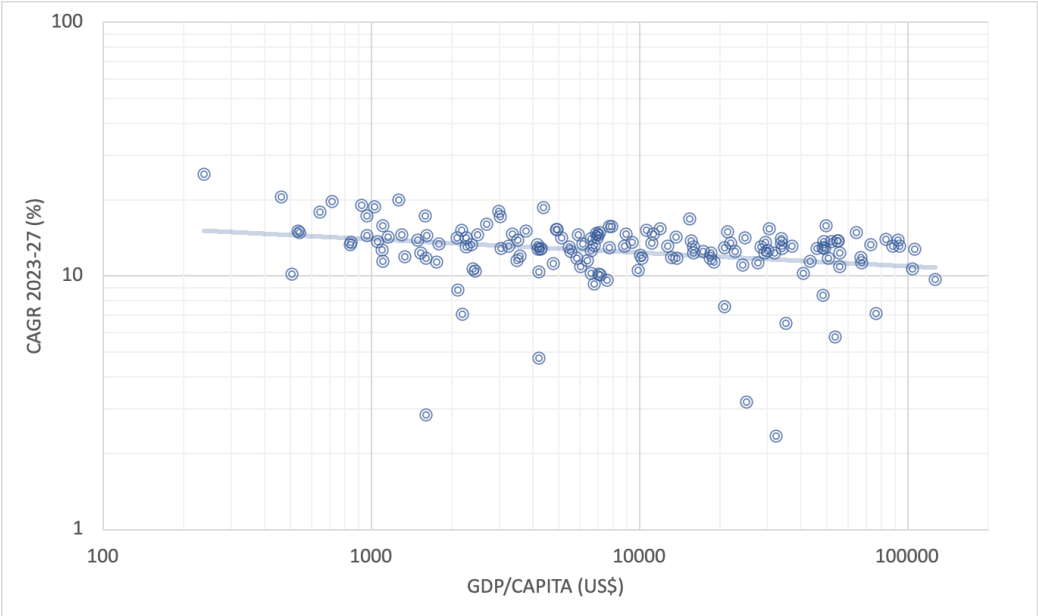
The average CAGR for the considered 5-year period is in the order of 13%, and it ranges from 2,33% (South Korea) to 25,13% (Burundi). Figure 49 shows the distribution of CAGR across the world. The fact that the lowest CAGR is recorded for South Korea reflects that the country's market is almost saturated thanks to an aggressive inventive measure and exigent MEPS taken from the government. On the other side developing and poor countries seems displays the highest CAGRs.

Figure 49: Lamps and Lighting market eCommerce revenue CAGR across the world (2023-27 period). Data from [STA-23g]

Source: G. Zissis

As shown in Figure 50, it is linked to the country's GDP per capita.

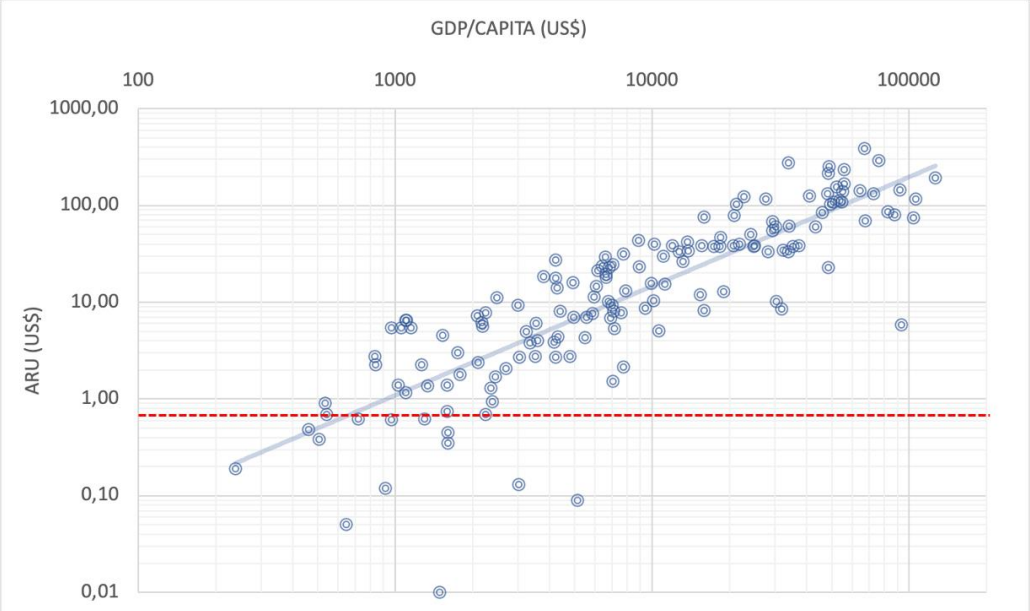
Figure 50: Lamps and Lighting market eCommerce revenue 2023-27 CAGR correlated to GDP/capita. Data from [STA-23g]



Source: G. Zissis

Finally, in 2023 the annual Average Revenue per User (ARU) is USD 41,30 and ranges from virtually zero (î cent) up to USD 390 for Denmark. Once again, as shown in Figure 51, there is a clear correlation between ARU and GDP per capita. Consumers in countries with ARU less than USD 0,7-0,8, obviously can't acquire LED lighting products.

Figure 51: Annual Average Revenue per User (ARU) vs GDP per capita. Red line is the lower limit for acquiring LED products. Data from [DAT-23g]

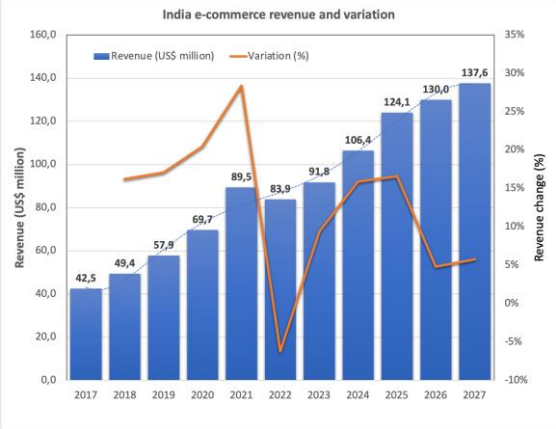


Source: G. Zissis

Lamps and Lighting products eCommerce key players in the market are companies like Amazon, JD, Homedepot, IKEA, Wayfair and Lowes. [STA-23g]

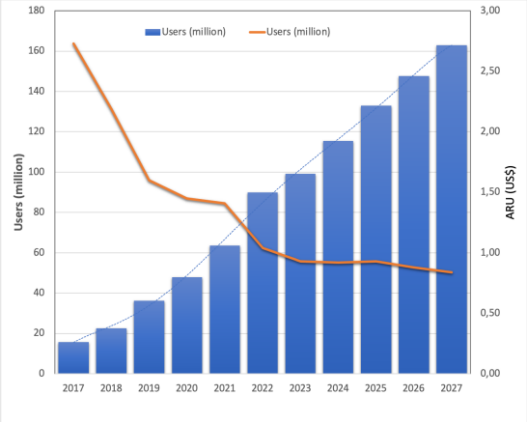
Figure 52 gives, as example the revenue generated/forecasted for India, the most populated country of the world. The annual variation of the revenue shows an important gap in 2022 which is linked to a post-pandemic ARU drop as shown in Figure 53.

Figure 52: Indian eCommerce revenue and revenue variation for the period 2023-27. Data from [STA-23g]



Source: G. Zissis

Figure 53: Indian eCommerce number of users and annual ARU. Data from [STA-23g]

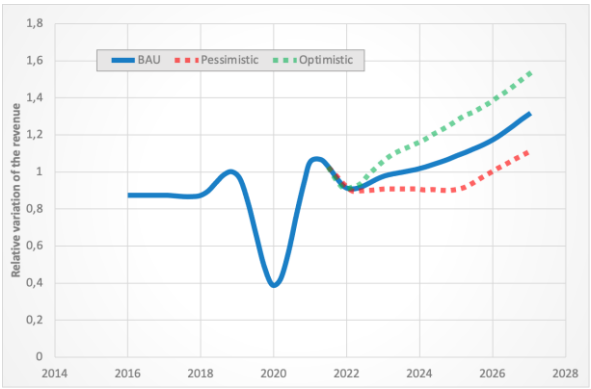


Source: G. Zissis

2.2.4 Pandemic and geopolitical situation impacts on lighting market

The COVID-19 pandemic has disrupted the progress of the LED lighting market, with major economies, such as USA, China, India, and several countries in Europe, witnessing the closing down of construction sites and postponement of residential projects. Moreover, the implementation of restrictions on the movement of goods caused severe supply chain disruptions, which, in turn, affected manufacturing operations. [MAR-22] As example, CSIL in 2020 expected worldwide market for lighting fixtures to contract by 7% due to the COVID-19 pandemic. [CSI-20] However, since the end of pandemic restrictions the market is healing rapidly and it is expected that the revenue of lighting manufacturers will show a 5-10% annual growth in 2021. [MKL-21] It shall be noted also that pandemic boosted some niche segments: As example, in North America has accelerated the process of lifting the ban on cannabis, which has played a significant role in promoting the demand for LED grow lights. [MKL-21] Brand Essence Research analysts proposed 3 scenarios for the post-pandemic market evolution. [BER-22b] Based on the data given in by that study, Figure 54 shows the 3 scenarios as the relative variation of the market revenue, the reference point is pandemic starting date. Today, we can say that (1) the COVID-19 drop (-40%) has been largely overestimated and (2) event the optimistic scenario that shows that revenue will be multiplied by 1,56 is well beyond the expected evolution of the market which suggests that 2027 revenue will be multiplied by more than 3 compared to the reference date (see paragraph 3.3 of this report).

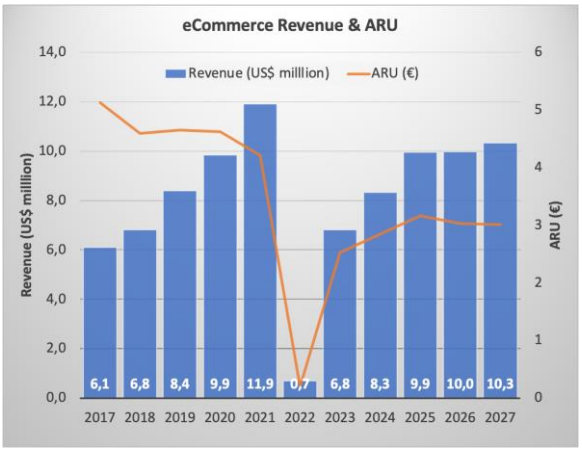
Figure 54: Estimated Pandemic effect on LED Lighting market revenue and post-pandemic scenarios. Reference date is the pandemic start. Data from [BER-22b]



Source: G. Zissis

Following International SSL Alliance report, COVID-19 pandemic induced supply chain issues and worker shortages have limited LED device and lighting product advancement. [ISA-23]. Therefore, most Original Equipment Manufacturers (OEM) and lighting integrators see a shortage of electronic components, such as LED chips and drivers. This created an imbalance, which resulted in a gap between supply and demand. This induced an increase in the prices of lighting products. For example, Signify has announced a temporary price hike for all electronic components for LEDs and lamps, as its supply chain costs are increasing due to the pandemic [MDF-23] With the pressure of rising raw material costs, lighting brand manufacturers continue to increase product prices by 3% to 15%. [MKL-21]

Figure 55: Ukrainian lighting products market revenue evolution (eCommerce) and Average Revenue per User (ARU). Data from [STA-23g]



Source: G. Zissis

Further, broad response to the war in Ukraine has resulted in a substantial interruption in oil and gas exports from Russia. With these traditional energy sources constrained and costs high, the LED industry has an opportunity to regain traction as "motivation to replace traditional forms of lighting have been strengthened". [ISA-23] However, the ongoing war is further expected impact trades and businesses worldwide. Market and Markets report, relates a World Trade Organization (WTO) estimate that prospects for the global economy 2022 growth in merchandise trade volumes (import/export goods) will downgrade from 4,7% to 3%. This will lead to sharply rising commodity prices of goods including LED lighting products. [MAM-22] As an indication Figure 55 shows the impact on Lighting product market revenues from eCommerce distribution channel in Ukraine. The gap is directly due to war conditions; however, the forecast shows that the country's market is slowly healing. [STA-23g]

Last but not least, as USA and China are hubs for giant manufacturers of lighting products, including lamps, luminaires, and fixtures, the recent USA–China trade conflict impacted the import and export scenarios across the world. A sharp drop in imports from China drove the decline, with tariffs in place on about USD 370 billion in US-bound Chinese goods. [MAM-22] [EMG-23]

2.3 Update on Industrial Ecosystem

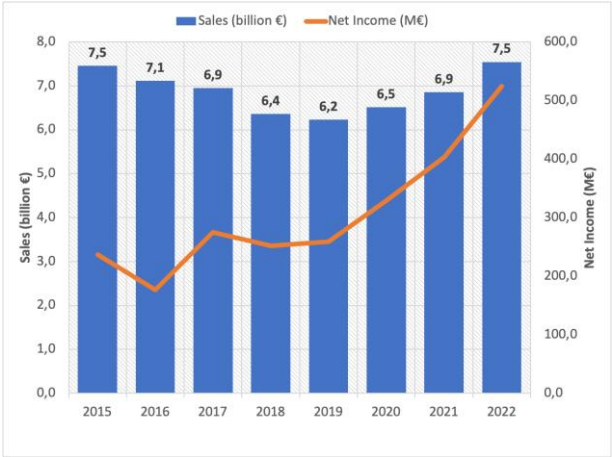
Even if it is rather complex to define the top 10 of the largest lighting enterprises the European lighting industry is still the leading global player with companies like Signify/Philips, LEDVANCE/Osram or Zumtobel Group.

Signify, before May 2018 officially known as Philips Lighting, was Philips' light division. Philips, now active in medical equipment, and Philips Lighting split up in 2016 and are now separate companies, each with their own IPO (Integrated Product Ownership). Signify, however, is allowed to use the brand name "Philips" for their products up until 2030.

Looking at the total Signify's revenue, it was of over EUR 7,5 billion in 2022. Compared to the previous year, the annual sales revenue increased by over EUR 650 million (Figure 56). Digital and conventional products combined generated around EUR 3,26 billion and roughly EUR 2,63 billion came from the digital solutions. Despite previous fluctuating trends, Signify's total net income has steadily increased each year since 2019 (Figure 56). In 2022, Signify reported over EUR 530 million in net income. The earnings before interest, taxes

and amortization (EBITA) of Signify amounted to EUR 844 million in 2022, representing an increase of over EUR 200 million compared to 2021. [STA-23]

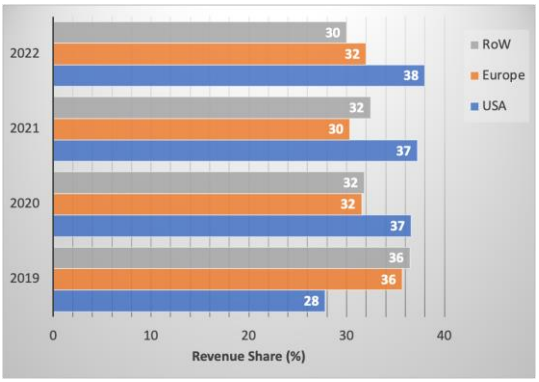
Figure 56: Variation of Signify's sales revenue and net income from 2015 to 2022. Data from [STA-23]



Source: G. Zissis

In 2022 38% from sales revenue came from the Americas. As can be seen in Figure 57, since 2019, the Americas' share of total sales is higher than Signify's sales share in Europe (32%) and the rest of the world. That way, during 2022, around 2,5 billion euros of Signify's revenue came from the U.S., when approximately 2.2 billion euros were generated in the European market (revenue EUR 655 and 421 million are from Netherlands and Germany, respectively). [STA-23] In 2019, Signify, formerly Philips, was the largest company in the lighting market in Poland. Its net revenue amounted to PLN 6,6 billion and its net profit was PLN 132,8 million [SAS-23] In October 2019, Signify acquired Cooper Lighting Solutions, a business unit from Eaton Corporation, to strengthen its position in North America. This acquisition allows the latter to emphasize innovation and eventually strengthen its position in connected lighting and systems. [STR-23]

Figure 57: Signify's revenue geographical origin. Data from [STA-23]



Source: G. Zissis

In October 2019, Signify acquired Cooper Lighting Solutions, a business unit from Eaton Corporation, to strengthen its position in North America. This acquisition allows the latter to emphasize innovation and eventually strengthen its position in connected lighting and systems. [STR-23] In May 2022, Signify has acquired Fluence from ams OSRAM. [SPH-23]

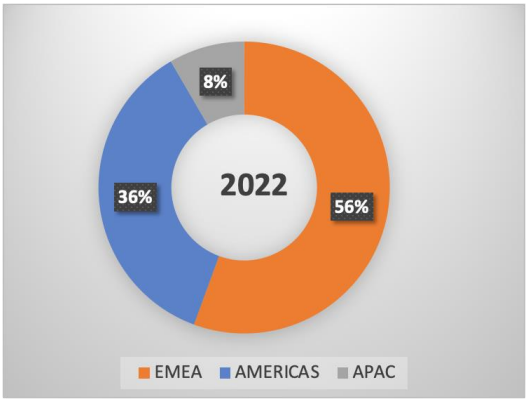
In March 2018, Signify launched Philips SunStay, a solar streetlight that combines solar panel, battery, and light in one housing, and Philips LifeLight, a solar lantern that comes with a replaceable battery. With the launch of these products in India, the company is accelerating a strategic push into solar-powered lighting. [MAM-19]

LEDVANCE, before 2016 it was officially known as Osram, since April 2018 is part of the Chinese group MLS Co Ltd, which is one of the world's largest producers of LED packages. LEDVANCE is licensee of product trademark OSRAM for lamp products in general lighting and SYLVANIA for products in general lighting. The

company is a world leader lighting products and intelligent, connected lighting solutions. In 2022, it employs more than 3 200 people (65% in EMEA, 23% in Americas and 12% in APAC regions). It shall be noticed that 44% of LADVANCE staff members are females. In 2022 the company hired 561 new staff.

With a 2021 revenue of approximately USD 2,42 billion LEDVANCE's is well behind Signify. [ROC-23] The revenue is mainly generated in EMEA region; Figure 58, shows the geographical origin of revenue in 2022. With 56% of generated revenue, the main market for the company is EMEA region. [LED-23]

Figure 58: LEDVANCE's geographical origin of 2022 revenue. Data from [LED-23]



Source: G. Zissis

According to LEDVANCE Ltd, the UK branch of the company, latest financial report submitted on 2021-12-31, the company has a turnover of GBP22M, a gross-profit of GBP4M while the cash was GBP1M. Compared with the previous year, the company reported a turnover increase of 13,43%, but at the same time, the gross-profit, of GBP 0,806 million (after tax) went down by -1.96%. [UKD-22]. The UK branch, in 2021 employed 23 people. Compared with the previous year, the company has reported a staff decrease of 34%, which is an equivalent of 12 employees. [UKD-22] The USA branch (located in Boston, MA, in the premises of the Sylvania), had an estimated revenue annual revenue of USD 749,8 million [GRO-23]. In 2022, their employee count grew by 8%, compared to the previous year. [GRO-23]

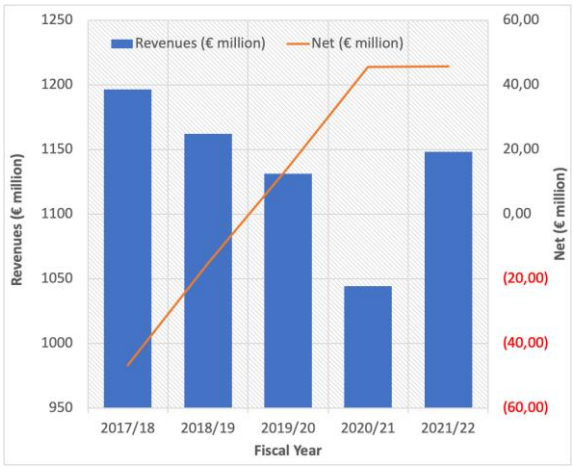
LEDVANCE estimated that in 2022 the direct greenhouse gas (GHG) emissions from its production activities accounted for 29 460 t CO_2 equivalent. [LED-23]

In October 2021, Skyview Capital, a global investment firm, acquired the digital lighting business from the OSRAM Licht AG. [FBI-22]

Zumtobel Group AG: The Zumtobel Group's business model covers all key areas of the professional lighting value chain – from components, luminaires and light management systems to complete lighting solutions and services.

The last report of the Group confirms the financial recovery of the group. Group's Revenues rose by 9,9% to EUR 1 148,3 million. The associated EBIT margin of 5,3%, exceeded the group's targets. The group set a goal to generate an EBIT margin of 6% to 8% by the end of the 2024/25 financial year. [ZUM-22] Figure 59 shows the evolution of group's revenues and net result. The COVID-19 effect is clearly visible in FY 2020/19 revenues. The group is active worldwide, but Europe remains the most important market with approximately 85% of total revenues. [ZUM-22]

Figure 59: Zumtobel Group AG revenues and net result for the period 2017-22. Data from [ZUM-22]



Source: G. Zissis

In parallel, at the beginning of 2021/22, the Group established a sustainability team to define concrete goals. The first identified goal was to achieve climate neutrality in company's production plants by 2025. [ZUM-22]

It shall be noticed here that European lighting industry is well organized around LightingEurope association that represents the industry in Europe. This association represents more than 1000 lighting companies who employ more than 100 000 people throughout Europe and turning over in the region of EUR 20 billion. [LEU-16]

In 2019, Cree, Inc. announced the signing of a definitive agreement for the sale of "Cree Lighting" business unit, which includes luminaires, lamps, and LED lighting solutions for business applications commercial, industrial and consumer, at IDEAL INDUSTRIES, INC. for approximately USD 310 million before tax. [MDF-23]

In 2019, Acuity Brands, Inc. announced that its wholly-owned subsidiary, Acuity Brands Lighting, Inc., has completed the acquisition of all interests in The Luminaires Group, a leading provider of luminaires Quality for the commercial, institutional, hotel, and municipal markets. [MDF-23] Further, in March 2022, Acuity Brands, Inc. has come up with Verjure which is a professional horticulture LED lighting solution which provides efficacious and consistent performance for indoor horticulture applications. [SPH-23]

Emerging Chinese LED lighting brands ambition becoming major world players. China's lighting industry is concentrated in the five major production bases: Guangdong, Zhejiang, Jiangsu, Fujian and Shanghai. The number of lighting manufacturers in these five cities and regions makes up more than 80% of the total number of lighting related enterprises in China. Table 8 gives the more important Chinese lighting companies including the multinational subsidiaries established in China.

Table 8: Top-10 of Chinese lighting industry in 2023

#	Company	City
1	Osram Lighting China	Shenzhen, Hangzhou, Wuxi
2	Philips Lighting China	Shenzhen & Nanjing
3	George Buildings	Foshan
4	Foshan Lighting	Foshan
5	Opple Lighting	Shanghai
6	Huayi Lighting	Zhongshan
7	NVC Lighting	Huizhou
8	TCL Lighting	Huizhou
9	Guangdong PAK Corporation Co., Ltd.	Guangzhou
10	Zhejiang Yankon Lighting	Zhejiang

Source: G. Zissis

Beyond the large lighting multi-national companies originated from Europe, in each European country there are a number of SME dealing with manufacturing of electric lighting equipment (this corresponds to Section C274 of NACE Rev 2, [EUS-23]). Following data harvesting principally from Statista publications, Table 9 summarizes some of our findings for European Union and Source: *G. Zissis*

Table 10 for non-EU countries, always for year 2020.

Table 9: Manufacturing of electric lighting equipment companies in European Union Countries

Country	
Greece	The country accounted for 324 enterprises in the domain. The number decreased by 17 within one year and the previous two years Eurostat recorded a significant higher number of enterprises. In 2010 the country accounted for 591 companies. This spectacular decline is most probably linked to the important financial crisis that faced the country. [STA-23b]
Finland	The number of enterprises increased by 8,33% (6 new enterprises) in 2020. In total, the number of enterprises amounted to 78 enterprises in 2020. This increase was preceded by a slightly declining number of enterprises in the domain since 2010 [STA-23b]
Romania	The number of enterprises in in Romania decreased by 2 enterprises (-1.87%) since the previous year; it accounts 105 companies. With 107 and 100 companies in 2019 and 2018 respectively, the domain recorded a significant higher number of enterprises than the preceding years. It shall be noted that in 2009 it was 121 companies active in the country. [STA-23c]
Spain	The number of enterprises in Spain decreased by 2.07% (10 companies shut-down) since the previous year. The country recorded a significant higher number of enterprises in the bast year (up to 571 in 2011). [STA-23d]
Malta	The number of enterprises in the manufacture of electric lighting equipment industry in Malta decreased by 1 enterprise (-20 %) to 4 companies. This marks the lowest number of enterprises in this industry since 2015 (6 enterprises). [STA-23b]
Belgium	The number of companies in Belgium experienced a spectacular increase of 48,12% corresponding to 77 new enterprises since 2019. With 237 enterprises, the number of enterprises thereby reached its highest value since 2011. [STA-23b]
Netherlands	Signify's home country accounted for 406 additional lighting related companies in 2020. Still, the number of enterprises reached its highest value in the observed period in 2020. The global trend shown in Source: *G. Zissis* Figure 60a indicates a regular increase of the lighting related companies quantity. [STA-23b]
Denmark	In 2020, the number of enterprises in Denmark decreased to 99 enterprises since the previous year. This decrease represented 6 companies vanish. However, looking at the global trend the situation in the country is rather stable (the number of enterprises varies between 95 and 109 in the 2009-20 period). [STA-3c]
Sweden	The number of enterprises in Sweden is globally declining since 2011 (264 companies). An abrupt decrease has been recorded in 2018 (55 companies disappeared). However, it 2020 increased by 3 enterprises (1,57% increase) since the previous year. In total, the number of enterprises amounted to 194 enterprises in 2020. [STA-23b]
Ireland	The number of enterprises in the increased by 4,76% (3 new companies) in 2020. In total, the number of enterprises reached 66 in 2020. Even if the annual figures are rather fluctuating, the 2020 increase was preceded by a declining number of enterprises in this industry. [STA-23b]
Slovenia	The number of enterprises in Slovenia sawn no significant changes in 2020 in comparison to the previous year 2019 and remained at around 71 enterprises. [STA-23c]
France	Among European countries, France accounts for one of the highest number of enterprises in the domain after Italy. In 2020, the number of enterprises in France remained nearly unchanged at around 924 enterprises. However, 2020 marked the second consecutive increase of the number of enterprises in this industry. The global trend of the country shows a

	constant slight increase since 2011 (Source: *G. Zissis* Figure 60b). [STA-23c]
Austria	Austria is the home country of Zumtobel group. The number of enterprises in Austria increased by 7 new companies (+7.78 percent) in 2020. In total, the number of enterprises amounted to 97 enterprises in 2020. This increase was preceded by a declining number of enterprises in this industry, but the global trend corresponds to an almost stable situation [STA-23b]
Lithuania	The number of lighting related enterprises in Lithuania increased by 1 enterprise (+4%) in 2020 in comparison to the previous year. The trend is clearly increasing and with 26 enterprises, the number of enterprises thereby reached its highest value since 2009. [STA-23b]
Hungary	Hungary was the historic home country of Tungsram lighting company, established in 1896 and which has been absorbed by GE-Lighting in 1990. In 2018, the CEO of GE-Hungary baud GE's lighting business in Europe, the Middle East, Africa and Turkey, as well as its global automotive lighting business. The business continued to operate again under the historical name of Tungsram Group. In April 2022, Tungsram laid off 1 600 employees and then in May they filed for bankruptcy protection [HUN-22] and the company has been going into liquidation few months later [DBH-23]. Further, even if the trend is rather stable since 2009, the number of enterprises in Hungary decreased in 2020 by 7 enterprises (-4,64%) since the previous year. In 2020 the country accounts for 144 lighting related companies. [STA-23c]
Estonia	The number of enterprises in Estonia decreased to 26 enterprises since the previous year. Nevertheless, the last two years in this industry recorded a significant higher number of enterprises than the preceding years, but the global trend seems to stabilize. [STA-23c]
Bulgaria	The number of enterprises in the lighting domain in Bulgaria saw no significant changes in 2020 in comparison to the previous year 2019 and remained at around 99 enterprises. In comparison to 2019, the number of enterprises decreased not significantly by 1 enterprise, but the global trend, since 2015, is rather growing. [STA-23c]
Italy	The number of enterprises in in Italy declined to 1 344 enterprises in 2020. The number of enterprises in this industry is continuously decreasing, but 2018, over the last years. Year 2018, with 1886, companies recorded, is a singular point in the big picture and it is difficult to explain. [STA-23c]
Croatia	In 2020, the number of enterprises in Croatia did not change in comparison to the previous year. The number of enterprises remained at 86 enterprises and the global trend is rather stable. The highest number has been recorded in 2010 (99n companies) and the lowest in 2009 (83 enterprises). [STA-23d]
Slovakia	In 2020, the number of enterprises in Slovakia decreased to 100 enterprises since the previous year. Even if, the last two years (2018 and 2019) the country recorded a significant higher number of enterprises than the preceding years, the global trend since 2009 is growing. [STA-23c]
Poland	In 2020, the number of enterprises in in Poland remained nearly unchanged at around 736 enterprises. Even if, the number of enterprises has been subject to fluctuation over the observed period, the trend is rather growing. [STA-23c] In 2021, the value of sold production of lighting and electrical equipment in Poland decreased and amounted to nearly PLN 6,3 billion [STA-21].
Portugal	In 2020, the number of enterprises in the country did not change in comparison to the previous year. The number of enterprises remained at 168 enterprises. However, the global trend shows a declining number of enterprises (starting from 247 companies in 2009) with relative stabilization since 2017. [STA-23c]
Latvia	In 2020, the number of enterprises in the manufacture of electric lighting equipment industry in Latvia increased by 2 enterprises (+6,45%) since the previous year. Therefore, the number of enterprises in Latvia reached a peak in 2020 with 33 enterprises. Over the observed period, the number of enterprises has been increased [STA-23c]. It shall be noted that the country strongly supports research and development in the domain of lighting and displays through its national Smart Specialization Strategy founded by the Latvian Central Financial Agency.
Czech Republic	In 2020, the number of enterprises in the Czech Republic decreased by 4,67% (12 enterprises disappeared) since the previous year. Therefore, the number of enterprises in the Czech Republic saw its lowest number in that year with 245 enterprises. The global trend shows a constant decrease since 2009 (475 companies recorded at that year which almost twice the

	2020 number). [STA-23c]

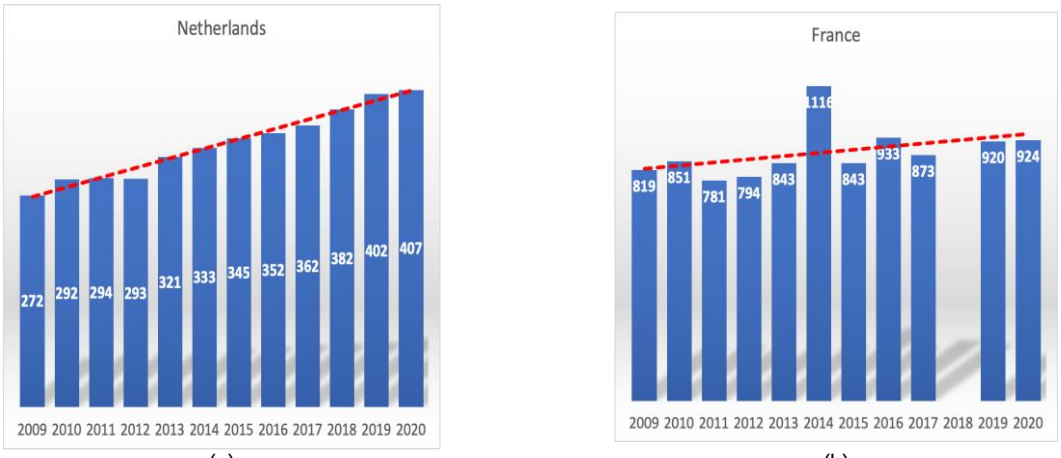
Source: G. Zissis

Table 10: Manufacturing of electric lighting equipment companies in non-EU Countries

Country	
Norway	The number of enterprises in the manufacture of electric lighting equipment industry in Norway decreased to 28 enterprises since 2019. In 2020, the number of enterprises thereby reached its lowest value in the recent years. The global trend shows a decrease from 2009 till 2015 and a stabilization in the following years. [STA-23d]
Switzerland	The number of Suisse enterprises in the manufacture of electric lighting equipment industry decreased by 5,88% (six enterprises less) in 2020 in comparison to 2019. In 2020, the number of enterprises thereby reached its lowest value in the recent years. The global trend is a decrease the seams accelerating since 2017. [STA-23c]
North Macedonia	In 2020, the number of enterprises in North Macedonia decreased to 18 companies since the previous year. The number of enterprises in the country is continuously decreasing since 2014. As a result, the number of enterprises in North Macedonia saw its lowest number in 2020. [STA-23a]
Turkey	The number of enterprises in the manufacture of increased by 75 enterprises (+2,31% percent) in 2014. With 3 315 enterprises, the number of enterprises thereby reached its highest value in the observed period. [STA-23a] However, regular data are difficult to find for this county. [STA-23b]

Source: G. Zissis

Figure 60: Number of companies dealing with manufacturing of electric lighting equipment in various European countries. (a) Netherlands, (b) France. Data from [STA-23b], [STA-23c]



(a) (b)

Source: G. Zissis

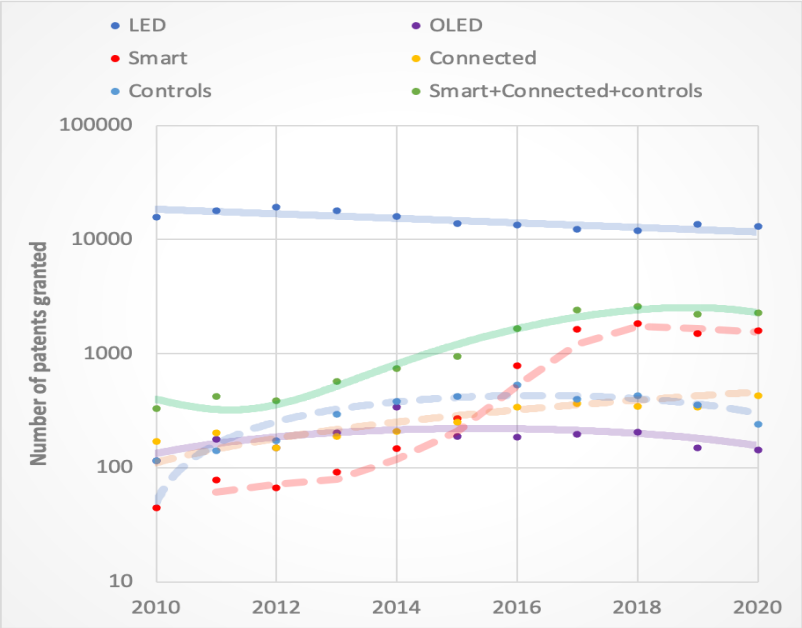
3 Part II – Smart Lighting systems

Today lighting is witnessing the its 4th revolution: the transition to Smart Lighting. This is attested by harvesting data concerning the number of patents grated from 2000 to 2022 for four specific segments:

- LED lighting,
- OLED lighting,
- Connected lighting,
- Lighting Controls
- Smart Lighting

Globally within that period when more than 100 000 patents have been granted for LED Lighting, almost 7 600 have been granted for OLED lighting technology and 33 800 for smart/connected lighting and lighting controls together. It is however very interesting to analyse the annual evolution of the number of patents by segment, as shown in Figure 61.[11] It can be seen that the number of patents concerning LED and OLED lighting is declining when the segment of smart (lighting controls and connected lighting) is increasing, even if a plateau appears from 2018. We can anticipate that in the next years and during the next decade, smart lighting systems will supersede simple SSL systems.

Figure 61: Evolution of number of patents from 2020 to 2021. Data harvested by G. Zissis in from Google Patents



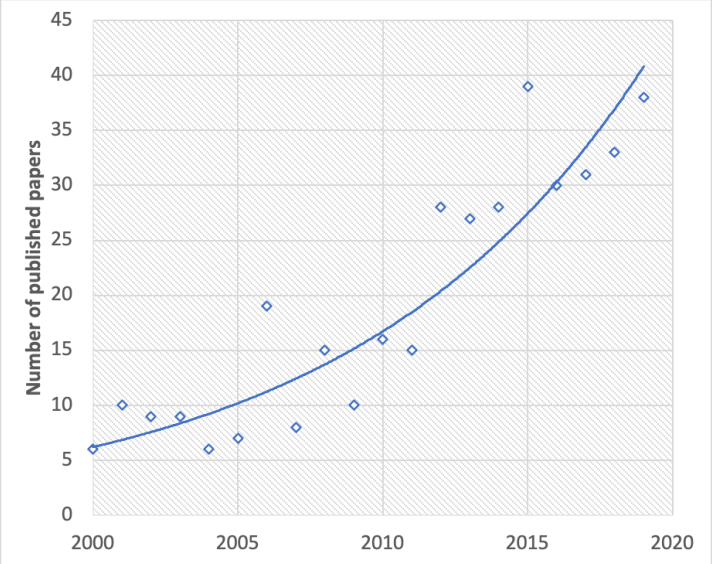
Source: G. Zissis

In addition, a review paper published in 2021 by Füchtenhans et al., shows the growth of scientific papers on smart lighting systems published in recognized journals. As can be seen in Figure 62 the growth is exponential. [FUC-21] The analysis of a sample of 384 papers shows that the sampled papers were published primarily in technically oriented journals that focus on facilities and buildings: Energy and Buildings (72), Lighting Research & Technology (40) and Building and Environment (27) were the three most common outlets for research in this area. [FLU-21] In 232 papers on 384 (60,4%) energy savings induced by smart lighting are the main objective and for 128 the light quality was the central idea (33,3%). Further, 63% of the papers

[11] Methodology: Author used the online google patent search engine (https://patents.google.com/) and formulated queries for each of the listed terms (exact form) in the full patent document, year-by-year (January 1st to December 31st). from 2010 to 2023. Only granted patents have been retained from any country. The years 2022 and 2023 are not added to the graphics because many of the submitted patents are still pending.

dealing with light source technology, 44,7% concerned light sensors and 44,3% were related on lighting controls.

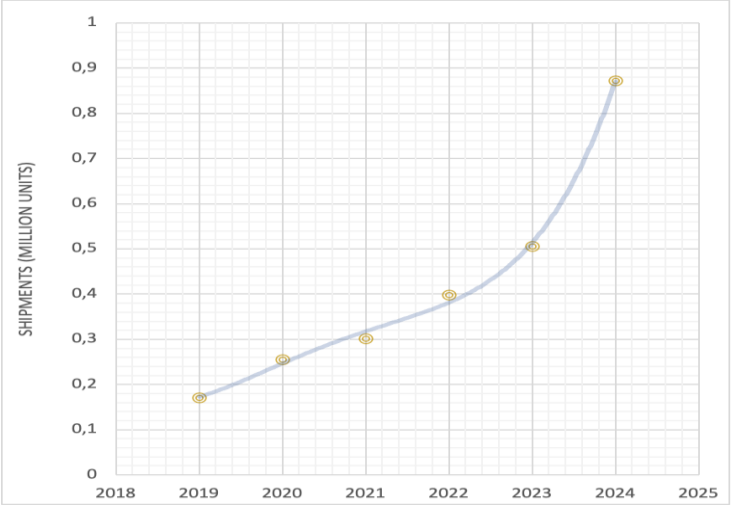
Figure 62: Evolution of number of published papers on Smart Lighting Systems. Data from [FLU-21]



Source: G. Zissis

A last indicator is given in Figure 63 which shows the exponentially increasing number of shipments of Smart Lighting units.

Figure 63: Shipments of Smart Lighting units. Data from [SHI-21]



Source: G. Zissis

Before going further, it is important to define a smart lighting system and the associated concepts.

3.1 Definitions

Generally speaking, a smart technological object is characterized by an intelligent sensing technology that is increasingly being integrated with internet technologies, thereby allowing the react to react to and communicate with the changing environment around it. In principle, this is leading to optimal operation and global improvement in efficiency. [PER-16]

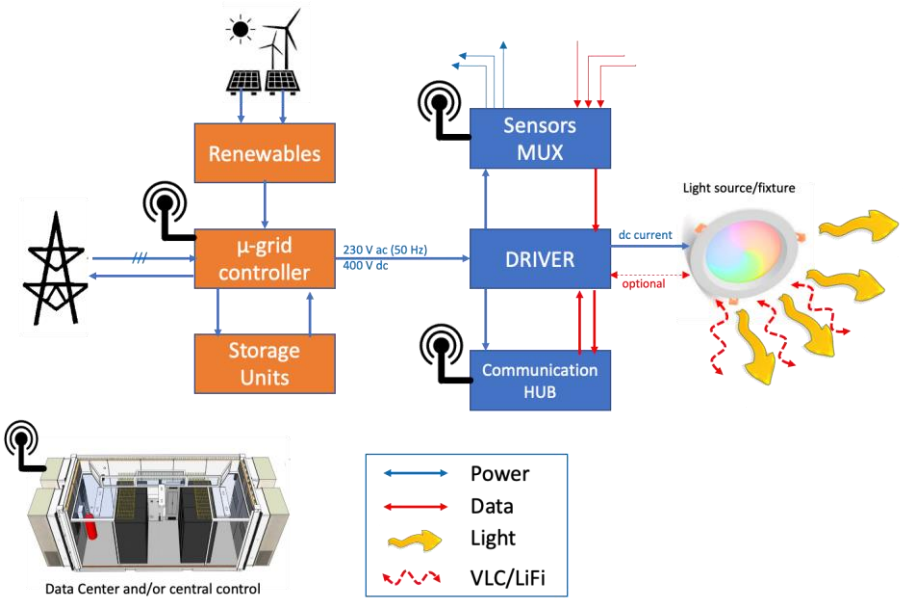
Further, it is necessary to define the term "system". Following IEA 4E TCP white paper, in general, a system can be defined a "functional unit" that consists of two or more "physical parts" that need to be assembled at the location where the system is used. The "functional unit" draws a boundary between the system and the environment or other systems. A "part" is a single, identifiable piece that contributes to the function of the system and which needs to be assembled at the location. A system is assembled by connecting the parts together on location and is typically undertaken by a professional actor. Systems and products must also be installed, i.e., connected to another system in the environment such as an energy grid. [T43-22]

Looking at the literature, the formal definition of a "smart lighting system" is unclear. Based on the fact that a such "smart" system shall serve at best the human needs and reduce as much as possible the impacts on environment and biotope, Zissis et al., proposed in 2023 the following definition: [ZIS-23]

"A smart lighting system has a principal function which is to produce, at any moment, the right light: where it is needed and when it is necessary. It should adapt the quantity and quality of light to enhance visual performance in agreement with the type of executed tasks. It must guarantee well-being, health and safety of the end-users. It should not squander passively the resources of our planet and limit actively the effects of light pollution on the biotope, or, any other impacts on the environment. Optionally, the system could offer additional services (geo-localization, data connectivity…) to the end-users preferably through Visible Light Communication protocols."

Figure 64 gives an interpretation of system definition given by 4E TCP in the case of smart lighting (functional unit) connected to grid. Blue boxes and the light source are the parts of the system. [ZIS-21] Note that, in an ultimate approach, end-user shall be also considered as part of the system and this complexifies the concept.

Figure 64: A smart lighting system and its parts. [ZIS-21]



Source: G. Zissis

Solid State Lighting components (mainly LEDs and OLEDs) are the backbone of any Smart Lighting System because very efficient and easily controllable. Lighting controls, sensors and communication protocols are also the other pillars of smart lighting.

3.1.1 Lighting controls and sensors

Lighting control refers to the management and manipulation of artificial lighting systems within a space or environment. It involves the use of various technologies and techniques to regulate the brightness, colour, and distribution of light in order to create desired lighting effects, enhance visual comfort, save energy, and improve overall ambience. Globally, lighting control systems offer increased flexibility, energy savings, and improved user experience by tailoring the lighting environment to specific needs and preferences.

Before the SSL era, lighting controls existed by their actions was extremely limited by either by the difficulty to control discharge lamps or by the absolute inefficiency of incandescent bulbs.

Beyond manual on/off switches, lighting control systems can range from simple dimmers to complex automated systems that use sensors, timers, and programmable logic to adjust lighting based on factors such as occupancy, time of day, natural light levels, and user preferences. Table 11: Usual Lighting Control Technologies list the more usual technologies used in the domain of lighting. It shall be noted however, that the effectiveness of a lighting design is virtually inseparable from the effectiveness of its lighting controls design. [LOU-22]

Table 11: Usual Lighting Control Technologies

Legacy Manual Controls	This involves using switches, dimmers, and manual adjustments to control the lighting in a space. It's the most basic form of lighting control and allows users to modify the lighting levels based on their immediate needs. Dimmers allow users to adjust the light level. This can be useful for creating different moods.
Colour Control	Some advanced lighting systems allow users to control not only the intensity of light but also the colour temperature and even the colour itself. This is often used in applications like architectural lighting and entertainment venues.
Time-Based Controls	Timers can be used to schedule when lights turn on and off. This is common for outdoor lighting, decorations, and corridors in buildings. Astronomical clocks are widely used in street lighting systems for achieving energy savings.
Centralized Controls	In larger buildings or commercial spaces, lighting control can be centralized through a building management system (BMS) or a lighting control panel. This allows for coordinated control of lighting across different areas of the building.
Cameras	Cameras can be integrated into lighting systems to provide various functionalities and benefits. Cameras can track the movement and position of individuals in a space and adjust lighting to optimize visibility for specific tasks. In urban or suburban environments, cameras with image processing can distinguish between humans, animals, cars, bicycles, etc., and command the system to light-up when and where necessary. Cameras with facial recognition capabilities can identify individuals and adjust lighting preferences according to their pre-defined settings. Cameras can monitor activity patterns and adjust lighting in real time to ensure that lights are only on when needed, contributing to energy savings. Cameras with colour sensors can analyse the colour temperature of the natural light in a room and adjust the artificial lighting to match or complement it

Source: G. Zissis

3.1.2 Communication protocols for lighting systems

Communication protocols are sets of rules and conventions that define how devices in a (smart) lighting system exchange information and commands. These protocols ensure that different components, such as light fixtures, sensors, controllers, and software applications, can communicate effectively and work together within the lighting ecosystem. Table 12 lists some commonly used communication protocols for lighting systems. The choice of communication protocol depends on factors such as the scale of the lighting system, the desired features, the type of fixtures and controls being used, and the compatibility with other building automation systems. Some systems might use a combination of protocols to achieve the desired functionality.

Table 12: Usual communication protocols for lighting systems

Wire	Power Line Communication (PLC)	The ancestor. PLC is a technology that enables data communication over existing electrical power lines. It utilizes the power distribution infrastructure to carry data signals, allowing devices to communicate without the need for dedicated communication cables. PLC was often employed in the past to control and monitor street lighting systems. This allows for remote adjustments to lighting levels and schedules, contributing to energy savings. It is not compatible with smart lighting needs.
	0-10V and 1-10V Analogue	It is analogue voltage-based protocol used to control dimmable fixtures. A control signal ranging from 0 V (or 1 V) to 10 V is sent to the fixture to adjust

	Control	its light output. It was a standard for street lighting in end 90's – beginning of 2000's. It is not compatible with smart lighting needs.
	Digital Addressable Lighting Interface (DALI)	DALI is a widely used digital communication protocol specifically designed for lighting control. It allows for two-way communication between lighting devices and controllers, enabling features such as individual luminaire control, dimming, and status reporting. Initially designed for indoor lighting, it has been adapted to street lighting with success. Easy to install, it needs 2 additional wires. Today, DALI is "the largest wired digital open protocol in the world for lighting and DALI is built to enable smart, data-rich networks. It shall be noted that DALI compatible products are fully traceable in a web platform[12]. [DRO-21] DALI enables modular systems/designs with components that can be interchangeable; Further DALI products can be Plug and Play if socketed and standardized e.g., Zhaga-D4i. Briefly, DALI is fully compatible with circular economy principles. [DRO-21]
	Digital Multiplex (DMX)	Originally developed for stage lighting, DMX is a protocol used for controlling lighting fixtures and effects in entertainment and architectural lighting. It allows for controlling multiple fixtures (up to 256) with a single controller by sending digital signals over a DMX cable. DMX is also used in commercial aircrafts for cabin lighting. The advantage with DMX versus DALI is speed and number of addresses in one system.
	Digital Serial Interface (DSI)	DSI is a digital lighting control protocol for controlling lighting in buildings. The advantages of using DSI are the simplicity of the system and not needing to program the system separately, only the lighting situations need to be saved to the memory. DSI enables the use of up to 100 controlled devices for each controller. The lighting is switched on and off with a digital control command, therefore the lighting fixtures are still live even when they are switched off.
Wire or Wireless	KNX	KNX is a standardized communication protocol used for building automation, including lighting control. It supports wired and wireless communication and provides a comprehensive framework for various building systems to work together
Wireless	Bluetooth Mesh	Bluetooth Mesh is a wireless communication protocol that allows for scalable and flexible control of lighting systems. It enables devices to communicate with each other in a mesh network, allowing for decentralized control and reliable communication.
	Zigbee	Zigbee is a wireless communication protocol commonly used in home automation and lighting systems. It supports low-power, short-range communication and can be used to create networks of interconnected devices. Zigbee communication nodes can powered by small dry batteries.
	Thread	Thread is another wireless protocol designed for smart home applications, including lighting. It's built on low-power, mesh networking technology and supports IPv6, enabling devices to communicate over the Internet.
	Z-Wave	Z-Wave is a low-power, low data rate wireless communications technology designed for home automation applications to communicate with lights, HVAC, automated window treatments, smoke alarms, sensors, access controllers, entertainment systems, and other domestic appliances. Z-Wave is also used in battery-operated consumer electronics devices such as remote controls. Z-Wave supports data rates of 9,6 Kbit/s, 40 Kbit/s, and 100 Kbit/s in 900 MHz band. Transmission range is 30m in free space, with reduced range in indoor environments. Z-Wave defines two types of nodes: controllers and slave devices. Each network can support up to 232 nodes in mesh network architecture and has one primary controller and zero or more secondary controllers that control routing and security. This protocol is well adapted to lighting.
	EnOcean	EnOcean is a wireless protocol that relies on energy harvesting technology,

[12] DALI registered products can be found at https://www.dali-alliance.org/products

		allowing devices to operate without batteries. It's often used for sensor networks in lighting control and building automation.
IP protocols	Local Operating Network (LON)	LON is a protocol used for building automation and control applications, including lighting. It supports decentralized and distributed control and is known for its interoperability. LON is not used very often in lighting.
	SigFox	Sigfox is a global Low Power Wide Area Network (LPWAN) technology and network operator that provides connectivity for the Internet of Things (IoT). It was founded in France in 2010 and has since expanded its network coverage to numerous countries worldwide. Sigfox is primarily designed for applications that transmit small amounts of data infrequently. It's not suitable for high-bandwidth applications but excels in scenarios where periodic, low-rate data transmission is sufficient. When incorporating Sigfox into smart lighting applications, it enables connectivity and communication between lighting devices and a central control system. However, the use is rather limited due to the low data transmission rate which incompatible with additional services.
	Long Range Wide Area Network (LoRaWAN)	LoRaWAN is a low-power, wide-area networking protocol designed to wirelessly connect devices over long distances. LoRaWAN supports a mesh networking topology, allowing devices to relay messages for each other. It's particularly well-suited for applications that require long-range communication and low power consumption, such as lighting control systems. However, the pass-band is poor. LoRaWAN can enable remote control and monitoring of lighting systems. This can include turning lights on/off, adjusting light quantity, and changing colour in smart lighting setups. It is often used in street and parking lots lighting. By connecting lighting fixtures to a LoRaWAN network, maintenance personnel can receive real-time alerts about failures or anomalies in the lighting system. This helps in proactive maintenance and reduces downtime. LoRaWAN may be abandoned during the next couple of years.
	IP500	This is an emerging technology. The IP500 solution is able to connect thousands of data points of assets and sensing products, like streetlights, energy supply devise (wind and solar) to a local IP500 network (edge), which has not cost of operations within the IP500 network. The network devices are then connected via the IP500 mesh network to a 3/4/5G Gateway (Controller). The IP500 solution is provide OEMs a turnkey and most reliable solution for wireless connectivity of streetlight, energy and other large-scale systems. [IP5-23]
	Power over Ethernet (PoE)	PoE is a protocol that delivers both power and data over Ethernet cables. It's used to power and control network-connected lighting fixtures.
Light Communic.	IEEE 802.15.7	IEEE 802.15.7 is a standard developed by the IEEE for short-range wireless communication using visible light. It defines the physical layer (PHY) and medium access control (MAC) sublayer specifications for VLC. It supports data rates ranging from a few hundred kilobits per second to several megabits per second.

	Light Fidelity (LiFi)	LiFi (or Li-Fi) is a wireless communication technology that uses visible light, including LED light, to transmit data. Li-Fi is based on the principle that light can be modulated at extremely high speeds, allowing it to carry data. This technology is often seen as a complement to traditional radio frequency (RF) communication methods like Wi-Fi. Li-Fi can achieve very high data transmission rates, often reaching into the gigabit-per-second range. This is possible because visible light can be modulated much faster than radio waves used in traditional wireless communication. Li-Fi has the advantage of being more secure than RF-based communication methods since visible light does not penetrate through walls. This means that the signal is confined to the area illuminated by the light source, reducing the risk of unauthorized access. However, there are challenges with Li-Fi as well. It requires a direct line of sight between the transmitter (LED) and the receiver (photodetector), which can limit its range and use cases. Additionally, the signal can be blocked by obstacles, so maintaining a continuous connection might be difficult in certain scenarios. Last but not least, the light source shall be on in order to transmit signals. Li-Fi technology is still being under development, and various companies and researchers are working on refining its capabilities and addressing its limitations. Li-Fi has a range of 10 meters, when Wi-Fi has a range of 32 meters.

Source: G. Zissis

3.1.3 Towards Global Smart Lighting Systems

Since 2000 several ideas developed around SSL technology, by lighting industry and academic research, are converging to form the ultimate smart lighting concept. The following paragraphs depicts these concepts.

3.1.3.1 Human-Centric lighting

A Human Centric Lighting (HCL) system, known also as "Cognitive lighting", is an advanced lighting technology designed to mimic natural daylight patterns in indoor environments in order to positively impact human well-being, mood, and health. The system aims to provide lighting conditions that align with the body's natural circadian rhythms, promoting alertness during the day and supporting relaxation and sleep at night.

The concept behind HCL is rooted in the understanding that exposure to natural light plays a crucial role in regulating our internal body clock, known as the circadian rhythm. This rhythm influences various physiological processes, including sleep-wake cycles, hormone production, and overall mood. Artificial lighting that doesn't take these rhythms into account can disrupt our circadian rhythms, potentially leading to issues like sleep disorders, mood disturbances, and reduced productivity. Human Centric Lighting systems that can have positive effects on mood, productivity, concentration, and sleep quality. However, it's important to note that the effectiveness of these systems can vary based on individual preferences and needs.

Such systems often use smart lighting controls and sensors to monitor ambient light levels, human presence, and time of day. They can be integrated into various settings, including homes, offices, healthcare facilities, and educational institutions, to create a more supportive and adaptive lighting environment for occupants. That way the system can dynamically adjust the colour temperature and intensity of artificial lighting throughout the day.

3.1.3.2 Adaptive/dynamic Lighting

Adaptive lighting, also known as dynamic lighting or responsive lighting, refers to a lighting system that can automatically adjust its settings, such as colour temperature, intensity, and distribution, in response to changing conditions. The goal of adaptive lighting is to provide the most appropriate and comfortable lighting levels for various activities, times of day, and environmental factors. This concept is often associated with creating optimal lighting conditions to support human well-being, productivity, and energy efficiency.

The lighting system can be programmed to provide different lighting scenes for various activities. For example, brighter and cooler light might be suitable for focused work, while dimmer and warmer light can create a relaxing atmosphere.

Adaptive lighting often incorporates sensors, including cameras, that detect factors like occupancy, ambient light levels, and user preferences. These sensors inform the lighting system's adjustments in real-time.

Adaptive lighting is used in various contexts, such as offices, healthcare facilities, educational institutions, hospitality venues, and public spaces. It can enhance the user experience, increase comfort, and improve the aesthetics of the environment. Adaptive lighting is a part of the broader trend towards creating intelligent and user-centric lighting solutions that enhance the interaction between humans and their built environments.

3.1.3.3 Connected lighting

A connected lighting system refers to a networked and smart lighting setup where individual light fixtures, components, and controls are interconnected and can communicate with each other and external devices. Such systems can incorporate sensors that detect motion, occupancy, ambient light, and other environmental factors (i.e., weather conditions…), or even cameras, enabling dynamic lighting adjustments for better energy management and user experience. These systems are often designed to be scalable, allowing for easy expansion and addition of new fixtures or components as needed.

As reported by Caldani et al., in 2024 there will be 22 billion connected Internet of Things (IoT) devices, with an average IoT devices CAGR of 17% during at least 10 years from now. [CAL-19]

Smart Lighiting systems leverage modern technologies, such as the IoT and wireless communication, to provide advanced functionality, customization, and control over lighting environments. Connected lighting systems offer various benefits in terms of energy efficiency, user comfort, automation, and data collection. In commercial and entertainment settings, connected lighting systems can create immersive and dynamic lighting displays for artistic, branding, or marketing purposes.

Users can control the lighting system remotely through smartphones, tablets, or other devices, enabling them to adjust lighting levels, colours, and schedules from anywhere. Connected lighting systems often allow users to create personalized lighting scenes for different moods, activities, or times of day, enhancing the ambiance of a space.

Connected lighting systems can gather data on occupancy patterns, energy usage, and user behaviour. This information can be used for optimizing space utilization, identifying trends, and making informed decisions using deep learning algorithms. We can imagine that these data can be monetised as products. However, this data harvesting can be intrusive and problematic to end-users' privacy.

Connected lighting systems can provide insights into the health and status of individual fixtures. That way they can help facilities managers identify maintenance needs more efficiently and even imagine the system enabling self-healing sequences to avoid brutal service interruption.

Connected lighting systems are used in a variety of applications, including homes, offices, retail spaces, hospitality venues, healthcare facilities, and outdoor environments. They offer a higher level of control, flexibility, and automation compared to traditional lighting systems, contributing to enhanced comfort, convenience, and efficiency.

3.2 Smart lighting, energy and services

Smart lighting is a lighting technology designed for energy efficiency.

At a first glance, to save energy controls of various technologies can be coupled with sensors. Occupancy and Motion sensors detect the presence of people in a room and automatically turn lights on or off based on occupancy. This is particularly useful in spaces like hallways, bathrooms, corridors and also in parking spaces, where lights can be automatically turned off when the space is empty. This kind of sensors are also installed some time in streetlighting configurations. Ambient Light sensors are used Daylight Harvesting in buildings. This technique involves using sensors to measure the amount of natural light entering a space and then adjusting artificial lighting levels accordingly. The objective is to maintain a consistent light level while minimizing energy usage. Arrow Intelligent Systems, based on 2016's sensors technologies estimated that use of sensors can achieve nice energy savings and Table 13 shows these estimations. In addition, legacy "dummy" (personal tuning) controls can save up to 21% of energy and any combination of those techniques can to higher savings. [ARR-17]. Today, five years later, the use of sensors allows to achieve much higher savings.

Table 13: Potential energy savings using sensors combined with controls in 2016. Data from [ARR-17]

Sensor	Action	Savings
Occupancy	Adjustment of light levels according to the presence of occupants	24%

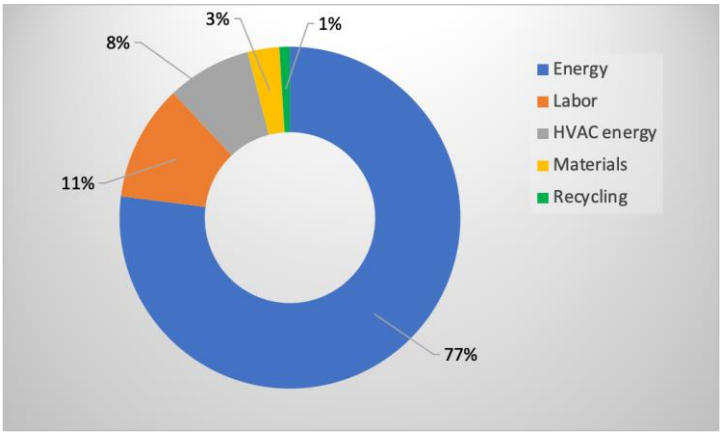
Ambient Light	Adjustment of light levels automatically in response to presence of natural light. This also called daylight harvesting.	28%
Centralized control	Adjustment of light levels, through commissioning and technology to meet location specific needs or building policies.	36%

Source: G. Zissis

Azad et al., estimated that, in USA, with a total labour and materials cost of USD 516 for smart wireless lighting system installation and 41% savings compared to wired solutions, the payback period for the wireless control environment is in the order of 2,3 years. [AZA-22]

Following Nair, the global lifecycle impact of smart LED lighting is still linked to energy use during the full life cycle. [NAI-21] Figure 65 shows a split of the lifecycle impact for smart lighting, it shall be noted in this life cycle assessment study the HVAC power necessary to control temperature variations in light bulbs is included.

Figure 65: Smart lighting impact within the full life. Data from [NAI-21]



Source: G. Zissis

3.2.1.1 Non-residential lighting sector

Europe is setting the bar for developing performance and safety standards for specific indoor commercial smart lighting for parking lots, roads, and garages. [MMR-23]

An early study related by Craig Di Louie, concerned 1 200 control zones in 114 commercial buildings found that networked lighting control systems saved 47% on average in lighting energy, thanks to their intelligence and responsiveness. [LOU-22]

Following Nair, many global general retailers in USA, such as Wal-Mart, Target, and Costco have adopted advanced cloud-based lighting control systems to reduce energy consumption. They successfully reduced annual energy usage from 26,6 TWh to 10,7 TWh or 40,2% reduction of electricity demand. [NAI-21]

3.2.1.2 Street lighting sector

LEDs and smart controls have advanced greatly in recent years and provide many features and advantages that improve amenity, environmental, safety and financial outcomes in towns and cities. However, there is generally a lack of knowledge amongst the public and (local) governments regarding digital solutions. [COL-22]

Converting to smart LED lights can save an additional 10-20% over and above the cost savings achieved with switching to LEDs because smart lights turn on and off more intelligently, adjusting brightness by taking ambient light into account. But there are many more benefits to switching to smart street lights. [INT-17]

Smart street lights can deliver a wide range of capabilities. Thanks to the Internet of Things (IoT) and connectivity services, safe city solutions enable governments and police departments to better protect their citizens from many threats; from terrorist attacks to natural disasters.

Lighting systems equipped with city video cameras can play a decisive role in this evolution because there are almost everywhere in the cities and beyond. [CAL-21] Following a Solution Brief from INTEL, video monitoring can help cities better understand traffic and pedestrian patterns, make adjustments, as well as route emergency-response vehicles around congested areas. Street light sensors can provide information about available parking in densely populated areas, as well as monitor vehicles for parking violations without sending personnel out on the street. Street lights with video cameras can aid police in solving crimes after they happen, as well as deter new crimes from occurring. With sound sensors, police can pinpoint specific information, such as gunshots, and then rapidly secure an area. Atlanta, Georgia, has reduced crime by 28% through its use of smart street lights. [INT-17] Street lights can be equipped with sensors that identify toxic chemicals, pollen counts, or air pollution levels. Speaker-equipped lights can be used to warn people in the vicinity of storms or other imminent dangers. Street lights can serve as public aids that provide directions to area shopping or public transit schedules. [INT-17]

However, for citizens, the smart lighting with cameras raises primary privacy and surveillance concerns, given the data that could be collected. [COL-22]

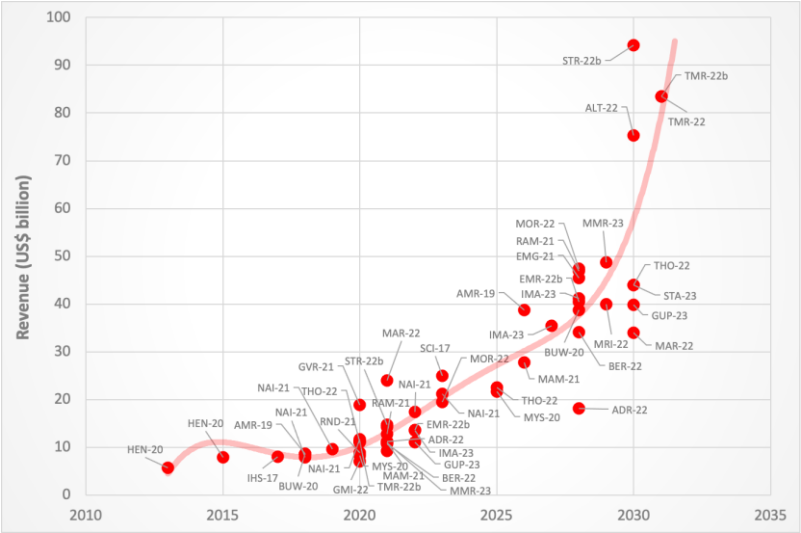
Further, city budgets are often limited, prohibiting the investment in the transition to smart connected lighting or integrated smart lampposts. Further, the deployment of additional networks (internet, additional power supply) can lead to high costs. [COL-22]

3.3 Smart Lighting Market

Historically, in 2013, the global smart lighting market industry size exceeded USD 5,7 billion. Among them, the market size of smart lamps and related accessories exceeded USD 1,2 billion. In 2015, the global smart lighting market size reached USD 7,83 billion. [HEN-20] An HIS Markit report indicates that in 2017 the smart lighting and connected lighting controls market was estimated to have been worth USD 8 billion; That year, 1,8% of luminaires shipped included connected ballasts and wireless adapters. [HIS-17]

Following a mysupplier online publication, the Smart Lighting market is forecasted to grow from USD 8,2 billion in 2020 to USD 21,7 billion by 2025 at a CAGR of 22,3% in the forecast period. [MYS-20] According to Business Wire news, the global smart lighting market is expected to generate revenue worth USD 8,68 billion in 2018, and is projected to reach USD 38,68 billion by 2028, to register a CAGR of 20,5% during the 2018-28 period. [BUW-20] Research and Markets reports that the global smart lighting market size is expected to reach USD 46,9 billion by 2028, registering a CAGR of 20,4%, from USD 12,75 billion 2021 to 2028. [RAM-21] Nair reports that the global smart lighting market will reach USD 21 billion in 2023, and is expected to grow at a CAGR of 22% from 2018 until 2023. [NAI-21] Maximize Market Research reports that smart Lighting Market was valued at USD 10,9 billion in 2021 and is expected to reach USD 48,78 billion. by 2029, at a CAGR of 20,6 % during a forecast period. [MMR-23] Following Data Bridge report, the market is expected to witness market growth at a rate of 20.45% in the forecast period of 2021 to 2028. [DBR-21] Mordor Intelligence expects the Smart Lighting Market size to be at USD 19,42 billion in 2023, and to reach USD 49,37 billion by 2028, growing at a CAGR of 20,52% during the forecast period (2023-2028). [MOR-22] Meticulous Research says that the Smart Lighting Market is expected to reach USD 39,91 billion by 2029, at a CAGR of 12,2% during the period of 2022–29. [MRI-22] Transparency Market Research forecasts that the global smart lighting market who was valued over USD 11,29 billion in 2020 will estimated to expand at a CAGR of 20,3% from 2021 to 2031 to cross the value of USD 83,52 billion by the end of 2031. [RMR-22] Emergen Research believes that the global market size will reach USD 45,47 billion in 2028 and register a revenue CAGR of 19,7% during the forecast period. [EMG-21] Market and Markets analysts said that the global smart lighting market size is estimated to be USD 10,9 billion in 2021 and projected to reach USD 27,7 billion by 2026, at a CAGR of 20,5% during the forecast period. [MAM-21] B. Thormundsson, published in Statista that the world smart lighting market will reach USD 43,97 billion by 2030. [THO-22] Figure 66 gives a global overview of the harvested data concerning the Global Smart Lighting market size.

Figure 66: Smart Lighting market size as given by different analysts. Data harvesting from literature by G. Zissis, the labels in the graph indicate the source.



Source: G. Zissis

In the literature, smart lighting market is usually decomposed into:

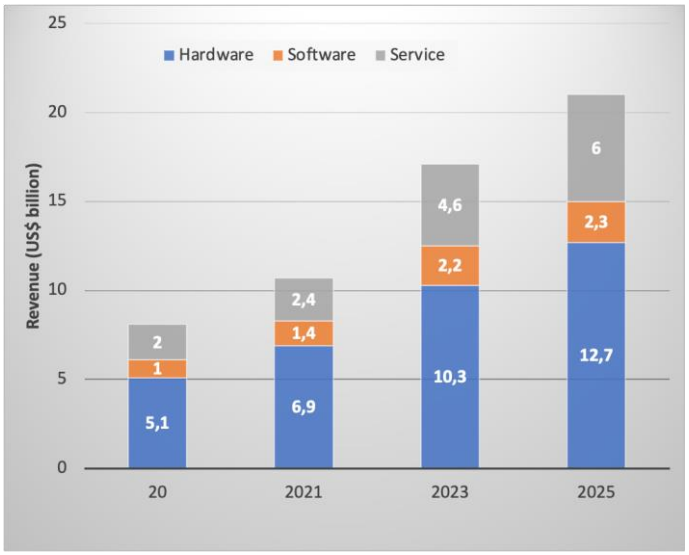
- Hardware segment
- Software segment
- Service segment

The hardware segment is expected to attain the highest revenue contribution in 2020 as lamps and fixtures are an inseparable component of smart lighting. [RAM-21] The segment is forecasted to grow from USD 5,1 billion in 2020 to USD 12,7 billion in 2025 at a CAGR of 20%. [MYS-20] In 2022, the hardware segment is expected to account for the largest share of the global smart lighting market. The large market share of this segment is mainly attributed to factors such as rising penetration of smart lights, rising demand for intelligent streetlights in developing countries and rising popularity of connected lighting bulbs and fixtures that can change hues, dim lights, and switch on/off using a controlling device such as a smartphone or tablet. [MRI-22]

The Software segment is to grow from USD 1 billion to USD 2,9 billion at 22,3% CAGR. [MYS-20] The software segment is expected to register the highest CAGR during the 2022-29 period. The software application is required to facilitate the controlling of lights using smartphones or tablets. The apps also help connect smart lights with smart platforms such as Alexa, Crotona, and Siri to control using voice commands. The immense popularity of creating an ambient atmosphere and aiding in data collection in smart cities is expected to boost segment growth over the forecast period. [MRI-22]

The services segment is forecasted to grow from USD 2 billion in 2020 to USD 6 billion in 2025 at a CAGR of 24,7 [MYS-20] Emergen predicts a CAGR of 20,8%. [EMG-21] Figure 67 gives the revenue evolution of the 3 segments from 2020 to 2025.

Figure 67: Revenue distribution among the 3 marker sub-segments from 2020 to 2025. Data from [MYS-20]



Source: G. Zissis

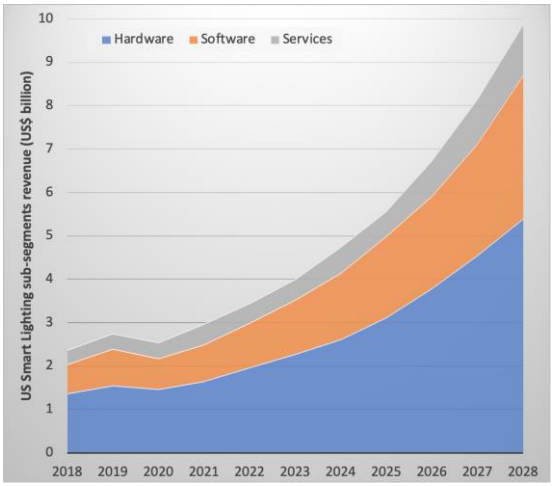
Smart lighting is targeting both new Installations and retrofit. That way, mysupplier online publication, forecasted that new installations will grow from USD 5,8 billion in 2020 to USD 14,7 billion in 2025 at 20,6%, when retrofits will expend from USD 2,4 billion to USD 7 billion at 23,7% CAGR in the 5-year 2020-25 period. [MYS-20]

The HCL market is expected to reach USD 3,91 billion by 2024. [SCI-17]

3.3.1 Geographical segments

In 2019, North America dominated the market, contributing more than a 33% share of the overall revenue. [BUW-20] For 2020, Emergent attributed 41,1% of the market shares to this region. [EMG-21] Figure 68 gives the USA market split among the 3 usual subsegments.

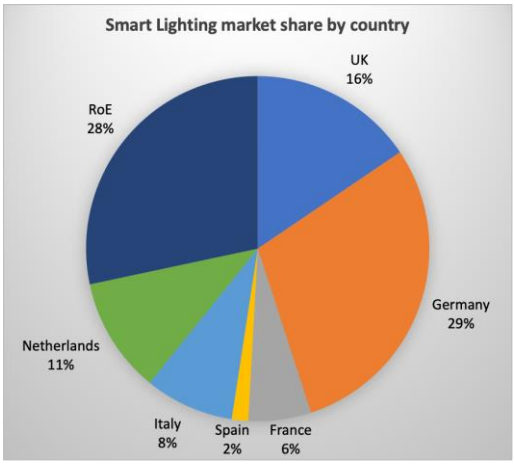
Figure 68: USA smart lighting revenue by sub-segment. Data from [GVR-21]



Source: G. Zissis

In 2022 Europe leads the market. [MMR-23] However, following [BUW-20] The European smart lighting segment is approximately worth USD 2 billion in 2018 and is expected to grow at CAGR of 20% from 2018 to 2024. [NAI-21] [MGI-22]. A. Gupta, in 2023 gave the European Segment value at USD 4,04 billion. [GUP-23] The largest European market in 2021 was Germany. [GMI-22] Figure 69 gives the market shares in various European countries.

Figure 69: Smart Lighting market share by country. Data from [SRT-22b]



Source: G. Zissis

From 2023 Asia-Pacific is expected to dominate the smart lighting market share, garnering 23,70% of the total share. [NAI-21] Following Straits Research analysts, the regional market is estimated to reach an expected value of USD 4,6 billion by 2030 at a CAGR of 19,5%. [STR-22b] APAC region is expected to witness the highest growth rate owing to the large-scale development of smart city projects in China, Japan, and South Korea. Moreover, increasing investment from India, Singapore, Thailand, and Malaysia to install energy-efficient smart lighting will boost the market growth across Asian countries. [RAM-21] APAC region market is expected to grow at a CAGR of 8,5% between 2017 and 2025. [NAI-21] China is expected to become the country with the highest market share globally and the highest revenue contribution. Due to their growing economies and significant investments in smart city initiatives, nations like Japan, India, and South Korea are expected to be at the forefront of the adoption of smart lighting. [MMR-23]

The Japanese market has witnessed the launch of a series of smart home products tailored for them from global tech giants, such as Google and Amazon. Amid the gloom surrounding the reduced penetration rate of traditional home appliances Y-o-Y in the country, the smart home industry promises unlimited potential in the future, owing to the rising integration of AI-empowered products and services in homes. The market for smart lighting in the country is also driven by the increased adoption of smart devices, including smartphones, due to their ability to connect conveniently to IoT devices. [MOR-22]

The demand for smart lighting in India is expected to grow owing to the increasing demand for features such as voice recognition or remote operation and the exceptional experience of smart home automation. [MOR-22]

In the UAE, Israel, and Qatar the market for smart lighting is currently seeing tremendous growth. The UAE has also modernised the lighting equipment in shopping malls, retail stores, and other commercial projects in addition to installing smart lighting systems in significant portions of city streets. [MMR-23]

For lighting controls, following Nair, the segment is dominated by the Asian market, with a share of 40%, followed by Europe (20%) and North America (15%).

3.3.2 Controls and Communication protocols segments

The global smart lighting controls (hardware) market is expected to grow at a CAGR of 21% from 2018 to 2024. [NAI-21] Vantage Market Research predicts that smart lighting control systems sub-segment Size will grow from USD 56,2 billion in 2021, to reach USD 108,5 billion by 2028. This is a CAGR of 11,6%. APAC region shall drive the market growth. [VMR-22] Following Vantage Market Research, the global Smart Lighting Control Systems Market is valued at USD 62,44 billion in 2022 and is projected to reach a value of USD 149,20 billion by 2030. The Market is expected to grow at a Compound Annual Growth Rate (CAGR) of 11,5% over 2017-30 period. [VMR-22]

North America is expected to dominate the growth of Smart Lighting Control Systems Market in 2021. [VMR-22]. Vantage Market Research attributed 31,8% market share in 2022. [VMR-22]

The APAC segment size was valued in 2022 at USD 20,8 billion. APAC is the fastest growing region. The growth of Asia Pacific is primarily attributed to a rise in government investments in the development of good homes in emerging countries such as China, and India. [VMR-22]

Concerning communication protocols associated to the smart systems, mysupplier predicts that the wired segment is forecasted to grow from USD 5,3 billion in 2020 to USD 13,1 billion in 2025 at 19,6%, while the wireless communication segment's forecast shows a 25% CAGR growth in 2020-25 period, from USD 2,8 billion to USD 8,6 billion. [MYS-20] Straits Research analysts forecasted that the wired segment accounted for the largest market share and is estimated to grow at a CAGR of 22,1% during the 2021-29 period. [STR-22b]

The APAC wired smart lighting market valued at USD 1,5 billion in 2021. [GMI-22]

The DALI segment accounted for the highest smart lighting market in 2018, with USD 2,08 billion, growing at a CAGR of 15%, from 2019 to 2026. [BUW-20]

The advent of Power over Ethernet (PoE) and solar lighting solutions has further increased the adoption of Smart Lighting Solutions. Commercial buildings have been deploying PoE lighting solutions, as these solutions offer intelligent lighting controls, a comfortable work environment, and flexible control. [MAM-21] However, network components' interoperability and IoT-based security systems are points of concern for investors and business owners. [MYS-20]

The global wireless lighting market is estimated at USD 1,32 billion in 2022. Sales of wireless lighting are expected to increase at a 3,48% CAGR over 2022-32 10-year period to reach USD 1,85 billion by 2032. [SAH-22] North America currently dominates the wireless lighting market, which is attributed to the presence of leading manufacturers in USA. In addition, there is a high demand for smart lighting across schools, colleges, universities and work spaces. Further, demand for event wireless lighting in Canada is also gaining traction amid high influx of international tourists and rising interest in media and film communities. [SAH-22]

Demand for wireless lighting and smart lighting systems across Europe is expected to account for 31% of the total wireless lighting market valuation in the next years. [SAH-22] Consumers in Germany, France, and Italy are preferring smart lamps and lighting systems in garages, indoor theatres, entertainment rooms, and art studios. High adoption of LED luminaires, along with the replacement of traditional systems with smart lamps in the residential sector are some of the emerging wireless lighting market trends in Europe. [SAH-22]

The wireless control segment shown a penetration of 33% in 2017. But, the segment in the market is anticipated to witness the fastest growth over the forecast period. The growth is attributed to demand for quick connectivity using Z-wave, ZigBee, Wi-Fi, and Bluetooth. [RAM-21] It will lead the growth from 2018 onwards. [NAI-21]

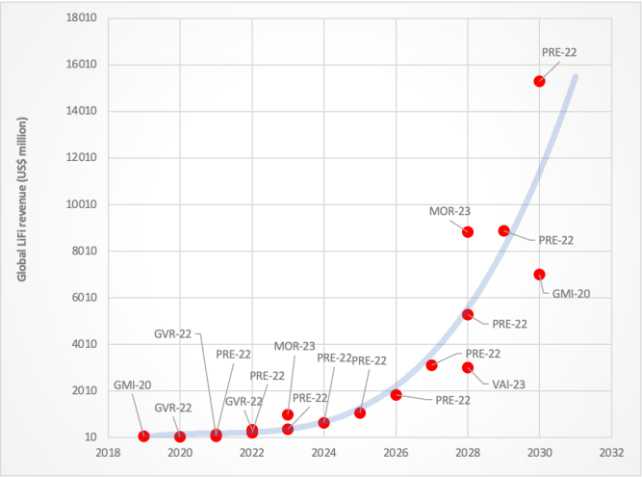
Furthermore, advancement in wireless communication technology, growth in developments of smart city projects, especially in Asia-Pacific, and emergence of IoT technology for smart lightning is expected to provide lucrative opportunities for the market growth. [BUW-20]

The emerging trend of light fidelity (Li-Fi) technology and the increasing adoption of smart lighting in commercial and residential sectors are expected to create promising opportunities for major vendors in the global smart lighting market during the forecast period[13]. [MAR-22] Li-Fi is a disruptive technology that will affect numerous industries is Li-Fi. The technology can unleash the IoT's potential, enabling Industry 4.0 applications and the lighting sector's impending light-as-a-service (LaaS). This VLC protocol can enable big data and other technologies, including IoT. In July 2022, Kyocera SLD Laser, commercialization of laser light sources, was announced, demonstrating a LiFi data rate of 90 Gbps from their LiFi system. [MOR-23]

One year after the LiFi entering the market, the revenue jus just USD 1,8 million. [MOR-23] Following Global Markets Insight analysts, Li-Fi Market size exceeded USD 70 million in 2019 and is poised to grow at USD 7 billion with a CAGR of over 50% between 2020 and 2030. [GMI-20] The LiFi market size was reached at USD 127,66 million in 2021 and it is expected to reach USD 15,31 billion by 2030 (CAGR of 51%). [PRE-22] A more recent analysis (2023) from Mordor Intelligence valuated the global 2023 LiFi market at USD 0,98 billion in 2023 and predicts, higher growth to USD 8,83 billion by 2028, at a CAGR of 55,18% during the forecast period (2023-2028). [MOR-23] This can be attributed to an increase in smart and connected devices has generated a large volume of data, straining the capabilities of current Wi-Fi, 5G, and other networking technologies. Therefore, by offering high-speed connectivity, greater capacity, and improved security, Li-Fi technology can resolve these problems. [MOR-23] Figure 70 gives a global view of various data harvested from literature.

[13] The Li-Fi technology was first introduced in the year 2011

Figure 70: Global LiFi market size as given by different analysts. Data harvesting from literature by G. Zissis, the labels in the graph indicate the source.



Source: G. Zissis

The aerospace sector will have the fastest CAGR of 40% till 2030 [GMI-20] and, owing to ability of LiFi networking system to provide precise location information services in indoor environments, the location-based services segment is expected to have a significant growth 50-51% [PRE-22] [GMI-20] According to the Global Markets Insight report, application to LED Lighting was representing 45% of the market share is 2019 and will reach USD 600 million at 2025. [GMI-20] The revenue share of increased slightly at 47% in 2021 and is expected to hit around USD 650 million by 2030. [PRE-22] The Li-Fi technology is anticipated to witness demand from automotive industry to facilitate Vehicle to Vehicle (V2V) communication in connected cars. The ability of V2V communication to exchange data with other vehicles aids in preventing potential crashes and congested traffic jams. [GMI-20]

in 2019, European market accounted for USD 30 million[14] in 2019. [MOR-23] UK held 30% of the revenue share in 2019[15], [PRE-22], but France will become the largest market followed by Germany from 2025 [GMI-20]. North American market dominated the LiFi market in 2022 and accounted for a revenue share of more than 32% [GVR-22] and is expected to grow to reach USD 2,5 billion by 2030. [MOR-23] One of the critical markets for Li-Fi technology is Asia-Pacific. The region is making significant technology investments to improve its internet infrastructure, which presents enormous prospects for the market vendors under study. In China, as a high-quality VLC system would be faster and less expensive than the typical Chinese broadband connection, the Chinese government has been investing in R&D to push LiFi technology in the next years. [MOR-23]

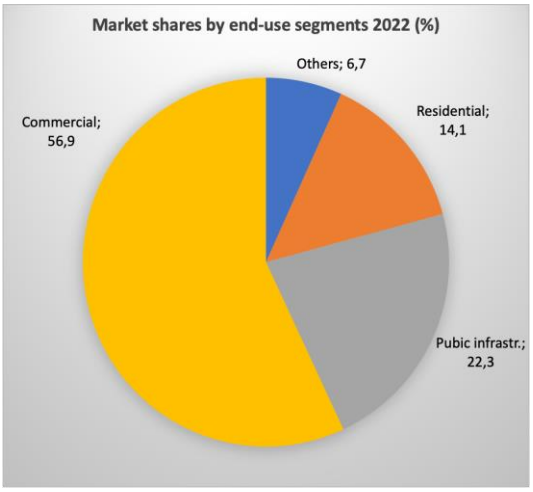
The companies operating in the LiFi market are currently in the R&D phase and have yet to launch products. As a result, the market is fragmented. However, the competition for innovation and production of advanced products is high as companies constantly engage in bringing Li-Fi into use. Among those actors we can list Signify Holding BV (Netherlands), pureLiFi Ltd (UK), LVX System (USA), Oledcomm SAS (France). [MOR-23]

3.3.3 End-use segments

In this paragraph the smart lighting market is split by end-use segment. Figure 71 gives a rapid overview of the relative share of the principal segments in 2022 as given by [SMR-22b]

[14] Valued at USD 33 million in 2020 by [PRE-22]
[15] According to the Central Intelligence Agency Factbook, there are 62,9 million active internet users in the UK as of 2019 [GMI-20]

Figure 71: 2022 Smart lighting market split among the main end-use segments. Data from [SMR-22b]



Source: G. Zissis

3.3.3.1 Residential segment

The Smart Lighting Indoor applications segment is expected to rise from USD 5,3 billion in 2020 to USD 13,6 billion in 2025 at a CAGR of 20,5%. [MYS-20] Following [MAM-21] the CAGR of the sub-segment is estimated to be 21,2% from 2021 to 2026. This is an indication of market acceleration.

It shall be noticed that in 2019, Serrenho et al., based on a study on smart homes and associated appliances in Europe, found that the majority of people within the sample (70%) do not plan to buy any connected devices in the near future, and only plan to replace lighting with connected devices once they need to. [SER-19] This situation changed radically since 2020 then as shown from the figures given in [MYS-20]. The new trend of home automation is penetrating houses with middle and high-income group consumers. The trend is further fuelled by constantly evolving IoT technology for smart homes; wherein smart lights can be connected to control the functions of electronic devices. Moreover, personal assistants such as Alexa, Crotona, and Siri can be synced with a smart light app to control lighting hue, brightness, on/off time, and other functions using only voice commands. [RAM-21]

Further, the residential segment seeks customizable lighting options to create ambiance and cater to individual preferences. As architectural designs become more innovative and intricate, the demand for lighting solutions that complement and accentuate these designs continues to rise. Thus, a significant trend in the architectural lighting market is the increasing adoption of human-centric lighting solutions. [SQM-23]

The use of smart lighting systems is increasing in residential places as they offer control over lighting products. Smart lighting systems also integrate the concept of the internet of things (IoT), as it helps the customers control the lighting products through the apps installed on their mobile devices. [TCA-22]

The global revenue in the comfort and lighting segment of the smart home market was forecast to continuously increase between 2023 and 2027 by in total USD 7,287 billion (+62,23%). After the fourth consecutive increasing year, the revenue is estimated to reach USD 19,0 billion and therefore a new peak in 2027. [STA-23k] From the selected regions, the ranking by revenue in the comfort and lighting segment of the smart home market is led by the United States with USD 3 billion and is followed by China (USD 1,4 billion). In contrast, the ranking is trailed by Turkey with USD 10,52 million. [STA-23i]

The global user penetration in the comfort and lighting segment of the smart home market was forecast to continuously increase between 2023 and 2027 by in total 13,2%. After the fourth consecutive increasing year, the user penetration is estimated to reach 21,51% and therefore a new peak in 2027. [STA-23k] The user penetration ranking in the comfort and lighting segment of the smart home market is led by Germany with 19,98%, while the United Kingdom is following with 19,67%. In contrast, India is at the bottom of the ranking with 3,27% percent. [STA-23k]

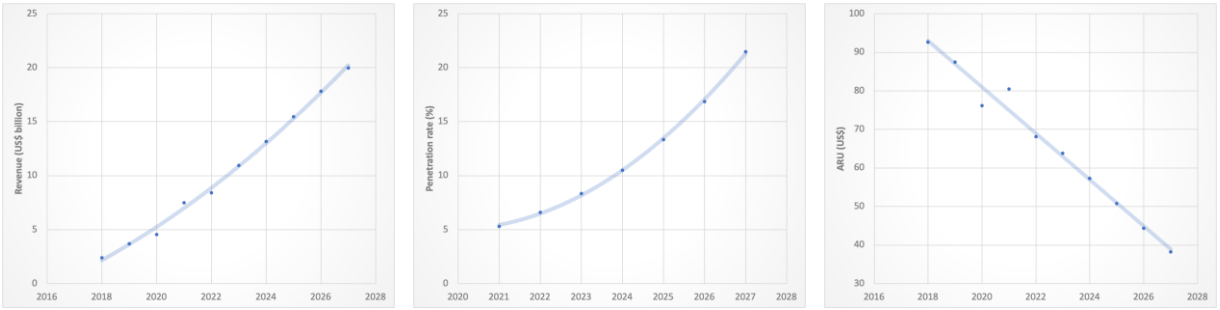
The global number of households in the comfort and lighting segment of the smart home market was forecast to continuously increase between 2023 and 2027 by in total 317,9 million homes (+172.97%).

According to this forecast in 2027, the household number will have increased for the fourth consecutive year to 501,64 million homes. [STA-23k]

The global average revenue per user (ARU) in the comfort and lighting segment of the smart home market was forecast to continuously decrease between 2023 and 2027 by in total USD 25,8 (-40,5%). The revenue per user is estimated to amount to USD 37,87 in 2027. [STA-23k]

Figure 72 gives an overview on the evolution of comfort and lighting segment of the smart home market from 2018 to 2027 (a) revenue, (b) penetration rate and (c) average revenue per user.

Figure 72: Evolution of comfort and lighting segment of the smart home market from 2018 to 2027 (a) revenue, (b) penetration rate and (c) average revenue per user. Data from [STA-23k]



(a) (b) (c)

Source: G. Zissis

Table 14 gives some more details by country about comfort and lighting segment in households.

Table 14: comfort and lighting segment in various countries. Data and information from [STA-23k]

France	The revenue in the comfort and lighting segment of the smart home market in France was forecast to continuously increase between 2023 and 2027 by in total USD 197,3 million (+57.68%). After the fourth consecutive increasing year, the revenue is estimated to reach USD 539,35 million and therefore a new peak in 2027.
Germany	The revenue in the comfort & lighting segment of the smart home market in Germany was forecast to continuously increase between 2023 and 2027 by in total USD 528,4 million. The number of households in the comfort and lighting segment of the smart home market in Germany was forecast to continuously increase between 2023 and 2027 by in total 24,1 million households (+211.59%). According to Statista's forecast in 2027, the household number will have increased for the fourth consecutive year to 35,44 million households.
UK	The revenue in the comfort and lighting segment of the smart home market in the United Kingdom was forecast to continuously increase between 2023 and 2027 by in total USD 1,008 billion (+78.05% percent). According to Statista's forecast in 2027, the revenue will have increased for the fourth consecutive year to USD 2,3 billion. The average revenue per user in the segment was forecasted to continuously decrease between 2023 and 2027 by in total USD 68,1 (-40.07%). The ARU is estimated to reach USD 101.87 in 2027. The number of households in the comfort and lighting segment of the smart home market in UK was forecast to continuously increase between 2023 and 2027 by in total 15 million households (+197,37%). After the fourth consecutive increasing year, the household number is estimated to reach 22,57 million households and therefore a new peak in 2027.
Poland	The revenue in the comfort and lighting segment of the smart home market in Poland was forecast to continuously increase between 2023 and 2027 by in total USD 39,3 million (+108,09%). After the fourth consecutive increasing year, the

	revenue is estimated to reach USD 75,63 million and therefore a new peak in 2027.
Spain	The revenue in the comfort and lighting segment of the smart home market in Spain was forecast to continuously increase between 2023 and 2027 by in total USD 50,8 million (+71,07%). According to Statista's forecast in 2027, the revenue will have increased for the fourth consecutive year to USD 122.27 million.
Italy	The number of households in the comfort and lighting segment of the smart home market in Italy was forecast to continuously increase between 2023 and 2027 by in total 2,1 million households (+127,27%). According to this forecast in 2027, the household number will have increased for the fourth consecutive year to 3,73 million households.
USA	The revenue in the comfort and lighting segment of the smart home market in the USA was forecast to continuously increase between 2023 and 2027 by in total USD 1,419 billion (+42.33%). According to this forecast in 2027, the revenue will have increased for the fourth consecutive year to USD 4,8 billion. The average revenue per user in the segment was forecast to continuously decrease between 2023 and 2027 by in total USD 41,5 (-33.21%). The revenue per user is estimated to amount to USD 83,43 in 2027. The user penetration in the USA was forecast to continuously increase between 2023 and 2027 by in total 21,7%. According to Statista's forecast, in 2027, the user penetration will have increased for the fourth consecutive year to 41,94%.
China	The revenue in the comfort and lighting segment of the smart home market in China was forecast to continuously increase between 2023 and 2027 by in total USD 1,265 billion (+74,32%). According to Statista's forecast, in 2027, the revenue will have increased for the fourth consecutive year to USD 3,0 billion.
Turkey	The revenue in the comfort and lighting segment of the smart home market in Turkey was estimated to be USD 10,52 million in 2023. This the lowest worldwide.
India	The global user penetration in the comfort and lighting segment of the smart home market was estimated to be 3,27% million in 2023. This the lowest worldwide.

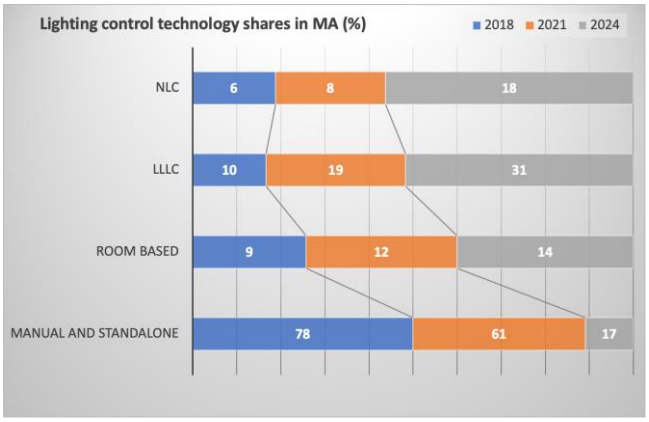
Source: G. Zissis

3.3.3.2 Non-Residential segment

Following Research and Markets work, retail sub-segment emerged as the top beneficiary of smart lighting for non-residential buildings indoor lighting. [RAM-21]

In USA, and more specifically Massachusetts a DNV study on 2020 commercial and industrial (C&I) Lighting Controls Market shown that in 2020 just 1% of lighting fixtures in C&I premises are using either Luminaire-Level Lighting Controls (LLLC) or Network Lighting Controls (NLC). Among them 83% is still using manual lighting controls (MLC) and 13% standalone controls. It also states that 4% of the lamps stays on 24 hours on 24. [DNV-21]. However, the same report shows that 90% of the users are familiar with lighting controls (66% among them knows about LLLC and 66% about NLC) and 80% of users that have advanced controls reported that they received training on how to use them. [DNV-21] Only 24% of the users said be interested to change existing LES fixtures to include controls. The high cost of smart systems doesn't seem to be the main barrier for the adoption of the technology; lack of awareness is more problematic. Contractors and service provides (including ESCOs) consider that lack of training in the installation and commissioning is also a critical issue for a wide adoption. [DNV-21] Lighting control manufacturers estimated the market share for control technologies in C&I segment in Massachusetts (Figure 73); NLCs shall be dominant in 2024. It is also important to notice that price per fixture with controls and/or smart functions is also decreasing (Figure 74). For smart fixtures the observed price variation from 2017 and 2020 was of -16%, when for LLLC's was of -28%. [DNV-21]

Figure 73: Lighting control technologies shares in C&I segment in Massachusetts in the period 2018-24. Data from [DNV-21]



Source: G. Zissis

Figure 74: Average selling price for fixture units imbedding controls ("Claver": LLLC; "Clever Hybrid": Includes a standalone gateway and provide additional functionality such as energy monitoring; "Smart": Includes all "clever" capabilities but can also analyse and communicate energy and non-energy data to inform decision-making processes for a wide variety of IoT use cases). Data from [DNV-21]

Source: G. Zissis

3.3.3.3 Street and outdoor segments

The dynamics such as rise in demand for intelligent street lighting systems in developing and developed nations, growth in need for energy-efficient lighting systems for sustainable development drive the street-smart lighting market. Reports and Data analysts estimated, in 2022, that the number of smart street lights that would be installed in cities across various countries would reach around 73 million by 2026. [RND-22]

Globally smart street lighting segment size is in the order of 2-3% of the global IoT for smart city market. A Market and Markets report published in 2022 estimates that the global IoT Smart Cities market is estimated to be in 2021 in the order of USD 130,6 billion and it is forecasted to grow up to USD 312,2 billion by 2026 (19% CAGR in the 5-year period). [MAM-22b]. This is an excellent driver for smart street lighting development. Another analyst predicts, that outdoor lighting applications segment will grow from USD 2,8 billion to USD 8,1 billion at a CAGR of 23,4% within 2020-25 period. [MKL-21] An older analysis from SciTech shown that the CAGR was in the order of 2% in the period 2017-21. [SCI-17] MKLights relating a TrendForce forecast, estimated that the scale of the smart street lamp market will grow by 18% annually in 2021, and the CAGR will be 14,7% in 2020-25, which is higher than the overall general lighting average. [MKL-21] The reality is most probably between those two growth predictions, but we can expect a stabilisation in the next decade.

The Singapore government roll out connected street lights in five districts - Tampines and Pasir Ris in the east, Jurong West in the west, and Sembawang and Yishun North near the northern tip of Singapore in 2017 at an

estimated cost of USD 1 billion over 10 years. Each district will have about 4 000 to 5 000 connected street lights. In comparison, there were 500 such "smart" connected street lights in Singapore at the end of 2014. [VMR-22]

In November 2019, in Spain, Barcelona deployed more than 3 000 streetlights based on LED technology. Hence, the increasing development of infrastructure across several countries is bolstering the demand and production of smart lighting solutions, which, in turn, is helping the market advancement globally. [PSI-22]

The Spanish town of Pozuelo de Alarcón, located 15 kilometres west of Madrid, now benefits from a state-of-the-art, energy-efficient and centrally controllable lighting solution. Tridonic has equipped the municipality with 2,700 smart, dimmable LED drivers for the entire outdoor area. The town can thus save more than 50% in energy costs and take a crucial step closer to its ambitious climate targets. [TRI-21]

In August 2021, Signify launched a new range of Philips Smart Wi-Fi lights in India. With this, it expanded its Phillips Smart Wi-Fi ecosystem in India under Wiz Smart Light Range. [EMG-21]

3.3.3.4 Automotive smart lighting segment

Automotive intelligent lighting enhances light distribution from the headlights as per vehicle driving circumstances. Depending on vehicle steering input and speed, the automotive intelligent lighting points the low-beam headlights toward the direction the chauffer intends to drive. The automotive intelligent lighting uses artificial intelligence while adjusting the illumination during switching lights on and off. [TMR-21]

In 2021, the rate of adoption of car smart lighting in Europe was larger than in other world's regions. [TMR-21]

The global automotive intelligent lighting market is highly fragmented with top manufacturers across the global market. A few of the key players operating and potential in the global automotive intelligent lighting market are: HELLA GmbH & Co. KGaA, Magneti Marelli S.p.A, Texas Instruments Incorporated, Koito Manufacturing Co. LTD., Valeo SA, Stanley Electric Co. LTD., Neolite ZKW and Continental AG. [TMR-21]

3.4 Business models for smart Lighting trade and governmental incentives

Business models for lighting are evolving very fast from traditional trade product-oriented models to non-traditional service-oriented cases. Detailed information on financial models and concrete examples is available can be found in the LUCIA INTERREG-Baltic See Region project's web page[16].

3.4.1 Traditional product-oriented models

The traditional product consists basically of two approaches: (a) Sales of LED products or other lighting technology systems and, eventually, (b) Installation and maintenance of lamps (so called product-as-a-service). The owner of the system is always the end-user and he/she is protected by a guarantee depending on local regulations. Beyond residential market, traditional procurement of equipment programs, focus on price, technical performance and energy/cost savings. [LUC-20]

A second type of traditional trade models is leasing. It is somehow a hybrid between product-oriented and service-oriented model. The service provider leases the lighting solution and can also offer leasing funding solutions. This kind of model, with variations, is often used for street lighting worldwide. Public Private Partnerships (PPP) are often used and in some cases energy savings are used to pay the provider. Ownership of the system stays with the provider and at the end of the leasing period is very often transferred to the end-user, but this is not always the case. Such kind of model can be also applied for non-residential building's indoor lighting but it is less frequent. A variation of this model is "short term hiring" of lighting equipment and it is particularly well adapted to events, festivals, etc. lighting. The service is usually connected with other audio-visual solutions and packages and it is very often tailored to fit the customer's needs. The service provide is always the owner of the system. [LUC-20]

[16] https://lucia-project.eu/

3.4.2 Lighting as a service

Lighting as a Service (LaaS) is a relatively new and innovative business model in the lighting industry. It represents a shift from traditional lighting procurement and maintenance practices to a more service-oriented approach. In a Lighting as a Service arrangement, instead of purchasing lighting fixtures outright, businesses or individuals pay a regular fee for the use of lighting services, including the fixtures themselves, installation, maintenance, and often upgrades. LaaS operates on a subscription or pay-per-use basis. Customers pay a monthly or annual fee for the lighting services they receive, rather than making a large upfront investment in purchasing lighting equipment.

LaaS aligns with sustainability goals as it promotes the use of energy-efficient lighting, reduces waste associated with obsolete fixtures, and often incorporates smart lighting controls that optimize energy usage. One of the main advantages of LaaS is the emphasis on energy-efficient lighting solutions. Service providers often use the latest LED technology to reduce energy consumption and lower operating costs for the customer.

The responsibility for the performance and reliability of the lighting system lies with the service provider, reducing the risk for the customer. LaaS providers are responsible for the ongoing maintenance and monitoring of the lighting system. This can include proactive troubleshooting, repairs, and replacements, minimizing downtime.

The global lighting as a service (LaaS) market size was valued at USD 616,5 million in 2022 and is projected to reach USD 9,06 billion by 2031, with a CAGR of 34,8% during the forecast period 2023-31. In terms of revenue, the software sub-segment dominated the market in 2021 with a 39,4% share. [STR-23b]

The expansion of the global market for lighting as a service can be attributed to the rising demand for energy-efficient lighting systems, the absence of capital expenditure requirements, and the increasing convergence of the Internet of Things (IoT) in lighting systems. [STR-23b] However, emerging markets' lack of awareness and infrastructure is one of the most significant market restraints for LaaS. There is a notable shortage of skilled and trained personnel to manage the market's modern lighting requirements. [STR-23b]

The Commercial Subsegment of the Application is the market's largest investor. The municipal sector, which is projected to have a significant CAGR of 44,8% due to the adoption of LaaS by major cities and towns attracted to its energy-saving advantages over conventional lighting solutions. Indeed, the outdoor lighting represents the largest shareholder and is anticipated to grow at the highest CAGR during the 2023-31 period, 46,6%. [STR-23b]

North America is anticipated to be one of the leading regions contributing to the expansion of the global market at least till 2031. Asia-Pacific region is anticipated to experience significant growth also. Europe is witnessing the fastest growth in the lighting as a service market, backed by the widespread adoption of LaaS in European countries such as the U.K. and Germany. Latin America accounts for the least share in the lighting as a service market; however, increased efforts in reducing carbon footprint are driving the demand for LaaS. [STR-23b]

In 2022, the key players in the domain are: Koninklijke Philips, ABB (Cooper Industries), General Electric, Osram, SIB Lighting, Cree, RCG Lighthouse, Digital Lumens, Lutron and Future Energy Solutions. [STR-23b]

A variation of LaaS is the so called "Multifunctional performance as a Service" model. Here, the lighting system or its units can serve as a platform for other services (security, monitoring, tracking, displaying, charging etc.). Earnings can come from sales/rent of space, technology or performance for different functions. This mode can apply very well to cities. The ownership of the technological system and the harvested data are negotiable. [LUC-20]

On 23 March 2021, as part of its portfolio of smart city solutions, Nokia announced that it has signed a reseller agreement with ClearWorld, a producer of alternative energy systems, to sell ClearWorld's smart poles initially to American towns and military facilities. The ClearWorld-linked digital pole is installed in areas such as parks, parking lots, and roads and enables applications including video analytics, Wi-Fi access points, gunshot detection, smart lighting, and license plate scanning. Based on Nokia Bell Labs Future X architecture, Nokia's smart city solutions feature integrated, intelligent city platforms that make use of 5G, Industrial Internet of Things (IoT), and machine learning technologies to lay the groundwork for urban innovation. Nokia can be a complete solution provider of smart urban infrastructure solutions for cities owing to the relationship with ClearWorld for smart poles. [EMG-23]

3.4.3 Some exemples of ational incentives to support the transition to smart lighting

Due to the high energy savings, numerous government incentives, as well as, utility rebate programs are now supporting the smart lighting technologies. We are witnessing the transition from simple demonstrators (TRL-5-6) to large installations (TRL 8-9). The following paragraphs give some examples worldwide.

The governments in the US, Canada, and Mexico have always been promoting a green environment, which has resulted in a large number of smart homes in North America. Over the past few years, the governments of European countries have also been taking initiatives to adopt energy-efficient measures across the region. Regulations stated by the government are in favour of home automation systems. The governments of China, India, Japan, and South Korea are also supporting digitalization and eco-friendly measures to reduce energy consumption. [MAM-22] Additionally, governments of the United Arab Emirates, India, Austria, China, Spain, and Singapore are making huge investments in smart city projects, which is also propelling the advance of the LED lighting market.

For example, the Indian government has recently announced plans to develop 100 smart cities by 2030 and granted approval to an investment of nearly USD 15 billion for this project. [MAR-22] [PSI-22]

Similarly, in September 2022, the Government of United Arab Emirates launched a smart city strategy to transform Dubai into a smart city, which includes over 100 initiatives for the development of infrastructure, transport, and communications. [PSI-22]

in January 2019, N.Y. Power Authority allocated a fund of USD 7,5 million to municipalities across the state for installing new smart LED street lights. [GVR-21]

China since 2016, had 542 cities under Smart City development and that number is expected to increase with rising government investment into this industry. It is estimated that the annual amount of investment into Smart City projects will rise from CNY 375,7 billion in 2017 to 1,23 CNY trillion CNY from 2021. [BER-22b] This a fabulous driver for smart lighting projects.

4 Conclusions

Artificial light sources play an indispensable role in the daily life of any human being. It is impossible to neglect it or, even more, switch it off.

Today, lighting is responsible for a worldwide emission of CO_2 1,38 billion metric tons per annum. Electricity demand for lighting is estimated to be in the order of 2 900 TWh (which 13,5% of world's net electricity production) for a global light production of 216 Plmh. It is foreseen that in 2040 the needs for artificial light shall attain almost 280 Plmh corresponding to an increase of 25% in lighting service demand. Further, beyond the implication of lighting in energy, greenhouse gas emissions and depletion of abiotic resources of our planet, artificial lighting, has some additional important side-effects like the light pollution of the skies and the associated erosion of the biotopes.

The challenge for the next decade will be to harness the increase of electricity demand, limit the associated greenhouse gas emissions and avoid undesirable effects on the biotope. The only light source technology evolutions, even supported by ambitious policies, are not sufficient to stem uncontrollable growth. This report illustrates the effect of some regulations and policies to harness uncontrollable increase of lighting demand and to the promotion of innovative technologies.

In fact, since 2000's, the rise of Solid-State Lighting (SSL) has been considered as the 3rd revolution in the domain of lighting. The best commercialised non-directional LED lamps are 210 lm/W over 15 times more efficient than incandescent, 4 times more efficient than compact fluorescent lamps and 2 more efficient than fluorescent tubes. However, this is not sufficient to inhibit the well-known rebound effect. Only the transition from the conventional "analogue" lighting technologies to "digital" lighting can do it!

Smart lighting will become the 4th revolution and it will be the heart of the "Internet of Things" in smart cities and smart buildings. However, only the "Sustainable Smart Lighting" SSL^2 concept introduced in this report could solve the above-mentioned issues.

From the market side, the global lighting revenue reached EUR 130 billion in 2021 and it is growing steadily, at least till 2025, with a consolidated annual rate higher than 10%. Today, in lighting market LED technology share is higher that 50% of the global revenue and it expected to reach at more than 85% by 2035. LED prices are expected to strongly decrease in the medium to long term (up to 70% by 2050 in USA) and high-quality products (e.g., RGB White) which are able to provide different light temperatures and new services have been placed on the market.

Retail and wholesale distribution channels are the most popular in the LED lighting market. This distribution channel is likely to hold the largest market share during 2022-27 as it is likely to be the most preferred choice among consumers. However, eCommerce of lighting products is rapidly rising: following [EMG-23] eCommerce displays a CAGR of 11,2% for the period 2022-32. eCommerce distribution segment is used by 954,2 million users worldwide (roughly 12% of world's population). The total revenue of this distribution channel is estimated for 2023 to reach USD 25,2 billion. This is roughly 33% of the full LED Lighting market size.

Geo-political situation has strong impact on lighting market. The COVID-19 pandemic has disrupted the progress of the LED lighting market, However, since the end of pandemic restrictions the market is healing rapidly. In this report we can say that (1) the foreseen COVID-19 drop (-40%) has been largely overestimated and (2) event the optimistic scenario that shows that revenue will be multiplied by 1,56 is well beyond the expected evolution of the market which suggests that 2027 revenue will be multiplied by more than 3 compared to before pandemic figures. The ongoing war in Ukraine is impacting trades and businesses worldwide by constraining traditional energy sources leading to high costs. The LED industry has an opportunity to regain traction as "motivation to replace traditional forms of lighting have been strengthened". Last but not least, as USA and China are hubs for giant manufacturers of lighting products, including lamps, luminaires, and fixtures, the recent USA–China trade conflict impacted the import and export scenarios across the world.

As has been shown by patent and lighting technology shipments evolution, Smart Lighting is on the way to take more and more shares. Smart Lighting can achieve more than 40% additional energy savings in the next decade and the market size can exceed EUR 90 billion by 2030. In Smart Lighting, the residential segment seeks customizable lighting options to create ambiance and cater to individual preferences. As architectural designs become more innovative and intricate, the demand for lighting solutions that complement and accentuate these designs continues to rise. Thus, a significant trend in the architectural lighting market is the increasing adoption of human-centric lighting solutions. In fact, the global user penetration in the comfort and

lighting segment of the smart home market continuously increased between 2023 and 2027 by in total 13,2%. The dynamics such as rise in demand for intelligent street lighting systems in developing and developed nations, growth in need for energy-efficient lighting systems for sustainable development drive the street-smart lighting market. Reports and Data analysts estimated, in 2022, that the number of smart street lights that would be installed in cities across various countries would reach around 73 million by 2026. The emerging trend of light fidelity (Li-Fi) technology and the increasing adoption of smart lighting in commercial and residential sectors are expected to create promising opportunities for major vendors in the global smart lighting market. Li-Fi is a disruptive technology that will affect numerous industries is Li-Fi. The technology can unleash the IoT's potential, enabling Industry 4.0 applications and the lighting sector's impending light-as-a-service (LaaS). This VLC protocol can enable big data and other technologies, including IoTs.

The legacy lighting industry is healthy and generates benefits. However, the numerical transformation of lighting is changing dramatically the lighting industry world. New challengers coming from IT world appear (and disappear) in the industrial ecosystem. Business models for lighting are also evolving very fast from traditional trade product-oriented models to non-traditional service-oriented cases; the Light as a Service is the perfect example.

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List of abbreviations and definitions

4E	Energy Efficient End-use Equipment IAE TCP
ADEME	Agence de le transition écologique, France
AI	Artificial Intelligence
APAC	Asia Pacific World region
ARU	Average Revenue per User
ASP	Average Selling Price
BAU	Business as usual
BEIS	Department for Business, Energy & Industrial Strategy, UK
BMS	Building Management System
C&I	commercial and industrial
CAGR	Compound Annual Growth Rate
CFL	Compact Fluorescent Lamp
COB-LED	Chip-On-Board Light Emitting Diodes
DALI	Digital Addressable Lighting Interface
DMX	Digital Multiplex
DOE	Department of Energy, USA
EBIT	Earnings Before interest, Taxes
EBITA	Earnings Before interest, Taxes and Amortization
EIA	Energy Information Administration, USA
EISA	Energy Independence and Security Act, USA
EMEA	Europe, Middle East, and Africa
ESCO	Energy Service Company
EU14	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Republic of Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden
EU27	European Union - 27 countries
FY	Fiscal Year
GHG	Greenhouse Gas
GLS	General Service Lamps
HCL	Human-Centric Lighting
HID	High Intensity Discharge lamps (high pressure mercury)
HPS	High Pressure Sodium lamps
IEA	International Energy Agency
IoT	Internet of Things
IPO	Integrated Product Ownership
IT	Information Technology
LaaS	Lighting as a Service
LED	Light Emitting Diode
LFL	Linear Fluorescent Lamp (or tube)
LLE	LED Lighting Engines
LLLC	Luminaire-Level Lighting Controls
LON	Local Operating Network
LoRaWAN	Long Range Wide Area Network

LPWAN	Low Power Wide Area Network
MEA	Middle East, and Africa
MELISA	Model for European Light Sources Analysis
MEPS	Minimum Energy Performance Standards
MHL	Metal Halide Lamps
MLC	Manual Lighting Control
NLC	Networked Lighting Controls
NZE	Net Zero Energy scenario for buildings
OASEAN	Oceania and Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam
OEM	Original Equipment Manufacturer
OLED	Organic Light Emitting Diode
PC-WLD	Phosphor Converted White Laser Diode
PLC	Power Line Communication
PNNL	Pacific Northwest National Laboratory, USA
PoE	Power over Ethernet
PPP	Partner Public Partnership
R&D	Research and Development
RF	Radio Frequency
RoE	Rest of Europe
RoW	Rest of World
SLS	Smart Lighting System
SSL	Solid State Lighting
TCP	Technology Cooperation Program (IEA)
TRL	Technology Readiness Level
U4E	United for Efficiency, a UNEP program
UAE	United Arab Emirates
UK	United Kingdom
UNEP	United Nations Environment Programme, United Nations
USA	United States of America
VLC	Visible Light Communication
YoY	Year-over-Year

Devises and typical exchange rate to Euro[17]

		Exchange rate			Exchange rate
AUD	Australian dollar	0,59470	MYR	Malaysian Ringgit	0,1994
EUR	Euro (€)		PLN	Polish zloty	0,2248
GPB	UK Pound	1,158000	USD	US Dollar ($)	0,9186
INR	Indian Rupee (Rs)	0,011050	CNY	Chinese Renminbi	0,1264
JPY	Japanese yen	0,006283			

[17] Typical exchange rates to Euro as given by the French Ministry of Finances (https://www.economie.gouv.fr/dgfip/taux_chancellerie_change)

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