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Smart Lighting systems: Dream or reality?

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Abstract

Today, lighting is responsible for 5% of worldwide CO₂ emissions. World's electricity demand for lighting attained 2,900 tera-watt-hours (TWh) corresponding to a global light energy production of 215 Plmh (peta-lumen-hours). It is foreseen that in 2040 the needs for electric lighting will increase by ~32% to reach 285 Plmh. The challenge for the next decade will be to harness the increase of electrical electricity use for lighting. Only light source technology evolutions are not sufficient to stem uncontrollable growth. Even the best commercialized LED lamps which are almost 2 times more efficient than fluorescent tubes, are 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. Smart Lighting is on the way to become the 4th revolution in the domain. It can achieve more than 40% additional energy savings and encompass rebound effect. Smart Lighting market size can exceed USD 98 billion by 2030 which is comparable to USD 134 billion revenues from global lighting industry. This paper highlights the evolutions in the domain of smart lighting technologies and its impacts.

The context

Humanity's electric light needs are foreseen to attain, by 2040, at least 285 Plmh (peta-lumen-hours is the energy carried by the generated light). This corresponds to a light demand increase of 25% compared to 2020. As of 2009, electrical lighting consumed in this single year 2,650 TWh of electricity (this represented 19% of world electrical production) [1]. Since then thanks to various actions from governments and industry, the electricity consumption for lighting seems to be better mastered. As of 2019, the estimated electricity used for lighting is around 2,900 TWh stabilized (less than 1% annual growth rate), or 13.5% of the world's annual usable electricity¹. [2] Even if the absolute value slightly increased in the last years, the relative part of lighting reduced drastically (~5.5% annual decrease rate). The observed decrease, in percent of used electricity, is the effect of combined effort of technological developments and worldwide energy policies. For instance:

- LED technology developed 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 color rendering and stability. Following K. Lane, since 2010, the average efficacy of LEDs has improved by around 4 lm/W each year. [3]. Today, the best commercialized non-directional LED lamps are in the order of 210 lm/W over 15 times more efficient than incandescent and four times more efficient than compact fluorescent lamps (CFLs). [4]
- 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, despite these efforts, 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, CO₂ emissions from lighting rose slightly in 2022. The emissions intensity of electricity, an important factor for CO₂ emissions, fell too little to offset increased lighting demand [3]. 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

¹ “Usable electricity”: electricity generation minus an average 7% losses related to the electricity transport and distribution [5]

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 electric 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%. [6] The same authors conclude that, even if “these dynamics vary by region, but there is limited evidence that advances in lighting technology have led to decreased emissions.” [6] 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!

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. In fact, as solid-state lighting (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.

Considering that the use of fire to the primitive times used exclusively to generate light was the first revolution, the use of electricity to generate light can be seen as the 2nd revolution while the arrive of LEDs in late 20th century marked the 3rd revolution. Today, lighting is witnessing 4th revolution: the transition to Smart Lighting systems. Smart Lighting can achieve more than 40% additional energy savings and its market size can exceed USD 98 billion by 2030.

Generally speaking, a smart technological object, including smart lighting, is characterized by an intelligent sensing technology that is increasingly being integrated with internet technologies, thereby allowing the react to and communicate with the changing environment around it. In principle, this is leading to optimal operation and global improvement in efficiency. Based on the fact that a such “smart” lighting 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 [2]:

“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. Further, the system could offer additional optional services (geo-localization, data connectivity...) to the end-users preferably through Visible Light Communication protocols, but not only”.



Figure 1: Illustrating the SSL² concept for lighting

To achieve such ambitious objectives to a sustainable manner, Zissis, introduced in 2023, the SSL² concept, that defines a “Sustainable Smart Lighting (the 1st SSL in SSL²) system uses and optimizes

to an intelligent way the best existing technology (Solid State Lighting, the 2nd SSL in SSL²) to best fulfil present needs for electric light of humans and reduce undesirable side-effects, without compromising the ability of future generations to innovate.” [2]. Figure 1, illustrates the SSL² concept.

In this paper, to assess the penetration and effects of smart lighting systems, we are 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. Further we analyzed published patents and scientific papers databases.

Smart Lighting Penetration Progress Assessment

Our first analysis was based on harvested data concerning the number of global patents granted from 2000 to 2022 for five specific segments: (1) LED lighting, (2) OLED lighting, (3) Integrative lighting², (4) Lighting Controls, and (5) Smart Lighting. Globally, in that period when more than 10,000 patents have been granted for LED Lighting, only 760 have been granted for OLED lighting technology and 3,800 for smart/connected lighting and lighting controls together. It is however very interesting to analyze the annual change in the number of patents by segment, as shown in Figure 2. It can be seen that the number of patents concerning LED and OLED lighting is declining when the segment of smart lighting that includes either controls and connected devices, is increasing, even if a plateau appears from 2018. We can anticipate that in the next years and during the next decade, smart SSL lighting systems will supersede simple SSL systems.

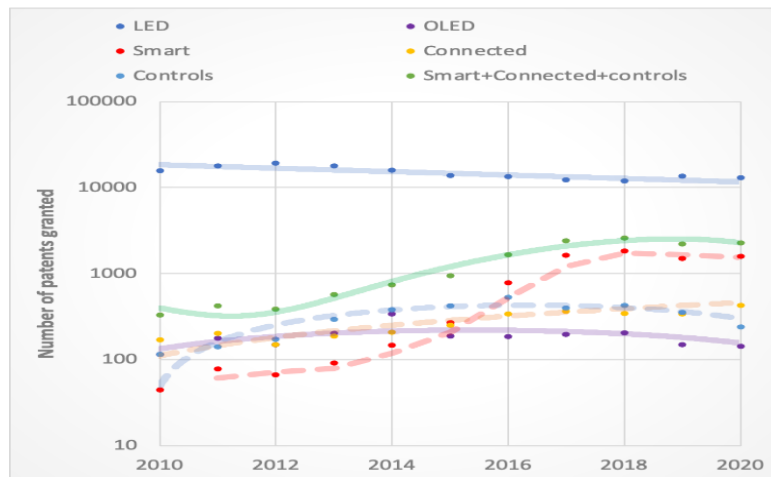


Figure 2: Number of global patents from 2010 to 2021 (log scale). Data harvested by G. Zisis in from Google Patents

² “Integrative Lighting” is now the dedicated term proposed by the International Commission of Illumination (CIE) that shall be used instead of “Humancentric Lighting”

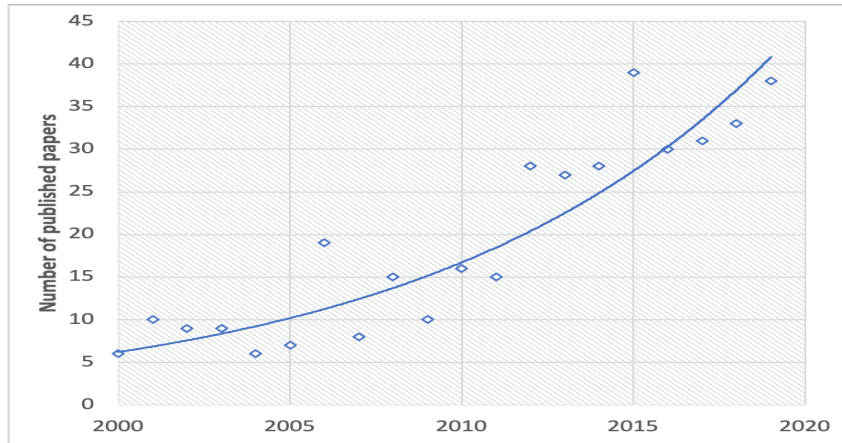


Figure 3: Number of published papers on Smart Lighting Systems from 2000 to 2020

In addition, a review paper published in 2021 by Fächtenhans et al., shows the growth of scientific papers on smart lighting systems published in recognized journals. As can be seen in Figure 3 the growth is rapid [7] 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. In 232 papers of 384 (60%) energy savings induced by smart lighting are the main objective and for 128 the light quality was the central focus (33%).

A last indicator is given in Figure 4 which shows the exponentially increasing number of shipments of Smart Lighting units.

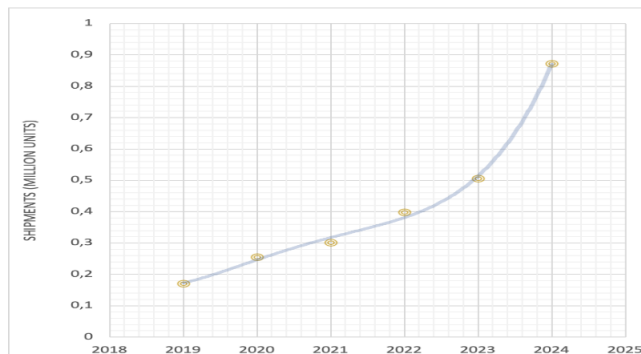


Figure 4: Shipments of Smart Lighting units. Data from [8]

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, the remaining USD 4.5 billion refers to smart functions implemented in fixtures or in distributed systems. In 2015, the global smart lighting market size reached USD 7.83 billion. [9] A 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 drivers and wireless adapters/sensors. [10]

Following a various analyst the Smart Lighting market is forecasted to grow, but the predictions are variable. The following list give some examples:

- Following mysupplier the revenue will 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. [11]
- According to Business Wire news, the global smart lighting market was 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. [12]

- Research and Markets reports that the global smart lighting market size is expected to reach USD 46
- Nair reports that the global smart lighting market should reach USD 21 billion in 2023, and is expected to grow at a CAGR of 22% from 2018 until 2023. [14]
- 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. [23]
- Data Bridge report, believes that the market is expected to witness market growth at a rate of 20.45% in the forecast period of 2021 to 2028. [15]
- 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). [16]
- 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. [17]
- Emergen Research estimates 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. [18]
- 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. [19]
- B. Thormundsson, published in Statista that the world smart lighting market will reach USD 43.97 billion by 2030. [20]

Figure 5 combines all the above harvested data and gives a global overview concerning the Global Smart Lighting market size. Based on our data harvested from the literature our forecast shows that the segment should exceed USD 90 billion by 2035 and this is comparable with the USD 133 billion revenue achieved in 2020 by legacy lighting industry.

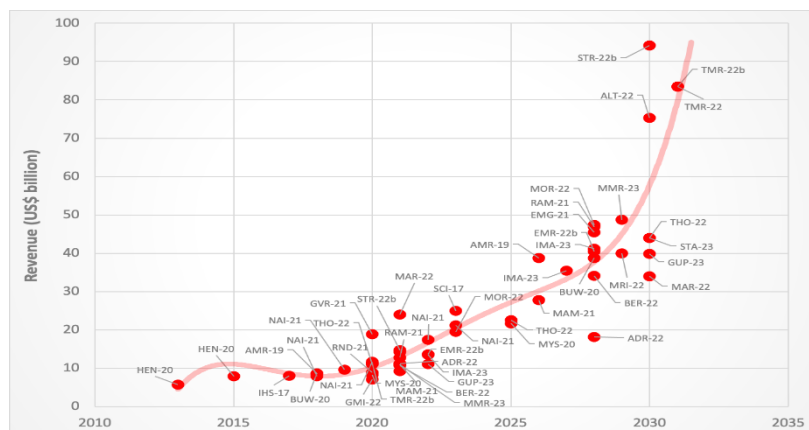


Figure 5: Smart Lighting market size as given by different analysts. Data harvesting from literature by G. Zissis, the labels in the graph indicate the source.

In the literature, smart lighting market is usually separate three parts: (1) hardware segment; (2) software segment; and (3) service segment.

The hardware segment is expected to attain the highest revenue contribution as in 2020 lamps and fixtures are an inseparable component of smart lighting. [13] The segment is forecast to grow from USD 5.1 billion in 2020 to USD 12.7 billion in 2025 at a CAGR of 20%. [11] 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. [17]

The software segment is to grow in 2022-29 period from USD 1 billion to USD 2.9 billion at 22.3% CAGR during the. [11] The software segment is expected to register the highest CAGR. 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, Cortana, 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. [17]

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 [11] Emergen predicts a CAGR of 20.8%. [18] Figure 6 gives the revenue change of the 3 segments from 2020 to 2025.

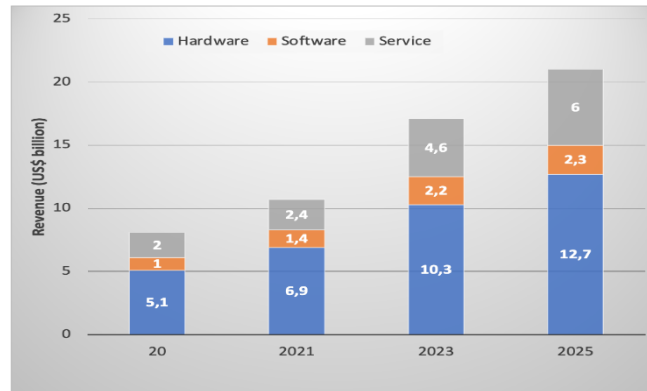


Figure 6: Revenue distribution among the 3 market sub-segments from 2020 to 2025.

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 expand from USD 2.4 billion to USD 7 billion at 23.7% CAGR in the 5-year 2020-25 period. [11] Further, integrative lighting systems market is expected to reach USD 3.91 billion by 2024. [21]

In 2019, North America dominated the market, contributing more than a 33% share of the overall revenue. [12] For 2020, Emergent attributed 41% of the market shares to this region. [18] Figure 7 gives the USA market split among the 3 usual subsegments.

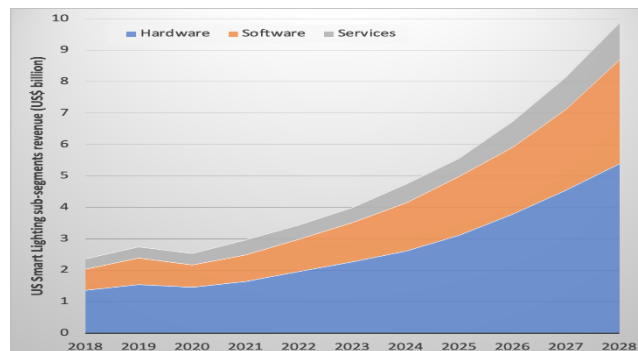


Figure 7: USA smart lighting revenue by sub-segment. Data from [22]

In 2022 Europe leads the market. [23] However, following [12] the European smart lighting segment revenue is approximately USD 2 billion in 2018 and is expected to grow at CAGR of 20% from 2018 to 2024. [14]. A. Gupta, in 2023 gave the European Segment revenue at USD 4.04 billion. [24] The largest European market in 2021 was Germany. [25] Figure 8 gives the market shares in various European countries (RoE is rest of Europe).

From 2023 Asia-Pacific (APAC) is expected to dominate the smart lighting market share, garnering 24% of the total share. [14] 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 20%. [26] 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. [13] APAC region market is expected to grow at a CAGR of 8.5% between 2017 and 2025. [14] 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. [23]

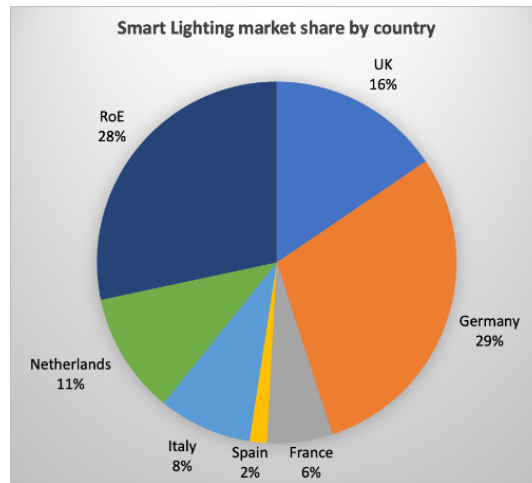


Figure 8: Smart Lighting market share by European country. Data from [SRT-22b]

The global smart lighting controls (hardware) market is expected to grow at a CAGR of 21% from 2018 to 2024. [14]

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% CAGR, [11] Straits Research analysts forecasted that the wired segment accounted for the largest market share and is estimated to grow at a CAGR of 22% during the 2021-29 period. [26]

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. [28] 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 workspaces. 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. [28] 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. [13] It will lead the growth from 2018 onwards. [14] 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 period³. [29] The Li-Fi technology can unleash the internet of things (IoT)'s potential, enabling Industry 4.0 applications. This visible light communication (VLC) protocol can enable big data and other technologies, including IoT. One year after the LiFi entering the market, the revenue was just USD 1.8 million. [30] Following various markets Insight analysts, Li-Fi Market size exceeded USD 70 million in 2019, reached at USD 127.66 million in 2021 and is poised to grow at something between USD 7 and USD 15.1 billion with a CAGR of over 50% between 2020 and 2030. [31, 32] This growth can be attributed to an increase in smart and connected devices generating 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. [30] Figure 9 gives a global view of various data harvested from literature.

³ The Li-Fi technology was first introduced in the year 2011

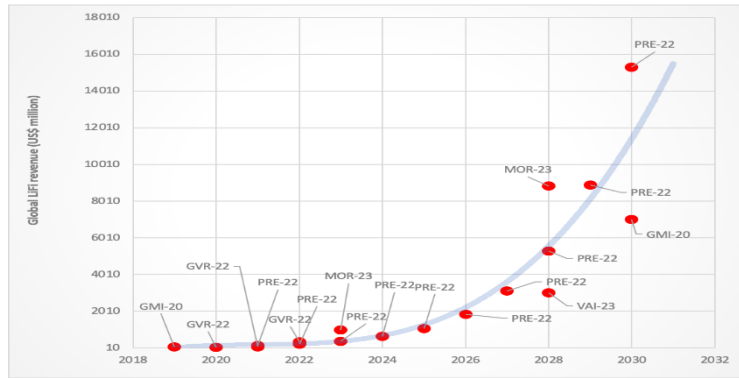


Figure 9: Global LiFi market size as given by different analysts.

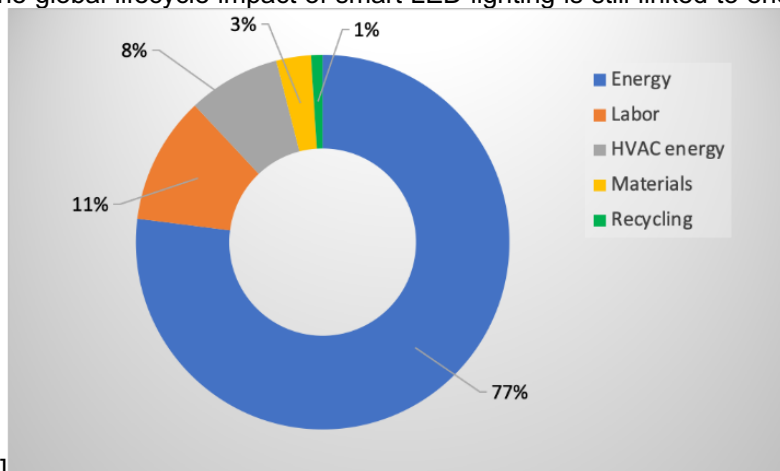
Smart lighting, energy and market impacts

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 /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 in daylight harvesting in buildings. This technique involves using sensors to measure the amount of day light entering a space and then adjusting electric lighting levels accordingly. The objective is to maintain a consistent light level while minimizing energy usage. Arrow Intelligent Systems metanalysis based on 2016’s sensors technologies estimated that use of sensors can achieve energy savings and Table 1 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. [33]. Today, five years later, the use of sensors allows to achieve much better savings assuming that daylight use is not jammed by architectural elements.

Table 1: Potential energy savings using sensors combined with controls in 2016.

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%

Following Nair, the global lifecycle impact of smart LED lighting is still linked to energy use during the



full life cycle. [14]

Figure 10 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.

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.

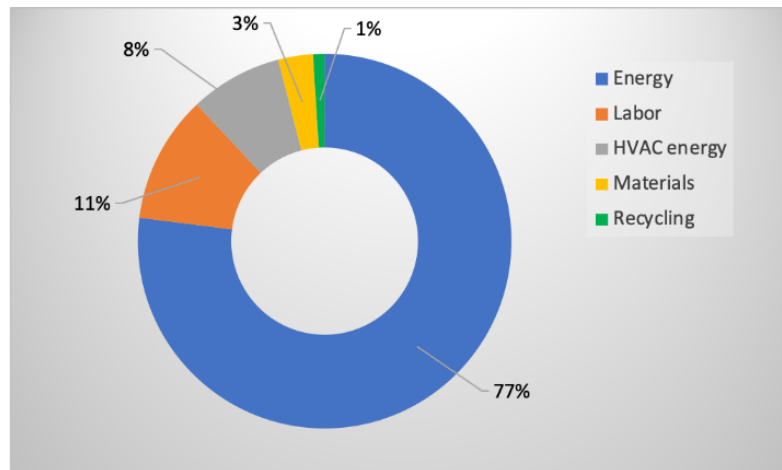


Figure 10: Smart lighting impact on energy within the full life.

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 favor 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. 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.

Azad et al., estimated that, in USA, with a total labor and materials USD cost of 516 for smart wireless lighting system installation and 41% savings compared to wired control solutions, the payback period for the wireless control environment is in the order of 2.3 years. [34] 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 streetlights. [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 60% reduction of electricity demand. [14]

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). [35]. 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. [36] An older analysis from SciTech shown that the CAGR was in the order of 2% in the period 2017-21. [21] MKLights relating a TrendForce forecast, estimated that the scale of the smart streetlamp 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. [36] The reality is most probably between those two growth predictions, but we can expect a stabilization in the next decade.

The Singapore government rolled out connected streetlights 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 the next 10 years of operation. Each district will have

about 4,000 to 5,000 connected street lights. In comparison, there were 500 such “smart” connected streetlights in Singapore at the end of 2014. [27]

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. [29],[37] 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. [18]

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. [37]

China since 2016, had 542 cities under Smart City development and that number is expected to increase with rising government investment into this industry. The annual amount of investment into Smart City projects rose from USD 52.7 billion in 2017 to USD 173 billion in 2021. [38] This a fabulous driver for smart lighting projects provide that this momentum will be maintained.

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. [37] The Spanish town of Pozuelo de Alarcón, located 15 kilometers 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. [38]

In the non-residential lighting sector, an early study reviewed 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. [40]

In the streetlighting sector, 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 surrounding light into account. But there are many more benefits to switching to smart streetlights. [41] The dynamics such as rise in demand for intelligent streetlighting 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 streetlights that would be installed in cities across various countries would reach around 73 million by 2026. [42]

Smart streetlights 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. 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. Streetlights 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 streetlights. [41] 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. [41] However, for citizens, the smart lighting with cameras raises primary privacy and surveillance concerns, given the data that could be collected. [43] 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. [43]

Conclusions

Today, lighting is responsible for an annual worldwide CO₂ gas emission of 1.38 billion metric tons. 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 electric light shall attain almost 285 Plmh corresponding to an increase of 32% in lighting service demand. Further, beyond the implication of lighting in energy, greenhouse gas emissions and depletion of abiotic resources of our planet, electric 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 the early 2000s, the rise of Solid-State Lighting (SSL) has been considered as the 3rd revolution in the domain of lighting. The best commercialized 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 linear T5 fluorescent tubes. However, this is not sufficient to inhibit the well-known rebound effect. Only the transition from the conventional legacy (“dummy”) lighting technologies to “digital” driven smart lighting can do it and that because use of smart technologies assists, in the most cases, the end-user to take the good decision. That way, smart lighting is becoming the 4th revolution and it expected to be the “heart” of the “Internet of Things” in smart cities and smart buildings.

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 USD 98 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 integrative lighting solutions. 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 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. The technology can unleash the IoT's potential, enabling Industry 4.0 applications well beyond lighting.

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