# Changing the colour of night on urban streets - LED vs. part-night lighting system

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**Changing the Colour of Night on Urban Streets - LED vs. Part-Night Lighting System**

**Abstract**

Many cities in the United Kingdom are upgrading the streetlights to white light-emitting diode (LED) lamps for reducing the electricity costs and attaining the sustainable energy solutions. Installation of LED lamps on urban street requires higher installation costs and a long-term period to payback benefits of replacing outdated streetlights in terms of energy savings and costs. To achieve the short-term energy efficiency of urban street lighting, city councils sometimes adopt the part-night lighting system particularly in the residential areas. The Coventry City Council recently replaced 29,701 existing sodium lights with LED lamps. This paper performs the economic analyses to understand the feasibility of two street lighting systems: LED lamps and 'part-night' lightings on the Coventry streets during the twenty-year period assuming the return period of investment is twenty years. The projection of energy consumption and costs for LED lamps and part-night lighting systems shows that electricity can be saved by 44 percent and 21 percent comparing to current electricity usages, respectively. Considering the budgetary constraints of Coventry City Council, this paper concludes that the part-night lighting system may be beneficial in short-term period, but it is economically feasible to replace the existing lower efficiency lights with LED lamps.

**Keywords**: LED lamps, part-night lighting, energy efficiency, economic feasibility, health.

## 1. Introduction

Streets lit by technologies dating back to the 1960s are one of the largest energy drains for the municipalities in the United Kingdom (UK) that is approximately 40 percent of their total electricity consumption (Griffiths 2017). The electricity costs for street lighting are a significant expenditure for a small city like Coventry in the UK with approximately 32,000 lighting columns (Balfour Beatty 2011). There is a substantial increase in the electricity cost particularly through the rapid increase in the cost of oil and gas (much of which comes from abroad) that generate around 80 percent electricity in the UK (Loe 2009). For promoting energy efficiency at street lighting, focus should be given on the consumption, production patterns and program costs ensuring the minimisation of electricity consumption as well as high quality lit environment and safety for the people. The UK cities are upgrading the streetlights to white light-emitting diode (LED) lamps to ensure not only the energy efficiency but also to help fight crime and promote safe cycling despite the objections from some city dwellers for its brightness and changing the colour of night on urban streets. For example, Kent County Council is installing 118,000 LED lamps, Leicestershire plans to have 68,000, Manchester will have 56,000 and Gloucestershire will have 55,000 LED lamps on the streets.

Several studies (Escolar et al. 2014, Iveland et al. 2013, Bilec et al. 2010) assessed the energy efficiency of LED lamps comparing to the traditional fluorescent lamps. Escolar et al. (2014) claimed that LED lamps could improve energy efficiency by up to a factor of five without altering light intensity levels that is appealing to lighting authorities for significant energy savings on street lighting.  Higher electricity savings cause less carbon footprint as electricity is still mostly generated from fossil fuel. Bilec et al. (2010) stated that LED lamps could reduce 25 percent emission of airborne toxins and particulates comparing to the metal halide and High-Pressure Sodium (HPS) lights. Iveland et al. (2013) compared different street lighting systems and argued that LED lamps were more efficient on urban streets because of not only consuming less energy but also ensuring safety by providing bright lights. Zhang et al. (2014) examined the technology on proficiencies of different lighting foundations through laboratory examinations of visual performance as well as brilliance awareness and concluded that LED lamps are more appropriate for highways comparing to other lights.

Cost effectiveness due to longer lifespan and less maintenance operations is another advantage of LED lamps (Li et al., 2015; Xu et al., 2012). In addition, LED lamps can be remotely controlled by a central computer system such as the system developed by OSRAM Licht AG. This allows a specific selection of lights to be simply switched on and off from one location, which also aids in implementing a part-night lighting system. Also, LEDs aren't restricted to on or off states: the ability to dim an LED light can be built. Several studies (Falchi et al. 2011, Sacks et al. 2011, Welsh et al. 2008) examined the benefits of LED lamps on the urban streets in the UK. Falchi et al. (2011) and Sacks et al. (2011) ascertained that LED lamps significantly reduced the road accidents and crimes on major roads in the UK. Welsh and Farrington (2008) found the similar findings after assessing the impact of LED lamps on the crime rates at five cities in the UK and argued that street lighting was more plausible than surveillance and deterrence since it increased the community pride and informal social control. In addition, higher ambient light levels of LED lamps increase the effectiveness of other security measures, such as closed-circuit television (CCTV) and automatic number-plate recognition (ANPR) at night.

Installation of LED lamps on urban street requires higher installation costs and a long-term period to payback benefits of replacing outdated streetlights in terms of energy savings and costs. To achieve the short-term energy efficiency of urban streetlighting, city councils sometimes adopt a 'part night' lighting system particularly in the residential areas where lights of relatively lower importance (in respect of traffic accident and crime rate) are dimmed or switched off at times during the night when they are least likely to be needed (Plainis et al. 2006). The city councils require strategies to upgrade the street lighting considering the budgetary constraints and ability to develop, implement and evaluate the programmes of installing the LED lights on the streets. The Coventry City Council recently replaced 29,701 existing sodium lights with LED lights of which the current total energy usage is 8,290,965 kWh. This paper performs the economic analyses to understand the economic feasibility of two street lighting systems: LED lamps and part-night lighting system on the streets in Coventry city during the twenty-year period (2010-2030) assuming that the return of investment period is twenty years. Data were collected from the Traffic and Network Management and Street Lighting departments of the Coventry City Council. Data were also collected from Balfour Beatty who are in partnership with Coventry City Council carrying out the installation of 28,700 new LED lighting columns on the streets of Coventry city that was started on the 1st November 2010.

## 2. Energy efficiency of new LED lighting project in Coventry city

The projection of energy usages by existing, new LED lamps and part-night lighting system during the period of twenty years starting from the year of 2010 is shown in Figure 1. The prediction of energy usages assumed that the existing lights would be replaced by LED lamps evenly across the first year (year 2010) accounting for the energy usage of 6,003,173 kWh. During the period of 2011 - 2030, all 29,701 lighting columns have new LED lamps resulting in a total energy usage of 4,568,799 kWh per year.

To reduce energy consumption, maximise the cost efficiency of the existing lighting system and compare with the energy efficiency of new LED technology, this study proposes a 'part-night' lighting regime in four phases for the urban streets of Coventry city (Table 1). In this lighting scheme, street lights will be 20 percent dimmed (80 percent brightness) until midnight starting from 8:00 pm and the lights will be 100 percent dimmed after mid-night until 5:00 am. The lights will be switched back on at 80 percent brightness until the standard morning switch-off. This study considers two factors to propose the part-night lighting regime: the possibility of road accidents and severity of possible road accidents. Residential areas have much less traffic during the night, especially late at night when the part-night lighting system will take effect.

**Table 1: Part-night lighting regime**

| Lighting Schemes | Phase 1 | | Phase 2 | | Phase 3 | | Phase 4 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Start | Dim% | Start | Dim% | Start | Dim% | Start | Dim% | End |
| Current | Switch on | 0% | 20:00 | 0% | 00:00 | 0% | 06:00 | 0% | Switch off |
| Part-time | Switch on | 0% | 20:00 | 20% | 00:00 | 100% | 05:00 | 20% | Switch off |

The energy savings of two lighting systems (LED lamps and part-night) are projected during the period 2010-2030 comparing with the current usage per year (Figure 2). Figure 2 shows that annual electricity usage for street lighting can be reduced by 36.20 percent to 43.70 percent with the new LED lamps except for the year 2010 (27.60 percent savings of electricity usage) due to the installation process. On the other hand, the annual electricity saving rates for part-night lighting scheme are almost at similar values ranging from 16.10 percent to 20.50 percent comparing to the existing lighting system (Figure 2).

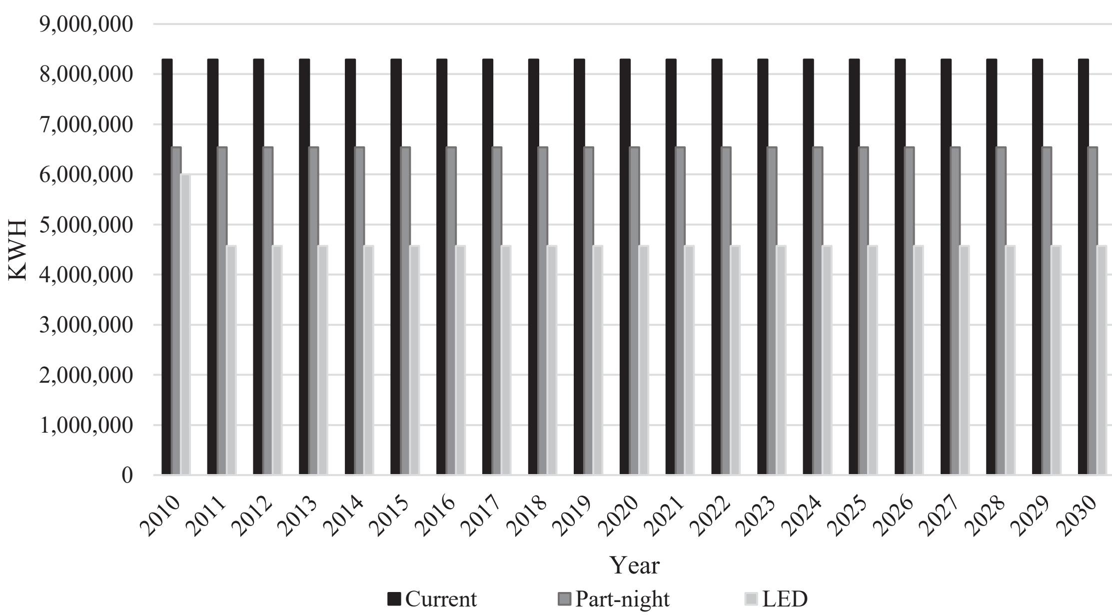


**Figure 1: Energy usages by different schemes during 2010-2030**

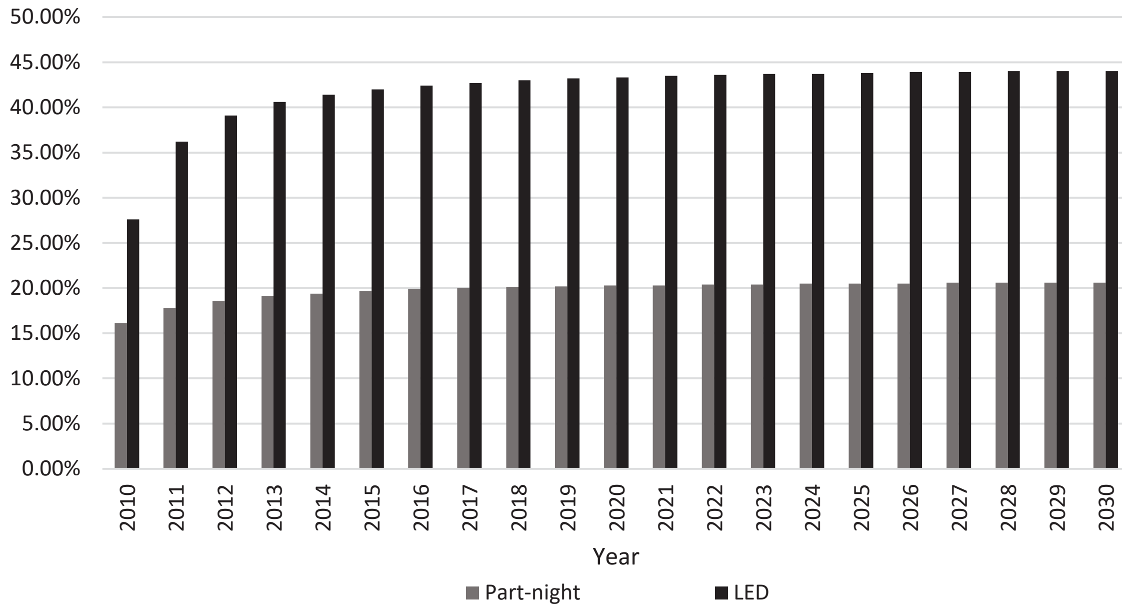


**Figure 2: Predicted energy savings generated by LED Replacement and part-time Schemes during 2010-2030**

Energy prices are now 33% higher than these were six years ago in the UK (Figure 3), the present value of electricity consumption and savings for the street lighting systems was calculated during the period of 2010-2030 (Figure 4 and 5). The discount and inflation rates of 3.5% and 2.4% are applied in the economic analysis methods to estimate the present values of energy costs for different lighting schemes (HM Treasury, 2017). Since the electricity price is fluctuating in recent years, the current electricity cost of street lighting at Coventry city that is £870,551 per year is considered in the projection of electricity costs for LED lamps and part-night lighting systems. The first-year energy cost while the LED lamps were replacing existing lights was estimated £630,333 (excluding the replacement cost). For succeeding years, the cost was calculated as £479,724 per year. The total replacement costs for LED lamps including vehicles and transportation, labour, materials, overhead and a standard profit margin were estimated as £7,296,752. The Coventry City council is responsible for approximately 32,000 street lights with an annual maintenance costs of approximately £1.3 million. This study only considers the 28,700 new LED lighting columns that were installed on 1st November 2010 for the project appraisal purposes. Therefore, the annual maintenance costs for the old 28,700 street lights are approximately £1.17 million. Using the current price of electricity, the predicted costs of energy for street lights in part-night lighting scheme were estimated as £686,890 per year. The present value of energy costs with and without the maintenance costs of existing lights and installation costs of LED lamps are presented in Figure 4 and 5. The economic analyses reveal that LED lamps will be highly energy efficiency over existing lighting system that yields energy savings of 44 percent resulting in a total savings of £7,240,482 during the period of 2010-2030 (Figure 4 and 5). But this scheme requires replacing the existing lights at an initial cost of £7,296,752; and there is no energy savings on the first year because of the replacement of exiting lights with LED lamps (Figure 5). On the other hand, opting part-night lighting system can save the energy up to 21 percent that equals to £ 3,473,289 during the design period (Figure 4 and 5).

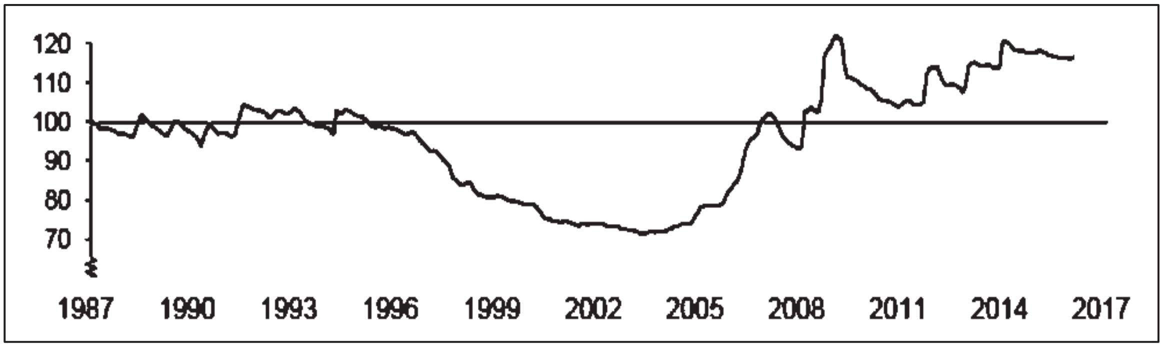


**Figure 3: Electricity prices relative to 1987 (Dempsey et al. 2016)**

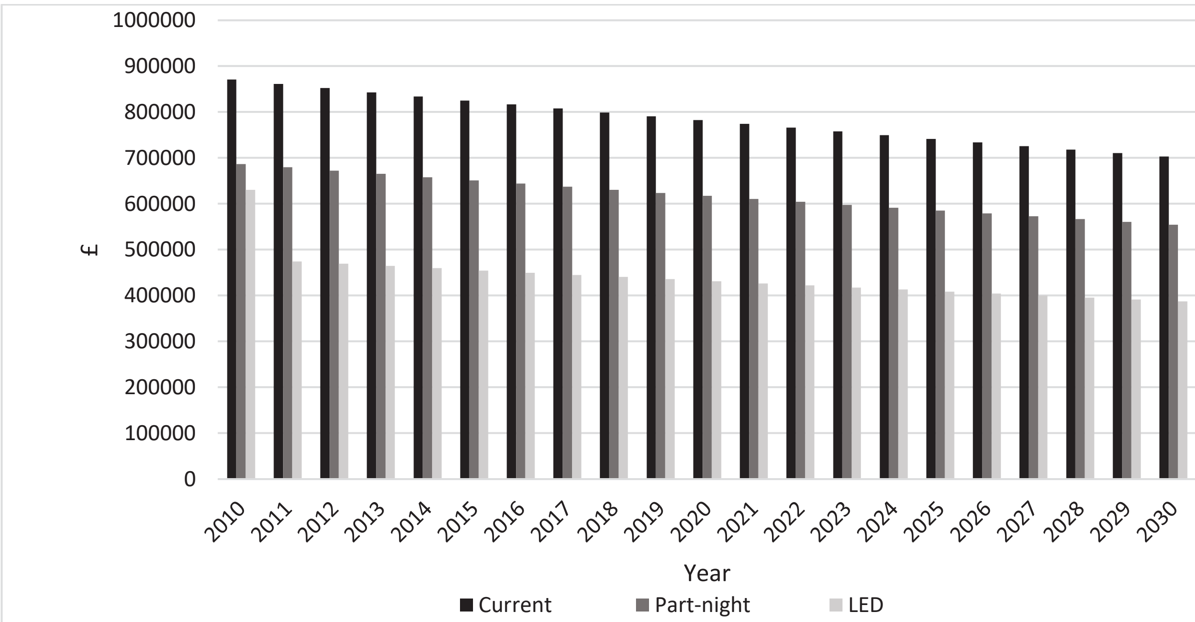


Figure 4. Present value (base year 2010) of energy costs (£) of street lighting schemes during 2010-2030

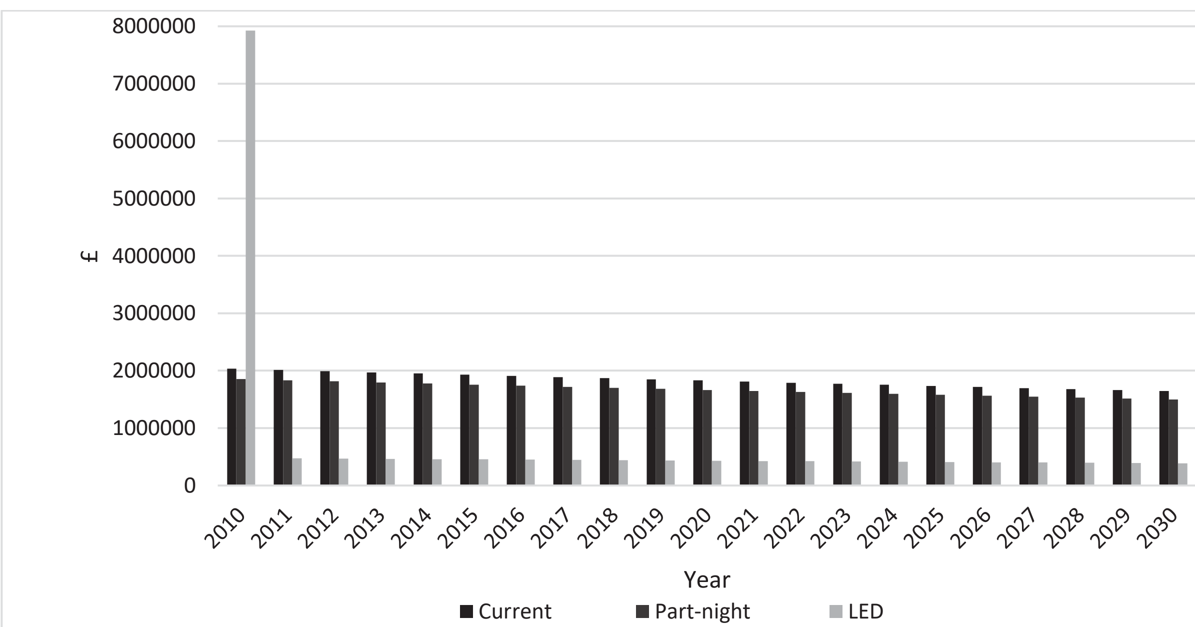

Figure 5. Present value (base year 2010) of total costs (£) of street lighting schemes during 2010-2030

The net-present values (NPVs) of total energy savings for part-night and LED lighting schemes comparing to current lighting system are estimated as £3,473,289 and £ 7,240,482 during the period of 2010-2030, respectively (Figure 6). The NPV of total savings for part-night scheme remains same during the design period including the installation costs for LED lamps and annual maintenance costs for old lights (no maintenance cost for new LED lamps during the design period as the LED lamps have a lifespan of 50,000 to 100,000 hours) (Figure 7). However, the NPV of total savings for LED lamps is increased by approximately 204% (£21,993,256) during the same period after the inclusion of present value of installation costs and annual maintenance costs into the economic assessment (Figure 7).

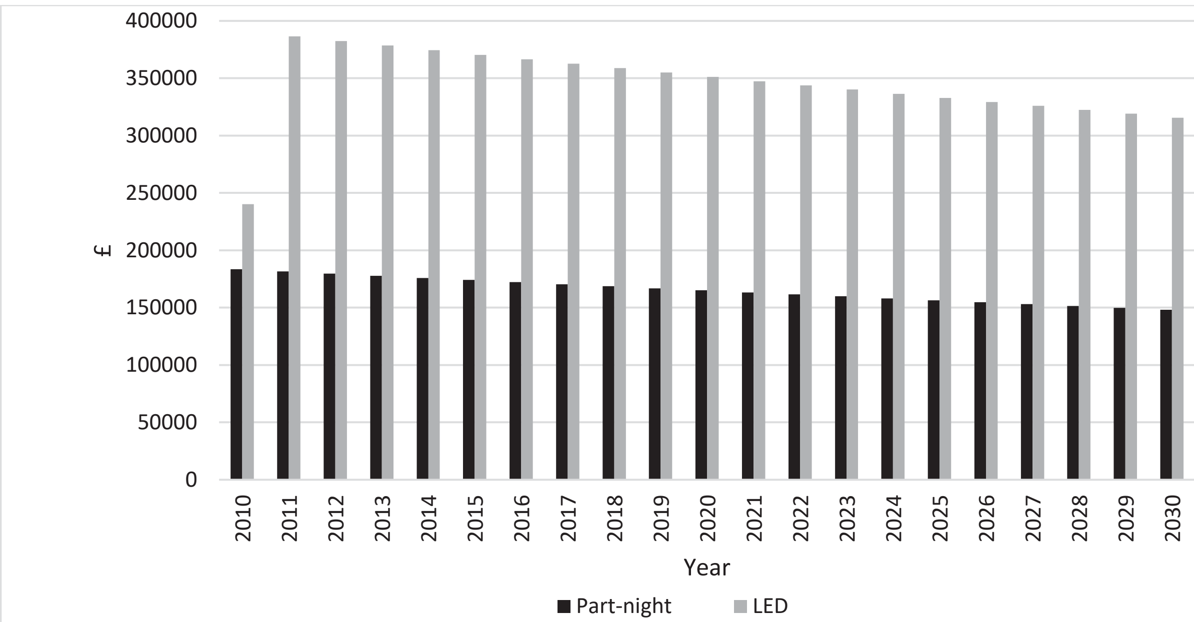


Figure 6. Present value (base year 2010) of predicted energy savings generated by LED Replacement and part-time Schemes during 2010-2030

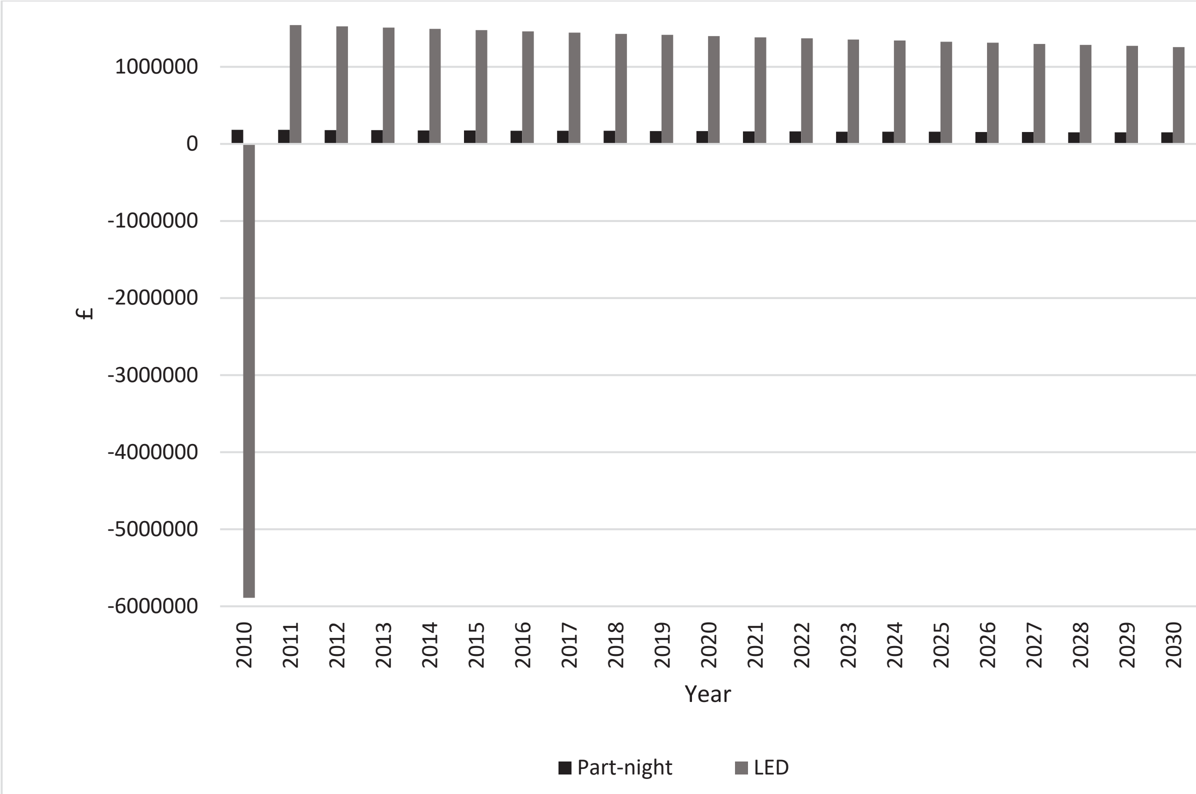


Figure 7. Present value (base year 2010) of predicted total savings generated by LED Replacement and part-time Schemes during 2010-2030

The experience of part-night lighting scheme (switched off lights between hours of midnight and 5:30 am during weekdays and between 1:00 am and 6:30 am during weekends) at the nearby Warwickshire County Council reveals that there is no evidence of increasing road accidents and crime rates because of introducing this system. A recent study by the London School of Hygiene and Tropical Medicine reveals that there is a little evidence of harmful effects of switch off, part-night lighting, dimming, or changes to white lights (LED lamps) on road collisions or crime rates in England and Wales (Steinbach et al. 2017). However, Steinbach et al. (2017) acknowledge that the effectiveness of part-night lighting varies greatly depending on many factors such as locations, road lighting class, population density and economic resources. Moreover, part-night lighting system ensures no artificial light at night and dimmer lights near dusk and dawn that helps to reduce negative impacts on nocturnal wildlife and lower light exposure to the sleep cycle. The part-night lighting system still utilises existing lower efficiency lights which will have to be changed some time in the future although it is beneficial for the Coventry City Council in short-term period.

The newly installed LED lamps at Coventry streets can reduce the carbon emissions by 38% and will contribute additional savings on carbon reduction commitment (CRB) tax that is £16 per ton of Carbon dioxide emissions. For instance, the Surrey County Council (SCC) has initiated to convert 89,000 street lights to LED lamps at a cost of £18.5 million. The SCC estimated that the new LED lamps will save approximately £2 million of energy cost per year, reduce carbon impact by 6,200 tonnes and avoid the CRB tax altogether (SurreyLive 2018). The currently costs of CBR tax for the SCC are up to £160,000 a year (SurreyLive 2018). In addition, the central monitoring system of remotely controlled network of LED lamps can optimise the street lighting and adjust the brightness where necessary. For example, the LED lamps on the urban streets in Cardiff city are dimmed between 12 midnight and 6 am (Cardiff News Room, 2018).

The LED lamps have better visual presence that supports active transports and reduces street crimes. College of Policing (2013) reviewed several studies on the relationship between improved street lighting and crime rate and stated that improved street lighting was associated with a relative reduction in crime of 21 per cent in areas it was introduced, compared to similar areas where there was no such improvement. College of Policing (2013) argued that improved street lighting helps to increase surveillance, community pride and informal social control that reduce the crime not only in areas where street lighting was enhanced but also in the adjacent areas. Welsh and Farrington (2008) reviewed thirteen studies related to improved street lighting and concluded that the UK studies showed the positive effects of improved street lighting on crime reduction in some circumstances although these studies unable to determine the optimal circumstances.

There are other methods of smart lighting aside from the energy efficiency by LED lamps and part-night lighting. Smart systems can consist of many different aspects, but mostly involve some form of interconnectivity using an ‘Internet of Things (IoT)’. An example of this is the MAYRISE Central Street Lighting Management System which is currently in use on some streets in the Coventry city on an experimental basis. The system allows for remote monitoring and control of the street lights in the city. The combination of MAYRISE Street Lighting and bespoke reporting can improve the monitoring performance of the operational system with respect to energy targets. If these smart systems can be integrated with LED technology, the advantage is to adapt the brightness and colour of specific groups of lights at any location. The appropriate example is the lighting system planned by the Dutch city of Eindhoven. Another form of smart lighting involves using sensors to minimise the amount of time the lights need to spend turned on. For example, light sensors could detect the light levels around a street light decreasing to a certain level and automatically switch on the light, or a proximity sensor could detect vehicle or pedestrian movement from a certain distance and automatically switch on street lights as they pass (Escolar et al. 2014). This would allow the street lights to be off for most of the time, and only switched on when they are needed, which is the logical progression from a part-night lighting scheme. However, many of these methods are new developments which require further testing before they can be utilised in a real-world environment or are simply too expensive for the budget of most lighting authorities or city councils.

There is a debate on the adverse health and environmental effects of LED lamps. Lim et al. (2011) investigated the potential environmental effects of LEDs applying the hazardous waste regulations and considering the resource depletion and toxicity aspects. Lim et al. (2011) concluded that LEDs contain hazardous materials such as lead, arsenic, copper, nickel, iron, silver and other toxic substances at excessive levels. The prolonged exposure of LED lamps can damage the cell in retina of human eyes. The French Agency for Food, Environmental and Occupational Health & Safety (ANSES) published a report on the health effects of LED lamps and identified the photochemical effects of blue lights and glare such as spectral imbalance and high level of radiance that may damage the eyes (ANSES, 2010). Dr. Celia Sánchez-Ramos, of Complutense University in Madrid argued that LED lamps had short wave, high-energy blue and violet end of the visible light spectrum that might damage the light sensitive tissues of retina under prolonged exposure (thinkSPAIN, 2013). Moreover, too much lights from LED lamps can threaten the nocturnal animals, plants and micro-organisms. This study only focuses on the long-term energy savings for replacing traditional lighting system with LED lamps avoiding the imponderable negative effects of LED lamps on health and environment. In addition, this study unable to quantify the positive effects of crime reduction, remote monitoring and IoT interconnectivity technologies within the economic feasibility analyses. Future studies should include all aspects of health and environmental effects as well as benefits installing LED lamps in the economic feasibility analysis.

## 3. Safety and health issues of LED lamps

Despite the energy efficiency and lower carbon emissions, people including Public Health England are decrying the long-term negative impacts of LED lamps on people's eyesight and leaving them with disruption of the circadian system (sleep cycle) that eventually have adverse impacts on people's wellbeing and safety. For example, after the replacement of around 185,000 yellow HPS street lights with LED lamps in Rome on March 2017, residents of the city described the new whiter lights as harsh and dazzling and argued that LED lamps lessened the ambience of the city.

Falchi et al. (2011) stated that replacement of widely used sodium lamps with white lamps (Metal-halide and LED) would produce an increase of (light) pollution in the scotopic and melatonin suppression bands of the human eye more than five times of the present levels that might cause the degradation of neuronal cells and potential damage of eyesight. The brightness and wavelength of lights from LED lamps may have adverse impacts on the circadian cycles, behaviour and niche partitioning of diurnal, nocturnal and crepuscular animals; day-length that activates seasonal phonological events such as bud burst, flowering and senescence; and deduce the position of leaves within a canopy (Gaston et al. 2012). Since LED lamps have larger range of light spectrum than traditional fluorescent lights (Figure 8), LED lamps has the potential to negatively impact a much wider range of light-sensitive organisms than fluorescent lamps (Peitsch et al. 1992; Briscoe and Chittka 2001). However, Seang Mei Saw, a professor of epidemiology and ophthalmology at the National University of Singapore had suggested that light with a higher proportion of blue in its spectrum might help to protect against the effects of myopia, especially in children (Lougheed 2014).

The most efficient blue-rich light (above 4500 Kelvin) can affect sleep patterns but the Coventry is using a warm white light (3000 kelvins) that reduces glare and are well within the current British standard (BS EN 13201-2:2003). Research about the health effects of LED lamps is still ongoing, so there may still be unknown health benefits or detriments that can impact the decision to implement them in the street lighting.

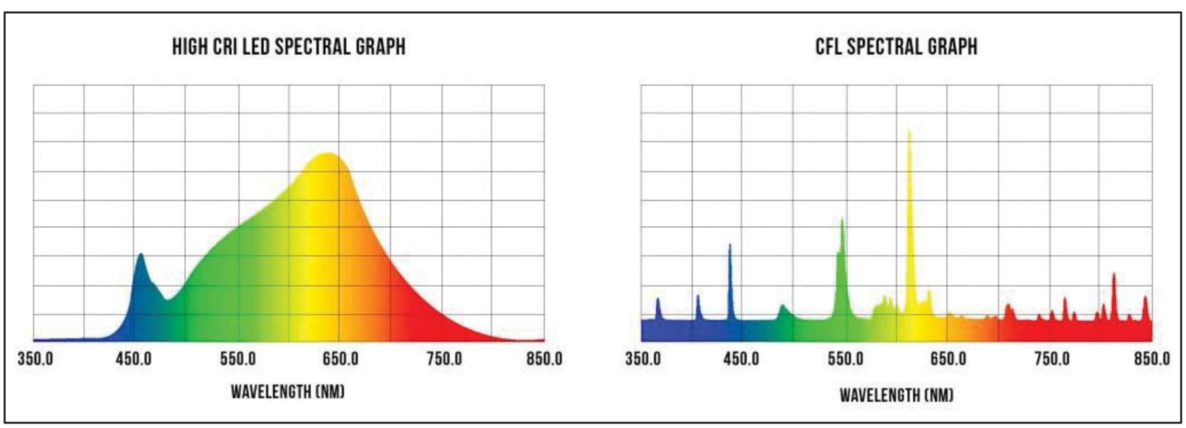


**Figure 8: Sample wavelengths of light emitted by LED and CFL lamps (Sonderen 2017)**

## 4. Conclusions

Increasing energy demand urges for sustainable energy solutions to mitigating the climate changes and ensuring energy security especially for countries like the UK who are mostly dependent on other countries for the generation of electricity. Many cities in the UK upgrading the streetlights to white LED lamps for reducing the electricity costs since lighting urban streets costs approximately 40 percent of total electricity consumption in a city. Installation of LED lamps on urban street requires higher installation costs and a long-term period to payback benefits of replacing outdated streetlights in terms of energy savings and costs. To achieve the short-term energy efficiency of urban streetlighting, city councils in the UK sometimes adopt a part-night lighting system particularly in the residential areas. The Coventry City Council recently replaced 29,701 existing sodium lights with LED lamps. This paper performs the economic analyses to understand the feasibility of two street lighting systems: LED lamps and part-night lightings on the streets of Coventry during the twenty-year period (2010-2030) assuming that the return period of investment is twenty years. The part-night lighting regime is proposed in four phases: street lights will be 20 percent dimmed (80 percent brightness) until midnight starting from 8:00 pm, lights will be 100 percent dimmed after mid-night until 5:00 am and switching back of lights at 80 percent brightness until the standard morning switch-off.

The savings of energy usages and total costs for LED lamps and part-night lighting are projected comparing with the current lighting system during the period of 2010-2030. The projection estimates that LED scheme can save the energy of 44 percent comparing to current electricity usages resulting in savings of £7,240,482 during the projection period. The total replacement costs for LED lamps are estimated as £7,296,752. The total savings for LED lights are increased by approximately 204% (£21,993,256) during the same period after the inclusion of installation costs of LED lamps and annual maintenance costs for existing lighting system into the economic assessment. The projected energy savings for the part-night lighting scheme is 21 percent comparing to current electricity usages that yields a saving of £3,473,289 during the same period. Since the part-night lighting system is using the existing lighting system incurred with current annual maintenance costs, the predicted saving for this lighting system is £3,473,289 during the twenty years. The part-night lighting system still utilises existing lower efficiency lights which will have to be changed some time in the future although it is beneficial for the Coventry City Council in short-term period. The evidence from different cities shows that LED lamps increase active transports and reduce the street crimes; however, this study unable to quantifies the levels of crime and accident reduction for including in the economic feasibility analysis.

Despite the energy efficiency and low carbon emissions, LED lamps are criticised for the adverse impacts on the wellbeing and safety of human and nocturnal wildlife. In the part-night lighting scheme, there is no artificial light at night and dimmer lights near dusk and dawn reducing the negative impacts on nocturnal wildlife and lower light exposure to the sleep cycle. The Coventry City Council is also using the MAYRISE Central Street Lighting Management System as a pilot project on some streets to improve the monitoring performance of street lighting system. There are other smart lighting systems that are newly developed and more energy efficient but require further testing before they can be utilised within the budget constraints of cities. Many European cities are replacing the traditional street lights with energy efficient LED lamps such as Albertslund (Denmark), Birmingham (UK), Eindhoven (The Netherlands), Hódmezővásárhely (Hungary), Lyon (France), Mechelen (Belgium) and Tilburg (The Netherlands). Struggling to reduce the energy drains in street lighting system, a growing number of UK city councils are installing LED lamps at the streets although having budget deficits and high installation costs for LED street lights. The findings of this study depict the long-term monetary and energy savings of replacing the traditional street lighting system with

LED lamps and giving the hopes particularly to the small city councils like Coventry that are tussling to reduce the energy consumption in street lighting system and CRB tax.

This study estimates the long-term energy savings for replacing traditional lighting system with LED lamps; however, unable to address the imponderable negative effects of LED lamps on health and environment. Future studies should include all aspects of health and environmental effects as well as benefits installing LED lamps within the economic feasibility analysis. Future studies should carry out a comparative feasibility analyses (considering indirect benefits and health impacts) of these technologies for lighting the urban streets of cities which are always struggling with the budget insufficiency.

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