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Energy Savings Potential for Street Lighting in India

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1. Introduction

In India, providing public lighting[1] is one important function that urban league bodies (ULB), commonly known in the US as municipalities, fulfill. Street lighting provides an important function; keeping pedestrians, drivers, and other roadway users safe, while promoting use of public spaces. Studies have shown that proper street lighting can substantially reduce fatalities and crashes with pedestrians[1] and lighted intersections and highways have fewer crashes than their unlit counterparts[2].

However, public lighting is costly for local governments. Street lights have high hours-of-use (they are on for over 4,000 hours per year) and thus are large consumers of energy. The Clinton Climate Initiative indicated that municipal street lighting can represent from 5% to over 60% of a municipal government's electric bill, depending on the municipality's size, the services it offers, and the efficiency of its public lighting [3]. In fact, one ULB in India, the Surat Municipal Corporation, estimates that 17% of the total annual municipal bill is due to street lighting [4]. Further, the Central Electricity Authority (CEA) of India reports that 1% of all electricity consumption in India, equal to 6.7 TWh in FY2010-11, goes to providing public lighting[5], costing ULBs more than $500M annually[2].

Despite the considerable expense and electricity use of public lighting, underserved areas exist throughout India as street lighting in Indian towns and cities is sometimes ill-maintained. In some municipalities non-functioning street lights are rampant, up to 70% reported non functionality[6] and areas still exist with no electricity or street lights[7], despite guidance from the Bureau of Indian Standards (BIS) in IS 1944 Parts I and II: Code of Practice for Lighting of Public Thoroughfares and the National Lighting Code[8][9], on proper levels of lighting for public streets. Thus, there is significant potential not only for energy-efficiency retrofits, but also for improved operation procedures in new or relocated street lighting installations. In a 2010 report, the United States Agency for International Development (USAID) and the Bureau of Energy Efficiency in India (BEE) published guidelines to increase

[1] According to the Delhi Electricity Regulatory Commission, the public lighting tariff is applicable to all street lighting customers in the specific categories of street lights and signals and blinkers of Traffic Police. We conclude that public lighting is predominately street lighting and use the terms interchangeably throughout this review article.

[2] Assuming ULBs are billed at an average rate of 4 Rs/kWh and an exchange rate of 50 Rs/$1 USD.

awareness of the BIS standards, to provide practical guidance on energy-efficient street lighting best practices, and to inform future updates to the standards. They provided basic information on design, procurement, operations and maintenance, and measurement and verification options for street lighting projects in India. USAID commented that the most common reasons for inefficient street lighting in India are[10]:

- Selection of inefficient luminaires
- Stocking problem (due to lack of storage space and poor storage conditions)
- Poor design and installation
- Poor power quality
- Poor operation and maintenance practices

They determined that tremendous potential exists to improve lighting quality, reduce energy use, costs, and greenhouse gas emissions through energy efficient retrofits for street lighting and improved operations and maintenance practices.

This report seeks to build on the USAID report by providing a quantitative estimate of the energy efficiency potential for public lighting in India and to provide some insight into the costs and benefits of a variety of public lighting technology options for the specific conditions in India.

2. Public lighting energy use in India: current and 2020 projections

2.1 Estimating the baseline

The first step of providing an efficiency potential is to determine the baseline for public lighting in India; how much energy is used, which technologies are installed, in what quantities, and the annual hours of operation. Data from a number of reports was collected in order to estimate the baseline electricity consumption.

2.1.1 Estimating Current Electricity Use

One report published in 2004 by USAID and The Energy Research Institute (TERI) estimated that the cumulative street lighting load was approximately 4,400 MW and that street lighting alone consumes 21 TWh of energy each year[11]. No information regarding the methodology for this estimate is available. Recently, the United Nations Environmental Programme (UNEP) sponsored en.lighten[3] initiative has been established to accelerate global market transformation to environmentally sustainable lighting technologies. As part of this program, they developed country lighting assessments, including estimates of current (2010) energy use for India. These assessments use national stocking estimates provided by lighting manufacturing partners, by country officials via a survey on the national lighting market, and by modeling data based on import and export data in the UNComtrade system to develop their estimate. Their estimate considered all lighting, categorized as residential, commercial/industrial, and outdoor, with the outdoor category presumably including more lighting than only public lighting. The en.lighten initiative does provide definitions of how they or the manufacturers categorized the luminaire types. Their outdoor energy use estimate is derived from quantities of luminaires and makes assumptions for average wattage and hours of use. The en.lighten initiative estimates that in 2010, outdoor lighting in India consumed 18.1 TWh[12].

[3] http://www.enlighten-initiative.org/portal/Home/tabid/56373/Default.aspx

The government of India (GOI) via the CEA reports annual electricity statistics for India each year, including public lighting use[5], [13], [14]. They reported that for FY2010-11, India as a whole consumed 6.7 TWh for public lighting. The CEA data is aggregated from metered data collected by regional regulatory commissions. This CEA reported value will be used as the baseline electricity consumption for public lighting in India for 2010 in this analysis.

2.1.2 Current luminaire types in use

Unfortunately, there is no comprehensive data available for street or public lighting specifying luminaire types currently installed. Some public lighting retrofit reports give detailed information on luminaire types replaced, but do not provide detail on current public lighting installations. A recent Times of India article provided such information for one ULB in India, the Bhopal Municipal Corporation, BMC[7].
The en.lighten initiative estimate is based on stocking data, which is a god representation of lighting by luminaire type in India. We use the en.lighten estimate of outdoor lighting as a base case for the distribution of lamps currently utilized for public lighting in India. The en.lighten initiative baseline estimate of outdoor lighting electricity use by luminaire type is presented in Table 1, along with their assumptions on wattage and hours of use[12]. The table also includes the information found in the article on the BMC. This study only utilizes the distribution of electricity use by luminaire type in our analysis.

Table 1: Enlighten Estimates for Outdoor lighting in India 2010

Luminaire Type	Units (million units)	Assumed Wattage	Assumed Hours of Operation	GWh	% of Total (units)	BMC % of Total (units)
Incandescent	1.78	70	2,920	364	2%	
Tungsten halogen	13.34	61	2,920	2,363	17%	
Compact fluorescent	4.97	18	2,920	254	6%	10%
Light emitting diode	3.75	15	2,920	160	5%	
High intensity discharge	19.80	120	3,650	8,673	26%	57%
Efficient high intensity discharge	0	96	3,650	0		
Linear fluorescent	31.70	52	3,650	6,017	41%	32%
Efficient linear fluorescent	1.86	39	3,650	265	2%	2%
Total	77.19			18,094	100%	94%

Similarly to the en.lighten initiative, the Electric Lamp and Component Manufacturers Association of India (ELCOMA), tracks stocks of luminaires with data from manufacturers. The ELCOMA estimate of stocking specifies the types of HID lamps in stock and this breakdown is given in Table 2. This data and interviews with experts supports that HID technologies are prominent in India for street lighting.

Table 2: ELCOMA estimates of HID lamp distribution in India

HID Lamp Type	2010 Stock (in million pieces)	% Stock
Mercury Vapor (MV)	7.2	28%
High Pressure Sodium (HPS)	9.1	36%
Metal Halide (MH)	9.0	36%
Total	25.3	100%

This estimate aligns well with the en.lighten initiative's estimate; it is 22% higher in overall volume in the HID category than the en.lighten initiative estimate, but it is reasonable to assume that the remaining stock is for other applications such as commercial or industrial lighting. In this analysis, the ELCOMA HID lamp distribution will be applied to the en.lighten HID category.

2.1.3 2010 Baseline Estimate by luminaire type

Our baseline estimate for public lighting by luminaire type is derived by combining the data from the CEA for electricity use, the en.lighten initiative for luminaire type use, and ELCOMA for HID luminaire type use. The baseline for energy use by luminarie type is presented in Table 3.

Table 3: 2010 India Baseline Public Lighting by luminaire type

Luminaire Type	% of Total (UNITS)	% GWh	2010-2011 GWh
Incandescent	2%	3%	169
Tungsten halogen	17%	16%	1,096
Compact fluorescent	6%	2%	118
Light emitting diode	5%	1%	74
Mercury Vapor	7%	14%	916
High Pressure Sodium	9%	14%	965
Metal Halide	9%	17%	1,145
linear fluorescent	41%	32%	2,147
Efficient linear fluorescent	2%	1%	101
TOTAL	100%	100%	6,731

2.2 Estimating growth in public lighting energy use

Public lighting energy use in India is growing. Additions to transportation networks is one primary reason. McKinsey reports that between 2010 and 2030, 2.5 billion square meters of roads will be paved across the country and 7,400 kilometers of metros and subways will be constructed[15]. Further growth may come from BIS standard compliance and improved lighting quality. Without significant efficiency improvement in public lighting, electricity use for public lighting is expected to increase throughout the next decade.

To estimate the growth rate of total public lighting energy use, we calculated the compound annual growth rate (CAGR) for the last 10 years from the annual public lighting energy use information published annually by the CEA[5] [13] [14]. The values for public lighting by year and the corresponding annual growth rate and CAGR are given in **Error! Reference source not found.**[16].

Table 4: Recent Public lighting energy use and growth rates

Year	Year	Public Lighting (GWh)	Annual Growth Rate	CAGR
0	2000-01	3,422	NA	NA
1	2001-02	3,587	4.8%	4.8%
2	2002-03	3,975	10.8%	7.8%
3	2003-04	4,426	11.4%	9.0%
4	2004-05	4,968	12.2%	9.8%
5	2005-06	5,177	4.2%	8.6%
6	2006-07	5,825	12.5%	9.3%
7	2007-08	6,131	5.3%	8.7%
8	2008-09	6,141	0.2%	7.6%
9	2009-10	No Data	No Data	No Data
10	2010-11	6,731	No Data	7.0%

As shown in Table 4, the average growth rate per year over the last 10 years is 7.0%. To calculate the business-as-usual case for public lighting electricity use, we use the observed CAGR of 7.0% through 2020. We found that the public lighting energy consumption will increase to 13.2 TWh by 2020, or essentially double from its use in 2010. We then apply the same proportions of luminaire types as given by the en.lighten initiavite and ELCOMA to complete the 2020 base-case scenario. The public lighting base case scenario for 2020 by technology type is given in **Error! Reference source not found.**, along with the 2010 case derived from the en.lighten and CEA data.

Table 5: Public Lighting Base case scenario for 2020 by technology type

Luminaire Type	Estimated Energy use 2010	Energy 2020 in Base Case	% GWh
Incandescent	169	332	3%
Tungsten halogen	1,096	2,156	16%
Compact fluorescent	118	232	2%
Light emitting diode	74	146	1%
Mercury Vapor	916	1,802	14%
High Pressure Sodium	965	1,898	14%
Metal Halide	1,145	2,253	17%
Linear fluorescent	2,147	4,224	32%
Efficient linear fluorescent	101	198	1%
Total	6,731	13,241	100%

3. Calculation of public lighting electricity savings potential in India

The potential impact for energy savings in street lighting in India is substantial. McKinsey lists street lighting efficiency as one of seven key levers that India can use to reduce carbon emissions[15]. Public lighting could have a large, swift impact, as each municipality has a substantial lighting footprint.

3.1 Mesopic Lighting

Public lighting designers are tasked with implementing lighting to meet a standard. The most commonly used approach for public lighting standards is to set a minimum value of luminance to be maintained on the roadway for the life of the installation, prescribed in candela/m^2, such as in the Indian National Lighting Code[8]. Currently, all illumination standards and testing instruments available on the market are based on the photometric standard of the photopic lighting state[17]. This system of light measurement determines the amount of light needed to perform a task, in lumens, regardless of the time of day or lighting conditions.

Humans can see in drastically different lighting conditions, from near total darkness to bright sunlight. Enabling this range are different visual responses to light levels by the human eye. There are three primary modes of vision, each of which uses the eye's complementary sensors of cone cells, rod cells, or a combination of both. Cones are the dominant visual receptor under daylight and lit interior conditions, known as photopic conditions. Rods are dominant under dark and low light conditions, known as scotopic conditions. Under medium lighting conditions, which are typically found outdoors at night (such as in moonlight or in a commercial district at night), a combination of cones and rods are required. This is known as mesopic lighting conditions.

Light sources with shorter wavelengths (and higher color temperatures), are considered "cooler", or more blue and green, and produce better mesopic visibility. Therefore, "cooler" sources, with high color temperature (expressed in degrees Kelvin) require lower luminance levels to provide the same or better visibility in mesopic lighting conditions. Jin et al. reported the *mesopic* luminous efficacy of cool white light is 53% higher than that of warm white light while the *photopic* luminous efficacy of the same lighting technology was only 11% higher[17]. Thus, street light sources tuned to be effective under mesopic conditions can provide additional energy savings, as less light (and less energy) can provide the same or improved visibility[18].

Recently, after considerable research on visual task performance, the Commission Internationale de l'Eclairage (CIE) has adopted a mesopic system, as specified in CIE 191:2010. This system provides a methodology for translation of mesopic luminance levels (cd/m^2) from corresponding photopic luminance levels based on the luminaire type scotopic/photopic (S/P) ratio[19]. However, the CIE did not provide recommendations on the implementation of the mesopic system for street light designers or a method of measuring mesopic luminances. Kostic and Djokic provide a corrected photopic luminance table specifically to enable lighting designers to use standard design and measurement procedures[20]. For example, consider a lighting standard that calls for low levels of lighting, on the order of 0.3 cd/m^2. This standard can be met with either LEDs or HPS lamps. The LED is a cooler light source, giving it a higher S/P ratio. At 0.3 cd/m^2, an LED with an S/P ratio of 2.05 would require 23% fewer lumens to give the same lighting effectiveness - or give the same ability to perform a task as an HPS lamp with an S/P ratio of 0.62. A LED tuned to take advantage of this effect, with an S/P ratio of 2.65, could save even more, on the order of 33%. The savings due to mesopic effects are highly dependent on desired lighting levels; the higher the lighting level, the more receptor cones become dominant in our eyesight, and the outdoor lighting conditions become similar to photopic conditions, negating the effect. The same LED lamps with S/P ratios of 2.05 and 2.65 would save 16% and 23% over HPS respectively at 0.75 cd/m^2. The higher the S/P ratio, the more effective the visual performance will be for low light levels encountered in road and street lighting. Thus, when LEDs are considered under mesopic photometry, its performance improves. The tables provided by Kostic and Djokic can be found in the Appendix. Savings from mesopic effects are included in our potential savings estimates.

3.2 Methodology for determining savings

In order to calculate savings potential , we determined the effective lumens per watt for the following lighting types currently installed in public lighting applications: halogen, CFL, LED, mercury vapor (MV), high pressure sodium (HPS), metal halide (MH), linear fluorescent, efficient linear fluorescent, next generation LED, and future LED. Effective lumens per watt by lighting type accounts for mesopic effects (if any), lumen maintenance, and fixture efficiency. The following equations were used to determine the effective mesopic lumens/watt for the each luminaire.

$$\text{Effective lumens/Watt} = L_e/W_i$$

$$L_e = (1+C_m) * B * L_m$$

$$L_m = (L_i + (L_i * m))/2)$$

and

$$W_i = B * W_r / E_f$$

Where

L_e is effective lumens (accounting for mesopic effects);

C_m is the mesopic constant, derived from Kostic 2012 and the S/P ratio of the luminaire;

L_m is the mean fixture lumens;

B is the ballast factor;

L_i is initial lumens of the luminaire;

m is the luminaire maintenance factor;

W_i is the input power;

E_f is fixture efficiency;

And W_r is rated power of the luminaire

The values for these variables used in our analysis are given in **Error! Reference source not found.**.

Table 6: Values assumed for LBNL analysis

Luminaire Type	S/P ratio	C_m*	L_m	B	E_f	W_r	L_e	W_i	L_e/W_i
Incandescent	1.50	9%	5,150	1.0	1	375	5,630	375	15
Tungsten halogen	1.50	9%	5,110	1.0	1	300	5,590	300	18
Compact fluorescent	1.78	13%	5,030	1.0	0.9	64	5,670	89	64
Light emitting diode	2.05	16%	8,100	1.0	0.9	100	9,400	110	85
Mercury Vapor	1.62	2%	10,070	1.0	0.86	250	10,270	285	36
High Pressure Sodium	0.62	0%	18,890	1.0	0.75	194	18,890	243	73
Metal Halide	1.52	11%	35,640	1.0	0.65	468	39,220	585	59
Linear fluorescent	1.62	12%	7,160	0.9	0.98	39	7,410	112	65
Efficient linear fluorescent	1.62	12%	14,540	1.0	0.90	38	17,750	187	94
Next Gen LEDs	2.05	16%	19,000	1.0	0.90	100	22,040	110	200
Future LEDs	2.65	23%	29,250	1.0	0.94	100	35,880	105	342

*For lighting level of 0.75 cd/m2. Note, that savings potential will vary for different levels of lighting.

3.3 Efficient Lighting Scenarios

From effective lumens per watt by luminaire type and the 2020 base case determined in section two, we calculate the energy savings potential for public lighting in India. To do so, a number of assumptions are made:

- 100% of all luminaires are replaced. Exceptions are efficient lighting in the 2020 BAU case (LED and efficient linear fluorescents). 100% of efficient luminaires are assumed to remain (not be replaced).
- The values for initial lumens, ballast factors, fixture efficiencies, lumen maintenance, mean lumens, end of life lumens were averaged from over 100 different lamp, fixtures, and ballasts from major manufacturers' catalogs[21]–[24]. Many of these lamp, fixtures, and ballasts are not necessarily designed for street lighting.
- All lighting types had the same hours of operation, 4,380 hours/year and that the power draw is constant in all hours.
- All technologies perform equally. Once lumens are adjusted to account for mesopic effects of different S/P ratios, all lumens are equal.
- An average luminance level of 0.75 cd/m^2. The National Lighting Code of India (via CIE recommendations), recommends this lighting level for M4 class roads. M4 class roads connect less important roads, are local distributor roads, or are major residential access roads. The CIE scale five roadway class types, M1-M5, with M1 having the highest lighting recommendation at 2.0 cd/m^2[8].

While making these assumptions allows for calculating a savings potential estimate, each street lighting case is unique and should be considered on an individual basis. Variables such as road configurations, pole configurations, fixture type, light level, and luminaire light uniformity ratio can impact potential savings. Our purpose is to provide a high level public lighting savings estimate.

3.3.1 LED Lighting Scenario

Today, light emitting diodes, LEDs, are practically synonymous with efficient lighting. A growing number of cities are installing them in public lighting applications in the US, including Los Angeles, Seattle, Boston, and Pittsburg. However, despite the 80% savings claims from manufacturers, cities generally report lower savings, on the order of 58%[25], and more data is emerging on savings as well as durability and performance of LED products.

India is leader in the development of comprehensive LED performance, safety and quality standards. In 2012, they released nine standards, with two more on the way[26], becoming the first country to comprehensively standardize LEDs, although voluntary. This paves the way for widespread manufacturing and use throughout the country, particularly in street lighting. Adoption of LEDs in the public lighting sector could help break down any remaining barriers of adaptation for LEDs in other lighting sectors. As of 2011, The Climate Group has completed three LED street light pilot projects throughout India[27]. However, there have been mixed results with the pilots and some problems have arisen due to lack of knowledge about quality LED procurement and India air and power quality, but feedback and early results are encouraging[28].

One recent study completed a full techno-economic analysis on LEDs for street and road lighting, including the additional savings due to mesopic vision effects[29]. They considered numerous lighting levels and configurations and calculated the full installed costs for both LEDs and HPS systems. They found that for most lighting configurations and light levels, LEDs did save energy, up to 43% over HPS when mesopic effects were taken into account. However, there were cases when LEDs consumed more energy. Financially, when considering initial investment (assumed capital cost of $1400 per point), maintenance, and electricity costs (assumed value of 0.10 €/kWh), LED lighting systems did not payback the additional upfront cost over a 24 year life, even at a low 5% discount rate. The study concluded that both higher efficiency and lower priced LEDs are needed to achieve cost savings with LEDs. This is indeed the trend, the economics of LEDs are improving. Recent prices are being quoted at under $300 per point[30][31].

We calculate the potential energy savings from replacing all non-efficient lighting types with LEDs. LED potential savings are given for currently available LEDs, next generation LEDs, and future LEDs are given by the luminaire type replaced in Table 7. The next generation and future LED cases are assumed values and have the following additional assumptions:

- base efficiency of LEDs doubles from 100 lumens/Watt to 200 lumens/Watt for next generation LEDs
- in the future, the efficiency of the LED approaches it's theoretical limit, synthesizing white light while emitting no light outside the visible band, assumed here to be 300 Lumens/Watt with a S/P ratio of 2.65, within the range cited in literature, 250-370 lm/W[32].

Table 7: Savings estimates for public lighting in India using a)current generation LEDs, b)next generation LEDs, and c)future generation LEDs.

Luminaire Type	Energy 2020 in Base Case (GWh)	a) LED Scenario		b) LED Next Gen Scenario		c) LED Future Gen Scenario	
		Savings	Energy Use (GWh)	Savings	Energy Use (GWh)	Savings	Energy Use (GWh)
Incandescent	332	82%	59	92%	25	96%	15
Tungsten halogen	2,156	79%	448	91%	191	95%	111
Compact fluorescent	232	25%	174	68%	74	81%	43
Light emitting diode	146	NA	146	NA	146	NA	146
Mercury Vapor	1,802	58%	753	82%	321	90%	187
High Pressure Sodium	1,898	19%	1,545	65%	659	80%	383
Metal Halide	2,253	34%	1,476	72%	629	84%	366
linear fluorescent	4,224	14%	3,643	63%	1,553	79%	904
Efficient linear fluorescent	198	NA	198	NA	198	NA	198
TOTAL	13,240	**36%**	8,442	**71%**	3,796	**82%**	2,353

We find that if all inefficient public lighting is replaced by current LEDs, the electricity savings potential is 36%, or an estimated 4.8 TWh in 2020. Next and future generations of LEDs could save even more, 9.4 TWh and 10.9 respectively in 2020.

3.3.2 T5

While LEDs are the most common energy efficient technology for street lighting, other technologies, such as T5 linear fluorescents, have been implemented for lower costs, faster paybacks and high efficacy[10].

Tubular fluorescent technology is a mature technology that continues to improve. T5s are the most efficient technology currently used for street lighting. When combined with efficient electronic ballasts, and fixtures, the linear fluorescent lamps, both T5s and T8s provide excellent efficiency in terms of lumens/watt. The light produced by fluorescent lamps also has a high S/P ratio, making it a suitable technology for outdoor lighting. Currently, T5 use in public lighting applications is not widespread, but there are few reported cases of T5s being installed and providing efficient and effective public lighting. In 2007, the city of Austin, Texas, in collaboration with the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, replaced existing HPS fixtures with new T5 fluorescent fixtures. The retrofits reduced overall light lumen levels, but according to survey results, perceptions of safety, security and brightness actually increased due to the cool white light of the T5s. In the pilot installations, the T5 installations saved between 40% and 64%, averaging 50% over HPS technology[18].
We calculate the potential electricity savings for replacing all non-efficient lighting types with T5 lamp technology. This savings potential is shown in Table 8.

Table 8: Savings estimates for public lighting in India using efficient linear fluorescent lighting.

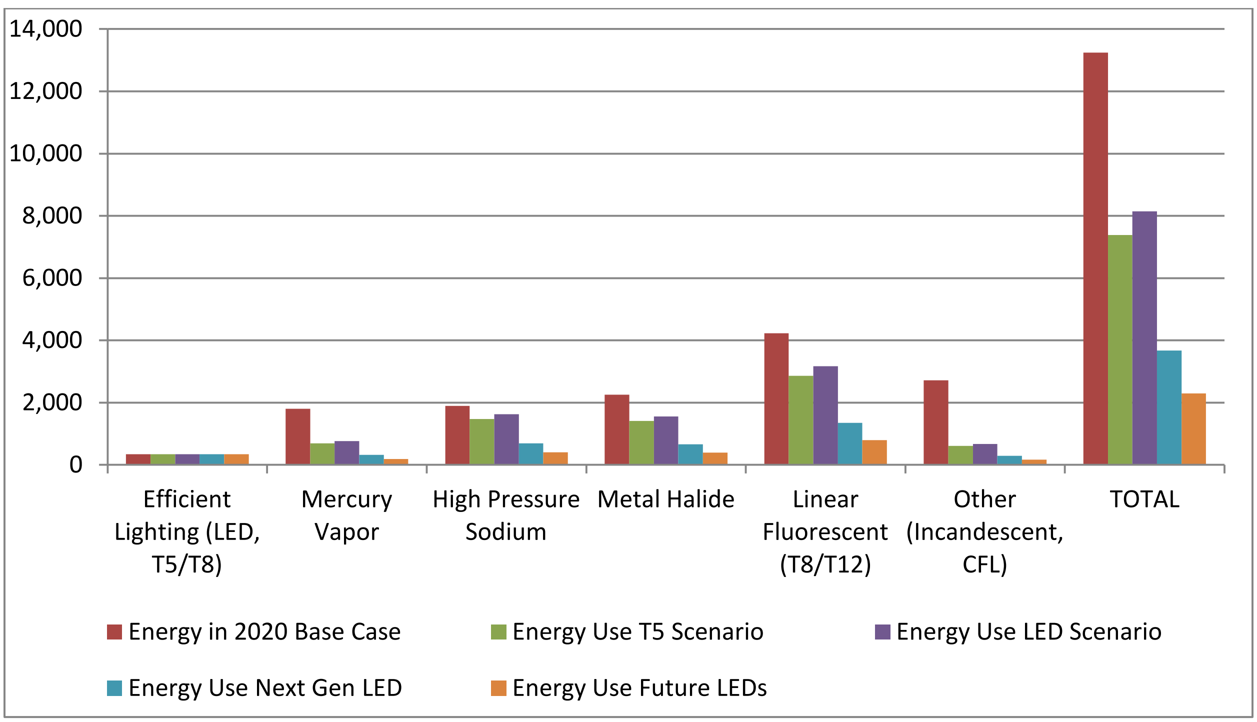
Luminaire Type	**Energy 2020 in Base Case**	**Efficient Linear Fluorescent**	
		Savings	**Energy Use (GWh)**
Incandescent	332	82%	57
Tungsten halogen	2,156	79%	435
Compact fluorescent	232	25%	169
Light emitting diode	146	NA	146
Mercury Vapor	1,802	21%	731
High Pressure Sodium	1,898	21%	1,501
Metal Halide	2,253	36%	1,434
linear fluorescent	4,224	16%	3,538
Efficient linear fluorescent	198	NA	198
TOTAL	13,240	**38%**	8,208

We find that if all inefficient public lighting is replaced by efficient linear fluorescents, the savings is 38%, or an estimated 5.0 TWh in 2020.

4 Results and Discussion

We find the savings potential for currently available technologies to be 36%, or 4.8 TWh in 2020 with LEDs or 38% and 5.0 TWh with efficient linear fluorescents. Figure 1 shows the energy use for both LED and efficient linear fluorescent replacement scenarios by the technology type they would replace. Further savings may be possible when dimmable LED street light systems are paired with motion sensors, wireless communication, and light level sensors. Dimming and/or telemanagement functions could be utilized at dawn, dusk, during full moons, and when no cars, cyclists, or pedestrians are in the vicinity, providing an additional savings of 5-10%[4] or more depending on traffic patterns. These systems are not widespread due to the additional level of complexity, cost, and proprietary aspect of the systems on the market today. Conservatively, at a cost of 4 Rs/kWh, these savings equal around 4,500 Cr or US$900 million annually and 4.5 million tons CO_2. The value of the savings is likely much higher, as one commission- the Delhi Electricity Regulatory Commission set the rate for public lighting for 2012-2015 to 7.25 Rs/kWh[33].

Figure 1: Efficient Scenarios Energy Use by Replaced Technology Type



[4] Assuming 50% savings for two hours every day (one at dawn, one at dusk).

In addition to energy savings, there are a number of additional benefits to efficient lighting. These benefits are summarized in Table 9.

Table 9: Additional benefits to adopting energy efficient lighting

T5 and LED	**LED Only**
Superior light quality and visibility Can reduce crime, traffic accidents Enhance commercial districts	Longer lifetime of lamps can reduce maintenance cost (Needs to be evaluated for conditions in India)
Reduction in toxicity	Directionality of light reduces light pollution More uniform distribution of light on the roadway
Improved lumen maintenance (HPS light sources lose up to 40% of the initial light output) Lower variability of lighting over lamp life (HPS lamps experience color shifts)	Implementation now will lay groundwork for future, improved LED products
Lower maintenance costs	No heavy metals involved in the manufacture of LED lighting

5. Conclusion

We find that there is significant energy savings potential for public lighting throughout India, on the order of five terawatt hours annually. We find that efficient linear fluorescents, a proven, inexpensive technology are competitive, and may even exceed savings with today's LED public lighting technologies. However, LED savings are expected to increase and costs are expected to decrease significantly. Investing in LED infrastructure now will enable Indian ULBs to capitalize on future saving potentials cost effectively. Public lighting savings are dependent on the type of roadway lighting employed, which in turn is determined by the type of roadway and its traffic patterns. Specifications such as mounting height, spacing, pole configuration, light overhang, light direction, technology type, and siting are all factors on final electricity use.

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Appendix: Kostic Table

Below are the values of the corrected photopic luminances published by AM Kostic 2013. The corrected values are given as a function of the relevant photopic luminances and lamp S/P ratio, determined assuming the existing recommendations and design criteria are based on the use of HPS lamps (S/P ratio 0.65).

	Lighting Level (cd/m^2)					
S/P Ratio	***0.3***	***0.5***	***0.75***	***1***	***1.5***	***2***
0.25	0.33	0.54	0.8	1.05	1.56	2.05
0.35	0.32	0.53	0.79	1.04	1.54	2.04
0.45	0.32	0.52	0.77	1.02	1.53	2.03
0.55	0.31	0.51	0.76	1.01	1.52	2.02
0.65	0.3	0.5	0.75	1	1.5	2
0.75	0.29	0.49	0.74	0.99	1.49	1.99
0.85	0.29	0.48	0.73	0.98	1.48	1.98
0.95	0.28	0.48	0.72	0.97	1.47	1.97

1.05	0.27	0.47	0.71	0.96	1.46	1.96
1.15	0.27	0.46	0.7	0.94	1.44	1.95
1.25	0.26	0.45	0.69	0.93	1.43	1.94
1.35	0.26	0.45	0.68	0.92	1.42	1.92
1.45	0.25	0.44	0.68	0.91	1.41	1.91
1.55	0.25	0.43	0.67	0.91	1.4	1.9
1.65	0.24	0.42	0.66	0.9	1.39	1.89
1.75	0.24	0.42	0.65	0.89	1.38	1.88
1.85	0.23	0.41	0.64	0.88	1.37	1.87
1.95	0.23	0.41	0.63	0.87	1.36	1.86
2.05	0.23	0.4	0.63	0.86	1.35	1.85
2.15	0.22	0.39	0.62	0.85	1.34	1.84
2.25	0.22	0.39	0.61	0.84	1.33	1.83