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Illuminating the Future: Cost-Benefit Analysis of the Installation of LED Street Lights in Townships

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ABSTRACT

Municipalities face decisions about maintaining and upgrading their streetlighting. Do they continue to replace bulbs in their existing lighting systems, or move to energy-efficient systems piecemeal or all at once? This research paper argues that the financial and environmental benefits of a complete shift to efficient Light Emitting Diode (LED) fixtures make the investment worthwhile. Analysis of data from Tredyffrin Township in southeastern Pennsylvania, that is currently making the switch to LED lighting systems, supports the conclusion that committing to one-time full replacement can maximize energy savings and that the issuance of green bonds, over standard municipal bonds, for financing is both viable and advantageous as it can lead to additional savings and budget surplus. Despite a higher initial investment, the extended lifespan of LED lights, compared with Mercury Vapor (MV) lamps, drastically lowers maintenance and replacement costs, leading to considerable long-term savings. By using green bonds, a financing instrument made available for environmentally beneficial projects, a municipality's financing costs can be kept low and large projects can be undertaken, for the fullest financial and environmental benefit.

Introduction

In the quest for a sustainable and energy-efficient future, the development of environmentally friendly lighting solutions has emerged as a prominent area of research and innovation. Among these new technologies, Light Emitting Diode has been hugely successful, transforming the way people's communities are illuminated[1]. LED bulbs' very long lifetimes (cited as up to five times the average Mercury Vapor (MV) lamps, depending on the model) and extremely low energy usage has made them the dominant choice for street lighting[2]. In addition, the Energy Policy Act (EPA) of 2005 prohibited the manufacturing and importation of MV ballasts after 2008, severely impacting the production of MV lamps[2]. In the past decades, LED lights have rapidly gained popularity across various applications, ranging from residential and commercial lighting to automotive and outdoor lighting. Cities across the nation have changed their roadway lighting systems from MV and high-pressure sodium (HPS) lamps to LED luminaires to decrease light pollution levels, optimize comfort and visibility, and maximize efficiency. In addition, because multiple LEDs work in one fixture, glare reduction can be achieved, improving driver's visual ability on the road[3].

This research paper looks at the financial advantages of changing from MV lamps to LED street lights in municipalities. Since street lighting is one of the largest energy uses for local governments, making up 25 to 50% of a municipal energy bill, many townships are able to reduce the costs of operations and maintenance after switching to LED lights[4]. LED lighting may have higher up-front costs that deter local governments. This research will show, by analyzing the results of a cost-benefit analysis through a discounted cash flow model and municipal green bond yield curve examination, that the long-term financial savings outweigh the initial cost.

It is noted that the economic evaluation of LED roadway lighting systems is site-specific and dependent on the local electricity demand (kW) and consumption (kWh) rates, installation and maintenance costs, lighting models, and the quantity of lights[5]. Although quantitative data from this study directly applies to Tredyffrin Township, the generalizations and conclusion reached remain viable for any similar municipality.

Methods

Using key data provided by the Department of Public Works of Tredyffrin Township in southeastern Pennsylvania, a discounted cash flow analysis was performed to produce a net present value (NPV) for the investment of changing all MV lamps to LED lights in prominent public recreational areas and streets. The paper analyzes the benefits of replacing all lights at the same time versus as old MV lights fail by focusing on plans for Wilson Farm Park, a 90-acre green space illuminated by 200 lights, offering an amphitheater, playgrounds, multipurpose fields, and pavilions.

Because the lifetime of an Autobahn Series ATB0 LED light at optimal performance is twenty years, the U.S. Department of Agriculture's predicted rate of inflation until 2032, or ten years into the installation, and the optimal rate of inflation (2%) for the last ten years until 2042 (Figure 1)[6] were used to project the township's increasing price per kilowatt hour (kWh) of electricity, or the cost of electricity, starting from $0.0618901 per kilowatt hour (Figure 2). Then, using the cost of purchase and installation of an average enclosed MV lamp at 17500 delivered lumens (350 Watt) and a LED bulb in the Autobahn ATB0 Series with 16193 delivered lumens (145 Watt), the average cost of MV lamps, and the U.S. Treasury bond yield interest rate of 3.79%, the net present value (NPV), which indicates the sum of all future cash flows over an investment's lifetime, discounted to the present value to consider inflation, of a single LED light can be found. Moreover, after finding the cost of electricity for Mercury Vapor and LED lights using the respective formula, it is revealed that the former is predicted to be continuously higher, due to more wattage being lost to heat in warming up MV lamps for use (Figure 3).

$$NPV = \frac{net\ cash\ flow\ at\ time\ t}{(1+discount\ rate)^t} \qquad kWh = \frac{(watt \times hours)}{1000}$$

$$Electricity\ Cost\ = \frac{price}{kWh} \times kWh \qquad Interest\ payment = \frac{principal \times bond\ rate}{100}$$

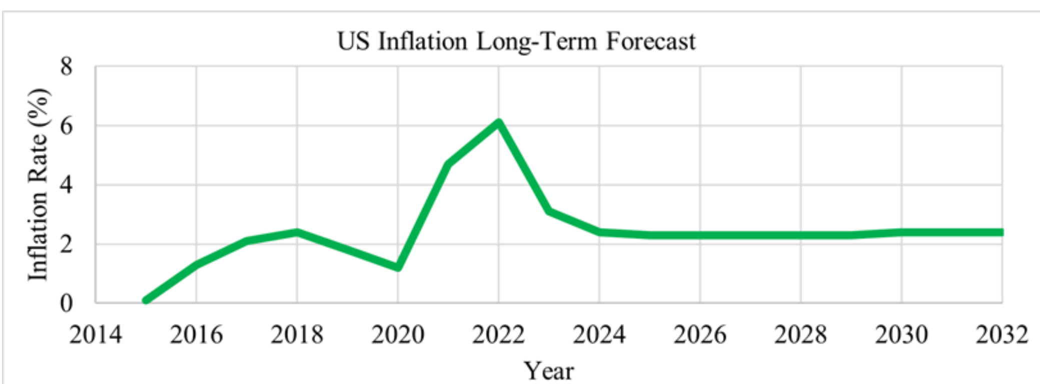

Figure 1. Rate of inflation of the Consumer Price Index (CPI) from 2015 to 2032. Source: USDA US Inflation Long-Term Forecast[6].

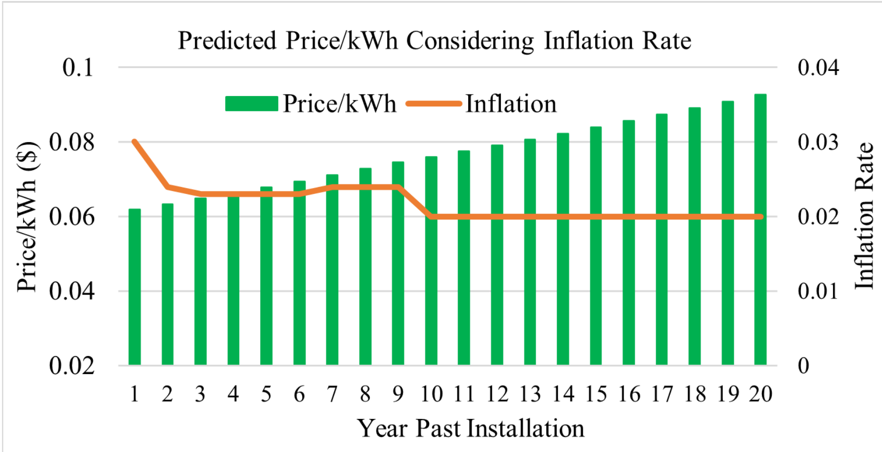

Figure 2. Predicted price per kilowatt hour of electricity in Tredyffrin Township over time.

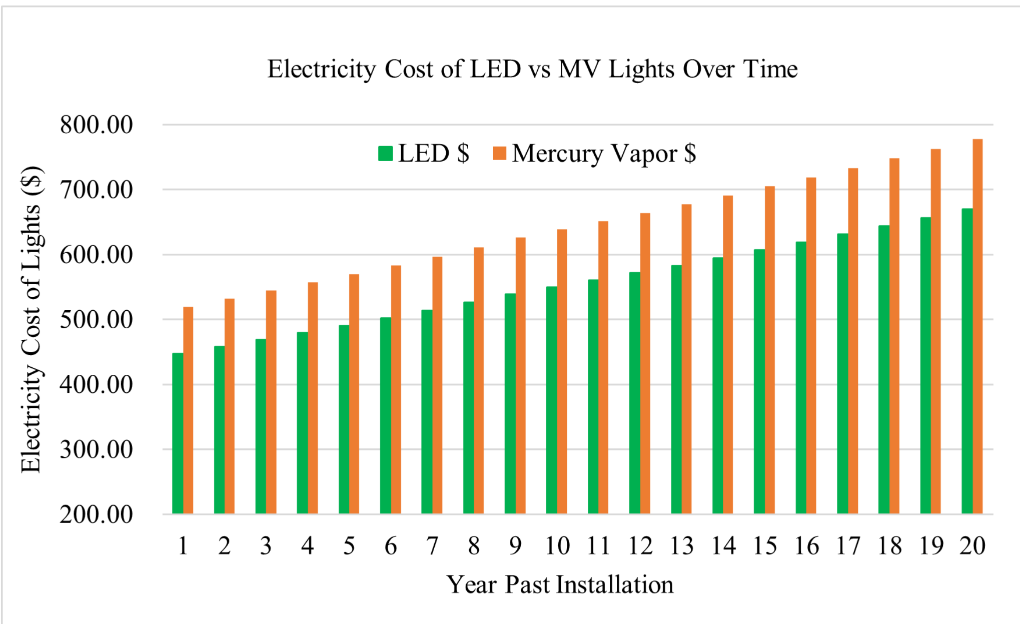

Figure 3. Predicted electricity costs of LED and MV lights in the next 20 years considering the rate of inflation, corresponding to the average lifetime of an Autobahn series ATB0 LED street light.

A municipality's financial situation may greatly affect the calculations behind its borrowing choices. Tredyffrin Township has a top-tier bond credit rating of AAA. Therefore, predicted interest rates for an AAA municipal bond yield curve from Tradeweb Markets, as of July 26th, 2023[7], were used to conclude that in the average peak lifetime of LED lights, or twenty years, the savings generated by a full installation of LED street-lights will far outweigh the total amount of debt the township owes to fund this project (Figure 4).

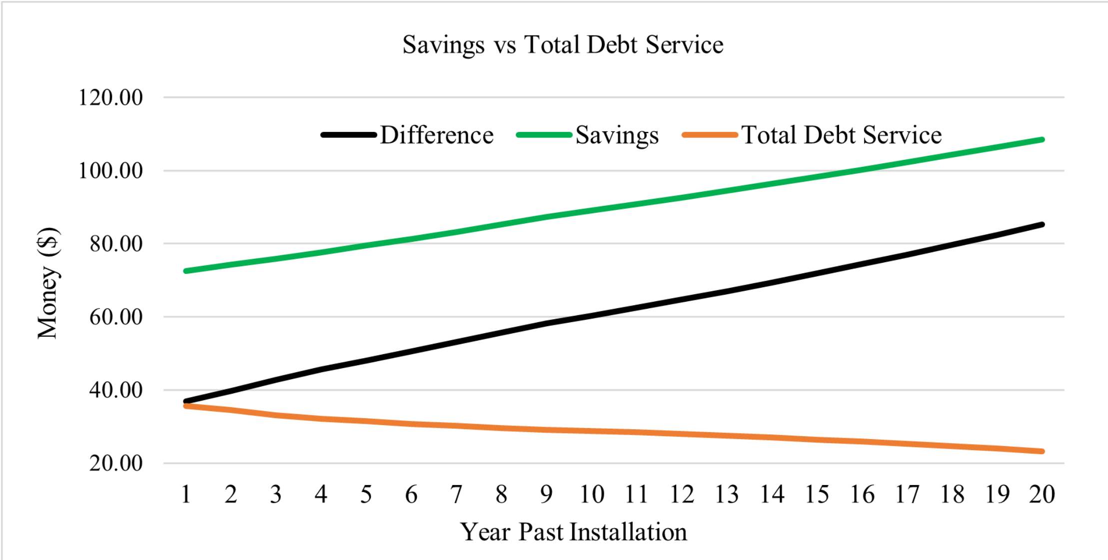

Figure 4. Comparison of the savings and total debt service of Tredyffrin Township in the 20-year peak performance lifetime of LED lights. The line representing the Difference shows the total annual improvement in the budget.

LED lights are the most sustainable choice for street lighting currently available. Therefore, certified "green bonds" are also issuable by municipalities for the purpose of raising money for LED light installations. Green bonds, which are debt securities designated specifically to finance environmentally friendly projects, provide an advantage for issuers. For municipalities, on average, green bonds have a yield spread that is 8 basis points lower, or 0.08%[8], than conventional municipal General Obligations bonds (Figure 5). As lower interest counterbalances the financial burden of the high initial costs of LED street lights, municipalities with a lower financial rating may benefit from issuing green bonds, not just monetarily with regard to energy savings, but also the municipality's financial profile.

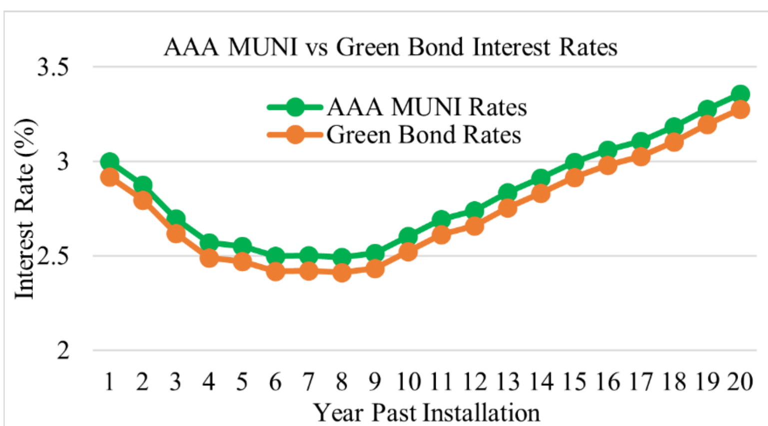

Figure 5. Comparison of the predicted interest rates of AAA credit level municipal bond and green bonds in the future 20 years, corresponding to the lifetime of LED bulbs.

Results/Conclusion

Using the kWh formula in the Methods section, the wattages of LED and MV lights are converted to kWh to match the unit of price of electricity per kWh in the Tredyffrin township, resulting in 7229.02 kWh and 8400 kWh, respectively. The Initial Price/kWh is $0.0618901 and cost of LED purchase and installation is $450 provided by Tredyffrin Township. The NPV of a single Autobahn Series ATB0 LED fixture, was then found to be $764.24. Since this value is positive, the data indicates that the installation plan should be implemented. Since the cost of purchasing all 2200 LED bulbs at the same time or within a short period of time is the premise for a discounted cash flow analysis, it can be concluded that changing the LED lights in one location all at the same time rather than piecemeal leads to the following results. After discounting the cost of one bulb over twenty years, the average peak performance lifetime of this LED light model, the total savings of one bulb is $1,799.95 (Table 1). Comparing the increase in savings per bulb in Table 1 with the total amount of money the township has to spend for this project in Table 2, the savings are shown to be higher than the amount of debt from the start of the investment, yielding financial benefits like additional savings for a township's budget (Figure 4). With an estimated number of 2000 street lights in the township beside the 200 in the park, the total cumulative savings could be as high as $3,959,885.03 over the course of the lifetime of the LEDs (Table 1).

Setting the cost per LED bulb, $450, as the principal amount of money Tredyffrin township must pay back, this value is divided by twenty to equal $22.50 of debt per year. Then, the total debt service of the township, which is the sum of the interest payment per year, found using the respective formula in the Methods section and $22.50, decreases until the money is paid back (Table 2). Therefore, it can be concluded that the investment will pay for itself with green bonds, instead of burdening the township, as the principal that needs to be paid decreases to zero at the end of the 20-year period. As the savings continue to increase and the amount of debt decreases, the difference between the two represents potential budget surplus and additional savings for the local government (Figure 4).

Discussion

Table 1. Discounted Cash Flow analysis of LED and MV lights. Source: Initial Price/kWh ($0.0618901) and cost of LED installation ($450) provided by Tredyffrin Township.

Year	Price/kWh ($/kWh)	Inflation	LED (kWh)	MV (kWh)	LED Electricity Cost ($)	MV Electricity Cost ($)	Savings ($)	NPV ($)
0								-450
1	0.0618901	0.0301	7,229.02	8,400	447.40	519.88	72.47	69.83
2	0.063375462	0.024	7,229.02	8,400	458.14	532.35	74.21	68.89
3	0.064833098	0.023	7,229.02	8,400	468.68	544.60	75.92	67.90
4	0.066324259	0.023	7,229.02	8,400	479.46	557.12	77.66	66.93
5	0.067849717	0.023	7,229.02	8,400	490.49	569.94	79.45	65.97
6	0.069410261	0.023	7,229.02	8,400	501.77	583.05	81.28	65.02
7	0.071076107	0.024	7,229.02	8,400	513.81	597.04	83.23	64.15
8	0.072781934	0.024	7,229.02	8,400	526.14	611.37	85.23	63.29
9	0.0745287	0.024	7,229.02	8,400	538.77	626.04	87.27	62.45
10	0.076019274	0.02	7,229.02	8,400	549.54	638.56	89.02	61.37
11	0.077539659	0.02	7,229.02	8,400	560.54	651.33	90.80	60.31
12	0.079090453	0.02	7,229.02	8,400	571.75	664.36	92.61	59.27

13	0.080672262	0.02	7,229.02	8,400	583.18	677.65	94.47	58.25
14	0.082285707	0.02	7,229.02	8,400	594.84	691.20	96.36	57.25
15	0.083931421	0.02	7,229.02	8,400	606.74	705.02	98.28	56.26
16	0.085610049	0.02	7,229.02	8,400	618.88	719.12	100.25	55.29
17	0.08732225	0.02	7,229.02	8,400	631.25	733.51	102.25	54.34
18	0.089068695	0.02	7,229.02	8,400	643.88	748.18	104.30	53.40
19	0.090850069	0.02	7,229.02	8,400	656.76	763.14	106.38	52.48
						Total savings/bulb ($)		1799.95
						Total savings ($)		3959885.03
						NPV/bulb ($)		764.24

This analysis intends to show the financial advantages of LED street lights. However, it is also important to consider the qualitative downsides. One of the prominent disadvantages is the issue of blue light emission. LED lights emit a higher proportion of blue light compared to traditional incandescent bulbs, which can lead to potential health concerns, particularly related to disruptions in circadian rhythms and sleep patterns of people and some nocturnal animals[9]. LED lights often have different indices in color temperature and color rendering variations, leading to inconsistencies in the quality of light produced.

Another drawback is the burden of the initial cost of LED lights for some municipalities. While LED technology boasts an extended lifespan and lower energy consumption, the higher upfront investment can deter some consumers from adopting this lighting solution. Although the prices of LED bulbs have been steadily declining as the market for these more sustainable lights grows, the initial expense remains a hurdle for local governments[10]. However, as this study shows, the savings are likely to far outweigh the principal cost and debt service.

Despite these shortcomings, LED street lights are remarkable in energy efficiency and lifespan, two factors that largely contribute to decreased levels of energy consumption and reduced maintenance costs[11]. In comparison with the limitations of traditional lighting technologies, including incandescent and HPS lamps, that are highly inefficient, convert a substantial portion of energy into heat rather than light, and require longer warm-up times, LED street lights provide an array of benefits[12].

Moving forward, future research and development efforts must focus on addressing these drawbacks and improving LED technology to mitigate the identified issues. By doing so, we can unlock the full potential of LED lighting, paving the way for a more sustainable, efficient, and environmentally conscious future in a brighter world. As municipalities, consumers, manufacturers, and policymakers collaborate to overcome these challenges, LED lights can continue to illuminate our lives responsibly while contributing to a greener world for generations to come.

Table 2. Cost-savings analysis of one LED street light fixture considering green bond rates.

Year	AAA MUNI Rates (%)	Green Bond Rates (%)	Principal ($)	Interest Payment ($)	Principal Repaid Per Year ($)	Total Debt Service ($)
0			450.00			0.00
1	3	2.92	427.50	13.14	22.50	35.64
2	2.877	2.797	405.00	11.96	22.50	34.46
3	2.698	2.618	382.50	10.60	22.50	33.10
4	2.569	2.489	360.00	9,52	22.50	32.02
5	2.552	2.472	337.50	8.90	22.50	31.40

6	2.5	2.42	315.00	8.17	22.50	30.67
7	2.503	2.423	292.50	7.63	22.50	30.13
8	2.493	2.413	270.00	7.06	22.50	29.56
9	2.514	2.434	247.50	6.57	22.50	29.07
10	2.605	2.525	225.00	6.25	22.50	28.75
11	2.693	2.613	202.50	5.88	22.50	28.38
12	2.74	2.66	180.00	5.39	22.50	27.89
13	2.836	2.756	157.50	4.96	22.50	27.46
14	2.912	2.832	135.00	4.46	22.50	26.96
15	2.996	2.916	112.50	3.94	22.50	26.44
16	3.061	2.981	90.00	3.35	22.50	25.85
17	3.106	3.026	67.50	2.72	22.50	25.22
18	3.184	3.104	45.00	2.10	22.50	24.60
19	3.278	3.198	22.50	1.44	22.50	23.94
20	3.358	3.278	0.00	0.74	22.50	23.24

Table 3. Cost-savings analysis of all 2200 LED light fixtures in Tredyffrin Township considering green bond rates.

Year	AAA MUNI Rates (%)	Green Bond Rates (%)	Principal ($)	Interest Payment ($)	Principal Repaid Per Year ($)	Total Debt Service ($)
0			990,000			0
1	3	2.92	940,500	28908.00	49,500.00	78,408
2	2.877	2.797	891,000	26305.79	49,500.00	75,806
3	2.698	2.618	841,500	23326.38	49,500.00	72,826
4	2.569	2.489	792,000	20944.94	49,500.00	70,445
5	2.552	2.472	742,500	19578.24	49,500.00	69,078
6	2.5	2.42	693,000	17968.50	49,500.00	67,469
7	2.503	2.423	643,500	16791.39	49,500.00	66,291
8	2.493	2.413	594,000	15527.66	49,500.00	65,028
9	2.514	2.434	544,500	14457.96	49,500.00	63,958
10	2.605	2.525	495,000	13748.63	49,500.00	63,249
11	2.693	2.613	445,500	12934.35	49,500.00	62,434
12	2.74	2.66	396,000	11850.30	49,500.00	61,350
13	2.836	2.756	346,500	10913.76	49,500.00	60,414
14	2.912	2.832	297,000	9812.88	49,500.00	59,313
15	2.996	2.916	247,500	8660.52	49,500.00	58,161
16	3.061	2.981	198,000	7377.98	49,500.00	56,878
17	3.106	3.026	148,500	5991.48	49,500.00	55,491
18	3.184	3.104	99,000	4609.44	49,500.00	54,109
19	3.278	3.198	49,500	3166.02	49,500.00	52,666
20	3.358	3.278	0.00	1622.61	49,500.00	51,123

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