

Analyzing Economic Feasibility in Green Energy Projects: A Case Study of a Green Streetlight Project

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Abstract

Green energy project proposals are often criticized for their high upfront cost and face concerns that anticipated cost savings will not materialize. An analysis showing that an initiative will benefit a given area economically will be key to securing funding and support for any city-wide infrastructure project. This paper offers a method to identify whether the benefits of green infrastructure projects justify the costs of implementing them. The Philadelphia Streetlight Improvement Project (PSIP) is used as a case study. This study conducts a thorough economic analysis of the implementation of light-emitting diode (LED) streetlight replacement projects through the lens of cost-benefit analysis.

The methods presented in this paper can be used as a framework for city agencies around the world considering similar sustainable projects. This study concludes that certain sustainable infrastructure projects are economically feasible and can provide a range of positives beyond cost savings. The key conclusions are: (i) the PSIP is economically profitable, with the project's net present value (NPV) around \$60 million; (ii) funding strategies such as serial green bonds can help spread out initial costs and decrease investor risk; and (iii) spillover benefits external to NPV calculations, including benefits to the environment and safety, boost the overall value of sustainable infrastructure.

Introduction

As communities around the world begin increasing their focus on sustainable development, cities are incorporating economic, environmental, and social factors in decision-making (Corbett et al., 2017). Urban areas have modernized existing systems to meet contemporary needs and future demands, all while limiting their carbon footprint (Lwasa et al., 2022). In particular, the utilization of efficient and reliable infrastructure has fallen on the agenda. Upgrading infrastructure with environmentally sound technology that supports human well-being and economic development is a key goal of the United Nations's 2030 Sustainable Development Goals (United Nations, 2015). Economic factors

including the significant rise in energy prices over the last few years have pushed politicians to explore ways to save city funds (Sadiq et al., 2022). These efforts extend beyond surface-level economic and environmental benefits, as sustainable infrastructure development such as improving essential utilities provides enhanced living standards across the board (Müller et al., 2024). Given that lightbulbs have seen significant innovation in recent years, it is no surprise that streetlighting is one of the first renovations municipalities choose to consider when planning for sustainable projects (Econoler, 2021). Streetlights are often cited as cities' biggest or second biggest energy demand, carrying anywhere from 25% to 50% of a city's entire energy bill, making streetlight renovation projects a prime chance for cities to benefit financially (Berg, 2012). Recent achievements in light-emitting diode (LED) technology specifically have encouraged many municipalities to transition away from traditional high-intensity discharge (HID) lamps in hopes of substantial economic and environmental benefits (Hood, 2016).

Since LED technologies do not produce white light on their own, using them as effective light sources requires the combination of complex materials, such as semiconductors (U.S. Office of Energy Efficiency & Renewable Energy, n.d.; Irfan, 2023). As a result, early LEDs had limited functionality and were much more expensive than traditional high-intensity discharge (HID) lamps (TCP Lighting, 2020). Over the decades, though, engineers have made progress on improving essential technology used in LEDs, allowing them to become brighter, more cost effective, and more versatile (Bernard, 2020). While 90% of energy in traditional HID systems is released as heat with only 10% of energy actually producing light, advancements in LED technology have made it so most of the energy consumed by LEDs create light, drastically improving efficiency (Katz, 2007). Moreover, more advanced LED systems allow for accurate management with new features including timer-based control and infrared sensors that are able to dim lights by sensing surrounding light intensity (Javed et al., 2021). LEDs typically incur lower maintenance costs with their longer lifespan as they do not produce much heat and are thus unlikely to burn out, and provide direct energy savings since they require less wattage to operate (Arcadia, 2020). The savings for both these areas are substantial (Ganandran et al., 2014).

However, LED streetlighting technology has commonly been dismissed by many due to the substantial initial capital demands of both the technology itself and new infrastructure required to support the technology (Müller et al., 2024; Slocum, 2005). Issues including perceived investment risks and long payback periods also make the decision to invest difficult, even though most analysts believe that new LED systems or other energy efficiency retrofits will pay for themselves in the long run (Polzin et al., 2016). Lack of scientific literature analyzing different proposals for such a transition could contribute to overall hesitancy to budget and fundraise for such projects (Campisi et al., 2018). Furthermore,

many researchers would agree that the biggest barrier to municipalities looking to pursue an LED project is the high initial cost of LED systems and the perception of significant economic obstacles (Landis et al., 2011; Arnold et al., 2015; Santo, 2019). As a result, this study aims to investigate whether city-wide energy efficiency initiatives, such as LED projects, can provide economic benefits despite these perceived barriers.

A case study review related to the economic implications of LED streetlights is needed because it can help hesitant cities decide whether such a project is a good one to take on from a financial standpoint. To do this, the study analyzes the adoption of LED streetlights in the Philadelphia Streetlight Improvement Project (PSIP) to replace outdated lighting systems in Philadelphia, Pennsylvania. Specifically, this paper addresses the following questions: (i) Using a method of cost-benefit analysis, is investment in LED technology by the City of Philadelphia financially beneficial? (ii) Can the current strategy to finance the LED retrofits be improved upon? (iii) In addition to economic considerations, what potential spillover effects may this project have? In order to investigate these three questions, economic feasibility by analyzing savings in energy and cost is computed, and additional environmental and social effects that the project may provide are discussed. Moreover, this study carries out a detailed economic cost-benefit analysis of the project and includes financing recommendations regarding the bond payment structure.

This paper is organized in five sections. Section 2, following, provides an overview of the general characteristics of the project to be analyzed including associated costs and savings. Section 3 presents the financial calculations regarding the Philadelphia Streetlight Improvement Project's bond structure and proposes recommendations based on the data. Section 4 is a discussion of additional benefits that the project may bring. Finally, Section 5 summarizes the main findings.

Background

With construction beginning in August 2023, the PSIP is an ambitious plan to convert all approximately 130,000 streetlights in the city of Philadelphia to energy-efficient LED lights linked in a new lighting management system (LMS) (Philadelphia Streetlight Improvement Project, 2024). The mayor's announcement states that the purpose of kicking off the city's largest energy efficiency project is primarily to improve infrastructure so that it can meet the needs of a "resilient and climate-ready Philadelphia" (Office of Transportation and Infrastructure Systems, 2022). On top of this, local analysts believe that the project will increase public safety, diminish the presence of excessive artificial lighting, and most importantly, pay for itself (Alliance to Save Energy, n.d.).

PSIP was launched as a collaboration between the Philadelphia Energy Authority, the authority building Philadelphia's clean energy economy, and Ameresco, an energy company selected to manage the project. Planning of the project involved consultations with multiple stakeholders, including conversations with city officials, municipal departments, and the public. Officials generally agree that this project was long overdue, with former Mayor Jim Kenney describing it as a "win-win infrastructure investment" and City Council President Darrell Clarke praising the project as "addressing Philadelphia's biggest challenges". Director of the Office of Sustainability Saleem Chapman called it a "once-in-a-generation energy conservation project" and President and CEO of Philadelphia Energy Authority Emily Schapria said they know "how important it is to get it right" (Office of Transportation and Infrastructure Systems, 2022). Moreover, different streetlighting systems were tested in live demonstrations to assess public sentiment, varying between warmer and colder colors. While many believed the streetlights would provide an array of benefits to the community, others criticized them as too harsh or too bright (Robinson, 2022). In response, project leaders took public feedback into account, aiming to find a balance between visibility, safety, and community comfort in their final design choices.

This project was selected for this case study primarily due its scale, but also because of Philadelphia's position as a major U.S. city with aging infrastructure in need of upgrades and Philadelphia's experience with energy-efficient retrofits (U.S. Department of Energy, n.d.). PSIP represents one of the largest LED retrofit programs undertaken in the country, and the largest energy efficiency project taken on by Philadelphia, allowing for a robust data set for financial analysis and evaluation (Bartolotta, 2023). These initiatives align with Philadelphia's broader push to modernize their infrastructure, reduce energy consumption and improve sustainability outcomes. Furthermore, Philadelphia has demonstrated a strong commitment to sustainability, with Mayor Cherelle Parker pledging to make it the "cleanest, greenest big city in the nation" and setting a goal to reach net-zero carbon emissions by 2050 or sooner (Miller, 2024). These factors collectively position PSIP as a compelling case study for examining the implications of energy efficiency initiatives.

The data presented in Tables 1, 2, and 3 were obtained from the City of Philadelphia from early January to late June 2024; these data are not publicly available.

Around 23,000 of the city's streetlights had already been converted to LEDs before the project began; the project will connect all previously installed LEDs to the LMS by adding new control nodes on each of these lights, allowing the city to track them more closely (Bartolotta, 2024). The remaining 106,000 lights will transition from HID to LED and will also receive control nodes to be linked to the LMS (McGinley, 2024a). The HID lights in PSIP include mostly existing high-pressure sodium lamps, but also include some induction and mercury vapor lamps. Conversion of

all 130,000 lights will occur from August 2023 to August 2025 and is part of the city’s broader Municipal Energy Master Plan. PSIP’s installations prioritize neighborhoods where public safety demands are highest, and gradually spread out across the entire city (Ameresco, 2024).

Table 1
Installation Cost per Lightbulb.

Typical Application	Control Node Cost (A)	Labor Cost (B)	Fixture Cost (C)	LED System Linkup Cost (A+B)	HID Replacement Cost (A+B+C)
Alley	\$200.00	\$275.00	\$90.00	\$475.00	\$565.00
Driveway	\$200.00	\$275.00	\$90.00	\$475.00	\$565.00
Local	\$200.00	\$275.00	\$150.00	\$475.00	\$625.00
Collector	\$200.00	\$275.00	\$165.00	\$475.00	\$640.00
Major	\$200.00	\$275.00	\$200.00	\$475.00	\$675.00
Major +	\$200.00	\$275.00	\$250.00	\$475.00	\$725.00
Residential Post Top	\$200.00	\$275.00	\$250.00	\$475.00	\$725.00
Spring City Franklin	\$200.00	\$275.00	\$2100.00	\$475.00	\$2575.00
Spring City Chinatown	\$200.00	\$275.00	\$2350.00	\$475.00	\$2825.00
Spring City Center City	\$200.00	\$275.00	\$1400.00	\$475.00	\$1875.00
Spring City Ben Franklin Pky	\$200.00	\$275.00	\$2200.00	\$475.00	\$2675.00
Spring City Columbia	\$200.00	\$275.00	\$1500.00	\$475.00	\$1975.00
Spring City Decoratives (others)	\$200.00	\$275.00	\$1300.00	\$475.00	\$1775.00
Misc	\$200.00	\$275.00	\$200.00	\$475.00	\$675.00

Table 1 estimates the installation cost of each lamp in PSIP based on numbers provided by the City of Philadelphia (McGinley, 2024a). In the table, the control node and labor cost are constant regardless of the lamp type, sitting at a rate of \$200 and \$275, respectively. The fixture cost depends on the lighting application type. (The term “fixture cost” of a particular application refers to the cost of converting the application’s HID light to an LED light, without accounting for external mark-ups such as the cost of labor.) For already existing LED lamp types that are not receiving a replacement of the lamp itself, the installation cost is calculated by adding up the labor and control node costs. The replacement cost for a streetlight transitioning from HID to LED is calculated by adding up the labor, fixture, and control node costs.

As Table 1 shows, the LED system linkup cost per streetlight across all applications is a constant of \$475, the combination of the control node and labor costs. The HID replacement costs are not constant across

applications. Differences in fixture costs cause this disparity. For example, the streetlights tagged as “Spring City” generally have much higher fixture costs compared to other applications, which is why their HID replacement costs are considerably more expensive.

Table 2
Total Installation Cost.

Typical Application	LED Qty (A)	LED System Linkup Cost (B)	HID Qty (C)	HID Replacement Cost (D)	Total Installation Cost (A*B+C*D)
Alley	2,820	\$475.00	14,050	\$565.00	\$9,277,750.00
Driveway	153	\$475.00	792	\$565.00	\$520,155.00
Local	3,455	\$475.00	30,876	\$625.00	\$20,938,625.00
Collector	4,369	\$475.00	29,417	\$640.00	\$20,902,155.00
Major	5,843	\$475.00	13,472	\$675.00	\$11,869,025.00
Major +	2,629	\$475.00	6,379	\$725.00	\$5,873,550.00
Residential Post Top	201	\$475.00	4,919	\$725.00	\$3,661,750.00
Spring City Franklin	0	\$475.00	517	\$2575.00	\$1,331,275.00
Spring City Chinatown	18	\$475.00	63	\$2825.00	\$186,525.00
Spring City Center City	2,298	\$475.00	2,256	\$1875.00	\$5,321,550.00
Spring City Ben Franklin Pky	73	\$475.00	126	\$2675.00	\$371,725.00
Spring City Columbia	121	\$475.00	242	\$1975.00	\$535,425.00
Spring City Decoratives (others)	754	\$475.00	1,995	\$1775.00	\$3,899,275.00
Misc	0	\$475.00	1,337	\$675.00	\$902,475.00
Total	22,734	N/A	106,441	N/A	\$85,591,260.00

To find the total cost of converting the current lighting system to the LED system, the cost of LMS linkage or replacements for LED and HID lights in each lighting application type are respectively multiplied by the quantity of current LED and HID lights. This yields the estimated total installation cost shown in Table 2. Other miscellaneous costs and possible expenses related to the project but outside direct installation costs, including project management and financial consulting, are not included in this calculation. However, these miscellaneous costs are included with the cost-benefit analysis presented in the Project Financing section.

Sources of savings for PSIP are calculated in two separate categories, the first of which is utility savings (Lee, 2024a). Utility savings describe energy cost savings; these may be direct energy savings in the form of reduced consumption of kilowatt hours (kWh) due to the energy-efficiency of LEDs, or the kWh savings realized through dimming controls enabled by the new LMS system (Lee, 2024b). With these factors in mind, some

estimate that these LED lamps will produce the same amount of light as the current HID systems while consuming 70 to 90% less energy (Jantz-Sell, 2017). Another factor contributing to utility savings in PSIP is a change in the cost of electricity itself. Most fixtures of the city’s lighting system prior to the project were on an SL-E rate with each of the lights billed assuming a blanket 4100 annual operating hours regardless of whether the light was operating correctly or not (McGinley, 2024b). The term “SL-E” refers to streetlights that are classified as customer-owned (PECO, 2024). The installation of more advanced controls associated with the LMS allows the city to move from the SL-E rate to a lower SL-C rate. The term “SL-C” refers to lights that can be classified under a “smart lighting control” category. The average savings from the reduced energy supply cost when switching from SL-E to SL-C is \$0.0693/kWh annually, a substantial decrease (Lee, 2024c). The LMS also ensures that lights are billed for their exact number of operating hours rather than the blanket 4100 hours, due to the LMS’s ability to track every light’s exact usage of electricity (McGinley, 2024a).

The second category of savings is operations and maintenance (O&M) savings (Bartolotta, 2024). O&M savings are realized from the longer life of LED lamps compared to HID lamps, resulting in a decrease in the need for light replacements (McGinley, 2024a). Previous research estimates the LED luminaires to last at least four times as long as traditional luminaires (Li et al., 2017). Furthermore, the city is also able to monitor all 130,000 lights in real time, decreasing the need for the city to use third-party contractor services for streetlight maintenance by allowing city personnel to repair lights rather than calling in third parties on an emergency basis (McGinley, 2024a).

Table 3
Combined Savings Considering Energy Savings, Rate Changes, and Maintenance Costs

Typical Application	LED Wattage (W)	Energy Savings (kWh/year)	Annual Utility Savings (\$)	Annual O&M Savings (\$)	Total Annual Savings (\$)
Alley	29	3,135,722	\$210,220.00	\$567,591.00	\$777,811.00
Driveway	40	153,211	\$10,271.00	\$31,995.00	\$42,266.00
Local	84	14,800,571	\$1,549,764	\$1,247,328	\$2,797,092.00
Collector	170	6,745,190	\$796,279.00	\$1,188,387	\$1,984,666.00
Major	199	6,310,122	\$624,150.00	\$544,241.00	\$1,168,391.00
Major +	319	2,001,468	\$148,005.00	\$257,699.00	\$405,704.00
Residential Post Top	60	1,482,673	\$169,461.00	\$198,718.00	\$368,179.00
Spring City Franklin	40	147,600	\$16,896.00	\$20,886.00	\$37,782.00
Spring City Chinatown	100	57,812	\$5,297.00	\$2,545.00	\$7,842.00
Spring City Center City	120	1,854,867	\$172,124.00	\$91,138.00	\$263,262.00

Spring City Ben Franklin Pky	155	231,324	\$19,939.00	\$5,090.00	\$25,029.00
Spring City Columbia	200	110,545	\$8,589.00	\$9,776.00	\$18,365.00
Spring City Decoratives (others)	85	0	\$29,884.00	\$110,478.00	\$140,362.00
Misc	N/A	0	\$14,535.00	\$68,547.00	\$83,082.00
Totals		37,031,105	\$3,775,414	\$4,344,419	\$8,119,833.00

The savings of the project in both the utility and O&M categories are estimated in Table 3 with numbers provided by the City of Philadelphia (Bartolotta, 2024; Lee, 2024d). The value of utility savings of some application types seems disproportionately greater than their kWh savings, but this is due to the rate change from SL-E to SL-C (Lee, 2024b). This includes the “Local” and “Collector” types (Lee, 2024e). For other application types, including “Alley” and “Driveway,” the city purchases at a rate which will not change with PSIP (Lee, 2024c). Similarly, the calculation of O&M savings depends on variables such as the different fixture costs per application type and is thus an estimate by application type, with the costs for some applications far greater than others (McGinley, 2024a).

Project Financing

Potential investors want to see an analysis that convincingly demonstrates that the project will pay for itself (Faster Capital, 2024a). Accordingly, the city has decided to pursue PSIP since analysis presented to the city demonstrates that the LED installation project can save enough money to pay for itself in a decade (Savage, 2024). In order for this analysis to hold, the project must be financed in a way where the potential for energy savings is clear, and does not create too large of an initial burden on the budget (Chen et al., 2017; Aasen et al., 2016). In the case of PSIP, the city chose to finance the project with a municipal serial bond, which is consistent with the financing structure of the majority of long-term infrastructural projects (Faster Capital, 2024b). Serial bonds’ maturity dates are spread over several years, allowing issuers to plan phased repayments in sync with the expected cost savings from infrastructural projects (Accounting Insights, 2024). Compared to non-serial bonds, this helps reduce immediate financial burden on the city, mitigating the risk of having a large outstanding debt obligation that comes with a lump sum repayment (Under30CEO, 2024). This section of the paper works to analyze the bonds issued for PSIP by investigating the project’s annual cash flows. The paper will additionally provide recommendations for PSIP’s bond structuring that would also apply to other municipalities that take on similar infrastructural projects.

Able to be processed through the Depository Trust Company system starting August 1, 2023, the \$91 million needed to fund PSIP are raised through the city’s Sustainability Bonds; these bonds are the city’s first issuance qualified for the Sustainability Bond designation (Kestrel, 2023). The city has split the bonds for PSIP into two series: Series A and Series B. Series A (2023A) Bonds have maturity dates ranging from 2028 to 2043 and a flat interest rate of 5%, are federally tax-exempt, and hold a principal amount of \$72,725,000.00. The 2023A Bonds are trading at a premium, resulting in total funds raised of \$81,645,157.75. Series B (2023B) Bonds have maturity dates ranging from 2024 to 2027 and interest rates hovering slightly over 5%, are federally taxable, and hold a principal amount of \$10,800,000.00. The 2023B Bonds are not trading at a premium. Overall, the 2023A and 2023B Bonds collectively provide the city with \$92,445,157.75 worth of funds. \$1,245,157.75 of this is used to pay the bonds’ cost of issuance including legal fees, rating fees, and other expenses related to the offering, leaving the city with \$91,200,000.00 for PSIP (Philadelphia Energy Authority, 2023).

Table 4
Interest Payment Calculations

Maturity Date (Calendar)	Principal repayments	Interest Rate	Interest on bond until maturity date
2023	N/A	N/A	N/A
2024 (Series A)	\$2,485,000.00	0.05587	\$138,836.95
2025 (Series A)	\$2,630,000.00	0.05387	\$141,678.10
2026 (Series A)	\$2,770,000.00	0.0509	\$140,993.00
2027 (Series A)	\$2,915,000.00	0.05048	\$147,149.20
2028 (Series B)	\$3,045,000.00	0.05	\$152,250.00
2029 (Series B)	\$3,200,000.00	0.05	\$160,000.00
2030 (Series B)	\$3,365,000.00	0.05	\$168,250.00
2031 (Series B)	\$3,535,000.00	0.05	\$176,750.00
2032 (Series B)	\$3,715,000.00	0.05	\$185,750.00
2033 (Series B)	\$3,905,000.00	0.05	\$195,250.00
2034 (Series B)	\$4,105,000.00	0.05	\$205,250.00
2035 (Series B)	\$4,315,000.00	0.05	\$215,750.00
2036 (Series B)	\$4,540,000.00	0.05	\$227,000.00
2037 (Series B)	\$4,770,000.00	0.05	\$238,500.00
2038 (Series B)	\$5,015,000.00	0.05	\$250,750.00
2039 (Series B)	\$5,275,000.00	0.05	\$263,750.00
2040 (Series B)	\$5,545,000.00	0.05	\$277,250.00
2041 (Series B)	\$5,830,000.00	0.05	\$291,500.00
2042 (Series B)	\$6,125,000.00	0.05	\$306,250.00
2043 (Series B)	\$6,440,000.00	0.05	\$322,000.00

The information from Table 4 was acquired from the Philadelphia Energy Authority. To calculate the annual debt payments on the 2023A and 2023B bonds, the interest payments are first calculated in Table 4. These are simply found by multiplying the principal repayments for each maturity

year by their corresponding interest rates to find the amount of interest the city will pay annually until maturity.

Table 5
Total Debt Service

Fiscal Year (Calendar)	Principal Balance	Principal repayments	Interest	Total Debt Service
2023	\$83,525,000.00	N/A	\$1,051,226.81	\$1,051,226.81*
2024	\$81,040,000.00	\$2,485,000.00	\$4,204,907.25	\$6,689,907.25
2025	\$78,410,000.00	\$2,630,000.00	\$4,066,070.30	\$6,696,070.30
2026	\$75,640,000.00	\$2,770,000.00	\$3,924,392.20	\$6,694,392.20
2027	\$72,725,000.00	\$2,915,000.00	\$3,783,399.20	\$6,698,399.20
2028	\$69,680,000.00	\$3,045,000.00	\$3,636,250.00	\$6,681,250.00
2029	\$66,480,000.00	\$3,200,000.00	\$3,484,000.00	\$6,684,000.00
2030	\$63,115,000.00	\$3,365,000.00	\$3,324,000.00	\$6,689,000.00
2031	\$59,580,000.00	\$3,535,000.00	\$3,155,750.00	\$6,690,750.00
2032	\$55,865,000.00	\$3,715,000.00	\$2,979,000.00	\$6,694,000.00
2033	\$51,960,000.00	\$3,905,000.00	\$2,793,250.00	\$6,698,250.00
2034	\$47,855,000.00	\$4,105,000.00	\$2,598,000.00	\$6,703,000.00
2035	\$43,540,000.00	\$4,315,000.00	\$2,392,750.00	\$6,707,750.00
2036	\$39,000,000.00	\$4,540,000.00	\$2,177,000.00	\$6,717,000.00
2037	\$34,230,000.00	\$4,770,000.00	\$1,950,000.00	\$6,720,000.00
2038	\$29,215,000.00	\$5,015,000.00	\$1,711,500.00	\$6,726,500.00
2039	\$23,940,000.00	\$5,275,000.00	\$1,460,750.00	\$6,735,750.00
2040	\$18,395,000.00	\$5,545,000.00	\$1,197,000.00	\$6,742,000.00
2041	\$12,565,000.00	\$5,830,000.00	\$919,750.00	\$6,749,750.00
2042	\$6,440,000.00	\$6,125,000.00	\$628,250.00	\$6,753,250.00
2043	\$-	\$6,440,000.00	\$322,000.00	\$6,762,000.00

*These bonds officially open for trading starting August 1, 2023; this figure is prorated (multiplied by 25% since the debt accumulates for three out of twelve months, August through October).

The interest payments per maturity year are aggregated to find the total interest that the city will pay per calendar year. As illustrated in Table 5, interest payments for each calendar year are found by adding the interest payments of each row in Table 4 with a maturity date that is the same or later than the calendar year with the exception of 2023. Since the bonds have interest payment dates on May 1 and November 1 of every calendar year, and the bonds were officially able to be traded on August 1, 2023, the interest paid in the 2023 calendar year is calculated with the same formula as all the other years and multiplied by 25%. The total debt service per calendar year is found by adding the interest payment and principal repayment amounts. This continues until the debt has been entirely paid off in the year 2043.

Table 6
Net Savings Calculations

Fiscal Year (Calendar)	Net Utility Savings (Electricity)	Electricity Inflation Factor	Net O&M Savings (Service)	Service Inflation Factor	Total Annual Net Savings
2023	N/A	1.000	N/A	1.00	N/A
2024	N/A	1.059	N/A	1.05	N/A
2025	\$4,092,520.08	1.084	\$4,778,246.16	1.10	\$2,956,922.08*
2026	\$4,189,103.56	1.110	\$4,990,878.12	1.15	\$9,179,981.68
2027	\$4,287,966.40	1.136	\$5,212,972.20	1.20	\$9,500,938.60
2028	\$4,389,162.41	1.163	\$5,444,949.46	1.25	\$9,834,111.87
2029	\$4,492,746.64	1.190	\$5,687,249.71	1.31	\$10,179,996.35
2030	\$4,598,775.46	1.218	\$5,940,332.32	1.37	\$10,539,107.78
2031	\$4,707,306.56	1.247	\$6,204,677.11	1.43	\$10,911,983.67
2032	\$4,818,399.00	1.276	\$6,480,785.24	1.49	\$11,299,184.24
2033	\$4,932,113.21	1.306	\$6,769,180.18	1.56	\$11,701,293.40
2034	\$5,048,511.09	1.337	\$7,070,408.70	1.63	\$12,118,919.79
2035	\$5,167,655.95	1.369	\$7,385,041.89	1.70	\$12,552,697.84
2036	\$5,289,612.63	1.401	\$7,713,676.25	1.78	\$13,003,288.88
2037	\$5,414,447.49	1.434	\$8,056,934.85	1.85	\$13,471,382.33
2038	\$5,542,228.45	1.468	\$8,415,468.45	1.94	\$13,957,696.89
2039	\$5,673,025.04	1.503	\$8,789,956.79	2.02	\$14,462,981.83
2040	\$5,806,908.43	1.538	\$9,181,109.87	2.11	\$14,988,018.30
2041	\$5,943,951.47	1.574	\$9,589,669.26	2.21	\$15,533,620.73
2042	\$6,084,228.72	1.612	\$10,016,409.54	2.31	\$16,100,638.26
2043	\$6,227,816.52	1.650	\$10,462,139.77	2.41	\$16,689,956.29

*The project is expected to be finished around August 2025; this figure is prorated (multiplied by 33% since the savings are calculated for four out of twelve months, September through December).

To compare the predicted savings with the cost of debt taken on by the project, the net savings calculations of the project are computed in Table 6. Since the installation of all 130,000 lights is expected to be fully finished around August 2025, the annual net savings are calculated beginning September 2025 for the sake of simplicity (Schmidt, 2023). However, given that LED retrofits will already be decreasing the city’s usage of kWh as installation occurs, this simplifying assumption yields a conservative estimate of the project’s true savings.

The net savings for both utility and O&M are found by multiplying the city’s estimate of total base year savings for each category as found in Table 3 by the inflation factor of their respective sectors. This refers to the electricity sector for utility savings and the service sector for O&M savings. PSIP’s base year is 2023, so the percent change in electricity inflation for 2024 of 5.90% is taken directly from the Consumer Price Index (CPI) calculations provided by the Bureau of Labor Statistics (BLS) (U.S. Bureau of Labor Statistics, 2024). The percent change from 2024 to 2025 and all subsequent years is estimated with data from the U.S. Energy Information Administration (EIA) regarding electricity prices for the past 25 years. The EIA estimates that electricity prices increase, on average, 2.36% annually (Zientara, 2024).

As for the service sector, the percent change in service inflation from 2023 to 2024 is similarly taken from the BLS’s CPI calculations and is an

estimated 5.30% (U.S. Bureau of Labor Statistics, 2024). Data for percent changes in service inflation from 2024 to 2025 and all subsequent years is estimated with statistics from the BLS for the past 74 years and is estimated to average around 4.45% annually (Trading Economics, 2024). After calculating the net savings for both utility and O&M, these values are added together to produce the value of total annual savings of the project. The only exception for this is 2025, in which the sum of the net savings for utility and O&M in the 2025 calendar year are additionally multiplied by one-third due to the assumption that savings of the project only begin accumulating at PSIP’s target completion date which is around the beginning of August 2025 (Bartolotta, 2023).

Table 7
Estimation of Project Value

Fiscal Year (Calendar)	Total Net Savings	Debt Service	Annual Cash Flow	US Inflation Projections	Net Present Value
2023	N/A	\$(1,051,226.81)	\$(1,051,226.81)	1.000	\$(1,051,226.00)
2024	N/A	\$(6,689,907.25)	\$(6,689,907.25)	1.041	\$(7,436,247.00)
2025	\$2,956,922.08	\$(6,696,070.30)	\$(3,739,148.22)	1.075	\$(10,675,825.00)
2026	\$9,179,981.68	\$(6,694,392.20)	\$2,485,589.48	1.097	\$(8,200,399.00)
2027	\$9,500,938.60	\$(6,698,399.20)	\$2,802,539.40	1.119	\$(5,534,649.00)
2028	\$9,834,111.87	\$(6,681,250.00)	\$3,152,861.87	1.141	\$(2,663,301.00)
2029	\$10,179,996.35	\$(6,684,000.00)	\$3,495,996.35	1.164	\$392,362.00
2030	\$10,539,107.78	\$(6,689,000.00)	\$3,850,107.78	1.187	\$3,627,474.00
2031	\$10,911,983.67	\$(6,690,750.00)	\$4,221,233.67	1.211	\$7,042,025.00
2032	\$11,299,184.24	\$(6,694,000.00)	\$4,605,184.24	1.235	\$10,632,107.00
2033	\$11,701,293.40	\$(6,698,250.00)	\$5,003,043.40	1.260	\$14,394,469.00
2034	\$12,118,919.79	\$(6,703,000.00)	\$5,415,919.79	1.285	\$18,326,468.00
2035	\$12,552,697.84	\$(6,707,750.00)	\$5,844,947.84	1.311	\$22,426,026.00
2036	\$13,003,288.88	\$(6,717,000.00)	\$6,286,288.88	1.337	\$26,687,853.00
2037	\$13,471,382.33	\$(6,720,000.00)	\$6,751,382.33	1.364	\$31,114,953.00
2038	\$13,957,696.89	\$(6,726,500.00)	\$7,231,196.89	1.391	\$35,703,102.00
2039	\$14,462,981.83	\$(6,735,750.00)	\$7,727,231.83	1.419	\$40,448,951.00
2040	\$14,988,018.30	\$(6,742,000.00)	\$8,246,018.30	1.447	\$45,353,417.00
2041	\$15,533,620.73	\$(6,749,750.00)	\$8,783,870.73	1.476	\$50,414,342.00
2042	\$16,100,638.26	\$(6,753,250.00)	\$9,347,388.26	1.506	\$55,633,605.00
2043	\$16,689,956.29	\$(6,762,000.00)	\$9,927,956.29	1.536	\$61,006,814.00

Using calculations of the annual total net savings from Table 6 and the annual debt service from Table 5, we calculate the financial value of PSIP by analyzing the project’s net present value (NPV) up until the year 2043. The annual cash flows for each year are represented in Table 7 by taking the difference between each year’s net savings, which is the second column, and debt service, which is the third column. To calculate the NPV

for a specific year, the project's cash flows up to and including that year are aggregated and divided by the general US inflation projection across all sectors. Consistent with data provided by the BLS, the inflation rate from 2023 to 2024 was an estimated 4.1% and the inflation rate from 2024 to 2025 will be an estimated 3.3% (U.S. Inflation Calculator, 2024). For the rate of inflation from 2025 to 2026 and all subsequent years, we use Federal Reserve's target inflation rate of 2%. The estimated project value is in Table 7.

Since NPV compares the project's savings with the costs, a positive NPV suggests that the project will have savings that outweigh the costs, and thus the project should be invested in (Ouyang et al., 2022). The breakeven point is found when the NPV (also commonly known as the internal rate of return) is equal to 0, which the calculations in Table 7 suggest will happen between 2029 and 2030 (Hartman et al., 2010). After this point, the NPV of PSIP is continuously increasing, and reaches around \$61 million, suggesting that it is a worthwhile investment. The annual cash flow used in calculating the NPV suggests that the project will begin producing a positive effect on the city's budget beginning in 2026. A year prior to this, the NPV is at its lowest point, with the project producing an approximately \$10.5 million loss.

Analyzing the NPV of the project produces some additional insights which can be used as recommendations in financing future projects related to PSIP. A potential recommendation is related to bond structuring and maturity dates, which are fully computed with the debt service evaluation above. Since this project could generate substantial fiscal savings, it may be beneficial to consider limiting the principal repayments on bonds until the end of 2025 when the project has been completed and is able to realize the full extent of its savings. This approach would relieve the immediate financial burden on the government since the savings would service the debt, which could boost investor confidence by decreasing perceived risk of the project (Bielenberg et al., 2020). It would drastically increase the NPV's lowest point and enhance overall financial attractiveness.

Discussion

In addition to the benefits mentioned above with improvements in energy efficiency through LED retrofits, investments like these are known to create externalities or "spillover effects" that are difficult to measure but may have significant implications on policy (Jones, 2018). Moreover, although many lighting projects save amounts on energy and maintenance that will offset the costs in the long run, we may identify additional benefits to society which would help close an efficiency gap by further encouraging investors to take advantage of a deeply profitable opportunity (Fowlie et al., 2018). A potential spillover benefit of investing in LEDs that is commonly cited is the environmental benefit from reduced use of energy, which is projected to decrease CO₂ emissions and reliance on

fossil fuels (City of Los Angeles, 2009). Another spillover benefit is improved nighttime visibility, increasing perceptions of safety and security while reducing crime (Kuhn et al., 2012).

On the other hand, investors and municipalities alike should consider decreasing investment or reconsider the project completely if the analysis finds substantial *negative* spillover effects (Bivens, 2017). The main argument against LED lighting is that the blue light it gives off may affect the circadian rhythms of both humans and animals, disrupting normal behaviors (Harvard Medical School, 2020). Fortunately, the versatility of LED lighting can let managers limit the blue-light effect.

Positive Spillover Effects

Environmental Effects

It is well known that the higher efficiency of LED streetlights compared to HID lights allows them to use less energy while performing the same task (Arnold et al., 2015). Given that lighting in the United States constitutes around 17% of its total electricity consumption, any reductions would decrease reliance on energy sources (U.S. Energy Information Administration, 2024a). This decrease in usage will in turn lead to a decrease in environmentally-harmful effects such as carbon emissions (U.S. Energy Information Administration, 2024b). The City of Philadelphia estimates that PSIP will reduce the city's annual streetlighting energy use by more than 50% and carbon emissions by more than 9%, an estimated 122,750 tons (Trading Economics, 2024; Acuity Brands, 2023). The reduction in carbon emissions comes from the decrease in demand for energy production sourced from dirty sources like fossil fuels, which lowers carbon emissions overall. The longer lifespan will also reduce the frequency of replacements and the associated environmental impact of manufacturing the lighting equipment (Gonzalez et al., 2012).

LED streetlights are also able to reduce light trespass, glare, and skyglow, which are all factors in light pollution (King, 2021). A significant factor in achieving this involves the LED's considerably shorter wavelength compared to the traditional HID, which could decrease light pollution in cities by approximately 7% (Barentine et al., 2018). In PSIP specifically, the LMS could also help mitigate some of the light pollution from the newly-installed LEDs by adjusting the brightness of lights based on the time of day, thus decreasing the amount of artificial light released. Minimizing the streetlights' contribution to light pollution is an important step in addressing the ecological cost it may have, which includes negative effects to both wildlife and human health (Shariff et al., 2019).

Safety Improvements

Streetlighting significantly influences criminal decision-making (Kaplan et al., 2022). For one, lighting can increase the perceived certainty of apprehension for a crime, thus deterring criminal activity (Akers, 1990). LEDs from the PSIP are able to contribute to decreasing crime with the presence of lighting itself due to their increased lifespans and ability for real-time monitoring, decreasing the chance and period a light may malfunction and thus also the window a crime could be committed in. The lights themselves also appear brighter than previous HID installations (Rahman, 2013). A second way lighting improvements can affect criminal activity is through the presence of witnesses. Since individuals tend to feel safer in well-lit areas, there could be increased activity in a particular area due to an increase in ambient lighting, deterring crime by increasing the amount of surveillance and “eyes on the street” (Chalfin et al., 2019). Evidence on street lighting suggests that its presence could reduce crime by an average of 20% (Welsh et al., 2008).

Better street lighting may also increase safety by preventing nighttime road injuries through improving drivers’ visual capabilities to detect roadway hazards (Beyer et al., 2009). An increase in lighting quality is associated with an earlier detection of intersections, earlier gas pedal release, and earlier speed reduction, which contributes to an increase in safety (found most in older drivers) (Rockwell et al., 1976). Research suggests that even a slight increase in the brightness of streetlights could decrease the number of night crashes by 19% (Jackett et al., 2012). Given that the estimated social cost of nighttime crashes in urban areas is around \$310M per year, these reductions are substantial.

Negative Spillover Effects

Disruptions to Wildlife

Concerns about potential negative harms of LED lights often make the point that brighter lights are not always better because they often carry significant ecological implications (Miguel et al., 2022). However, it is important to note that there is no significant organized body of information describing the effects of LEDs in wildlife (Longcore, 2023). Even without these bodies, it is generally agreed upon that LED streetlights increase the production of blue light which disrupts the circadian rhythms of both humans and animals (Levin, 2023). In fact, research shows that LED systems may become five times as disruptive to ecological surroundings compared to conventional lighting systems (Kramer, 2016). In PSIP specifically, some of these negative repercussions have already been experienced by citizens, with some complaining that the transition to the brighter LED system has affected both their own sleep and the behavior of wildlife in the area (Seal, 2024). It should be noted, however, that the flexibility of LEDs combined with different functions the LMS offers also means there are a variety of ways to mitigate these negative effects, whether it be changing the LED’s duration, direction,

intensity, or spectrum (Longcore, 2019). This means that LEDs can be tweaked or designed to mitigate these negative effects and still perform extremely well.

Conclusion

The goal of this paper was to analyze the economic feasibility of city-wide initiatives focused on energy efficiency. Specifically, this paper worked to identify whether the high initial cost of implementing LEDs is outweighed by the various benefits they bring in, both socially and economically, using Philadelphia's project for a case study in cost-benefit analysis. Overall, this study finds that the significant savings in energy and operations and maintenance make the decision to pursue implementing LED technology in street lighting systems an obvious one.

While this study focuses on Philadelphia, its findings can be applied to other municipalities experiencing uncertainty in financially committing to LED projects. The cost-benefit analysis provided in this research should serve to demonstrate that projects installing LED lights can yield great benefits if conducted and structured in the ways this paper recommends. These findings have important implications for cities considering proposals to raise money for LED retrofits, and the methodology used in this paper provides a scalable framework for assessing the economic feasibility in similar sustainability projects.

First, the paper finds LED replacement streetlight projects will lead to a decrease in overall energy and O&M costs. Some factors illustrated by PSIP include: the energy efficiency of LEDs, which decreases energy consumption; long lifetimes of LEDs, which reduces the number of replacement lamps needed; and opportunities for connections to an LMS, which increases energy-use optimization due to abilities like the dimming function. This paper shows that the NPV of PSIP will be positive six years after the project is completed, and annual cash flows will be positive three years after the project has been completed. The estimated NPV of the project in Philadelphia hovers around \$60 million. Additionally, considering factors like the growing rate of energy or service inflation, projects focused on energy efficiency such as PSIP may yield even greater benefits.

Second, there are strategies for funding that spread out initial construction costs and allow them to be serviced by long-term benefits. In the case of PSIP, serial bonds were issued with maturity dates ranging over 20 years. Cities have the potential to limit upfront cost by delaying principal repayments until after streetlight renovations are fully completed. Structuring fundraising optimally would decrease perceived investment risk and the hit a city's budget would take from high costs of implementation.

Third, spillover benefits to the environment and public safety not included in NPV calculations will also boost the value of the project. CO₂

emissions would be cut by over 100,000 tons annually, and light pollution could be cut by 7%. Furthermore, improvements to street lighting systems have been shown to reduce both general crime and nighttime motor accidents by around 20%. The main spillover harm cited with LED retrofits is disrupting wildlife through the production of blue light in which LEDs are five times more disruptive to the environment compared to traditional HID lights. But the flexibility permitted by LED fixtures connected to LMS systems can mitigate these concerns.

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