Economic Cost-Benefit Analysis of Smart LED Street Lights: *Providing Free Public WiFi to the Linden Neighborhood*

AEDE 4567 Capstone Final Report

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Executive Summary

The purpose of this study is to compare the monetary costs against the social benefits of implementing public WiFi into a test grid of smart street lights in Linden, Ohio. This project is part of the Smart City Grant awarded to Columbus, Ohio and is based out of the “Columbus Connected Transportation Network (CCTN)” grouping. This grant will set Columbus apart from other US cities through sustainable development and help improve the day-to-day operations of the community.

Through this study, our team aimed to provide a baseline understanding of the costs and benefits associated with implementing free public WiFi in the Linden neighborhood. This information is intended to help the City of Columbus make more informed decisions on the smart street light component of the Smart City Grant. Specifically, this report will aid the city in efficiently allocating funds towards its public sustainability goals, with a specific focus on increasing access to educational, health, and career development resources in underserved communities. In order to provide the most useful information, our team completed numerous rounds of data collection, identified implicit and explicit costs and benefits, monetized these impacts, and found their values over the lifespan of the project.

The results of our Cost-Benefit Analysis (CBA) found that the social benefits of WiFi provision far outweigh the costs. We found the Net Present Value (NPV) of the project to be between $4.5 - 10.5 million, given different projections, over a 25-year timespan with a constant discount rate of 3.0%. Given this result, we recommend implementing a test circuit of smart street lights to provide WiFi, while creating a comprehensive monitoring system to ensure cost-effectiveness and measure results.

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Introduction

The Smart Street Light Pilot Project is part of a larger grant-funded program known as Smart Columbus. In the summer of 2016, Columbus applied for and received the Smart City Grant, sponsored by various federal government agencies and private partners such as Vulcan Industries and AT&T. The funds awarded to Columbus through this grant started at a value of $50 million in both direct funding and in-kind support. Today, the value of the project is approaching $500 million. The goal of Smart Columbus is to better connect the people who live and work in the city through technological innovations. Projects proposed under the grant include: electrical grid modernization, commercial electric vehicle adoption, multi-modal payment systems, and automated electric vehicles. The emphasis is predominantly on increasing access to easy and efficient transportation and job acquisition. Goals set forth by Smart Columbus include promoting safety, increasing mobility, providing ladders of opportunity, and combating climate change. Through this project, our team aims to assist with these goals through carefully analyzing one facet of the smart street lighting project as a means to career and educational development.[1]

The goals of this project are to:

I. Understand the feasibility of a Smart Street Lighting Project in Columbus, Ohio through case-studies and research into similar projects,
II. Create a narrative within both the Smart Columbus literature and the community context of Linden to frame this project, and
III. Produce a Cost-Benefit Analysis (CBA) which can be instrumental to the Smart Columbus Working Group in justifying further direction with the project.

These goals will be accomplished by achieving the following objectives:

I. Conduct a study into all scholarly literature and other sources to understand precedent behind such a project,
II. Collect information about the Linden neighborhood, as well as information on costs and benefits of WiFi provision through street lighting infrastructure, and
III. Analyze these findings to create an accurate impression of the place this project would have within both the Smart Columbus Project and the Linden community specifically.

In discussions with various city employees, these goals and objectives were chosen to fill knowledge gaps around the Smart Street Lighting Project. Little was known about WiFi provision through street lighting infrastructure, but many individuals both inside and outside the community expressed interest in the potential improvements that widespread access to internet would have in Columbus. We decided to focus on light-emitting diode (LED) bulb conversion from high pressure sodium (HPS) bulbs, along with the possibility of providing free in-home WiFi. These two aspects were emphasized as the most important to both the City of Columbus and Linden residents. This was concluded through the Linden innovation session meetings where residents of the community and city officials collaborated to align the wants and needs of the neighborhood.

The area of focus for this CBA is the neighborhood of Linden, Ohio. Linden is located in the northeastern portion of central Columbus and is situated between a prosperous shopping center to the East, a major freeway that serves as a wall to the western portion of Columbus, and a North-South thoroughfare that provides some access to economic and transportation resources. This makes Linden particularly interesting to the Smart Columbus program for several reasons. The neighborhood is a low income area with a history of high unemployment and crime rates, along with above average high school dropout rates.[2] According to surveys done in the area, many residents do not have access to internet, which hinders students' ability to finish homework after school and restricts adults from other educational and employment opportunities that internet access provides. To better understand the needs and wants of Linden, the Smart Columbus working group held “innovation session” meetings to allow residents to express their feelings regarding various elements of the project. During these sessions, many community members expressed that WiFi would aid their children in academic success. Along with this, many residents expressed concerns of safe transportation within the community. Because of these factors, addressing access to opportunity and safety through street light infrastructure could be a worthwhile endeavor.[2,3]

Given this narrative, we proceeded to identify costs and benefits of smart street lights and find the value of these over the timeline of the project along the potential test circuit. After careful analysis, we found the Net Present Value (NPV) of this project to be between \$4.5 - \$10.6 million given different projections of costs and adoption. With these findings, we believe that implementing a test project within Linden would give a solid precedent for future expansion and justify actions taken by the city through the Smart City Grant. This is all contingent upon a robust set of objective measures to ensure documentation of outcomes.

Cost-Benefit Analysis

Methodology

Our team followed the standard 10-step model presented to the Environment, Economics, Development, and Sustainability (EEDS) Capstone course early in spring semester to conduct this cost-benefit analysis (CBA). The full list of steps included along with information that correlates with our project specifically can be found in Appendix A, while key information is explained in the following text.

Alternatives

This CBA compares three separate NPVs for the proposed project, representing three different potential outcomes based off the assumed percent changes for reduced unemployment and increased graduation impacts. Because this project would be one of the first of its kind if implemented, our team felt that providing a range of NPVs is appropriate for decision making. The NPVs provided are based upon the following scenarios:

I. Assumes a 0.5% reduction in unemployment and 2% increase in high school graduation
II. Assumes a 1% reduction in unemployment and 3% increase in high school graduation
III. Assumes a 2% reduction in unemployment and 4% increase in high school graduation

Stakeholder Standing

Four key stakeholders have standing in this CBA. The Smart Columbus working group and the Columbus Division of Power have primary jurisdiction over the proposed project, as they would be responsible for smart street light implementation. The third notable stakeholder is the company responsible for providing WiFi to the smart street lights. It remains unclear which company would provide these services, but a public-private partnership is necessary for successful implementation. Finally, residents of the Linden neighborhood hold significant standing, specifically those who reside along circuit #89 (see Figure 1). Our team considers the community members of Linden to be the most important stakeholders of this CBA because they will incur the social impacts most directly.

It is important to note that the first three stakeholders mentioned will incur all of the monetary costs included in this CBA, while Linden residents will receive a majority of the benefits. The discrepancy between private costs and social benefits is standard for government-funded projects and explains why the value of benefits are significantly greater than the costs.


Figure 1: Circuit 89

Evaluation Period

A 25-year time period was used for this CBA. Many of the benefits included, such as reduced unemployment, will not occur immediately after project implementation so a longer lifespan was decided on to keep the assumptions realistic, although not too long as to keep the projection relevant for current Smart Columbus working groups.

Discount Rate

Government-funded projects typically have a discount rate of 2-5%, depending on the potential impacts of the project. Our team believes that providing free public WiFi has considerable positive impacts for a community and should thus not be discounted at too high of a rate. For this reason, a discount rate of 3% was used for calculating the NPVs of this study.

Data Collection

Preliminary research

Much of this project's direction comes from the goals set forth in the Smart Columbus Grant. In preliminary ideation sessions regarding smart street lighting concepts, various ideas were mentioned for which features to incorporate. Examples include: traffic monitoring camera system, Greenhouse Gas (GHG) emission readers, air quality sensors, ambient light sensors for LED lighting adjustment, and WiFi provision through the streetlight infrastructure.

To become better versed in any previous work done on such projects, our team searched extensively to find any documentation on similar smart street lighting projects both domestically and abroad. The research looked into both grey literature (such as through Google searches) and scholarly literature. Though few examples were found initially, searches were refined to reflect various elements of the proposals, such as GHG emission detection and their implementation in street light infrastructure.

Project Focus

After this preliminary research, we met with members of the Smart Street Lighting Working Group and city employees to refine the scope of the analysis. During the meetings, numerous members of the Smart Columbus team expressed their interest in WiFi provision, while also expressing uncertainty in the feasibility of the element. Numerous members of the working group doubted both the feasibility and overall usefulness of the LED dimming, air sensors, and traffic monitoring in the Linden neighborhood. Having heard this input and gathering the results of the innovation sessions in Linden, the scope of this CBA was limited to only analyze WiFi provision coupled with LED bulbs. We believe WiFi fits into the narrative of the Smart Columbus program better than the other possible smart street light features.

With a new focus on public WiFi provision, we began another round of research into smart street lighting. Once again, few examples were found. To broaden our search, we began to explore municipality-driven public WiFi provisions of any kind. This switch was intended to help gain a better understanding on how similar projects may be implemented in a community, and perhaps give an insight into the feasibility of the project. A handful of examples were found on public WiFi projects, however, few were well-documented and comprehensive in nature. Two particularly interesting projects were found: the Scioto-Mile greenway in Columbus, Ohio and Old Brooklyn in Cleveland, Ohio.[4,5] These projects were recent, near Columbus, well-documented, and showed promise for further investigation. However, after numerous attempts at communication, we were unable to contact any individuals from these projects in a meaningful way.

<u>Benefit and Cost Accumulation</u>

Finally, a comprehensive CBA was performed given the provided and accumulated information. Our team identified a basic system through which to provide

WiFi in order to find the monetary installation costs, and quantified the benefits of this system accordingly.

The system used includes WiFi routers installed into the street light infrastructure, which are connected to a fiber network installed beneath the lighting. The main costs associated are hardware (routers, cable, etc.)[6,7,8] and the provision of the internet itself.[9] The hardware needed was based on information about the current street lights on circuit #89 provided to us by the city. For this CBA, the WiFi routers would be placed in each of the 207 light posts on the circuit and the length of cable was based on the distance between each light off of the main cable line located underneath Hudson Avenue (James Gross II, personal communications, February 21st, 2017). The costs of the cable and routers were retrieved from consumer-level internet hardware websites found through Google searches. While the city's contractors could likely get better rates, this was the best data available. As for pricing of the internet provision, several Internet Service Providers (ISP) were contacted to get estimates on potential rates, but no responses were received. The idea of the city becoming an ISP was infeasible given the costs associated with this process. The alternative is estimating bulk provision rates with a group discount. Initial analyses used consumer-level pricing. An article detailing a municipal program to provide inexpensive WiFi access for the city of Minneapolis through an ISP stated that the city offered internet at 2-5 MB/s for $9.99/month[9]. This was used as the ISP cost per subscribed household, and this cost acts as an effective indicator of the price Columbus would have to pay to provide the same service for free. These cost values were then used to calculate a total area cost by combining them with the number of houses on the circuit.

On the benefits side, our team considered many of the potential impacts expressed by the Smart Columbus group, along with potential outcomes related to the goals of the Smart City Grant. These included increased educational and career development opportunities, as well as increased access to health care resources. Our team considered the educational and career development impacts to be the most important to quantify; thus, to begin measurement we searched the scholarly literature on the effect that internet access has on joblessness and graduation rates. These effects were measured by quantifying: a) increased incomes from a given increase in employment, b) increased tax revenue for a given increase in employment, and c) increased high school graduation rates. Surprisingly, little was found after a search of numerous research databases. Given this, our team opted for a conservative change in these factors given the lack of a previous study.

To value these, we first needed to find the change in these factors given demographics in the community. For unemployment, we used the community fact data sheet to estimate the average number of individuals currently employed who reside along circuit #89 in Linden, given the average number of people per household in this neighborhood and the percent of working-aged people in this sample population. The value of increased employment, then, was monetized by assigning the average income per capita of this community to the number of individuals who would receive jobs from the project. The tax revenue is based on the tax rate in Columbus applied to this collective added income. Finally, the potential change in high school graduation rates was measured using Linden McKinley STEM Academy enrollment and graduation rates, and scaled for the test circuit. The annual value of this was calculated using the added revenue gained by high school graduates and cost savings from decreased incarceration of high school dropouts obtained from a study on the costs of school dropouts. For calculations, see Appendix C.[2,3,10,11]

Benefits and Cost Included

Benefits

The benefits included in this CBA have been identified as the most relevant for the proposed project after meeting with the various stakeholders. The proposal put forth by Columbus for the Smart City Grant included a social sustainability goal of increasing access to “career development and educational” resources through the use of smart street lighting, so our team decided to make this goal the heart of our CBA.[1] The benefits included in this study are as follows:

Energy Cost Savings

The Columbus Division of Power estimates that they will experience a 55% reduction in energy usage from converting the current street light fixtures to LED, from 37,935 MWh in 2015 to 20,917 MWh post-LED conversion (James Gross II, personal communications, February 21, 2017). By dividing the MWh by the total number of street lights under the Division of Power’s jurisdiction, we found the annual cost of operating one street light before and after LED conversion to be $60.37 per light and $27.17 per light, respectively. When comparing these values to the number of street lights along the proposed test circuit (207 street lights), an annual cost savings of $6,873.12 occurs from the pilot project alone, resulting in a total cost savings of over $170K for the timeframe of this CBA.

	Energy Usage (KWH)	KWH/Light	$/Light	$/Year (circuit 89)
2015	37935000	717.5553748	60.36984716	12496.55836
LED Conversion	17070750	322.8999187	27.16643122	5623.451263
			Cost Savings Per Year:	**$6873.1071**

Table 1. Energy usage and costs before and after LED conversion along the proposed pilot test circuit of 207 street lights.

Reduced CO_2 Emissions

One of the most common benefits of switching to LED street lights is the reduction of CO_2 emissions, making this a favorable project for cities trying to mitigate climate change. By using a unit-value benefit-transfer from a Los Angeles case study on converting the city's streetlights to LED, we found that each individual street light is responsible for mitigating 0.36 metric tons of CO_2 per year after LED conversion.[15] Along the proposed test circuit of only 207 lights, LED conversion would thus mitigate 73.91 metric tons per year.

The social benefits associated with reduced CO_2 emissions include higher air quality, more resilient environments, and increased public health, particularly in regards to asthma and other respiratory ailments. These factors are the fundamental basis for the "Social Cost of Carbon (SCC)" values put forth by the U.S. EPA, which were utilized in this CBA. Because the EPA's cost estimates increase every five years, a range of monetized benefits are included in this to correlate with the 25-year timeframe.[12]

Time Period	SCC	Value to Society ($/year)
0-7	$42	3,509.25
8-12	$46	3,843.46
13-17	$50	4,177.67
18-22	$55	4,595.44
23-25	$60	5,013.21

Table 2. The different values to society of mitigating 73.91 metric tons of CO_2 per year based off the different SCC values provided by the U.S. EPA.[12]

Reduced Unemployment

Internet access is vital for employment opportunities. The majority of Linden residents do not have WiFi in their homes, so they rely on library and other public computers to search job listings and fill out online applications (James Gross II, personal communications, February 11,2017). Without access to their email outside of the library, they seriously risk missing employment opportunities. In order to receive unemployment benefits from the government, recipients must meet strict job search requirements Sunday through Saturday, something that is not always possible while relying on public locations for internet access. In today's economy, we believe that WiFi has become a basic human right, as lack of internet access puts an individual at a huge systemic disadvantage known as the "digital divide."[14]

Because this project would be one of the first of its kind, there is limited data available on how this initiative would directly affect unemployment rates. However, there is extensive qualitative literature on how the digital divide traps low-income individuals and communities in unemployment, identifying internet as one of the most important resources for finding and keeping a job.[14] For this CBA, our team used a 0.5-2% range in the reduction of unemployment in the Linden neighborhood as a result of the project.

Considering how vital internet access truly is for job searching, we believe that this is a realistic estimate for the 25-year time period.

The current unemployment rate in Linden is 10.5%, compared to the Columbus average of 3.8%.[2] The estimate of Linden residents who would be directly affected by smart street lights was based upon the number of households along circuit #89, multiplied by the average number of individuals per household in Linden. This information can be found in the community fact report attached in Appendix C. People ages 18-64 make up 66% of the population in Linden, so we can infer that there are about 1,851 working-aged people along the proposed test circuit.[2] This data was used to approximate the number of employed people along circuit #89, from which we can pull the collective average annual income for the target area based off the average annual income per capita of $26,930 for Linden residents.[2] The difference in the average annual income found under each percent change and the current value indicated in row 1 of Table 3 represents the value added as a result of the project, ranging from $250K to almost $1 million.

Unemployment Rate	# of Employed People	Collective Average Annual Income	Value Added
10.5% (current)	1,656.90	$44,620,432.30	-
10%	1,666.16	$44,869,708.46	$249,276.16
9.5%	1,675.41	$45,118,984.62	$498,552.32
8.5%	1,693.93	$45,617,536.93	$997,104.63

Table 3. The value added in collective annual income of households along circuit #89 based off a 0.5%, 1%, and 2% reduction in unemployment rates among those households.

Increased Tax Revenue

Increased tax revenue is often associated with economic growth, which may help communities such as Linden if the funds from the increased tax revenue are allocated appropriately. In this case, the city government could spend the increased tax revenues from reduced unemployment in Linden on programs and initiatives that help this underserved neighborhood become competitive with more affluent parts of the city. The average income tax in Columbus is 2.5%.[10] The increased tax revenue resulting from a 0.5% reduction in unemployment would then be $6,231.90, a 1% reduction would add $12,463.81 in tax revenue, and a 2% reduction would nearly double that added value at $24,927.62.

Collective Average Annual Income	Tax Revenue	Value Added
$44,620,432.30	$1,115,510.81	-
$44,869,708.46	$1,121,742.71	$6,231.90
$45,118,984.62	$1,127,974.62	$12,463.81
$45,617,536.93	$1,140,438.42	$24,927.62

Table 4. The value added to the city in increased tax revenue from a 0.5%, 1%, and 2% reduction in unemployment along circuit #89 in the Linden neighborhood based off a 2.5% income tax.

Increased High School Graduation Rates

Similar to employment opportunities, internet access is increasingly vital to educational success. Schools have rapidly been transitioning towards completely online platforms, where students can receive, complete, and turn in their assignments online. While this change certainly makes perfect economic and environmental sense, it disproportionately affects students who live without internet in a negative way. Students who live without WiFi access makes up the majority of students at Linden McKinley STEM Academy, the primary public school near circuit #89 (James Gross II, personal communications, February 11, 2017).[3]

Along with the unemployed people of Linden, then, students in this neighborhood must rely on public locations or after-school programs to complete their homework. This might help explain the astonishingly low graduation rate of 62.4% observed in Linden McKinley STEM Academy. The current enrollment is 553 students, which results in an average annual dropout of about 208 students.[3] At the Innovation Session in Linden, community member stakeholders most heavily expressed concerns of their children not being able to complete their homework assignments at home. Because of this overwhelming consensus, our team chose a higher percent change for high school graduation rates than for unemployment, with an assumed 2-4% increase in graduation as a result of providing in-home WiFi. Increase graduation rates by 2% and the school would experience about 11 less dropouts, 3% would result in 17 less dropouts, and a 4% increase would reduce dropouts by about 23 students.

A comprehensive study from Northeastern University that researched the cost borne by taxpayers as a result of the "joblessness and jailing" of high school dropouts was used to estimate the social benefit of increased high school graduation rates. The authors of this report separated this social cost into two categories: the loss in state and local taxes due to dropouts not working or having lower paying jobs compared to high school graduates, and the cost of transfers and incarceration costs borne by the state.[11] It is the sum of these two components ($12,284) that is used to calculate the social cost of high school dropouts in Linden, from which we can derive the social benefit from.

Graduation Rate	Student Dropouts	Social Cost of Dropouts	Social Benefit of Increased Graduation Rates
62.4% (current)	207.93	$2,554,188	-
64.4%	196.87	$2,418,327	$135,861.04
65.4%	191.34	$2,350,396	$203,791.56
66.4%	185.81	$2,282,465	$271,722.08

Table 5. The different values of increasing high school graduation rates by 2%, 3%, and 4% to society.

Costs

Internet Infrastructure Costs

The costs associated with the implementation of free, in-home WiFi are made up of three components. First is the router used on each of the street lights, second is the fiber optic cable used to communicate data to and from the ISP, and third is the price of the internet service itself, as charged by the ISP.

In a traditional home WiFi network, there are two components: the modem which sends and receives information requested from the ISP, and the router, which broadcasts the WiFi signal. In contrast, in the context of a municipal in-home WiFi program, such as the one proposed for the Linden test grid, our team has decided to pursue an alternative solution, with one modem installed and maintained by the ISP. This modem is then connected to a number of the routers via fiber optic cable to transmit data to and from the ISP. This allows for more centralized management of the network, and reduces costs by eliminating the need to buy, install, and power a large number of modems. Routers are rated with a maximum range of transmission, which is the distance that their signal can travel and transmit data in an ideal situation. However, often the real world range is far smaller than the maximum range, as many building materials can create a partial or complete faraday cage, which can block weak radio transmissions. This study included only those structures located directly on the test grid, as this limitation of wireless communication penetrating through multiple, sequential, structures would present a technical challenge. To ensure that residents located on the test grid have reliable WiFi access in their homes, routers with a maximum range of 1000 ft were selected. This should allow for a signal strong enough to penetrate the walls of homes and businesses on circuit #89.

The next piece of the infrastructure requirements for the project is fiber optic cable. Fiber optic cable is the current leading edge of internet transmission technology, and the City of Columbus has already partially implemented fiber optic infrastructure. There is a length of the cable already installed on Hudson street through the test grid. The cable is needed to allow the flow of data to and from the routers mounted on the smart street lights and ISP. Fiber optic cable is most often used for very high speed internet, however, it is important in this context. Despite the relatively slow internet that would likely be provided, each router will be handling data from several homes at once, requiring greater communication capacity for each. The cost to purchase the desired cable was found to be $0.68 per foot. Google Earth was utilized to create a detailed estimate of the total length of streets on the test grid, excluding Hudson street as cable has already been implemented there, which produced a total distance of 29,233 feet. The cables would join with the line on Hudson to allow the grid to be connected to the larger system of cables implemented by the city. A total one-time cost of $19,874.44 was estimated to purchase the required fiber optic cable.

The final component of implementing free WiFi for the Linden residents is the Internet Service Provider. Initially, our team pursued the possibility of Columbus investing in the equipment needed to act as an ISP for the test grid. This way, if the project was successful, it could be expanded at a lower cost. However, it was discovered that the equipment required to operate an ISP changes based on the total number of users, meaning that the city would have to reinvest in new, increasingly expensive equipment in order to expand the service. This, combined with the added cost of maintaining the network internally, led our team to shift focus towards a public-private partnership with an existing ISP, such as AT&T or Time Warner Spectrum. A similar program in Minneapolis saw the city contract Time Warner to provide the services of an ISP, with the city acting as the outward facing part of the program.[6] The Minneapolis city government was able to sell its residents internet service for $9.99 a month, at a speed of 10 megabits per second. The team used this as a model to build from, developing annual internet service cost estimates based on that price per household, for a variety of levels of adoption, as is shown in Table 6 below.

Internet Service Cost			
Internet Price	**Level of Adoption**	**Total Monthly Cost**	**Annual Expense**
$9.99	20%	$2,407.59	$28,891.08
$9.99	40%	$4,815.18	$57,782.16
$9.99	50%	$6,018.98	$72,227.70
$9.99	60%	$7,222.77	$86,673.24
$9.99	80%	$9,630.36	$115,564.32
$9.99	100%	$12,037.95	$144,455.40

Table 6: Estimated price for ISP internet service based on Linden Resident Adoption

The 10 megabit per second speed of the internet would be sufficient for most internet activities, with the exception of streaming video. However, in comparison, the least expensive internet plan offered by Time Warner Spectrum is $44.99/month at 60 megabits per second, a price that would make it much more difficult to fund the project. Another advantage of using an existing ISP is the access to professional services to set up the user end of the network. The WiFi provided will require residents to login with a username and password, similar to the systems used by many colleges and universities. Utilizing an existing ISP allows providers to streamline this process, or for the city to negotiate this into the contract. The team's highest estimate for the monthly cost, assuming 100% adoption from homes on the test circuit, was $12,037.95 a month, or $144,455.40 per year.

LED Streetlight Conversion Costs

Estimating the cost of replacing conventional high pressure sodium (HPS) street lights with energy efficient LED Luminaires was a more streamlined process than the internet cost estimation process. James Gross, the Assistant Administrator for the Columbus Division of Power, provided a detailed conversion sheet for costs of each type of street light. The city-wide document compared costs for both the various street light wattages and the type of fixture itself. A specific list of the street light types along circuit #89 was also provided, as seen in Table 7 below.

Conv. Wattage	LED Equivalent	Quantity	Luminaire Cost	Total Cost (LED)
55 W	30 W	15	$185.00	$2,775.00
100 W	60 W	140	$225.00	$31,500.00
200 W	100 W	52	$238.00	$12,376.00

Table 7: Cost by type of light to purchase required LED luminaires

With the cost estimation information provided, each light was identified with the wattage of its LED luminaire replacement and its price. Our team then used the service fee information to produce an average installation expense of $170 for all three types of light. From there, the installation cost and luminaire cost for each type of light were combined, and the total cost for the conversion was found to be $46,650.99.

After the total conversion cost was obtained, the team used a Life Cycle Assessment on street lighting published by Pittsburg University to identify a lifespan for the LED luminaires. The study stated that during a 100,000 - hour period, the luminaires would need to be replaced 1.7 times. This information was used to calculate that over the course of the study period, the fixtures would need to be replaced 3.723 times. This, in tandem with the total cost for conversion calculated above, was used to produce the estimate $208,871.67 for the total cost of implementation of the LED streetlights (see Dataset #6 in Appendix E).

Key Assumptions

Cost Assumptions

Internet Infrastructure Cost Assumptions

Total Fiber Optic Cable Cost	**$19,874.44** - Assumes ISP will perform cable installation and maintenance, all cable can be connected to Hudson St. line, 24 count cable can be used in all areas, and street length data obtained via Google Earth is accurate.
Total Router Cost	**$8277.93** - Assumes no changes to light's power consumption to operate with the router, routers will last for the duration of the project, no major changes in router technology or regulation will occur, and router power is enough to penetrate walls of homes.

Annual Internet Service Fee (20% Adoption - 100% Adoption)	**$28,891.08 - $144,455.40** - Assumes consistent price per home can be negotiated with ISP for full study period at $9.99 per home, based on example in Minneapolis. Assumes no major change in internet infrastructure technology that would lead to abandonment of current model of distribution. Only includes structures located immediately on the roads in the test circuit.

LED Streetlight Conversion Cost Assumptions

LED Luminaire Cost	**$185 - $238 per Luminaire** - Obtained from James Gross via conversion cost estimate pdf. Assumes that the cost will not change over study period, and price to replace them at the end of their lifespan is the same as it is to install them, as the whole fixture must be replaced.
LED Luminaire Lifespan	**6.72 Years** - Obtained from Pittsburg University Street Lighting Life Cycle Assessment. Assumes, lifespan does not improve over the length of the study, and lights will not be damaged or destroyed by outside factors.
LED Luminaire Installation Service Fee	**$170 per Luminaire** - Average value obtained from James Gross via conversion cost estimate pdf. Assumes that fee to replace is the same as the fee to install the fixtures, and that the time needed to install will not change during the study period.

<u>Benefits Assumptions</u>

Energy Cost Savings Assumptions

Energy savings from LED conversion	**55%** – estimate provided by the city
Cost/KWh of LED lights	**$0.084** – assumes that the cost is the average of three different costs charged by the three different suppliers of electricity in Columbus, provided by the city

Reduced CO_2 Emissions Assumptions

CO_2 reductions from LED lights	**0.36 metric tons/light/year** – assumes that the smart street lights will experience the same reductions as LED street lights in LA
Social cost of carbon	**$42-60/metric ton** – provided by the U.S. EPA. Assumes a discount rate of 3% for the cost of carbon

Reduced Unemployment Assumptions

Change in unemployment rates as a result of in-home WiFi access	**0.5-2%** – based off qualitative literature and intuition, ranging from a conservative to high estimate
Number of employed people along the test circuit	**1,656 - 1,693** – assumes that the average number of people/household and the percent of people ages 18-64 in Linden applies to the households along circuit #89 specifically
Collective annual income of households along test circuit	**$44,620,432.30 - 45,617,536.93** – assumes that all employed people along the test circuit earns the average annual income per capita in Linden

Increased Tax Revenue Assumptions

Columbus Average Income Tax	**2.50% (known)** – this CBA assumes that the average income tax for Columbus will not change over the entire evaluation period
Tax revenues from households along test circuit	**$1,115,510.81 - 1,140,438.42** – assumes calculations for annual income for population sample are appropriate

Increased High School Graduation Rates

Change in graduation rates as a result of in-home WiFi access	**2-4%** – based off qualitative literature and intuition, ranging from a conservative too high estimate
Social cost of a high school dropout	**$12,284/year** – assumes a benefit-transfer is applicable from the "Consequences of Dropping Out of High School" case study

Results

After discounting the monetized costs and benefits to present values, the NPV of each project scenario was calculated. Our analysis shows that providing free public WiFi to households along the proposed test circuit in Linden presents significant value to the city. Unsurprisingly, the NPV increases as the unemployment rates decrease and high school graduation rates increase.

Project Scenario	**Unemployment Rate**	**Graduation Rate**	**NPV**
LED +WiFi (Low Estimate)	10%	64.4%	$4,555,806.47
LED + WiFi (Medium Estimate)	9.5%	65.4%	$8,075,605.21
LED + WiFi (High Estimate)	8.5%	66.4%	$10,620,101.51

Challenges

Because this project is in such the early stages of planning, we relied heavily on case studies and benefit transfers to accumulate data and monetize impacts. For this reason, the assumptions included in this CBA inherently encompass some margin of error. For example, our team used a benefit transfer from a report on "joblessness and jailing for high school dropouts" to monetize the impact of increased access to education by taking the report's estimates of the annual negative fiscal contribution of a high school dropout.[11] These numbers might not represent Linden residents on average and could cause some redundancy among benefits that were already included. It is also important to note that the values of the social benefits included in this study assume that all benefits will accrue to the current Linden neighborhood. It is possible that instead of providing Linden residents with greater access to educational and job resources, the smart street lights could increase property values in Linden and lead to gentrification.

Recommendations/Future Directions

After careful considerations, our team recommends that the City of Columbus moves forward with the implementation of the Smart Street Lighting Pilot Project along circuit #89. With each of the three scenarios in our analysis, the quantifiable benefits exceed the quantifiable costs, indicating that the project is beneficial to the targeted community and thus worthwhile for the city to invest in. The NPV of LED conversion and WiFi implementation with a resulting 0.5% reduction in unemployment and 2% increase in high school graduation is calculated at $4,485,230.72; a 1% reduction in unemployment and 3% increase in high school graduation is $8,005,709.44; and the NPV of a 2% reduction in unemployment and 4% increase in high school graduation is calculated at $10,552,293.84.

Although there is notable margin of error in the assumption that increased WiFi accessibility will directly impact high school graduation and unemployment rates, our team firmly believes that WiFi is crucial for success today. There have been many studies on the far-reaching consequences of the “digital divide” between those who have quality access to internet connection versus those who do not, especially in regards to career, education, transportation and health/social service opportunities. Detroit has become an important case study for the “digital divide” as a city that is fighting to get back on its feet, with four in ten of its residents without broadband internet.[9] Unemployment in Hope Village, a 100-block neighborhood in Detroit significantly impacted by lack of internet access, was more than double the city average in 2013, nearing an incredible 40%.[9] Although internet access isn’t the sole factor that impacts employment, it undoubtedly aids in the locating of new opportunities and information, the filling out of online job applications, and the increasing connectivity with job recruiters. Residents of Hope Village highlight the positive feedback loop system they are trapped in: the less access they have to WiFi, the less they can keep up with the evolving technical skillsets necessary for entry-level jobs and the less money they are able to make, therefore inhibiting their ability to purchase internet hardware and services. In 2015, the Federal Communications Commission defined high-speed internet as a public utility, yet the costs that accompany WiFi services, data plans and computers in general are typically too high for those currently searching for employment in underserved areas.[9]

In order to fulfill Columbus' social sustainability goals of improving transportation and career resource opportunities in the Linden area, it is critical that the city follows through with the following recommendations. From the Smart Columbus fact sheet, the city proposed a multi-modal trip planning application to aid in better transportation opportunities around Linden.[1] On February 11th, 2017, the City of Columbus conducted a survey with 54 residents from the Linden neighborhood regarding transportation opportunities and obstacles during an innovation session. When asked how they would like to receive transportation information, 34 of the 54 residents stated through their phone, whether it be via text or smart phone application. However, when asked about the obstacles of getting transportation information in the area, 17 of the 31 residents who answered this question stated that there is either a lack of available access to information because of poor WiFi connection in some locations, or that the cost to use data in areas with no WiFi is restricting to them (James Gross II, personal communication). Thus, we believe the proposed multi-modal application goes together with the smart street light WiFi implementation and would be beneficial in providing important trip planning information for those who rely on the public transportation to travel to work, to school, to extracurricular activities, or to carry out every day errands.

Additionally, it is important that the city continues with the innovation sessions to track the evolving needs of the community. From the innovation session on February 11th, 2017, a group of residents from the Linden community vocalized that they were most concerned about their children's access to additional educational resources during after school hours. An alternative scenario that could be explored is keeping the Linden schools open for extra hours to allow students to use the school library's computers and free WiFi. Unfortunately, we were unable to include this alternative in our CBA due to time constraints and lack of reciprocated communication. To track the costs and benefits of the pilot project, we suggest the city creates a monitoring plan. We believe a monitoring system can be an effective way to provide feedback on the project and on the extent to which the city's goals are being achieved. This will also highlight specific problem areas during the early stages of adoption and allow for potential solutions to be provided for similar projects elsewhere. Additionally, it is important to track factors outside of the control of the project that might impact the benefits incurred, such as rises in property values and gentrification. With an evaluation and monitoring plan behind the pilot program, future projects that are potentially implemented city-wide can be designed with greater ease and with more comparable data. Furthermore, we strongly encourage the city to provide a comprehensive case study should this project be implemented to create dialogue on project feasibility with cities alike.

Conclusions

This CBA will serve as valuable findings to the City of Columbus in reaching their overall vision of Smart Columbus and provide justification for future actions taken as a part of the Smart City Grant. The Linden community has expressed their concerns as an underserved neighborhood in Columbus with little access to everyday resources. These anecdotes are supported by the findings of our analysis. Given the results of this CBA, we found the total benefits derived from the project outweigh the costs in even the most conservative projections. Our team believes that providing free public WiFi to this community will enhance access to career development and educational resources and connect residents to more reliable transportation, allowing for greater high-school graduation and employment rate outlooks. These outcomes are inline with the goals set forth by Smart Columbus and would help increase resident satisfaction and generate revenue for the city through increased employment and educational opportunities. In order for the Linden community to fully benefit from the Smart Street Lighting project, the city should follow through with the implementation of complementary applications, such as the multi-modal transportation app; continue communications with community members through innovation sessions; design a monitoring program to evaluate the impacts during each stage of the project; and provide a public case study on the process. Since the work done through this report has little precedent, these findings are contingent upon many assumptions. Although the benefits calculated are social and may not directly profit the city, these findings remain valid and important for the vision of a smarter Columbus.

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Appendix A

Cost Benefit Analysis Steps

CBA Step	Project-Specific
1. Specify set of alternatives	- 0.5% reduction in unemployment & 2% increase in graduation -1% reduction in unemployment & 3% increase in graduation -2% reduction in unemployment & 4% increase in graduation
2. Identify stakeholders with standing	-Smart Columbus working group -Columbus Division of Power -Linden community members -Internet provider
3. Identify potential impacts to stakeholders	-Incurred costs of LED fixture installation -Incurred costs of providing free public WiFi -Energy cost savings for Columbus Division of Power -Reduced CO_2 emissions -Reduced unemployment among Linden neighborhood -Increased tax revenues from Linden neighborhood -Increased high school graduation rates in Linden neighborhood
4. Identify metrics for measuring impacts	-Obtained cost estimates of LED conversion -Benefit transfers from external smart street light projects -EPA Social cost of Carbon -Obtained data on Linden demographics
5. Predict impacts over life of project	-LED fixtures will cost Columbus Division of Power substantially -Energy consumption will be halved, leading to considerable CO_2 emissions reduction -Unemployment will decline 0.5-2% in Linden neighborhood -High school graduation rates will increase 2-4% in Linden neighborhood
6. Monetize impacts	See Appendix B and C
7. Discount costs and benefits to present values	Discount Rate = 3%
8. Compute net present value of each alternative	-Alternative 1: $4,485,230.72 -Alternative 2: $8,005,709.44 -Alternative 3: $10,552,293.84
9. Identify margins of error	-Appropriateness of benefit transfer values -Assumed percent change ranges -Potentially outdated obtained data
10. Make a recommendation	The city should move forward in implementing the pilot project to provide free public WiFi to the Linden neighborhood

Appendix B

Cost Calculations

Number of Streetlights	Price of Router	Total Router Cost
207	$ 39.99	$ 8,277.93

Table B1: Router Cost Calculation

Count	Price/Foot	Total Cable Price
24	$ 0.68	$ 19,878.44
144	$ 2.98	$ 87,114.34
288	$ 5.87	$ 171,597.71

Table B2: Fiber Optic Cable Price by Type

Length of Streets (ft)	Cable Price Per Foot	Total Cable Cost	Total Installation Expense
29,233.00	$ 0.68	$ 19,878.44	$ 28,156.37

Table B3: Fiber Optic Cable Cost Calculation

Internet Price	Level of Adoption	Total Monthly Cost	Annual Expense
$ 9.99	20%	$ 2,407.59	$ 28,891.08
$ 9.99	40%	$ 4,815.18	$ 57,782.16
$ 9.99	50%	$ 6,018.98	$ 72,227.70
$ 9.99	60%	$ 7,222.77	$ 86,673.24
$ 9.99	80%	$ 9,630.36	$ 115,564.32
$ 9.99	100%	$ 12,037.95	$ 144,455.40
Total Number of Homes:		1205	

Table B4: Internet Service Cost Calculation

Conv. Wattage	LED Equivalent	Quantity	Cost of Fixture	Installation Cost	Total Cost (LED)
55 W	30 W	15	$ 185.00	$ 170.00	$ 5,325.00
100 W	60 W	140	$ 225.00	$ 170.00	$ 55,300.00
200 W	100 W	52	$ 238.00	$ 170.00	$ 21,216.00
		207			$ 81,841.00

Table B5: Total Street Light Conversion Cost Calculation

Bulbs per 100000 Hrs	Lifespan (Hrs)	Lifespan (yrs)	Number of Replacements During Study	Full Study Luminaire Cost
1.7	58823.52941	6.715014773	3.723	$ 304,694.04

Table B6: Full Study LED Luminaire Cost

Appendix C

Benefit Calculations

	Number of Lights	Estimated KWH	Rate/KWH
DOP	37198	26,982,964	0.051298
AEP	15100	11,862,233	0.0816
SCP	569	408,768	0.1195
		Average:	0.08413266667

Table C1: Current average cost per street light in Columbus

	Energy Usage (KWH)	KWH/Light	$/Light	$/Year (circuit 89)
2015	37935000	717.5553748	60.36984716	12496.55836
LED Conversion	17070750	322.8999187	27.16643122	5623.451263
			Cost Savings ($/yr):	**6873.1071**

Table C2: Energy cost savings from switching to LED street lights

	Discount Rate and Statistic ($/metric ton)			
Year	**5% Average**	**3% Average**	**2.5% Average**	**High Impact (95th pct at 3%)**
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

Table C3: U.S. EPA Social Cost of Carbon

Metric Ton/Light/Yr	Metric Tons/Yr (207 Lights)
0.35707	73.91349

Table C4: CO_2 Reductions from switching to LED Street Lights

Linden Neighborhood - Circuit #89	
Current Unemployment	10.5%
# of Households	1205
avg. people/household	2.47
# of people total	2976.35
# of working-aged people (18-64)	1851.2897

Table C5: Number of Employed People along Circuit #89 in the Linden Neighborhood

Unemployment Rate	Employed People	Avg. annual income/capita	Annual income for neighborhood	Income Tax	Tax Revenue
0.105	1656.904282	26930	44620432.3	0.025	1115510.808
0.100	1666.16073	26930	44869708.46	0.025	1121742.711
0.0950	1675.417179	26930	45118984.62	0.025	1127974.615
0.0850	1693.930076	26930	45617536.93	0.025	1140438.423

Table C6: Collective Average Annual Income for Households along Circuit #89 in Linden and Resulting Income Tax Revenue

Linden McKinley STEM Academy	
Enrollment	553
Graduation Rate	62.40%

Table C7: Current Enrollment and Graduation Rate of Linden McKinley STEM Academy

Graduation Rate	Students Graduated	Student Dropouts	Cost of Dropouts
0.624	345.072	207.928	$2,554,188
0.644	356.132	196.868	$2,418,327
0.654	361.662	191.338	$2,350,396
0.664	367.192	185.808	$2,282,465

Table C8: Social Benefits of Increasing High School Graduation Rates

Benefit	Value ($/year)
Energy cost savings	6,873.12
CO2 Reductions (t=0-7)	3,104.37
CO2 Reductions (t=8-12)	3400.02
CO2 Reductions (t=13-17)	3695.67
CO2 Reductions (t=18-22)	4065.24
CO2 Reductions (t=23-25)	4434.81
Reduced Unemployment (0.5%)	249,276.16
Reduced Unemployment (1%)	498,552.32
Reduced Unemployment (2%)	997,104.63
Increased Tax revenue (0.5%)	6231.91
Increased Tax revenue (1%)	12463.81
Increased Tax revenue (2%)	24927.62
Increased HS Graduation Rates (2%)	135,861.04
Increased HS Graduation Rates (3%)	203,791.56
Increased HS Graduation Rates (4%)	271,722.08

Table C9: Itemized and Monetized Social Benefits

Appendix D

Net Present Value Calculations

LED + Free Public Wi-Fi (Low Estimate: 0.5% Reduced Unemployment + 2% Increased Graduation)							
Time Period	**Costs**	**Benefits**	**Net Benefits**	**Discount Rate**	**Discount Factor**	**Per Period PV**	**Cumulative PV**
0	$184,799.53	401,346.59	216,547.06	0.03	1	216547.0569	216547.0569
1	$156,643.16	401,346.59	244,703.43	0.03	0.9708737864	237576.1426	454123.1996
2	$156,643.16	401,346.59	244,703.43	0.03	0.9425959091	230656.4508	684779.6503
3	$156,643.16	401,346.59	244,703.43	0.03	0.9151416594	223938.3017	908717.9521
4	$156,643.16	401,346.59	244,703.43	0.03	0.8884870479	217415.8269	1126133.779
5	$156,643.16	401,346.59	244,703.43	0.03	0.8626087844	211083.3271	1337217.106
6	$156,643.16	401,346.59	244,703.43	0.03	0.8374842567	204935.269	1542152.375
7	$156,643.16	401,346.59	244,703.43	0.03	0.8130915113	198966.2806	1741118.656
8	$156,643.16	401,642.24	244,999.08	0.03	0.7894092343	193404.5382	1934523.194
9	$156,643.16	401,642.24	244,999.08	0.03	0.7664167323	187771.3963	2122294.59
10	$156,643.16	401,642.24	244,999.08	0.03	0.7440939149	182302.3265	2304596.917
11	$156,643.16	401,642.24	244,999.08	0.03	0.7224212766	176992.55	2481589.467
12	$156,643.16	401,642.24	244,999.08	0.03	0.7013798802	171837.4272	2653426.894
13	$156,643.16	401,937.90	245,294.74	0.03	0.68095134	167033.7796	2820460.674
14	$156,643.16	401,937.90	245,294.74	0.03	0.6611178058	162168.718	2982629.392
15	$156,643.16	401,937.90	245,294.74	0.03	0.6418619474	157445.3573	3140074.749
16	$156,643.16	401,937.90	245,294.74	0.03	0.6231669392	152859.5702	3292934.319
17	$156,643.16	401,937.90	245,294.74	0.03	0.6050164458	148407.3497	3441341.669
18	$156,643.16	402,307.46	245,664.30	0.03	0.5873946076	144301.8875	3585643.556
19	$156,643.16	402,307.46	245,664.30	0.03	0.5702860268	140098.9199	3725742.476
20	$156,643.16	402,307.46	245,664.30	0.03	0.5536757542	136018.3688	3861760.845
21	$156,643.16	402,307.46	245,664.30	0.03	0.5375492759	132056.6687	3993817.514
22	$156,643.16	402,307.46	245,664.30	0.03	0.5218925009	128210.358	4122027.872
23	$156,643.16	402,677.03	246,033.87	0.03	0.5066917484	124663.3325	4246691.204
24	$156,643.16	402,677.03	246,033.87	0.03	0.4919337363	121032.3617	4367723.566
25	$156,643.16	402,677.03	246,033.87	0.03	0.4776055693	117507.1472	4485230.713
						NPV:	**4485230.716**

LED + Free Public Wi-Fi (Medium Estimate: 1% Reduced Unemployment + 3% Increased Graduation)							
Time Period	Costs	Benefits	Net Benefits	Discount Rate	Discount Factor	Per Period PV	Cumulative PV
0	$184,799.53	469,277.11	284,477.58	0.03	1	284477.5786	284477.5786
1	$156,643.16	469,277.11	312,633.95	0.03	0.9708737864	303528.1055	588005.6841
2	$156,643.16	469,277.11	312,633.95	0.03	0.9425959091	294687.481	882693.1652
3	$156,643.16	469,277.11	312,633.95	0.03	0.9151416594	286104.3505	1168797.516
4	$156,643.16	469,277.11	312,633.95	0.03	0.8884870479	277771.2141	1446568.73
5	$156,643.16	469,277.11	312,633.95	0.03	0.8626087844	269680.7904	1716249.52
6	$156,643.16	469,277.11	312,633.95	0.03	0.8374842567	261826.0101	1978075.53
7	$156,643.16	469,277.11	312,633.95	0.03	0.8130915113	254200.0098	2232275.54
8	$156,643.16	469,572.76	312,929.60	0.03	0.7894092343	247029.518	2479305.058
9	$156,643.16	469,572.76	312,929.60	0.03	0.7664167323	239834.4835	2719139.542
10	$156,643.16	469,572.76	312,929.60	0.03	0.7440939149	232849.0131	2951988.555
11	$156,643.16	725,080.82	568,437.66	0.03	0.7224212766	410651.4634	3362640.018
12	$156,643.16	725,080.82	568,437.66	0.03	0.7013798802	398690.7411	3761330.759
13	$156,643.16	725,376.48	568,733.32	0.03	0.68095134	387279.7154	4148610.475
14	$156,643.16	725,376.48	568,733.32	0.03	0.6611178058	375999.7237	4524610.198
15	$156,643.16	725,376.48	568,733.32	0.03	0.6418619474	365048.2754	4889658.474
16	$156,643.16	725,376.48	568,733.32	0.03	0.6231669392	354415.8014	5244074.275
17	$156,643.16	725,376.48	568,733.32	0.03	0.6050164458	344093.0111	5588167.286
18	$156,643.16	725,746.05	569,102.89	0.03	0.5873946076	334287.9665	5922455.253
19	$156,643.16	725,746.05	569,102.89	0.03	0.5702860268	324551.4237	6247006.676
20	$156,643.16	725,746.05	569,102.89	0.03	0.5536757542	315098.4697	6562105.146
21	$156,643.16	725,746.05	569,102.89	0.03	0.5375492759	305920.8443	6868025.99
22	$156,643.16	725,746.05	569,102.89	0.03	0.5218925009	297010.5285	7165036.519
23	$156,643.16	726,115.61	569,472.45	0.03	0.5066917484	288546.9932	7453583.512
24	$156,643.16	726,115.61	569,472.45	0.03	0.4919337363	280142.7118	7733726.224
25	$156,643.16	726,115.61	569,472.45	0.03	0.4776055693	271983.2153	8005709.439
						NPV:	**8005709.439**

LED + Free Public Wi-Fi (High Estimate: 2% Reduced Unemployment + 4% Increased Graduation)							
Time Period	**Costs**	**Benefits**	**Net Benefits**	**Discount Rate**	**Discount Factor**	**Per Period PV**	**Cumulative PV**
0	$184,799.53	537,207.63	352,408.10	0.03	1	352408.0986	352408.0986
1	$156,643.16	537,207.63	380,564.47	0.03	0.9708737864	369480.0666	721888.1653
2	$156,643.16	537,207.63	380,564.47	0.03	0.9425959091	358718.5113	1080606.677
3	$156,643.16	537,207.63	380,564.47	0.03	0.9151416594	348270.3993	1428877.076
4	$156,643.16	537,207.63	380,564.47	0.03	0.8884870479	338126.6013	1767003.677
5	$156,643.16	537,207.63	380,564.47	0.03	0.8626087844	328278.2537	2095281.931
6	$156,643.16	537,207.63	380,564.47	0.03	0.8374842567	318716.7511	2413998.682
7	$156,643.16	537,207.63	380,564.47	0.03	0.8130915113	309433.739	2723432.421
8	$156,643.16	537,503.28	380,860.12	0.03	0.7894092343	300654.4978	3024086.919
9	$156,643.16	537,503.28	380,860.12	0.03	0.7664167323	291897.5706	3315984.489
10	$156,643.16	537,503.28	380,860.12	0.03	0.7440939149	283395.6997	3599380.189
11	$156,643.16	793,011.34	636,368.18	0.03	0.7224212766	459725.9163	4059106.105
12	$156,643.16	793,011.34	636,368.18	0.03	0.7013798802	446335.8411	4505441.946
13	$156,643.16	793,307.00	636,663.84	0.03	0.68095134	433537.094	4938979.04
14	$156,643.16	793,307.00	636,663.84	0.03	0.6611178058	420909.8	5359888.841
15	$156,643.16	793,307.00	636,663.84	0.03	0.6418619474	408650.2913	5768539.132
16	$156,643.16	793,307.00	636,663.84	0.03	0.6231669392	396747.8556	6165286.987
17	$156,643.16	793,307.00	636,663.84	0.03	0.6050164458	385192.0928	6550479.08
18	$156,643.16	793,676.57	637,033.41	0.03	0.5873946076	374189.9876	6924669.068
19	$156,643.16	793,676.57	637,033.41	0.03	0.5702860268	363291.2501	7287960.318
20	$156,643.16	793,676.57	637,033.41	0.03	0.5536757542	352709.9515	7640670.27
21	$156,643.16	1,304,692.69	1,148,049.53	0.03	0.5375492759	617133.1937	8257803.463
22	$156,643.16	1,304,692.69	1,148,049.53	0.03	0.5218925009	599158.4404	8856961.904
23	$156,643.16	1,305,062.26	1,148,419.10	0.03	0.5066917484	581894.4805	9438856.384
24	$156,643.16	1,305,062.26	1,148,419.10	0.03	0.4919337363	564946.0976	10003802.48
25	$156,643.16	1,305,062.26	1,148,419.10	0.03	0.4776055693	548491.3569	10552293.84
						NPV:	**10552293.84**

Appendix E

Dataset Descriptions

Dataset #1: LEDConversionConstructionCost.pdf
Source: James Gross, Assistant Administrator for Division of Power.
Email: JMGross@columbus.gov
Description: Documentation of the estimates the city project team has produced for the cost to convert all streetlights in Columbus to LED luminaires. It was used to produce data for wattage equivalent, fixture price, and installation cost in Table B5 in Appendix B.

Dataset #2: LindenNeighborhoodScoutReport.pdf
Source: Neighborhood Scout Website:
https://www.neighborhoodscout.com/oh/columbus/linden
Description: This data set includes the demographics within the Linden neighborhood used in Tables C5 and C6 in Appendix C.

Dataset #3: USEPASocialCostofCarbon.pdf
Source: https://www.epa.gov/climatechange/social-cost-carbon
Description: This dataset includes the following information on the social cost of carbon: per metric ton monetary values, projections on the increase in monetary values in future years, and different discount rates for monetary values. This CBA uses the estimates found with a 3% discount rate. This data was used to produce Table C4 in Appendix C.

Dataset #4: JoblessnessandJailingforHighSchoolDropoutsReport.pdf
Source: Sum, et al. 2009:
https://www.prisonlegalnews.org/media/publications/report_on_joblessness_and_jailing_for_high_school_dropouts_2009.pdf
Description: This report includes estimations for the social cost of high school dropouts based off (A) the the loss in state and local taxes due to dropouts not working or having lower paying jobs compared to high school graduates and (B) the cost of transfers and incarceration costs borne by the state. This data was used to produce Table C8.

Dataset #5: LEDSmartStreetLightDataset.xlsx
Source: Created by our team using data collected throughout the study
Description: This excel sheet shows our team's final calculations for the itemized costs and benefits included in this CBA, along with NPV calculations for our final recommendation.

Dataset #6: StreetLightLCA.pdf
Source: www.pitt.edu/news2010/Streetlight_Report.pdf
Description: A Life Cycle Assessment used to obtain the values for streetlight luminaire lifespans found in Table B6 in Appendix B.

Appendix F

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