Cost and Carbon Analysis of the Impact of Inaction

Final Report

Systems Synthesis, Spring 2020

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THE SEAL OF THE CITY OF PITTSBURGH · 1816 · BENIGNO NUMINE ·

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Executive Summary

The development of Pittsburgh's Climate Action Plan (PCAP 3.0) in 2017 spurred the City's activism in six key areas of interest. This project focuses on one of those six areas–Buildings and End Use Efficiency–and explores how the City's Sustainability and Resilience Division can better leverage the City's capital and operating budget investments toward achieving the buildings and energy goals set forth by PCAP 3.0.

The project team examines this problem using the City's thirty-five Healthy Active Living Centers (HALCs) as a case study. The question that guided this inquiry is defined as follows:

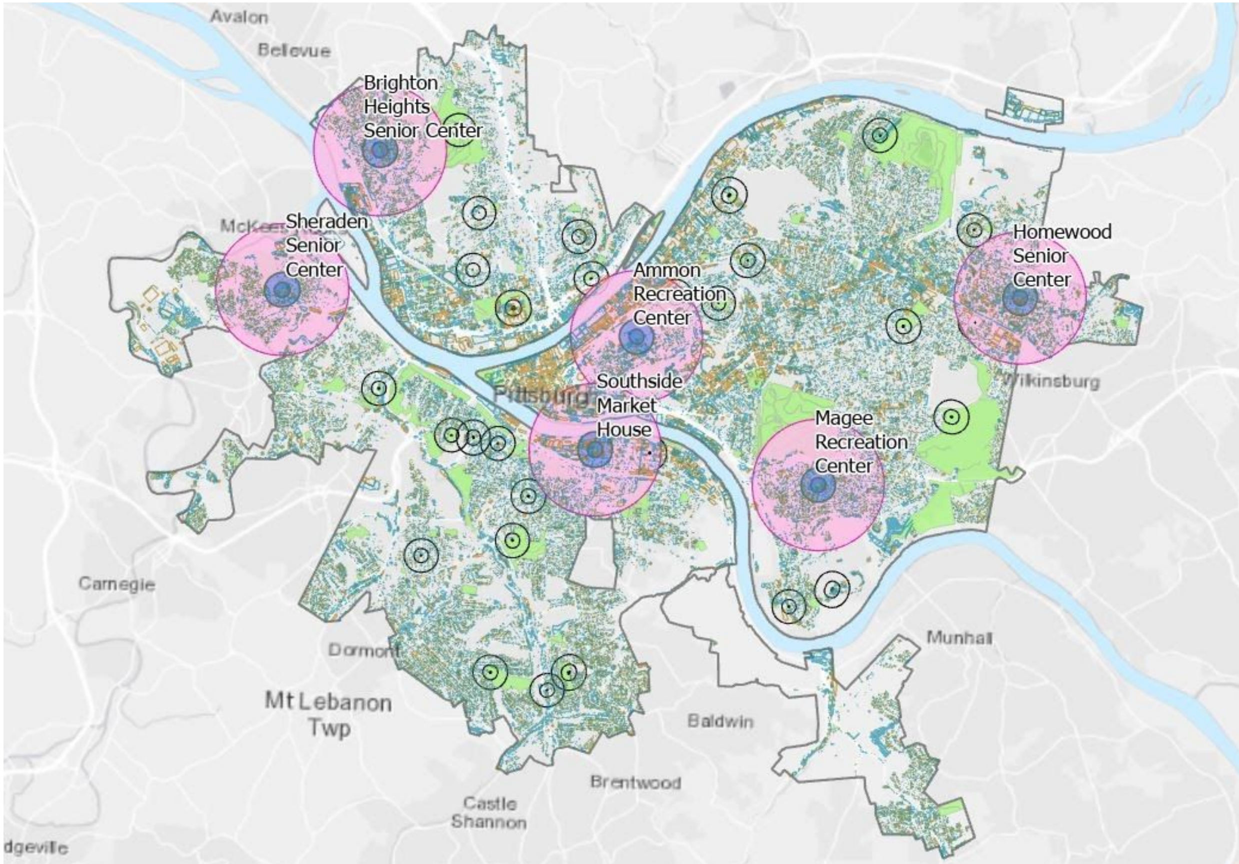
> Problem Statement: *How should the City allocate funding to the maintenance and renovation of its building stock in order to maximize resilience value to the community while minimizing long-term costs?*

This effort culminated in the development of two final deliverables: *(1)* a digital map tool designed to support resilience-oriented planning and analysis and *(2)* a dynamic accounting tool to aid in the planning of center-specific retrofit projects.

Resilience-Oriented Planning Map

Created in ArcGIS Pro, the Resilience-Oriented Planning Map shows an overlay of all thirty-five HALCs with additional layers that show the environmental hazards in and around the vicinity of each HALC (Fig. 1). Some of the hazards that the map takes into account are landslide events and flood zone areas. The map allows the user to assess the risk exposure of each HALC to these potential hazards and identify the highest-value retrofit projects for each one.

Figure 1: Resilience Oriented Planning Map



<u>Decision Support Tool</u>

The Decision Support Tool generates recommendations for retrofits that maximizes direct and indirect benefits. It uses a multitude of user inputs such as selection of specific HALC, budget constraint, and a measure of parameter importance to users garnered through the use of weights, to optimize the specific quantities of each retrofit that would maximize the net benefits experienced by the HALC and the community it serves. The benefits considered by the tool include societal benefits as well as overall benefits to the City, both of which are expressed both with monetary and non-monetary values. A snapshot of an example summary report produced after optimization, is shown below in figure 2.

Figure 2: Decision Support Tool Summary Report

5. Review report							
SUMMARY REPORT	Center:	Southside Market House					
Retrofit	**Qty**						
Air Purifier (unit/1,100sqft)	1						
Tree (unit)	1						
Green roof (sqft)	1						
Rain garden (sqft)	1						
Peameable pavement (sqft)	1						
Benefits for City of Pittsburgh							
Monetary, Net Benefits			**Non-Monetary, Annual Benefits**			City's Reduction Targets	
Energy cost saving	$0.00		Energy saving (kBtu)	194.29	0.000425%	45,750	million kBtu
Stormwater mgt cost saving	$481.14		Run-off reduction (gal)	501.38			
Societal benefits							
Monetary, Net Benefits			**Non-Monetary, Annual Benefits**				
CO2 reduction	$45.07		CO2 reduction (tCO2)	0.23	0.000007%	3,300,000	tCO2e
Air Quality improvement	$3,260.55		PM 2.5 removal (g)	32.71			
Severe temp mitigation							
Other benefits	$40,368.76						
Note: the following parameters are used to estimate monetary values above							
Carbon price	7.64	$/tCO2					
Value of Statistical Life	0.5	Mil$					
Interest Rate	3.00%						

Both deliverables were made to be flexible so as to allow for additional updates in future. This feature is especially important when we consider the expected climate change trends and how those trends are sure to have a drastic effect on Pittsburgh's HALC building stock. Because these trends—such as increased rainfall and flooding—are expected to exacerbate the stressors accounted for by the tool, the usefulness of the tool will become more compounded as the trends become reality. The built-in flexibility of the tool is also important so that the challenges and limitations faced by the team—particularly in relation to the availability and accuracy of source datasets—can be addressed in future iterations of the tool.

The following full report outlines in detail the problem, solution, and inner-workings of both of the deliverables. It is the hope of the project team that future work will be completed by other teams to expand on the work detailed here.

I. Introduction

In an effort to implement local solutions to the challenges posed by climate change, the City of Pittsburgh signed the Climate Protection Agreement on February 9, 2007. As a result of this agreement, the Green Government Task Force, the group charged with developing actionable plans to enforce the agreement, produced the Pittsburgh Climate Action Plan (PCAP 3.0) in 2017.[1] The PCAP 3.0 set reduction goals for Pittsburgh to achieve by 2030 and provided a methodology to measure progress towards those goals.

The Climate Action Plan is based on six areas of interest, including:

- Energy Generation and Distribution
- Buildings and End Use Efficiency
- Transportation and Land Use
- Waste and Resource Recovery
- Food and Agriculture
- Urban Ecosystems

In collaboration with various agencies, the City has worked diligently to address the issues that Pittsburgh faces in all six of the aforementioned areas of interest. In regards to the Buildings and End Use Efficiency area in particular, the Sustainability and Resilience division partnered with the Rocky Mountain Institute (RMI) to create detailed plans designed to help the City improve and upgrade their buildings in ways that achieve the goals set forth by PCAP 3.0.[2] These plans focus on how the City's budget can be efficiently invested in order to prioritize the PCAP 3.0 goals.

1.1 About the Client

Through their work with partner institutions, the City of Pittsburgh's Sustainability and Resilience (S&R) division, located within the City Planning Department, promotes and advocates for preventative resilience measures that seek to mitigate the many environmental hazards faced by the city. Such hazards include air pollution, flooding, extreme weather, public health challenges, and infrastructure failure. The division seeks to push progress on environmental stewardship so as to address these chronic stressors and ensure that all Pittsburgh residents live well. Beyond their work with their partners, the division achieves this goal by advising other

[1] City of Pittsburgh, "Climate Action Plan 3.0" (City of Pittsburgh, 2017), https://apps.pittsburghpa.gov/redtail/images/7101_Pittsburgh_Climate_Action_Plan_3.0.pdf.
[2] Matt Jungclaus and Victor Olgyay, "City of Pittsburgh Energy Master Planning Narrative," Slide Presentation (unpublished), 2019.

City departments in ways that lead to more holistic decision-making and guide residents toward a more adaptable city.[3]

1.2 Context and Problem Statement

The City of Pittsburgh would like to better anticipate and respond to the impacts of climate change on public facilities and the communities they serve. Such information is essential for ensuring that this critical infrastructure remains open and operational even as many climate-related hazards become more frequent and intense. The City intends to use this fine-grained information about the exposure of each of their buildings to various hazards to make sure that each building receives the right retrofits at the right time to mitigate financial losses and prevent closures and/or suspension of public services.

Given the context provided above, the team formulated the following problem statement to guide its efforts:

> Problem statement: *How should the City allocate funding to the maintenance and renovation of its building stock in order to maximize resilience value to the community while minimizing long-term costs?*

(For the purposes of this project, the term ”building stock” will be constrained to the city’s Healthy Active Living Centers. See the scope section below for more details.)

1.3 Scope

Within the scope of this project, the term Healthy Active Living Center (HALC) is used to refer to the thirteen Healthy Active Living Centers (Senior Community Centers), the ten community recreation centers, and twelve other public facilities managed by Citiparks.

Healthy Active Living is a program managed by the City of Pittsburgh’s Department of Parks and Recreation (Citiparks) committed to ensuring that all persons 60 and older live active and healthy lives. According to their website, “Citiparks Community Services operates 13 Healthy Active Living Centers open year round, Mondays through Fridays. Each center focuses on improving the lives of older Pittsburghers—physically, intellectually, socially, culturally and financially.”[4]

Similarly, Community Recreation Centers operate year round and help to engage their community members through a multitude of outdoor, sporting, educational, and leisure

[3] Sustainability and Resilience, City of Pittsburgh, https://pittsburghpa.gov/dcp/sustainability-resilience.
[4] City of Pittsburgh, “Healthy Active Living,” Cityparks, accessed May 12, 2020, https://pittsburghpa.gov/citiparks/for-seniors.

programs.[5] Additionally, they operate many youth targeted programs such as summer camps and afterschool programs.

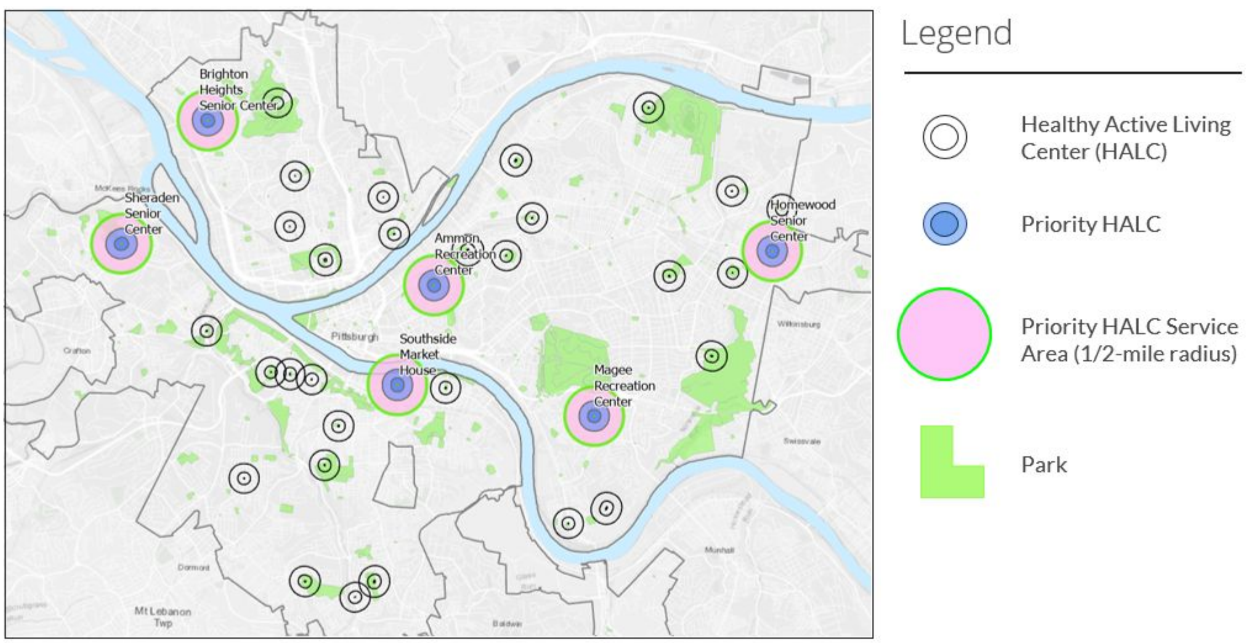
Of these thirty-five centers, the client has identified six priority centers. These six centers, enumerated below, were prioritized because of their extended hours of operation, additional use as heating and cooling facilities, and higher capacity.

Priority Centers:

1. Ammon Recreation Center
2. Brighton Heights Senior Center
3. Homewood Senior Center
4. Magee Recreation Center
5. Sheraden Senior Center
6. Southside Market House

Figure 1 below maps all thirty-five centers, highlights the six priority centers in blue, and displays a 1/2-mile radius, denoted by a pink circle, around the priority centers. For the purposes of this project we will use this 1/2-mile radius measurement as the service area for that HALC.

Figure 1. Map of Pittsburgh's Healthy Active Living Centers



[5] City of Pittsburgh, "Recreational Centers," Cityparks, accessed May 12, 2020, https://pittsburghpa.gov/citiparks/rec-centers-info.

II. Product Concept

The problem that the City faces is a prioritization of resources and alternative recommendations for retrofits that encompass the broader sustainability and resilience framework. The problem then becomes a decision analytics problem wherein the decision-makers are those in the S&R division as well as those belonging to other city departments such as Public Works and Parks and Recreation. The overall tool guides the budget allocation, retrofit recommendation, and retrofit prioritization.

2.1 Approach

Because this project encompasses multiple subproblems, the problem solution requires multiple steps:

1. Identification of HALCs that are at risk due to extreme weather events

   The first step is to identify the HALCs that are in the risk zones of flooding, landslides, poor air quality, extreme temperature events etc. This analysis is performed using ArcGIS. The resulting analysis also gives a proxy for the total catchment area and expected users of the HALCs.

2. Calculating the maximum possible benefits for each category of environmental risk

   The marginal benefit of each retrofit is calculated in the buckets of energy, carbon dioxide emission, air quality, temperature, and stormwater mitigation. These marginal benefits give direct and indirect savings from installing one unit of retrofit to the building.

3. Creating a retrofit recommendation engine for each HALC

   The retrofit recommendation engine is essentially a resource optimization that recommends certain retrofits after analyzing their costs and benefits with a constraint on the budget. The resulting optimization is embedded into a decision support tool that takes input of available budget and decision-maker's priorities and recommends the potential retrofits that maximize the benefits.

2.2 Product Package Deliverables

The result of the aforementioned three-tiered approach is a product package that consists of a Resilience-Oriented Planning Map and a Decision Support Tool. These two projects work together to help the user identify the resilience threats and recommend retrofits for the building to mitigate that threat in the future while keeping in mind the city budget. A brief description of both deliverables is introduced below. See the “Final Product Package” section below for more details on both deliverables.

Resilience-Oriented Planning Map

The Resilience-Oriented Planning Map overlays a layer all the HALCs over various environmental risk layers to assess the risks. The result provides input that is then used as input data for the decision support tool. It also provides a catchment area and population estimates that is used to provide an estimate of the number of potential users of the facility.

Decision Support Tool

The Decision Support Tool is an Excel workbook with multiple sheets that work coherently to provide useful information for the client on the *Dynamic Accounting* sheet. It provides a snapshot of the building attributes and it’s environmental savings potential. Then it takes input from the user on the budget available and generates recommendations for retrofit that maximizes direct and indirect benefits.

Combined, these deliverables allow S&R staff to aggregate quantitative and qualitative information about costs and benefits associated with renovation projects for specific HALCs for ready translation into recommendations to decision-makers, including the Office of Management and Budget (OMB), City Council, and others.

2.3 Use Cases

Use Case 1: Proposing revisions to budget proposals

During the City’s annual budget cycle, S&R staff are tasked with reviewing other departments’ operating and capital budget proposals. They have a narrow window to advocate for additions and revisions to bring those proposals into closer alignment with the City's sustainability and climate action goals. The product package can allow S&R to pitch retrofits that provide a higher environmental benefit while not deviating much from the budget. It can also help the client prioritize retrofits that provide higher benefits in a particular bucket as compared to originally proposed retrofits.

Use Case 2: Grant preparation

The tool can be used for preparing grant proposals for new HALC construction projects. The map can help in identifying what environmental risks the new construction site poses. The client can then use it to assess what retrofits are required to create a resilient structure and use budget numbers to assess cost of retrofits. In future, the map can be integrated with Cartegraph to display environmental risk layers for all the assets that are managed by Cartegraph.

III. Data Sources and Methodology

The following section outlines the assumptions and calculations used for the backend of the tool in all areas of interest.

3.1 Energy Efficiency

Improving the energy efficiency of buildings contributes to reduction in both, operational costs and energy-related CO2 emissions. Because of this double benefit, the City of Pittsburgh makes considerable efforts to invest in retrofits for energy efficiency improvement. This subsection discusses energy cost saving, and the next subsection describes the benefits for carbon emissions reduction, including energy-related carbon emissions reduction and carbon sequestration.

The following formula estimates potential benefits by energy efficiency improvement on energy costs.

$$Energy\ Cost\ Savings\ (\$)\ =\ Energy\ Use\ Intensity\ (EUI)\ Improvement\ (\%)\ \times Energy\ Cost\ (\$)$$

$$=\ \frac{Current\ EUI - EUI\ 2030}{Current\ EUI}\ \times Energy\ Cost\ (\$)$$

EUI is defined as a building's energy consumption per square foot. The team computed the improvement rate of EUI from the current level to 2030. S&R's previous study conducted by RMI used the formula above to prioritize facilities for retrofits;[6] therefore, it would be easier for S&R to utilize the results based on the past study rather than creating a distinct method to estimate energy efficiency gains. Limited availability of energy data also made it less plausible to use alternative methods, such as future projection based on the past energy use. The current EUI is based on a facility's floor space and actual energy consumption in 2018 that S&R prepared.[7] Regarding the 2030 EUI, the team used the American Institute of Architects (AIA)'s 2030 target by building type.[8] S&R's previous research also used AIA's target to estimate the cost saving potential.

Energy cost consists of electricity, gas, and direct heat costs and is based on the monthly bills of each resource in 2017 that S&R's dataset contains.[9] Because only 2017 cost data is available at this time, the team computed unit prices of electricity and gas per Btu for each facility and applied them to the estimated energy cost in 2018. In cases where the dataset lacked data for

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[6] City of Pittsburgh, "Pittsburgh Buildings Portfolio Carbon Calculator, Version 15" (City of Pittsburgh, n.d.), accessed January 29, 2020.
[7] Ibid.
[8] American Institute of Architects, "The 2030 Challenge," Architecture 2030, accessed May 6, 2020, https://architecture2030.org/2030_challenges/2030-challenge/.
[9] City of Pittsburgh, "Pittsburgh Buildings Portfolio Carbon Calculator, Version 15" (City of Pittsburgh, n.d.), accessed January 29, 2020.

some of the HALCs, the team used typical figures among HALCs as a substitute.. None of the HALCs purchased district heat service in 2017 and 2018.

It would be necessary for S&R to update the energy consumption and cost data annually to maintain the usefulness of the support tool. Since the City of Pittsburgh has been keenly conducting energy-efficient retrofits to meet its climate goals, the energy consumption of HALCs would be constantly decreasing. Meanwhile, unit energy costs could either increase or decrease, reflecting inflation and the fluctuation of energy commodity prices. Moreover, capturing missing data of a few HALCs would make the tool more effective.

3.2 Carbon Emissions

The team considered two types of carbon emission reduction in this report: energy-related CO_2 emission reduction and carbon sequestration to plants.

Using the EUI improvement rate and energy consumption in 2018 discussed above, the team calculated avoided cost of energy-related carbon emissions using the following formula.

$$Avoided\ Cost\ of\ Energy\ Related\ CO_2\ Emissions\ (\$) = EUI\ Improvement\ (\%) \times Current\ Energy\ Use\ (kBtu) \times Carbon\ Intensity\ of\ Energy\ Sources\ (tCO_2/kBtu) \times Carbon\ Price\ (\$/tCO_2)$$

The carbon intensity of electricity and gas comes from the following sources. EIA Pennsylvania Electricity Profile 2018 shows that the average carbon intensity of electricity in Pennsylvania is 787 lbs/MWh.[10] This figure seems relatively higher than Pittsburgh's local carbon intensity. The teams' estimate based on a hearing to Duquesne Light Company (DLC) is 469.5 lbs/MWh, assuming that DLC's power mix is roughly 70% nuclear, 15% coal, and 15% natural gas.[11] The carbon intensity of natural gas is 117 lbs/MMBtu on the U.S. nationwide average[12] and 118.2 lbs/MMBtu on PA's commercial sector in 2017, according to EIA data.[13] The carbon intensity of energy would change as the energy mix shifts and the composition of fossil fuel varies year by year. Thus, it would be recommended to review it as well when S&R updates energy data.

A wide range of carbon prices exist in the U.S. and the world, and there is no single right number to use. The tool, therefore, lists several options so that S&R could choose the appropriate price based on its use cases, as shown in Table 1. Since market prices of carbon in

[10] U.S. Energy Information Administration, "State Electricity Profiles," March 23, 2020, https://www.eia.gov/electricity/state/pennsylvania/.
[11] Emily Phan-Gruber, Sara Walker, & Joseph Pilch, interview by Kensuke Onishi and Cassia Smith, March 21, 2020, Pittsburgh.
[12] U.S. Energy Information Administration, "How Much Carbon Dioxide Is Produced When Different Fuels Are Burned?," Frequently Asked Questions, June 4, 2019, https://www.eia.gov/tools/faqs/faq.php?id=73&t=11.
[13] U.S. Energy Information Administration, "Pennsylvania Natural Gas Consumption by End Use," Natural Gas, April 30, 2020, https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SPA_a.htm.

the RGGI and California Cap and Trade scheme consistently move, S&R should periodically check and update the price options in the tool.

Table 1: Carbon prices (dollar per metric ton of CO2)

Price	Description
$52.22	$42 (2007$) used by the Obama Administration[14] with 1.69% of average inflation
$48.00	Social Cost of Carbon in the U.S. from academic literature[15]
$7.64	Global Social Cost of Carbon $28/tC from academic literature[16]
$5.00	RGGI carbon price: $5 (April 2019)[17]
$16.00	California C&T price: $16 (April 2019)[18]

Avoided cost by carbon sequestration is estimated as follows:

$$\begin{aligned} &Avoided\ Cost\ of\ CO_2\ Emissions\ by\ Sequestration\ in\ Trees\ (\$) \\ &= Number\ of\ Trees \times CO_2\ Sequestered\ in\ a\ Tree\ (tCO_2) \times Carbon\ Price\ (\$/tCO_2) \end{aligned}$$

The team estimated CO2 sequestered in a tree based on the Davey Resource Group (2015) *Pittsburgh i-Tree Ecosystem Analysis*, which estimates 4.4 million pounds of carbon are stored in 33,498 trees in Pittsburgh annually.[19] With the conversion to metric tons of CO2, a tree absorbs 0.23 tCO2 per year.

In the tool, the team embedded flexibility for S&R to estimate the avoided cost of carbon by selecting a carbon price from the list above.

While the team embedded the formula of carbon sequestration in the tool, the lack of detailed facility data made it difficult to estimate the space available for additional tree planting at HALCs and, accordingly, the number of trees added. However, S&R would be able to incorporate the number of trees into the tool easily once it gains access to facility data in the future.

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[14] U.S. Environmental Protection Agency, "The Social Cost of Carbon," Climate Change, n.d., https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html.
[15] Katharine Ricke et al., "Country-Level Social Cost of Carbon," Nature Climate Change 8, no. 10 (September 24, 2018): 895–900, https://doi.org/10.1038/s41558-018-0282-y.
[16] Richard S J Tol, "The Economic Impacts of Climate Change," *Review of Environmental Economics and Policy* 12, no. 1 (January 12, 2018): 4–25, https://doi.org/10.1093/reep/rex027.
[17] World Bank Group, "State and Trends of Carbon Pricing 2019," Open Knowledge Repository (World Bank Group, June 6, 2019), https://openknowledge.worldbank.org/handle/10986/31755.
[18] Ibid.
[19] Davey Resource Group, "Pittsburgh I-Tree Ecosystem Analysis" (City of Pittsburgh, Pennsylvania, July 2015), https://waterlandlife.org/wp-content/uploads/2018/02/i-Tree-Eco-Pittsburgh.pdf.

3.3 Air Quality

This project considers mortality rate caused by PM2.5 as a social cost of air quality.The tool assumes that HALCs can use air purifiers to reduce indoor PM2.5 concentration in order to provide benefits to their users.

Backed by econometrics research, this project calculated the reduction in mortality rate caused by decrease in PM2.5 concentration using the following formula:

$$\begin{gathered} \textit{Avoided air pollution cost per air purifier } (\$/\textit{air purifier}) = \textit{Reduced } PM2.5 \textit{ concentration}(\mu g/m3) \\ \times \textit{Mortality rate reduced per unit of } PM2.5 \ [(\textit{people/million people})/(\mu g/m3)] \\ \div \textit{Max number of air purifier allowed} \div \textit{Million people} \\ \times \textit{ Value of a statistical life}(\$/\textit{person}) \end{gathered}$$

Reduced PM2.5 concentration measures the reduction in PM2.5 concentration after intervention. It was calculated by subtracting Indoor PM2.5 concentration (after intervention) from Outdoor PM2.5 concentration (without intervention).

The outdoor PM2.5 concentration was taken from Allegheny County Health Department's Air Quality Annual Data Summary (2017). The median of three-year average PM2.5 concentration is 9.8 $\mu g/m^3$, which is used as the default value in the tool. Users can either use the default assumption, or manually enter the real-time PM2.5 concentration to customize the tool.

The indoor PM2.5 concentration is calculated as 60% of the outdoor PM2.5 concentration[20]. Reduced indoor PM2.5 concentration is estimated using a typical air purifier which removes 99.97% of PM2.5. Specification of air purifier can be customized by users for better estimation.

Mortality reduction: 1 microgram per cubic meter reduction in PM2.5 causes 0.685 less deaths per million elderly individuals.[21] This project modified the mortality reduction so that it states reduced probability of one person dying due to PM2.5 concentration in HALC.

Value of a Statistical Life (VSL) is a measure that quantifies mortality risk reduction benefits regardless of the age, income, or other population demographics.[22] In the tool, VSL has two available choices; the default value we use is $9.47 million, but which one to use is up to users' discretion (Table 2).

Table 2: Value of a Statistical Life (Unit: US Dollar)

$ Valuation	Citation

[20] W. J. Fisk and W. R. Chan, "Effectiveness and Cost of Reducing Particle-Related Mortality with Particle Filtration," *Indoor Air* 27, no. 5 (March 6, 2017): 909–20, https://doi.org/10.1111/ina.12371.
[21] Deryugina, Tatyana, et al, "The Mortality and Medical Costs of Air Pollution: Evidence from Changes in Wind Direction," *American Economic Review*, 3 Nov. 2016.
[22] U.S. Environmental Protection Agency, "Mortality Risk Valuation," U.S. Environmental Protection Agency, accessed May 12, 2020, https://www.epa.gov/environmental-economics/mortality-risk-valuation.

9.47 Million	EPA Mortality Risk Valuation $7.4mil (2006$) + 1.78% avg inflation https://www.epa.gov/environmental-economics/mortality-risk-valuation#whatisvsl
0.5 Million	Avg of $0.7mil for Age 65-74 and $0.3mil for Age 75+. Olivier Deschênes, Michael Greenstone, and Joseph S. Shapiro, "Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program," American Economic Review 107, no. 10 (October 2017): 2958–89, https://doi.org/10.1257/aer.20131002.

There are some limitations with the above air quality calculation that are worth noting. Due to lack of HALC visitor data for each day, to produce reasonable estimates of retrofits' values under such limitation, the team specifies the coverage of a typical air purifier, and then uses HALCs' area to estimate how much mortality rate is reduced by a single air purifier in respective HALCs for a single person. This method makes sure that the number is not artificially bloated, but it will also potentially underestimate the benefits, as the number of HALC visitors is more than one person.

3.4 Extreme Temperature

Temperature is another factor we took into account considering that air condition is one of the many services that HALCs provide. Since temperature is a fixed variable for all HALCs within the Pittsburgh area, we introduce avoided extreme temperature cost to measure the effect of extreme temperature on HALCs.

The following formula estimates mortality reduction, which is one of the components composing avoiding extreme temperature cost:

$$\begin{gathered} Mortality\ Reduction\ =\ Mortality\ Rate\ due\ to\ Extreme\ Temperature\ for\ age\ over\ 65\ years\ old \\ \times\ Population\ of\ age\ over\ 65\ years\ old\ by\ each\ HALC's\ service\ area \\ \times\ Number\ of\ Extreme\ Temperature\ days \end{gathered}$$

The factors used in the Mortality Reduction formula above are explained in detail below::

- The mortality rate from exposure to extreme temperature for those aged 65 or older is an estimate of the annual mortality rate of those aged 65 and over in average temperature below 20 or above 90 °F. This data is from a research paper titled "Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US." The author did research and econometric analyses on mortality rate by different age groups. Then, the author concluded that for ages over 65 years old, mortality rates are statistically significant when the day's temperature is below 20 or above 90 °F. In detail, for age groups over 65 years old, the mortality rate per 100,000 people when the temperature is less than 10 F is 3.438; between 10 and 20 F is 2.408; and greater than 90 F is 5.219.[23]

[23] Deschênes, O., & Greenstone, M. (2011). Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. American Economic Journal: Applied Economics, 3(4), 152-85

- Population over 65 years old is grouped by census tracts within each HALC's service area, defined as the area falling within a half-mile radius of the center.[24] This data is manipulated with ArcGIS Pro calculation based on 2017 American Community Survey population data from the U.S. Census Bureau. (Refer to the accompanying Hazards Maps Process Summary document for instructions on performing this analysis).
- Number of extreme temperature days is measured by the average number of days annually with average temperature is below 20 or above 90 °F (defined as extreme temperature). This data is retrieved from the database of the National Weather Service Forecast Office in Pittsburgh, PA. Annual and monthly historical data between 2015 and 2019 are used to estimate the annual number of days average temperature placed in the range of extreme temperature. From 2015 to 2020, on average, 13 days between 10 to 20 °F; 5 days below 10 °F; and 0 day above 90 °F.[25]

To estimate avoided extreme temperature cost (per unit), we multiply Mortality Reduction, which is comprised of components described above, by the Value of a Statistical Life.

The following formula estimates potential benefits by adjusting HALCs' indoor temperature in extreme temperature days.

$$Avoided\ Extreme\ Temperature\ Cost\ (per\ unit) = Mortality\ Reduction \times Value\ of\ a\ Statistical\ Life$$

The VSL in 2006 was $7.4 million as described earlier.[26] The default value we employed is roughly $9.4 million, which also accounts for an average inflation rate of 1.78% from 2006 to 2020. This figure was used in order to better estimate the effect of extreme temperature on associated potential benefit. There are two available choices for VSL, and which one to use is up to users' discretion.

There are some limitations in our formula due to the data collection.

First, the population data might be outdated. The population data utilized in the formula was collected from the 2017 American Community Survey. Second, detailed temperature data for specific locations were unavailable. The temperature data utilized in the formula were for the whole Pittsburgh area. If more detailed temperature data from individual sensor stations in Pittsburgh were used, the formula estimation would be more accurate. Third, the value of a statistical life used in the formula was estimated by EPA, this VSL might be too general for our situation.

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[24] U.S. Census Bureau. "2017 American Community Survey." U.S. Census Bureau. Accessed April 21, 2020. https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2017/.
[25] National Oceanic and Atmospheric Administration, "NOW Data - NOAA Online Weather Data," National Weather Service Forecast Office, April 30, 2018, https://w2.weather.gov/climate/xmacis.php?wfo=pbz.
[26] Ibid.

3.5 Stormwater Management

Avoided cost of stormwater management by mitigation measures at each HALC is estimated as follows.

$$\begin{aligned} &\textit{Avoided Cost of Stormwater Management by Green Infrastructure at a Facility}\ (\$) \\ &= \textit{Parcel Size of the Facility}\ (sqft) \times \textit{Annual Precipitation in Pittsburgh}\ (gallon/sqft) \\ &\times \textit{Additional Rainwater Retention Potential at the Facility}\ (\%) \\ &\times \textit{Avoided Capital Cost for System Improvement per Gallon of Runoff Reduced}\ (\$/gallon) \end{aligned}$$

The U.S. National Oceanic and Atmospheric Administration (NOAA)'s database provides historical annual precipitation data for Pittsburgh. The team used the average annual precipitation for the recent three decades (1981-2010) which was 38.1 inches/sqft.[27]

Avoided capital cost for system improvement per gallon of stormwater runoff reduced comes from Pittsburgh Water and Sewer Authority's *City-Wide Green Infrastructure Assessment Public Summary*.[28]

Additional rainwater retention potential at the facility can be estimated in various ways. Since the team did not have access to site-specific data for parcel size and rainwater retention characteristics at each HALC, the estimated figures displayed in the tool are currently arbitrary. Average rainwater retention rate at a facility is equal to the product of the proportion of permeable areas in the site and average retention rate of the permeable areas. For instance, the rate is 15% x 60% = 9%, supposing building (50% of the parcel), parking (15%), and pathway (5%) are all impermeable, a half of the remaining area (half of 30% = 15%) is permeable, and average retention rate of the permeable area is 60%. S&R is able to modify the estimate easily once it gains access to facility data in the future. It should be noted that the model described above is very simplified, and the tool provides only coarse estimates because the purpose of the support tool is to provide the first step to narrow down where and what types of retrofit the City should invest in. Therefore, facility management divisions for HALCs would need site-specific engineering studies for detailed benefit calculation once they prioritize facilities and retrofits. Several design manuals are available for local governments.[29] [30]

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[27] National Oceanic and Atmospheric Administration, "Pittsburgh Historical Precipitation Totals 1836 to Current," National Weather Service, accessed May 6, 2020, https://www.weather.gov/media/pbz/records/hisprec.pdf.

[28] Pittsburgh Water and Sewer Authority. *City-Wide Green Infrastructure Assessment Public Summary*, December 1, 2016: 10. https://www.pgh2o.com/sites/default/files/2019-11/PWSA-City-Wide-GI-Assessment-public-summary.pdf.

[29] Pennsylvania Department of Environmental Protection, "Pennsylvania Stormwater Best Management Practices Manual," eLibrary, December 30, 2006, http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4673.

[30] New York State Department of Environmental Conservation, "New York State Stormwater Management Design Manual (January, 2015) - NYS Dept. of Environmental Conservation," www.dec.ny.gov, January 2015, https://www.dec.ny.gov/chemical/29072.html.

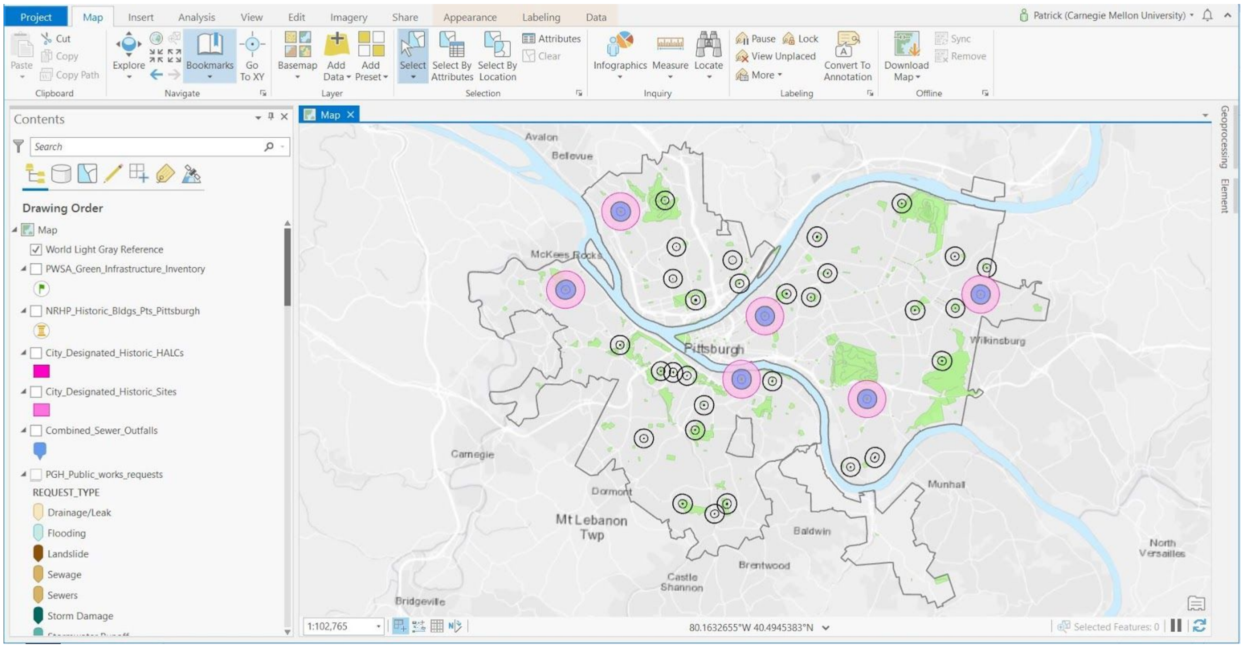
IV. Final Product Package

The final deliverables include the Resilience-Oriented Planning Map and the Decision Support Tool. The proceeding sections describe each of these products in detail.

4.1 Resilience-Oriented Planning Map

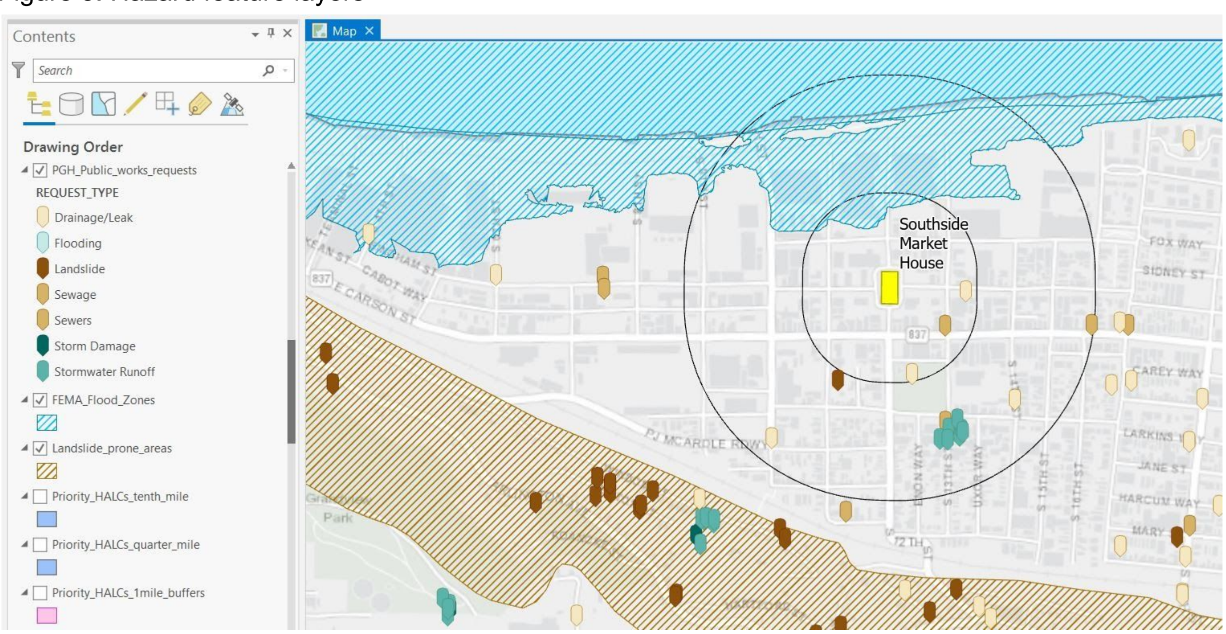
The Resilience-Oriented Planning Map is a geodatabase file created in ArcGIS Pro (v. 2.5.0) in order to provide quick reference of the 35 Healthy Active Living Centers in relation to the various hazards and other feature layers of interests. The user can easily turn on and off feature layers to answer specific queries, or add additional layers to open up entirely new fields of inquiry. Complete documentation of the data layers included in this map can be found in the accompanying Data Documentation file.

Figure 2. Resilience-oriented planning map, Pittsburgh zoom extent



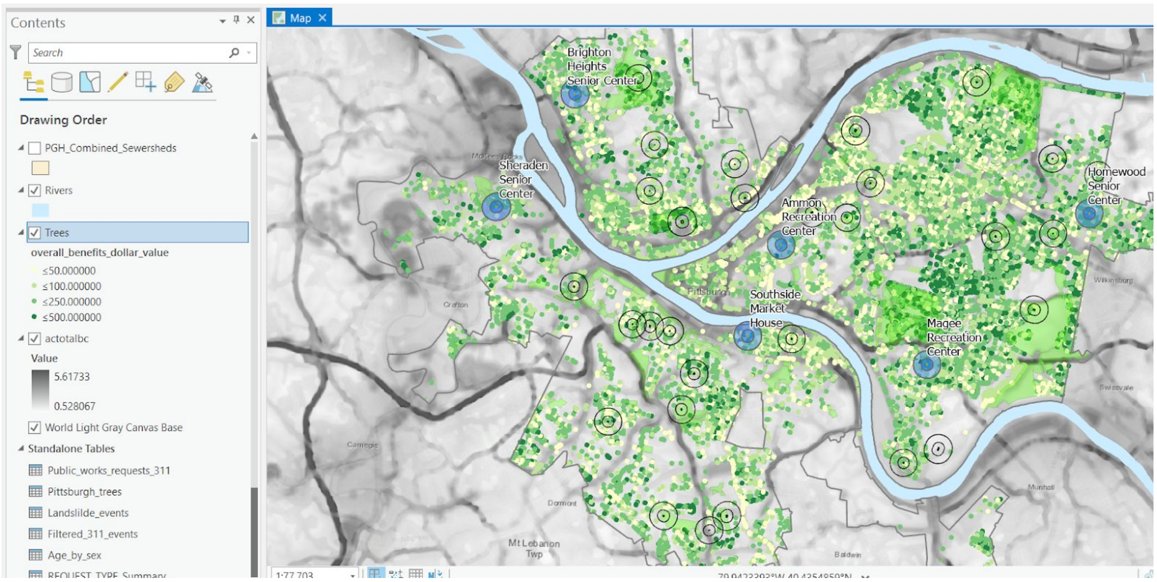
The map includes a number of hazard feature layers, which enable the user to assess the risk posed to specific Healthy Active Living Centers by proximity to established flood zones and landslide prone areas as well as a wide variety of discrete hazards, including storm damage, stormwater runoff, and sewage overflows. Within the map, these features are overlaid with tenth-mile and quarter-mile buffers around the Healthy Active Living Center to more accurately assess the risk exposure of each center (Fig. 3).

Figure 3. Hazard feature layers



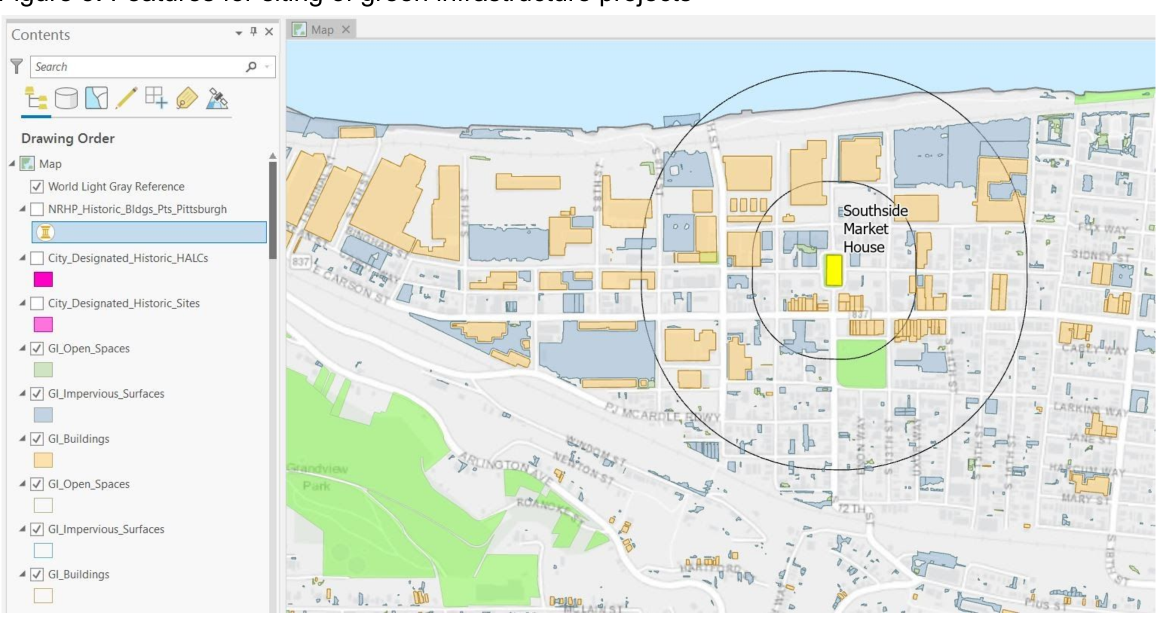
Likewise, S&R staff can use the trees and air quality layers to identify centers where black carbon (shown) or other pollutants may pose a threat to patrons for prioritizing the installation of air purifiers, filters, or planting trees (Figure 4).

Figure 4. Air quality and trees features



Also included in the map are feature layers useful for scoping suitable sites for the development of green infrastructure, including green roofs, permeable pavement, and rain gardens (Fig. 5). These layers were imported from a more comprehensive study into the siting and cost effectiveness of such green infrastructure projects for the city of Pittsburgh. For more information on this study and its findings, as well as links to project documentation, visit the project's website at https://wetweather.pitt.edu/green/.

Figure 5. Features for siting of green infrastructure projects



4.2 Decision Support Tool

The Decision Support Tool was built to allow S&R staff to aggregate quantitative and qualitative information about costs and benefits associated with renovation projects for specific HALCs for ready translation into recommendations to decision-makers, including the Office of Management and Budget (OMB), City Council, and others. Sections 4.2.1 and 4.2.2 below describe the front and back end of the tool, respectively.

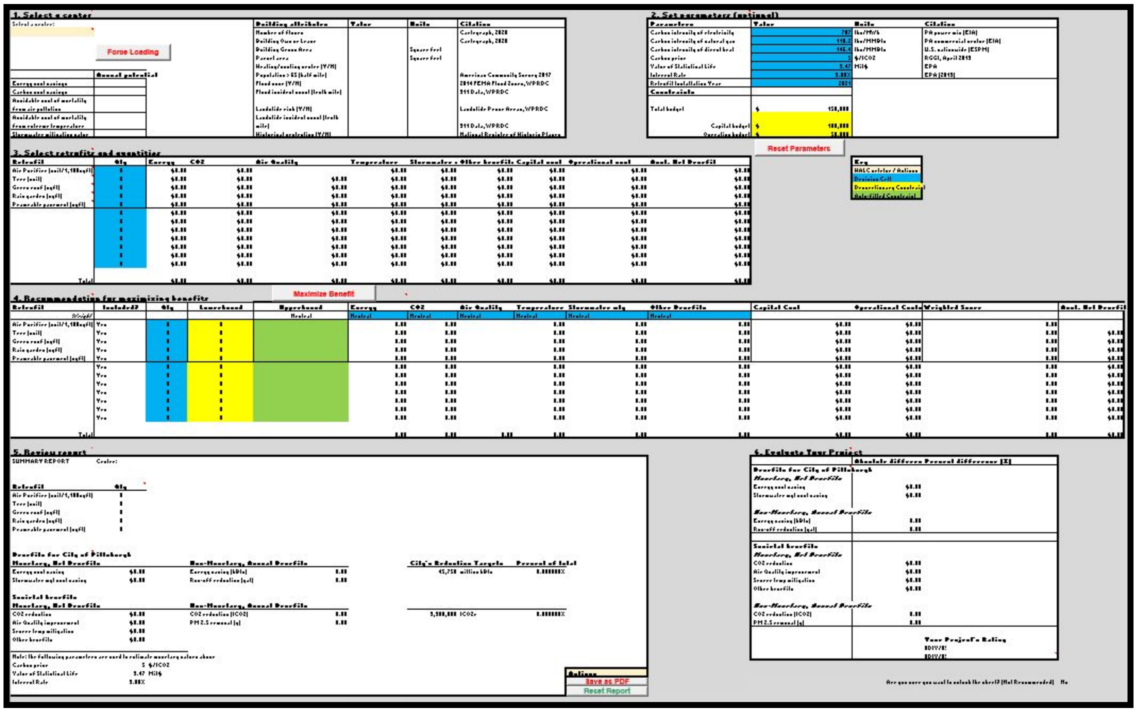
4.2.1 User Interface: Dynamic Accounting Spreadsheet

The user interface provides the user with a dynamic accounting-style spreadsheet that automatically calculates the costs and benefits associated with specific retrofit projects and evaluates these outcomes against the City's budgetary and climate goals (Figure 6). The outputs of this calculation are automatically customized to the specifications of the particular building selected by the user.

The user interface is composed of six boxes that guide the user through the various steps of the retrofit project planning process. These steps include:

1. Selecting a center for viewing
2. Setting the parameters for calculating costs and benefits
3. Inputting retrofit quantities and calculating total costs and benefits
4. Optimizing retrofit quantities using built-in solver function
5. Generating summary report of the custom retrofit project
6. Evaluating the custom retrofit project relative to optimized proposal

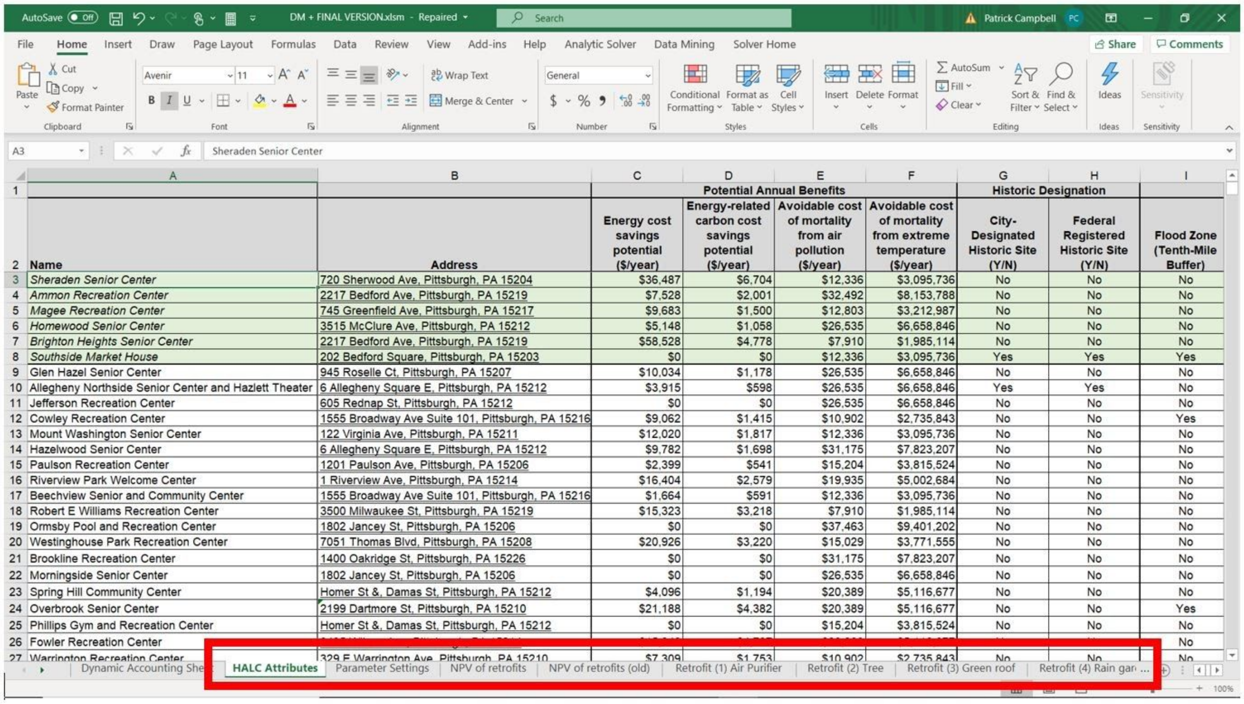
Figure 6.User Interface (Dynamic Accounting Sheet)



4.2.2 Back End

The back end of the Decision Support Tool (Figure 7) consists of multiple sheets for storing source data, running calculations, and documenting methodology. Below, we describe each of the component sheets and explain how they interact with the user interface.

Figure 7. Back end (comprises all sheets outlined in red). Shown: HALC Attributes sheet



	Name	Address	Potential Annual Benefits: Energy cost savings potential ($/year)	Potential Annual Benefits: Energy-related carbon cost savings potential ($/year)	Potential Annual Benefits: Avoidable cost of mortality from air pollution ($/year)	Potential Annual Benefits: Avoidable cost of mortality from extreme temperature ($/year)	Historic Designation: City-Designated Historic Site (Y/N)	Historic Designation: Federal Registered Historic Site (Y/N)	Flood Zone (Tenth-Mile Buffer)
3	*Sheraden Senior Center*	720 Sherwood Ave, Pittsburgh, PA 15204	$36,487	$6,704	$12,336	$3,095,736	No	No	No
4	*Ammon Recreation Center*	2217 Bedford Ave, Pittsburgh, PA 15219	$7,528	$2,001	$32,492	$8,153,788	No	No	No
5	*Magee Recreation Center*	745 Greenfield Ave, Pittsburgh, PA 15217	$9,683	$1,500	$12,803	$3,212,987	No	No	No
6	*Homewood Senior Center*	3515 McClure Ave, Pittsburgh, PA 15212	$5,148	$1,058	$26,535	$6,658,846	No	No	No
7	*Brighton Heights Senior Center*	2217 Bedford Ave, Pittsburgh, PA 15219	$58,528	$4,778	$7,910	$1,985,114	No	No	No
8	*Southside Market House*	202 Bedford Square, Pittsburgh, PA 15203	$0	$0	$12,336	$3,095,736	Yes	Yes	Yes
9	Glen Hazel Senior Center	945 Roselle Ct, Pittsburgh, PA 15207	$10,034	$1,178	$26,535	$6,658,846	No	No	No
10	Allegheny Northside Senior Center and Hazlett Theater	6 Allegheny Square E, Pittsburgh, PA 15212	$3,915	$598	$26,535	$6,658,846	Yes	Yes	No
11	Jefferson Recreation Center	605 Rednap St, Pittsburgh, PA 15212	$0	$0	$26,535	$6,658,846	No	No	No
12	Cowley Recreation Center	1555 Broadway Ave Suite 101, Pittsburgh, PA 15216	$9,062	$1,415	$10,902	$2,735,843	No	No	Yes
13	Mount Washington Senior Center	122 Virginia Ave, Pittsburgh, PA 15211	$12,020	$1,817	$12,336	$3,095,736	No	No	No
14	Hazelwood Senior Center	6 Allegheny Square E, Pittsburgh, PA 15212	$9,782	$1,698	$31,175	$7,823,207	No	No	No
15	Paulson Recreation Center	1201 Paulson Ave, Pittsburgh, PA 15206	$2,399	$541	$15,204	$3,815,524	No	No	No
16	Riverview Park Welcome Center	1 Riverview Ave, Pittsburgh, PA 15214	$16,404	$2,579	$19,935	$5,002,684	No	No	No
17	Beechview Senior and Community Center	1555 Broadway Ave Suite 101, Pittsburgh, PA 15216	$1,664	$591	$12,336	$3,095,736	No	No	No
18	Robert E Williams Recreation Center	3500 Milwaukee St, Pittsburgh, PA 15219	$15,323	$3,218	$7,910	$1,985,114	No	No	No
19	Ormsby Pool and Recreation Center	1802 Jancey St, Pittsburgh, PA 15206	$0	$0	$37,463	$9,401,202	No	No	No
20	Westinghouse Park Recreation Center	7051 Thomas Blvd, Pittsburgh, PA 15208	$20,926	$3,220	$15,029	$3,771,555	No	No	No
21	Brookline Recreation Center	1400 Oakridge St, Pittsburgh, PA 15226	$0	$0	$31,175	$7,823,207	No	No	No
22	Morningside Senior Center	1802 Jancey St, Pittsburgh, PA 15206	$0	$0	$26,535	$6,658,846	No	No	No
23	Spring Hill Community Center	Homer St &, Damas St, Pittsburgh, PA 15212	$4,096	$1,194	$20,389	$5,116,677	No	No	No
24	Overbrook Senior Center	2199 Dartmore St, Pittsburgh, PA 15210	$21,188	$4,382	$20,389	$5,116,677	No	No	Yes
25	Phillips Gym and Recreation Center	Homer St &, Damas St, Pittsburgh, PA 15212	$0	$0	$15,204	$3,815,524	No	No	No
26	Fowler Recreation Center	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	No
27	Warrington Recreation Center	329 E Warrington Ave, Pittsburgh, PA 15210	$7,309	$1,753	$10,902	$2,735,843	No	No	No

Dynamic Accounting She | HALC Attributes | Parameter Settings | NPV of retrofits | NPV of retrofits (old) | Retrofit (1) Air Purifier | Retrofit (2) Tree | Retrofit (3) Green roof | Retrofit (4) Rain gar ...

HALC Attributes sheet

The *HALC Attributes* sheet contains information about each of the 35 Healthy Active Living Centers, organized into six broad areas as outlined below. The information stored in this sheet is automatically loaded into box 1 of the User Interface whenever a center is selected and is subsequently used to run the optimization function in the *Dynamic Accounting Sheet* and the computation of annual potential benefits of each center.

- Potential annual benefits
    - Energy cost savings potential ($/year): Calculated in the tool.
    - Carbon cost savings potential ($/year): Calculated in the tool.
    - Avoidable cost of mortality from air pollution ($/year): Calculated in the tool.
    - Avoidable cost of mortality from extreme temperature ($/year): Calculated in the tool.
    - Stormwater mitigation value ($/year): Calculated in the tool.
- Historic designation
    - City-designated historic site (Y/N): Captured from the City of Pittsburgh Historic Designation
    - Federal-registered historic site (Y/N): Captured from National Register of Historic Places
- Heating/cooling center (Y/N): Information provided by City of Pittsburgh[31]
- Hazard exposure

[31] Casimir Pellegrini, interview by Patrick Campbell, Kensuke Onishi, Adhiraj Shekhawat, Haoran Yan, Shule Chen, & Chante Solomon, April 9, 2020, Pittsburgh.

- Flood zone (tenth-mile & quarter-mile buffers) (Y/N): Captured from 2014 FEMA Flood Zones shapefile, Western PA Regional Data Center
    - Flood incident counts (tenth-mile & quarter-mile buffers): Captured from Pittsburgh 311 Response Center database, Western PA Regional Data Center
    - Flood incident percentile (tenth-mile buffer): Calculated in the tool.
    - Landslide zone (tenth-mile & quarter-mile buffers) (Y/N): Captured from Landslide Prone Area shapefile, Western PA Regional Data Center
    - Landslide incident counts (tenth-mile & quarter-mile buffers): Captured from Pittsburgh 311 Response Center database
    - Landslide incident percentile (tenth-mile buffer): Calculated in the tool.
- Community statistics
    - Population of age 65 and over: Captured from 2017 American Community Survey, calculated as a proportional weighted average from census tracts falling within a half mile radius of the HALC (refer to accompanying Hazards Maps Process Summary document).
- Facility specs
    - Parcel size: Captured from GIS map. Those in red letters are missing data and estimated as a gross area divided by floor count.
    - Building area: All data are missing and estimated as the smaller figure of either a parcel size or a gross area divided by floor count.
    - Building gross area (total floorspace): Those in red letters are missing data and estimated as a half of the parcel size.
    - Floorspace for use: Current data is based on Pittsburgh Buildings Portfolio Carbon Calculator which S&R provided RMI dataset.[32]
    - Roof area: All data are currently the same as building area.
    - Parking area: Only "Open Lot" is currently counted as a parking area that is convertible to permeable pavement, and the smaller number of either [(parcel size) - (building size)] or [(building area) / 500 sqft * 180 sqft] is used. 180 sqft is a standard size of parking lot for a car,[33] and Pittsburgh parking requirement for community centers is 1/500 sqft building gross area.[34]
    - Remaining area: Space for potential green infrastructure, such as rain gardens and trees. Currently calculated as [(Parcel area) - (Building area) - (Parking area)].
    - Average rainwater retention rate of parcel: Currently assumed as [(50% of Remaining area) / (Parcel area) * (60% as a typical retention rate of green infrastructure)].

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[32] City of Pittsburgh, "Pittsburgh Buildings Portfolio Carbon Calculator, Version 15" (City of Pittsburgh, n.d.), accessed January 29, 2020.
[33] Angie Schmitt, "Parking Takes Up More Space Than You Think," Streetsblog USA, July 5, 2016, https://usa.streetsblog.org/2016/07/05/parking-takes-up-more-space-than-you-think/.
[34] City of Pittsburgh, "Code of Ordinances Supplement 35 Update 4," Municode Library, April 7, 2020, https://library.municode.com/pa/pittsburgh/codes/code_of_ordinances?nodeId=13525.

- Max number of trees (space for tree planting): Currently, [(Remaining area) / 625 sqft] is used for a rough estimate, assuming 625 sqft = 25 feet * 25 feet for a required space for a single tree planting.[35]
- Number of air purifiers: Floorspace for use divided by 1100 square feet (the size of an air purifier assumed for retrofits).[36]
- Floor count: Those in red are missing data and guessed using Google Map
- Own/lease: “Own” or “Lease,” registered in the Cartegraph.
- Parking type: “Open Lot,” “Street,” or “None,” registered in the Cartegraph. Those in red are missing data and guessed using Google Map.

Parameter Settings sheet

The *Parameter Settings* sheet (Figure 8) allows the user to adjust cost-benefit calculations, providing the decision-maker with a greater degree of control over messaging.

Specifically, the user may make adjustments to the following parameters:

- Carbon intensity of energy sources
- Carbon price
- Value of a Statistical Life (VSL)
- Discount rate (see Table 3 below for discount rates listed in the tool)
- Retrofit installation year
- Weights of optimization priority index
- City of Pittsburgh’s climate goals

[35] SFGate, “Distance Between Maple Tree Planting,” SFGate, accessed May 6, 2020, https://homeguides.sfgate.com/distance-between-maple-tree-planting-50041.html.
[36] Alencorp, “Alen BreatheSmart Classic True HEPA Air Purifier,” Alencorp, accessed May 6, 2020, https://www.alencorp.com/products/alen-breathesmart-hepa-air-purifier?gclid=Cj0KCQjwybD0BRDyARIsACyS8mvwN0GCnk9jJ7NuXzXOozBtKyIy1CtkauQIqtdtY8cgJzsPokPfU0UaAioQEALw_wcB&variant=12172983238723.

Figure 8. Parameter Setting Sheet

	A	B	C	D	E
1	**Selected parameters**				
2	1) Carbon intensity of energy sources	Value	Unit	Reference	
3	*a) Electricity*	469.5	lbs/MWh	DLC's power mix (estimate)	
4	*b) Natural gas*	117	lbs/MMBtu	U.S. nationwide (EIA)	
5	*b) Direct steam*	146.4	lbs/MMBtu	U.S. nationwide (ESPM)	
6					
7	2) Carbon price	7.64	$/tCO2	Tol (2018)	
8					
9	3) Value of Statistical Life	0.5	Mil$	Deschênes, Greenstone, & Shapiro (2017)	
10					
11	4) Interest Rate	3.00%		EPA (2013)	
12					
13	5) Retrofit Installation Year	2021			
14					
15		note			
16		Column value taken from Dynamic Accounting Sheet			
17					
18	**Parameter options**				
19	1) Carbon intensity of energy sources				
20	*a) Electricity*	Value	Unit	Reference	URL
21	PA power mix (EIA)	787	lbs/MWh	EIA Pennsylvania Electricity Profile 2018	https://www.eia.gov/electricity/state/pennsylvania/
22	DLC's power mix (estimate)	469.5	lbs/MWh	The authors' estimate based on a hearing to Dequesne Light (its power mix is assumed roughly 70% nuclear, 15% coal, 15% natural gas)	https://www.eia.gov/tools/faqs/faq.php?id=74&t=11
23					
24	*b) Natural gas*		unit	Reference	URL
25	U.S. nationwide (EIA)	117	lbs/MMBtu	EIA FAQ	https://www.eia.gov/tools/faqs/faq.php?id=73&t=11
26	PA commercial sector (EIA)	118.2	lbs/MMBtu	2017 PA commercial sector calculated from EIA data	See right
27					
28	*c) Direct steam*		unit	Reference	URL
29	U.S. nationwide (ESPM)	146.4	lbs/MMBtu	Energy Star Portfolio Manager: 66.4kg/MMBtu	https://portfoliomanager.energystar.gov/pdf/referenc
30					
31	2) Carbon price		unit	Reference	URL
32	EPA (2016)	52.22	$/tCO2	EPA (2016) The Social Cost of Carbon:	https://19january2017snapshot.epa.gov/climatechang
33	Ricke, Drouet, Caldeira, & Tavoni (2018)	48.00	$/tCO2	Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018). Country-level social cost of carbon. Nature Climate Change, 8(10), 895-900. Social Cost of Carbon in the U.S.	

Table 3: Various options for discount rate

Rate	**Description**
1.23%	30-year Treasury Bond as of April 20, 2020[37]
1.40%	Academic literature[38]
2.10%	30-year Municipal Bonds (AA-rated, national average) as of April 21[39]
2.27%	Academic literature[40]
2.60%	Academic literature[41]
3.00%	Used in EPA's Social Cost of Carbon calculation[42]

[37] U.S. Department of Treasury, "Daily Treasury Yield Curve Rates," Treasury.gov, accessed April 21, 2020, https://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=yield.

[38] William D Nordhaus, "A Review of TheStern Review on the Economics of Climate Change," *Journal of Economic Literature* 45, no. 3 (July 2007): 686–702, https://doi.org/10.1257/jel.45.3.686.

[39] FMS Bonds, Inc, "Municipal Bonds Market Yields," FMSbonds.com, accessed April 21, 2020, https://www.fmsbonds.com/market-yields/.

[40] Moritz A. Drupp et al., "Discounting Disentangled," *American Economic Journal: Economic Policy* 10, no. 4 (November 2018): 109–34, https://doi.org/10.1257/pol.20160240.

[41] Stefano Giglio, Matteo Maggiori, and Johannes Stroebel, "Very Long-Run Discount Rates," *The Quarterly Journal of Economics* 130, no. 1 (November 25, 2014): 1–53, https://doi.org/10.1093/qje/qju036.

[42] U.S. Environmental Protection Agency, "The Social Cost of Carbon," Climate Change, n.d., https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html.

4.30%	Academic literature[43]
5.00%	Used in EPA's Social Cost of Carbon calculation[44]
7.00%	EPA's typical upper value[45]

NPV of Retrofits sheet

The *NPV of Retrofits* sheet (Figure 9) is used for the calculation of net-benefits of retrofits listed below and consists of the following three boxes.

- CBA inputs (blue cells): Annual costs and benefits of each retrofit are stored. In addition to dollar values, some non-monetary values are also summarized to use for the *Dynamic Accounting Sheet.*
- CBA calculations (cream cells): Net present value (NPV) of benefits throughout the project lifetime is calculated using annual values listed in CBA inputs.
- CBA results (pink cells): NPVs resulting from CBA calculations are summarized.

Figure 9. NPV of Retrofits Sheet

[43] William D Nordhaus, "A Review of TheStern Review on the Economics of Climate Change," *Journal of Economic Literature* 45, no. 3 (July 2007): 686–702, https://doi.org/10.1257/jel.45.3.686.
[44] U.S. Environmental Protection Agency, "The Social Cost of Carbon," Climate Change, n.d., https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html.
[45] U.S. Environmental Protection Agency, "Guidelines for Preparing Economic Analyses" (U.S. Environmental Protection Agency, December 2010), https://www.epa.gov/sites/production/files/2017-09/documents/ee-0568-06.pdf.

	A	B	C	D	E	F	G	H	I	J
1	CBA results (Output to Dynamic Accounting Sheet)									
2	Retrofit items	Energy	Carbon	Air Quality	Temperature	Stormwater mgt	Others	Capex	Opex	Total
3	Air Purifier (unit/1,100sqft)	$0.00	$0.00	$2,653.69	$0.00	$0.00	$0.00	$600.00	$874.72	$1,178.97
4	Tree (unit)	$74.12	$45.04	$320.83	$0.00	$103.58	$40,368.76	$900.00	$3,100.44	$36,911.89
5	Green roof (sqft)	$1.52	$0.03	$286.02	$0.00	$95.07	$0.00	$19.70	$7.17	$355.78
6	Rain garden (sqft)	$0.00	$0.00	$0.00	$0.00	$141.25	$0.00	$19.00	$41.17	$81.08
7	Peameable pavement (sqft)	$0.00	$0.00	$0.00	$0.00	$141.25	$0.00	$1.77	$0.91	$138.57
8	Retrofit (6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
9										
10										
11	Insert additional retrofits above if neessary									
12										
13	CBA inputs									
14										
15	Discount rate (chosen in front page)	3.00%								
16										
17	Annual benefit in each parameter (Input from each retrofit calculation sheet)									
18	Retrofit items	Energy	Carbon	Air Quality	Temperature	Stormwater mgt	Others	Capex	Opex	Lifetime (year)
19	Air Purifier (unit/1,100sqft)	$0.00	$0.00	$579.45	$0.00	$0.00	$0.00	$600.00	$191.00	5
20	Tree (unit)	$2.88	$1.75	$12.47	$0.00	$4.03	$1,568.95	$900.00	$120.50	50
21	Green roof (sqft)	$0.07	$0.00	$12.37	$0.00	$3.80	$0.00	$19.70	$0.31	40
22	Rain garden (sqft)	$0.00	$0.00	$0.00	$0.00	$5.07	$0.00	$19.00	$1.60	50
23	Peameable pavement (sqft)	$0.00	$0.00	$0.00	$0.00	$5.07	$0.00	$1.77	$0.04	15
24	Retrofit (6)									
25										
26										
27	Insert additional retrofits above if neessary									
28										
29	CBA calculations									
30			PY0	PY1	PY2	PY3	PY4	PY5	PY6	PY7
31										
32										
33										
34	Air Purifier		Year							
35			PY0	PY1	PY2	PY3	PY4	PY5		
36		NPV	2021	2022	2023	2024	2025	2026		
37	Capital Cost	$600.00	$600.00							
38	Operational cost	$874.72		$191.00	$191.00	$191.00	$191.00	$191.00		
39	Energy	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00		
40	Carbon	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00		
41	Air Quality	$2,653.69		$579.45	$579.45	$579.45	$579.45	$579.45		
42	Temperature	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00		
43	Stormwater mgt	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00		
44	Others	$0.00		$0.00	$0.00	$0.00	$0.00	$0.00		
45										
46										
47	Tree		Year							
48			PY0	PY1	PY2	PY3	PY4	PY5	PY6	PY7
49		NPV	2021	2022	2023	2024	2025	2026	2027	2028
50	Capex	$900.00	$900.00							
51	Opex	$3,100.44		$120.50	$120.50	$120.50	$120.50	$120.50	$120.50	$120.50
52	Energy	$74.12		$2.88	$2.88	$2.88	$2.88	$2.88	$2.88	$2.88

Retrofit Guides 1-5

The back end currently contains five *Retrofit Guide* sheets (Figure 10), which detail the costs and benefits associated with each of our five stock retrofits, including:

- Air purifier
- Tree
- Green roof
- Rain garden
- Permeable pavement

Appendix 2 describes the methodology used for the cost-benefit analysis of these retrofits.

Figure 10. Example of Retrofit Guide Sheet. Shown: Retrofit Guide (1): Air Purifier

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Air Purifier**											
2				Note	Ref							
3	Lifetime	5	year		Alen Breathsn	https://www.consumerreports.org/air-purifiers/air-purifiers-and-the-cost-of-clean-air/						
4												
5	Capital expenditure (per unit)	$600.00			Alen Breathsn	https://www.consumerreports.org/air-purifiers/air-purifiers-and-the-cost-of-clean-air/						
6												
7	Operating expenditure (per unit)	$191.00			Alen Breathsn	https://www.consumerreports.org/air-purifiers/air-purifiers-and-the-cost-of-clean-air/						
8	- Filter cost	104										
9	- Energy cost	87										
10												
11	Energy											
12		$0.00										
13												
14	Carbon											
15		$0.00										
16												
17	Air quality											
18	Outdoor air PM2.5	9.20	microgram/m3	Laurenceville 2015-2017 avg (p.8)	Allegheny Cou	https://www.alleghenycounty.us/uploadedFiles/Allegheny_Home/Health_Department/Resources/Data_an						
19	Indoor air PM2.5 without intervention	5.52	microgram/m3	min 60% of outdoor PM 2.5 inhala	Fisk, W. J., &	https://onlinelibrary.wiley.com/doi/pdf/10.1111/ina.12371?casa_token=_vbmK7p8G3oAAAAA:jDS_o1oY_V_I						
20	Indoor air PM2.5 with air purifier	0.00166	microgram/m3	99.97% removal rate	Alen Breathsn	https://www.alencorp.com/products/alen-breathesmart-hepa-air-purifier?gclid=Cj0KCQjwvbD0BRDvARI						
21	Amount of PM2.5 removed (per unit)	1,691.81335	microgram	Assuming ceiling height 3m	1100	sqft	0.092903	m2/sqft				
22	Mortality reduction by air purifier	1,158.89215	/million people	Estimated increase in mortality wi	0.685	per million people						
23	Avoided air pollution cost (per unit)	$10,974.71		VSL on the front sheet	9.47	Mil$	EPA					
24												
25	Temperature											
26		$0.00										
27												
28	Stormwater management											
29		$0.00										
30												
31	Other values											
32		$0.00										
33												

Source Datasets

Finally, the remaining sheets (Figure 11) are used for the calculation of potential annual benefits of each facilities appearing in the *HALC Attributes* sheet, including:

- Energy use
- Carbon emissions
- Stormwater management
    - Annual precipitation projection (hidden sheet)
- Air quality
- Temperature

Figure 11. Example of Source Datasets sheets. Shown: *Energy* sheet

	A	B	C	D	E	F	G	H	I	J
1							Input column (using facilities' monthly energy bills to sum up annual values)			
2	name	Potential energy saving (kBtu)	Annual energy cost saving ($)	Annual carbon reduction (tCO2e)	Annual energy-related carbon cost saving ($)		Annual electricity cost ($)	Annual electricity use (kWh)	Annual natural gas cost ($)	Annual natural gas use (Mcf: thousand cubic feet)
3	Sheraden Senior Center	151,371.3	$4,946.60	9.4	$72.18		$6,163.46	55,278.0	$0.00	0.0
4	Ammon Recreation Center	2,262,766.7	$36,487.08	128.4	$980.82		$26,453.58	276,030.7	$12,275.59	1409.3
5	Magee Recreation Center	701,041.3	$7,527.60	38.3	$292.72		$4,243.15	42,478.6	$4,951.03	686.6
6	Homewood Senior Center	503,731.4	$9,683.17	28.7	$219.53		$9,900.00	82,204.0	$2,787.27	366.3
7	Brighton Heights Senior Center	363,135.8	$5,148.32	20.3	$154.79		$3,887.21	42,646.8	$3,195.99	341.8
8	Southside Market House	1,615,988.4	$58,528.39	91.5	$698.98		$55,268.08	204,696.6	$11,431.82	1103.5
9	Glen Hazel Senior Center	0.0	$0.00	0.0	$0.00		$0.00	0.0	$0.00	0.0
10	Allegheny Northside Senior Center and Hazlett T	361,273.4	$10,033.94	22.5	$172.27		$18,647.38	198,703.2	$185.43	0.1
11	Jefferson Recreation Center	203,259.3	$3,915.13	11.4	$87.44		$2,948.50	23,155.0	$1,448.14	144.1
12	Cowley Recreation Center	0.0	$0.00	0.0	$0.00		$2,764.57	12,810.3	$0.00	0.0
13	Mount Washington Senior Center	479,735.3	$9,062.14	27.1	$206.99		$7,186.30	58,520.0	$3,172.32	336.6
14	Hazelwood Senior Center	610,072.5	$12,020.18	34.8	$265.82		$9,545.69	83,956.5	$3,770.35	375.9
15	Paulson Recreation Center	583,087.8	$9,782.41	32.5	$248.37		$6,474.00	52,611.7	$4,017.38	430.3
16	Riverview Park Welcome Center	192,369.6	$2,399.10	10.4	$79.20		$864.31	5,354.6	$1,748.55	184.6
17	Beechview Senior and Community Center	832,122.9	$16,404.30	49.4	$377.31		$16,464.94	189,015.1	$2,458.61	304.0
18	Robert E Williams Recreation Center	213,240.7	$1,664.40	11.3	$86.46		$0.00	0.0	$2,122.29	262.5
19	Ormsby Pool and Recreation Center	1,127,395.0	$15,322.77	61.6	$470.78		$6,472.87	63,921.3	$10,989.20	1029.6
20	Westinghouse Park Recreation Center	0.0	$0.00	0.0	$0.00		$690.67	3,299.6	$0.00	0.0
21	Brookline Recreation Center	1,100,844.9	$20,926.14	61.7	$471.08		$15,791.36	112,769.8	$7,458.27	809.2
22	Morningside Senior Center	0.0	$0.00	0.0	$0.00		$1,683.98	14,151.1	$0.00	0.0
23	Spring Hill Community Center	592,490.3	$0.00	31.4	$240.23		$0.00	0.0	$0.00	571.9
24	Overbrook Senior Center	424,216.0	$4,096.00	22.9	$174.63		$1,269.84	12,204.7	$3,364.94	423.1
25	Phillips Gym and Recreation Center	1,496,424.0	$21,187.87	83.9	$641.17		$16,481.32	155,913.1	$6,896.89	1080.3
26	Fowler Recreation Center	0.0	$0.00	0.0	$0.00		$0.00	0.0	$213.96	34.4
27	Warrington Recreation Center	1,680,707.9	$15,240.33	90.5	$691.54		$4,787.80	47,800.5	$12,832.93	1718.3
28	Ream Pool Building and Recreation Center	608,454.7	$7,309.39	33.6	$256.53		$3,360.47	44,998.1	$4,799.11	507.4
29	Lawrenceville Senior Center	0.0	$0.00	0.0	$0.00		0.0	0.0	$0.00	0.0
30	Mellon Park Garden Society Center	0.0	$0.00	0.0	$0.00		0.0	0.0	$0.00	0.0
31	West Penn Recreation Center	2,415,076.4	$28,205.10	131.7	$1,005.84		$10,537.91	118,361.5	$20,019.62	2135.8
32	Bloomfield Pool and Recreation Center	414,287.9	$9,116.55	24.0	$183.25		$8,749.93	77,967.1	$2,590.34	240.7
33	West End Senior Center	0.0	$0.00	0.0	$0.00		0.0	0.0	$0.00	0.0
34	McKinley Park Recreation and Senior Center	899,676.2	$8,974.70	48.8	$372.91		$3,956.22	35,953.8	$5,714.26	817.3
35	Olympia Park Recreation Center	1,121,706.7	$26,468.13	60.4	$461.83		$7,422.77	30,036.7	$20,165.63	1029.6
36	Frick Park Environmental Center	0.0	$0.00	0.0	$0.00		$0.00	0.0	$0.00	0.0
37	Chadwick Recreation Center	0.0	$0.00	0.0	$0.00		0.0	0.0	$0.00	0.0
38							*need to update wi	*2018 data	*need to update wi	*2018 data

V. User's Guide

In this section, we provide instructions for the proper use of the deliverables. In section 5.1, we explain how to plan a retrofit project using the main user interface. In section 5.2, we provide walkthroughs of other common operations. In addition to this comprehensive User's Guide, please also reference the demo video for a quicker visual aid of how the tool works.[46]

5.1 Guide to the User Interface: Planning a Retrofit Project

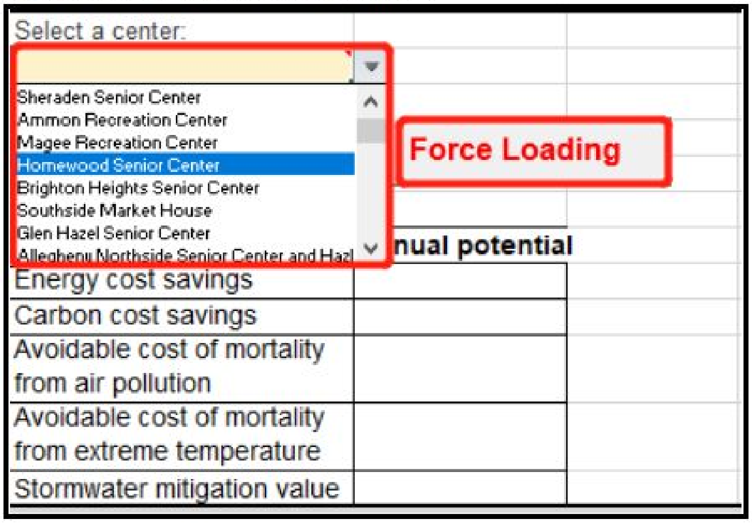
Step 1. Select a center

Navigate to the *Dynamic Accounting* Sheet (first sheet in the workbook). In Box 1, choose the center you'd like to retrofit by clicking on the drop down menu in the upper left hand corner and selecting the center's name (Figure 12).

The "Force Loading" button is designed to force the tool making calculation in case the tool cannot recalculate after the user reselects another center.

[46] Tool Demo Presentation. https://drive.google.com/open?id=1kH8A0MJpQ9QyT6PBgvkgyiO0it6adZcI

Figure 12. Selecting a center to retrofit



When a center is selected, information about the chosen center will be automatically imported from the *HALC Attributes* sheet and displayed in the two tables (Figure 13), representing building attributes (right) and annual savings potential (bottom). The center's address with a hyperlink to Google Maps is also loaded to the right of the center selection box.

Figure 13. Retrieve information associated with the selected HALC

1. Select a center					
Select a center:		**Building attributes**	**Value**	**Units**	**Citation**
Southside Market House	2 Bedford Square, Pittsburgh, PA 15203	Number of floors	2		Cartegraph, 2020
		Building Own or Lease	Own		Cartegraph, 2020
		Building Gross Area	24,260	Square feet	
		Parcel area	11,761	Square feet	
		Heating/cooling center (Y/N)	No		
	Annual potential	Population > 65 (half mile)	179		American Community Survey 2017
Energy cost savings	$58,528.39	Flood zone (Y/N)	Yes		2014 FEMA Flood Zones, WPRDC
Carbon cost savings	$698.98	Flood incident count (tenth mile)	4		311 Data, WPRDC
Avoidable cost of mortality from air pollution	$61.31	Landslide risk (Y/N)	No		Landslide Prone Areas, WPRDC
Avoidable cost of mortality from extreme temperature	$43,402.13	Landslide incident count (tenth mile)	0		311 Data, WPRDC
Stormwater mitigation value	$66,889.61	Historical protection (Y/N)	Yes		National Register of Historic Places

Step 2. Set parameters

The user can optionally set parameters in Box 2 which belong to the selected HALC in order to receive a more exploratory CBA analysis (Figure 14).

In order to restore these parameters to their default values, simply click the "Reset Parameters" button located directly below the box.

Figure 14. Set parameters for selected center

Parameters	Value	Units	Citation
Carbon intensity of electricity	787	lbs/MWh	PA power mix (EIA)
Carbon intensity of natural gas	118.2	lbs/MMBtu	PA commercial sector (EIA)
Carbon intensity of direct heat	146.4	lbs/MMBtu	U.S. nationwide (ESPM)
Carbon price	5	$/tCO2	RGGI, April 2019
Value of Statistical Life	9.47	Mil$	EPA
Interest Rate	3.00%		EPA (2013)
Retrofit Installation Year	2021		
Constraints			
Total budget	$ 150,000		
Capital budget	$ 100,000		
Operation budget	$ 50,000		

Reset Parameters

Step 3. Adjust quantity for each retrofit

The purpose of Box 3 (Figure 15) is to provide a benefit calculator measuring the effects of a specific retrofit and a series of retrofits respectively.

To measure the benefit of inputed retrofits, in Box 3, a value of Acct. Net Benefit will be calculated based on user's quantity input for each retrofit. Users can manually enter the quantity of their choice for each retrofit into the blue cells.

There are several empty lines left for the user to input additional retrofit options in the future. See section 5.2 below for instructions on how to do this.

Step 4. Receive an optimized recommendation

The purpose of Box 4 is to provide a recommendation of retrofits combination with particular quantities in order to maximize the net benefits.

To get the recommendation, follow the instructions below. See Figure 16 below to see each of the instructions highlighted in a red outline.

1. Set minimized/maximized quantity (lower/upper bound) for each retrofit if there are particular quantity

Figure 15. Input quantity for retrofits

3. Select retrofits and quantities

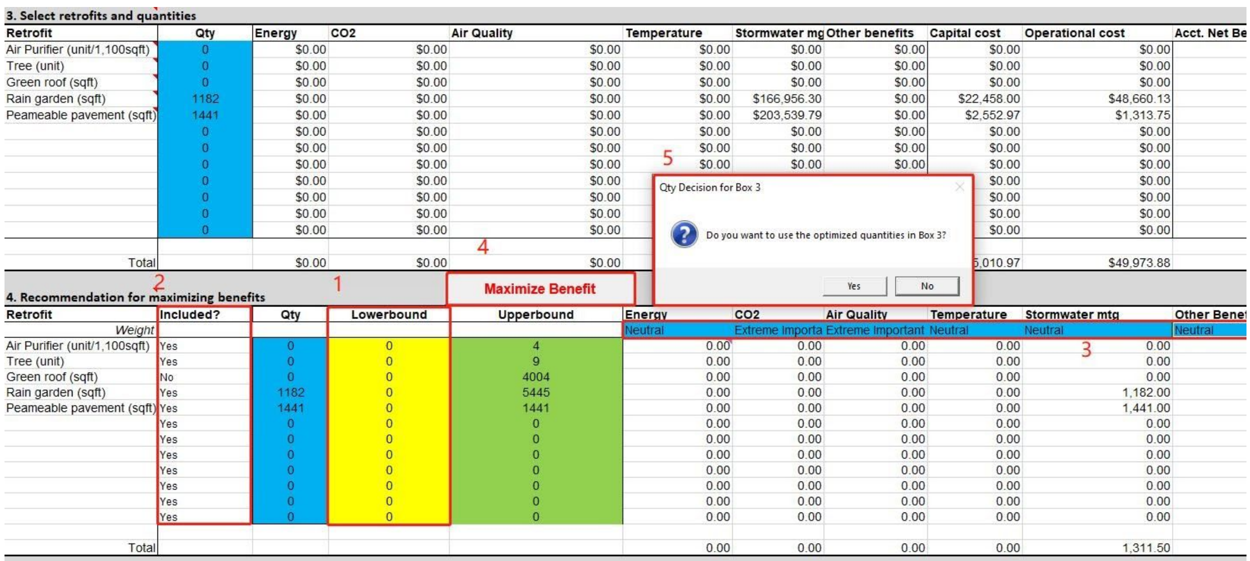
Retrofit	Qty	Energy	CO2
Air Purifier (unit/1,100sqft)	0	$0.00	$0.00
Tree (unit)	0	$0.00	$0.00
Green roof (sqft)	0	$0.00	$0.00
Rain garden (sqft)	0	$0.00	$0.00
Peameable pavement (sqft)	0	$0.00	$0.00
	0	$0.00	$0.00
	0	$0.00	$0.00
	0	$0.00	$0.00
	0	$0.00	$0.00
	0	$0.00	$0.00
	0	$0.00	$0.00
	0	$0.00	$0.00
Total		$0.00	$0.00

Operational cost	Acct. Net Benefit
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00
$0.00	$0.00

requirements for any of the retrofits.

2. The user can choose to include or exclude retrofits by selecting Yes/No in the drop down lists.
3. Set the priority by adjusting weights for each attribute.
4. Click the “Maximize Score” button, then the computer will give the maximize net benefit result, and give the recommended quantity for each retrofit.
5. A dialog box will pop-up asking the user whether or not they want to use the recommended quantities in Box 3. If the answer is yes, the recommended quantities will be copied and pasted into Box 3.

Figure 16. Input lowerbound, priority weights, and optimize results



Retrofit	Qty	Energy	CO2	Air Quality	Temperature	Stormwater mg	Other benefits	Capital cost	Operational cost	Acct. Net Be
Air Purifier (unit/1,100sqft)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
Tree (unit)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
Green roof (sqft)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
Rain garden (sqft)	1182	$0.00	$0.00	$0.00	$0.00	$166,956.30	$0.00	$22,458.00	$48,660.13	
Peameable pavement (sqft)	1441	$0.00	$0.00	$0.00	$0.00	$203,539.79	$0.00	$2,552.97	$1,313.75	
	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
	0	$0.00	$0.00	$0.00				$0.00	$0.00	
	0	$0.00	$0.00	$0.00				$0.00	$0.00	
	0	$0.00	$0.00	$0.00				$0.00	$0.00	
	0	$0.00	$0.00	$0.00				$0.00	$0.00	
Total		$0.00	$0.00	$0.00				5,010.97	$49,973.88	

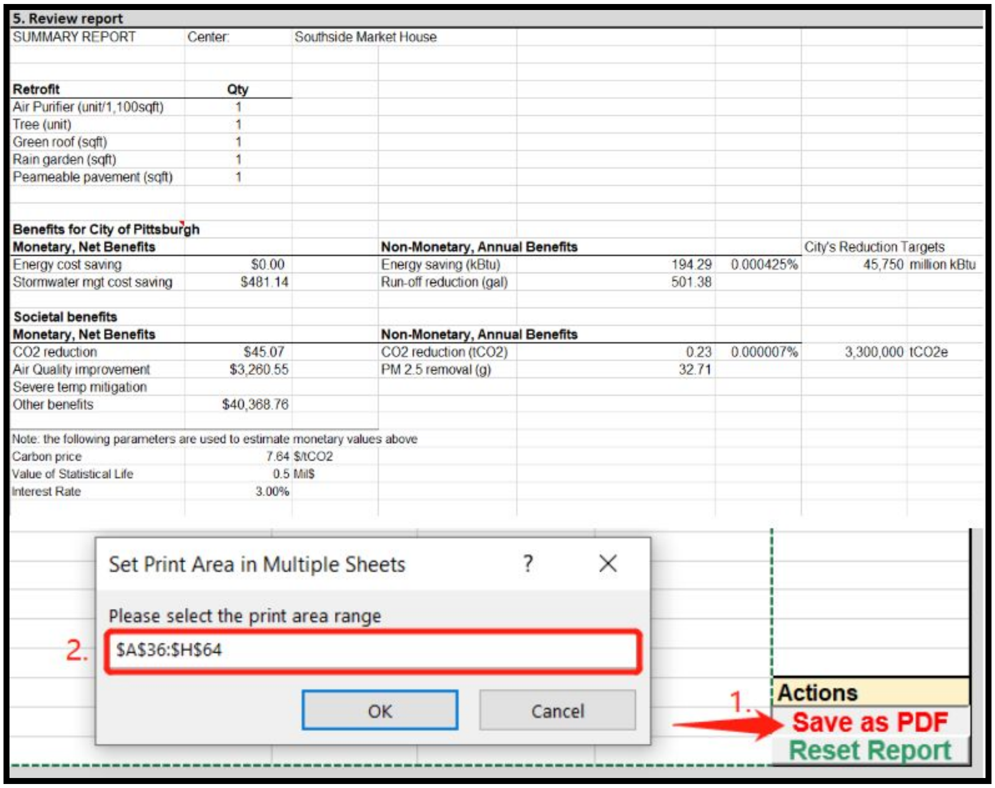
Retrofit	Included?	Qty	Lowerbound	Upperbound	Energy	CO2	Air Quality	Temperature	Stormwater mtg	Other Benef
Weight					Neutral	Extreme Importa	Extreme Important	Neutral	Neutral	Neutral
Air Purifier (unit/1,100sqft)	Yes	0	0	4	0.00	0.00	0.00	0.00	0.00	
Tree (unit)	Yes	0	0	9	0.00	0.00	0.00	0.00	0.00	
Green roof (sqft)	No	0	0	4004	0.00	0.00	0.00	0.00	0.00	
Rain garden (sqft)	Yes	1182	0	5445	0.00	0.00	0.00	0.00	1,182.00	
Peameable pavement (sqft)	Yes	1441	0	1441	0.00	0.00	0.00	0.00	1,441.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
	Yes	0	0	0	0.00	0.00	0.00	0.00	0.00	
Total					0.00	0.00	0.00	0.00	1,311.50	

Step 5. Save report as a PDF file or reset report for reselecting another center

Box 5 generates a summary report for a selected HALC listing relative information with both monetary and non-monetary values.

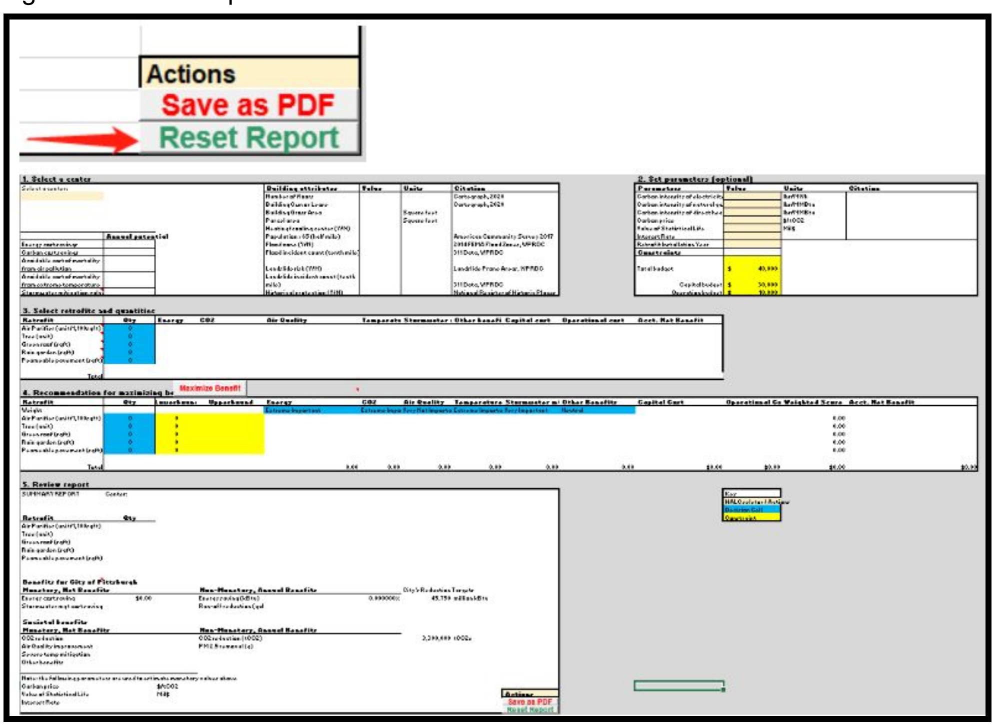
If the user wants to save the report as a PDF for printing, they can click “Save as PDF” under Actions (Figure 17, number 1). A dialog box will pop-up asking the user to select an area using the drag and drop function of the mouse/keypad (Figure 17, number 2). The user can print cells in the *Dynamic Accounting Sheet* and/or other sheets in the workbook as PDF.

Figure 17. Summary report, Save as a PDF file



By clicking the “Reset Report” button (Figure 18), all numbers inputted into the user interface will be resetted to be blanks and waited to be refilled.

Figure 18. Reset report



Step 6. Evaluate the quality of your retrofit project

Box 6 automatically computes the difference in net benefits between the user's retrofit project (defined by retrofit selections and quantities in Box 3) and the recommended retrofit project generated by the optimization engine from Box 4 (Figure 19). These differences are displayed in both absolute as well as relative (perfect difference) terms.

In the bottom right-hand corner, a comprehensive rating of the user's retrofit project is calculated on a 0-100% scale. A score of 100% indicates that there is no difference between the net benefits generated by the user's project and that recommended by the optimization engine, while a score of less than 100% indicates that the user's project could be improved by including more of the optimization's recommendations. A score of 80% or higher will receive a "Good!" rating, while scores of lower than 80% will be flagged in red.

Figure 19. Evaluation box

6. Evaluate Your Project		
	Absolute difference	**Percent difference (%)**
Benefits for City of Pittsburgh		
Monetary, Net Benefits		
Energy cost saving	-$1,368.66	-29%
Stormwater mgt cost saving	-$165,485.96	-34%
Non-Monetary, Annual Benefits		
Energy saving (kBtu)	-1855.02	-26%
Run-off reduction (gal)	-23466.59	-32%
Societal benefits		
Monetary, Net Benefits		
CO2 reduction	$26.03	16%
Air Quality improvement	-$285,335.24	-33%
Severe temp mitigation	$0.00	
Other benefits	$80,737.52	100%
Non-Monetary, Annual Benefits		
CO2 reduction (tCO2)	0.17	13%
PM 2.5 removal (g)	-18114.54	-33%
		Your Project's Rating
		79%

5.2. Other Common Operations

5.2.1 Adding new retrofits

The users can add a new retrofit in the tool in the following steps: (1) create a new Retrofit Guide sheet for unit cost and benefit settings of the retrofit using the *Retrofit (X) Sample*

Template sheet within the Decision Support Tool, (2) link the settings to *NPV of retrofits* sheet, and (3) incorporate the NPVs of the retrofit into *Dynamic Accounting* sheet.

There are seven blank rows for new retrofits. If you want to add more than seven, you might want to consult with a person who has expertise in excel VBA to modify the *Dynamic Accounting* sheet so that the functionality of the tool is secured.

Step 1: Create a new Retrofit Guide sheet

- Duplicate the *Retrofit (X) Sample Template* sheet (see Figure 20 below).
- Change the name of the new sheet with the retrofit name (e.g., Retrofit (6) Bioswale).
- Fill in the name in cell A1 with its unit (e.g., Retrofit (6) Bioswale (sqft)). This information will be shown in *Dynamic Accounting* sheet, so do not forget to write the unit.
- Fill necessary information in the sheet. *Retrofit (X) Sample Template* includes yellow cells which are supposed to have original data, such as energy saving (kWh) and carbon sequestration in green infrastructure (pound of carbon (C) per unit). You can add as many rows as necessary to calculate those yellow cells. For example, you may want to insert an “electricity saving (kWh)” row and a “natural gas saving (Mcf: thousand cubic feet)” row with a conversion factor from Mcf to kWh and replace the function in the yellow cell with the summation of electricity and gas savings at a kWh base. In addition, please feel free to use note and reference cells to cite any source materials so that your colleagues and successors can manage the dataset and modify them if they might need.
- The figures in the yellow cells are then converted to dollar values in the cells colored with light orange using relevant conversion factors. Some basic conversion factors are already included in the sheet, such as the conversion from kWh to kBtu. You can modify some parameters; for instance, you can change the amount of “avoided capital cost for system improvement per gallon of overflow reduced” to whatever you might want to use instead. Moreover, you do not need to worry about blue cells in this step; they refer to relevant parameters in the Dynamic *Accounting Sheet* you will use for the entire cost-benefit calculation of a facility.
- The data in light orange cells are the output cells and will be used in the following step as annual costs and benefits. These orange cells are already linked to the designated cells in *NPV of retrofits* sheet, so avoid deleting them.

Figure 20. Retrofit (X) Sample Template sheet

[Retrofit Name]							
			Note		Reference name	Reference URL	
Lifetime		year					
Capital expenditure (per [unit])	$5.00						
- initial cost for green retrofit	$10.00						
- initial cost for conventional retrofit	$5.00						
Operating expenditure (per [unit])	$6.00						
- Difference in maintenance cost	$1.00						
- Difference in energy cost	$2.00						
- Difference in cost for XX	$3.00						
Energy							
Energy saving (per [unit])	5	kWh					
Energy saving (per [unit])	17.06	kBtu		0.2930832356	kWh/kBtu		
Energy cost saving (per [unit])	$0.50		Assuming electricity price $0.10/kWh				
Carbon							
Energy-related CO2 reduction (per [unit])	2.35	lbs CO2	carbon intensity of electricity selected	469.5	lbs/MWh	DLC's power mix (esti	
	0.00106	tCO2	Conversion factor	0.000453592	ton/lb		
Carbon sequestration (per [unit])	1.0000	lbs C					
	0.00166	tCO2	Conversion factor	3.666666667	CO2/C		

+ ≡ Retrofit (3) Green roof ▾ | Retrofit (4) Rain garden ▾ | Retrofit (5) Peameable pavement ▾ | Retrofit (x) Sample Template ▾ | FacilitiesExp

Step 2: Link the settings to NPV of retrofits sheet

- Go to *NPV of retrofits* sheet (see Figure 21 below). The following work flow proceeds in order of CBA inputs (blue cells), CBA calculations (cream cells), and CBA results (pink cells).

Figure 21. NPV of Retrofits sheet

CBA results (Output to Dynamic Accounting Sheet)									
Retrofit items	Energy	Carbon	Air Quality	Temperature	Stormwater mgt	Others	Capex	Opex	Total
Air Purifier (unit/1,100sqft)	$0.00	$0.00	$2,709.92	$0.00	$0.00	$0.00	$600.00	$893.26	$1,216.66
Tree (unit)	$85.60	$52.01	$370.50	$0.00	$119.61	$46,617.42	$900.00	$3,580.35	$42,764.77
Green roof (sqft)	$1.71	$0.04	$323.01	$0.00	$107.17	$0.00	$19.70	$8.09	$404.14
Rain garden (sqft)	$0.00	$0.00	$0.00	$0.00	$163.25	$0.00	$19.00	$47.54	$96.71
Peameable pavement (sqft)	$0.00	$0.00	$0.00	$0.00	$163.25	$0.00	$1.77	$1.05	$160.43
Retrofit (6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Insert additional retrofits above if neessary									
CBA inputs									
Discount rate (chosen in front page)	2.27%								
Annual benefit in each parameter									
Retrofit items	Energy	Carbon	Air Quality	Temperature	Stormwater mgt	Others	Capex	Opex	Lifetime (year)
Air Purifier (unit/1,100sqft)	$0.00	$0.00	$579.45	$0.00	$0.00	$0.00	$600.00	$191.00	5
Tree (unit)	$2.88	$1.75	$12.47	$0.00	$4.03	$1,568.95	$900.00	$120.50	50
Green roof (sqft)	$0.07	$0.00	$12.37	$0.00	$3.80	$0.00	$19.70	$0.31	40
Rain garden (sqft)	$0.00	$0.00	$0.00	$0.00	$5.07	$0.00	$19.00	$1.60	50
Peameable pavement (sqft)	$0.00	$0.00	$0.00	$0.00	$5.07	$0.00	$1.77	$0.04	15
Retrofit (6)									
Insert additional retrofits above if neessary									
CBA calculations									
Air Purifier		Year							
	NPV	0	1	2	3	4	5		
Capital Cost	$600.00	$600.00							

Dynamic Accounting Sheet | HALC Attributes | Parameter Settings | NPV of retrofits | Retrofit (2) Tree | Retrofit (3) Green roo

- Most cells in the sheet contain automatic calculations. Unless you add seven retrofits or fewer, all you need is to rewrite the retrofit item name (column A) exactly the same as the name you wrote in the cell A1 of the sheet you created in Step 1 (you can copy and paste it from the sheet).
- Once the names match, the data in orange cells in the previous step will be shown in the blue cells in *NPV of retrofits* sheet. Confirm that they are right numbers.
- Those numbers in blue cells are then used for NPV calculation in cream cells below. Scroll down, and you will find the retrofit you just input in blue cells. NPV of each element is calculated. Confirm that the most left cell of each row matches the figure in the corresponding blue cell, and project year matches the lifetime of the retrofit.
- Then, NPVs calculated in cream cells are displayed in red cells at the top of the sheet. Confirm that the figures in red cells are the same as the numbers in column B of cream cells.

(Ref. Manual modification for Step 2)

- The following explanation in this step is for manual modification in case you will want to customize costs and benefits in NPV calculations or to add more than seven retrofits.
- Refer to the annual costs and benefits created in the previous step. Enter equal (=) in a blue cell (CBA inputs, see Figure 22 below) and then select the corresponding light orange cell in the Retrofit Guide sheet. Please note that the order of the parameters is different from the one appearing on the Retrofit Guide sheet. You can find an additional explanation by hovering your cursor over each parameter cell at the top row of blue cells, such as "Energy", "Carbon", and "Air Quality."

Figure 22. CBA inputs box

CBA inputs

Discount rate (chosen in front page): 2.27%

Annual benefit in each parameter

Retrofit items	Energy	Carbon	Air Quality	Temperature	Stormwater mgt	Others	Capex	Opex	Lifetime (year)		Energy (kBtu)	Carbon (tCO2)	Air quality (g)	Temperature	Stormwater (gal)
Air Purifier (unit/1,100sqft)	$0.00	$0.00	$579.45	$0.00	$0.00	$0.00	$600.00	$191.00	5		0.00	0.00	0.00		0.00
Tree (unit)	$2.88	$1.75	$12.47	$0.00	$4.03	$1,568.95	$900.00	$120.50	50		192.05	0.23	14.57		447.79
Green roof (sqft)	$0.07	$0.00	$12.37	$0.00	$3.80	$0.00	$19.70	$0.31	40		2.24	0.00019	18.14368		14.62
Rain garden (sqft)	$0.00	$0.00	$0.00	$0.00	$5.07	$0.00	$19.00	$1.60	50		0.00	0.00	0.00		19.49
Peameable pavement (sqft)	$0.00	$0.00	$0.00	$0.00	$5.07	$0.00	$1.77	$0.04	15		0.00	0.00	0.00		19.49
Retrofit (6)															

- Adjust project years (PYs) of cream cells in the CBA calculation box to the lifetime of the retrofit. The default format assumes a 50-year project (PY0-50). If the lifetime is 30 years, for instance, erase the information in the cream cells between PY31 and PY50 to avoid mistakes in auto-calculation.
- Link the aforementioned new blue cells with the corresponding cream cells (see Figure 23 below). The default setting automatically fills the blue-cell data in cream cells. Double check each parameter placed in the right row. The cream cells are preset to calculate a net present value (NPV) of each parameter automatically. The blue cell of Capex is expected to connect to PY0 (project year zero, namely the pre-operation/construction year) in the cream cells (right next to the NPV column). Other seven parameters are supposed to start from PY1, namely the first year in operation. Note that calendar years

appearing right below project years are linked to the retrofit installation year parameter designated in *Dynamic Accounting* sheet.

- If you want to include additional costs/benefits related to the capital investment, such as the additional investment for the retrofit (e.g., the replacement of inverters for rooftop solar PVs which would occur in a shorter term than the lifetime of PV panels) and salvage values at the end of life (e.g., resale values and recycling costs).
- Annual operational cost (opex) and benefits can be either static or dynamic. In default settings, you only need to fill in PY1, and the rest of project years are automatically filled with the same figure. If you want to change annual values as the project goes on, such as considering annual inflation of operational costs, you can modify the formula in the related cream cells. Furthermore, you can prepare for multiple annual costs/benefits on a particular parameter. For example, you can find that stormwater management cells of Retrofit (3) Green roof show different figures each year, reflecting the differences in projected precipitation among years.
- If you have costs/benefits which begin to appear in the middle of lifetime (e.g., operational costs appear in PY5 and after), fill zero values in the cells before the year (Opex in PY1-4 for the above-mentioned example) to avoid mis-calculation.

Figure 23. NPV calculation box

Retrofit (6)	NPV	Year PY0 2021	PY1 2022	PY2 2023	PY3 2024
Capex	$0.00	$0.00			
Opex	$0.00		$0.00	$0.00	$0.00
Energy	$0.00		$0.00	$0.00	$0.00
Carbon	$0.00		$0.00	$0.00	$0.00
Air Quality	$0.00		$0.00	$0.00	$0.00
Temperature	$0.00		$0.00	$0.00	$0.00
Stormwater mgt	$0.00		$0.00	$0.00	$0.00
Others	$0.00		$0.00	$0.00	$0.00

- A calculated NPV of each parameter is now displayed in the NPV column of the cream cells. Link the NPV to the corresponding pink cell (CBA results) at the top of the sheet (see Figure 24 below). The default setting automatically fills the NPV in pink cells. Double-check the links are placed in the right columns as the order of parameters is different from the cream cells.
- Total NPV will automatically show the summation of NPV in each parameter.

Figure 24. NPVs displayed in the CBA results box

CBA results (Output to Dynamic Accounting Sheet)									
Retrofit items	Energy	Carbon	Air Quality	Temperature	Stormwater mgt	Others	Capex	Opex	Total
Air Purifier (unit/1,100sqft)	$0.00	$0.00	$2,709.92	$0.00	$0.00	$0.00	$600.00	$893.26	$1,216.66
Tree (unit)	$85.60	$52.01	$370.50	$0.00	$119.61	$46,617.42	$900.00	$3,580.35	$42,764.77
Green roof (sqft)	$1.71	$0.04	$323.01	$0.00	$107.17	$0.00	$19.70	$8.09	$404.14
Rain garden (sqft)	$0.00	$0.00	$0.00	$0.00	$163.25	$0.00	$19.00	$47.54	$96.71
Peameable pavement (sqft)	$0.00	$0.00	$0.00	$0.00	$163.25	$0.00	$1.77	$1.05	$160.43
Retrofit (6)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Step 3: Incorporate the NPVs of the retrofit into the *Dynamic Accounting* sheet.

- Go to Box 3. (Select retrofits and quantities) in *Dynamic Accounting Sheet* (see Figure 25 below).The default setting automatically displays the retrofit data you entered in *NPV of retrofits sheet*. Double check each figure placed in the right column when you input the quantity of the retrofit by 1 in the blue cell.
- Only you need to add here is to set the upper-bound quantity (green cell in column E) of Box 4. Designate the upper-bound (green cell) in *HALC Attributes* sheet by either selecting an existing attribute or adding a column for a new attribute that is suitable for each retrofit (e.g., roof size, parking size). There is a VLookup command already filled in the green cell, so you can change two numbers left to "FALSE" (e.g., two "37"s in cell E40) to the number at the first row of the column in *HALC Attributes* sheet that you want to use as the upper-bound.

(Ref. Manual modification for Step 3)

- If you want to add more than seven retrofits and need to insert additional rows, you would need the following four bullets upon inserting an additional row.
    - Refer to the NPVs of the energy parameter calculated in the previous step by linking the blank cell on the Energy column to the corresponding pink cell in the *NPV of retrofits* sheet.
    - Multiply the filled cell above with the quantity of the retrofit (shown in blue "Qty" cells) to display the total NPV of energy benefits at the designated quantity of the retrofit.
    - Copy the edited formula of the cell on the energy column in *Dynamic Accounting Sheet* above and paste it over CO2 through Operational cost columns. You can do this procedure because the order of the parameters from "Energy" through "Operational cost" in *Dynamic Accounting Sheet* is the same as the pink cells in *NPV of retrofits* sheet.
    - Confirm that the calculation works properly by changing numbers in Qty cells as well as choosing different parameters in Box 2 in *Dynamic Accounting Sheet,* such as interest rate and the Value of Statistical Life.

Figure 25. Box 3. Select retrofits and quantities in *Dynamic Accounting Sheet*

3. Select retrofits and quantities

Retrofit	Qty	Energy	CO2	Air Quality	Temperature	Stormwater mgt	Other benefits	Capital cost	Operational cost
Air Purifier (unit/1,100sqft)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Tree (unit)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Green roof (sqft)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Rain garden (sqft)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Peameable pavement (sqft)	0	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total		$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

- In Box. 4, you need to set the upper-bound (green cells) that is suitable for each retrofit (e.g., roof size, parking size). You could find or add the information on HALC Attributes and use the VLookup command in the column E in *Dynamic Accounting Sheet*.
- This is the end of the process to add the new retrofit if you are adding retrofits within seven existing rows. In Box. 4 and below, users cannot easily insert or delete rows due

to VBA settings over the part. There are seven rows for additional retrofits, but talk to those who have expertise on Excel VBA to modify the part if you need more rows.

5.2.2 Editing existing retrofits

Users can also modify the existing Retrofit Guide sheets (e.g., Retrofit (1) Air Purifier) (see Figure 26 below). The overall calculation flow for the existing retrofits is the same as new retrofits explained above. Results in *Dynamic Accounting Sheet* will be recalculated automatically based on the light orange cells (or alternative year-by-year cost/benefit figures for stormwater management described in the same sheet) in the Retrofit Guide sheets.

Figure 26. Existing Retrofit Guide sheets

Air Purifier							
			Note	Ref			
Lifetime	5	year		Alen Breathsmar	https://www.consumerreports.org/air-purifiers/air-		
Capital expenditure (per unit)	$600.00			Alen Breathsmar	https://www.consumerreports.org/air-purifiers/air		
Operating expenditure (per unit)	$191.00			Alen Breathsmar	https://www.consumerreports.org/air-purifiers/air		
- Filter cost	104						
- Energy cost	87						
Energy							
	$0.00						
Carbon							
	$0.00						
Air quality							
Outdoor air PM2.5	9.20	microgram/m3	Laurenceville 2015-2017 avg (p.8)	Allegheny County	https://www.alleghenycounty.us/uploadedFiles/A		
Indoor air PM2.5 without intervention	5.52	microgram/m3	min 60% of outdoor PM 2.5 inhalation i	Fisk, W. J., & Cha	https://onlinelibrary.wiley.com/doi/pdf/10.1111/in		
Indoor air PM2.5 with air purifier	0.00166	microgram/m3	99.97% removal rate	Alen Breathsmar	https://www.alencorp.com/products/alen-breathe		
Amount of PM2.5 removed (per unit)	1,691.81335	microgram	Assuming ceiling height 3m	1100	sqft	0.092903	m2/sqft
Mortality reduction by air purifier	1,158.89215	/million people	Estimated increase in mortality with on	0.685	per million people		
Avoided air pollution cost (per unit)	$579.45		VSL on the front sheet	0.5	Mil$	Deschênes, Greenstone, & Shapiro	
Temperature							
	$0.00						

Retrofit (1) Air Purifier | Retrofit (2) Tree | Retrofit (3) Green roof | Retrofit (4) Rain garden | Retrofit (5) Peameable pavement | Retrofit (x) Sample Template

5.2.3 Updating parameters and data in backend sheets

Users are expected to update some parameters and data in (i) *HALC Attributes*, (ii) *Parameter settings*, and (iii) *Energy* sheets. Users can also modify parameters in (iv) *Carbon*, (v) *Stormwater management*, (vi) *Air quality*, (vii) *Temperature* sheets if necessary. Cells highlighted in yellow are those that the user may want to update periodically in order to maintain the accuracy of the tool's calculations and outputs. This section outlines what information needs to be updated in each of these backend sheets and how to complete that task when necessary.

Unlock Sheet

Sheets are protected with a password to prevent accidental demolition. The password is "Heinz", case sensitive. It can also be retrieved from the frontend of the tool. Users can toggle the safety check under Box 6, from No to Yes, and then the password will be displayed.

HALC Attributes sheet

- Initial setup with precise information is preferred (only occasional updates are required after the initial setup). The following parameters are used for defining the capacity constraints for the optimization calculation in the *Dynamic Accounting Sheet*.
  - Parcel size: Captured from GIS map. Those in red letters are missing data and estimated as a gross area divided by floor count.
  - Building area: All data are missing and estimated as the smaller figure of either a parcel size or a gross area divided by floor count.
  - Gross area (total floorspace): Those in red letter are missing data and estimated as a half of the parcel size.
  - Roof area: All data are currently the same as building area.
  - Parking area: Only “Open Lot” is currently counted as a parking area that is convertible to permeable pavement, and the smaller number of either [(parcel size) - (building size)] or [(building area) / 500 sqft * 180 sqft] is used. 180 sqft is a standard size of parking lot for a car,[47] and Pittsburgh parking requirement for community centers is 1/500 sqft building gross area.[48]
  - Max number of trees (space for tree planting): Currently, [(Remaining area) / 625 sqft] is used for a rough estimate, assuming 625 sqft = 25 feet * 25 feet for a required space for a single tree planting.[49]
  - Floor count: Those in red letter are missing data and guessed using Google Map
  - Own/lease: Choose “Own” or “Lease”
  - Parking type: Choose “Open Lot,” “Street,” or “None.” Those in red letter are missing data and guessed using Google Map
  - Remaining area: Space for potential green infrastructure, such as rain gardens and trees. Currently calculated as [(Parcel area) - (Building area) - (Parking area)].
  - Average rainwater retention rate of parcel: Currently assumed as [(50% of Remaining area) / (Parcel area) * (60% as a typical retention rate of green infrastructure)]. Users can modify this to [(approximate rate of actual green/permeable areas out of parcel area) * 60%] or more precise estimate.
- Periodic update once every few years
  - Flood incident counts (tenth-mile & quarter-mile buffers): Periodic update is preferred (percentiles are auto-calculated and no modification is required). Use the Summarize Within tool within ArcGIS Pro to count the number of discrete events within the relevant buffer distance.

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[47] Angie Schmitt, “Parking Takes Up More Space Than You Think,” Streetsblog USA, July 5, 2016, https://usa.streetsblog.org/2016/07/05/parking-takes-up-more-space-than-you-think/.
[48] City of Pittsburgh, “Code of Ordinances Supplement 35 Update 4,” Municode Library, April 7, 2020, https://library.municode.com/pa/pittsburgh/codes/code_of_ordinances?nodeId=13525.
[49] SFGate, “Distance Between Maple Tree Planting,” SFGate, accessed May 6, 2020, https://homeguides.sfgate.com/distance-between-maple-tree-planting-50041.html.

    - Landslide incident counts (tenth-mile & quarter-mile buffers): Periodic update is preferred (percentiles are auto-calculated and no modification is required). Use the Summarize Within tool within ArcGIS Pro to count the number of discrete events within the relevant buffer distance.
    - Population of age 65 and over: Periodic update is preferred using US census data. Refer to the accompanying Hazards Maps Process Summary document for detailed instructions on how to perform this analysis.
    - Floorspace for use: Periodic update is preferred based on actual status of room/floor use. Current data is based on Pittsburgh Buildings Portfolio Carbon Calculator provided by S&R.[50]
- Occasional update (if any necessary)
    - Historic designation (Y/N): Only when any change in designation happens
    - Heating/cooling center (Y/N): Only when any change in designation happens
    - Flood zone (tenth-mile & quarter-mile buffers) (Y/N): Only when any change in designation happens. Update using the most current version of FEMA Flood Zones shapefile, accessible through the Western PA Regional Data Center.
    - Landslide zone (tenth-mile & quarter-mile buffers) (Y/N): Only when any change in designation happens. Update using the most current version of Landslide Prone Areas shapefile, accessible through the Western PA Regional Data Center.
    - Number of air purifiers: If you want to use a different size of air purifier, change "1100" square feet in the calculation to the new capacity of the equipment.
- No modification is necessary
    - Potential annual benefits (energy, carbon, air quality, temperature, stormwater): All auto-calculated in other backend sheets.

Parameter Settings sheet

- Initial setup with precise information is preferred (only occasional update if any change occurs is required after the initial setup).
    - City of Pittsburgh Climate goals (energy, carbon emissions): The energy saving target is currently estimated with 2013 energy data due to data unavailability. Users should replace it with one based on 2003 energy data. These parameters are shown in the "Dynamic *Accounting" Sheet* to compute the effects of additional retrofits.
- Annual update
    - Carbon intensity of electricity (PA power mix): Annual update from EIA is available
    - Carbon intensity of natural gas: Annual update from EIA is available

[50] City of Pittsburgh, "Pittsburgh Buildings Portfolio Carbon Calculator, Version 15" (City of Pittsburgh, n.d.), accessed January 29, 2020.

    - Carbon price (market prices at RGGI and CA C&T): Users should update price data once a year to reflect the recent prices. Users can also use annual or multi-year average of prices instead of a particular date.
    - Interest rate (governmental bonds): Users should update rate data once a year to reflect the recent rates. Users can also use annual or multi-year average rates instead of a particular date.
- Periodic update once in a few years
    - Carbon intensity of electricity (DLC's power mix): Users should hear an approximate share of power mix from DLC to reflect its shifting power mix
    - Carbon price (from EPA and academic literature): Carbon price used in EPA's documentation could be reviewed once in a few years. Carbon prices from academic literature are not necessarily updated, but users can follow the recent trend in academic literature and revise the price list if necessary.
    - Value of Statistical Life (from EPA and academic literature): VSL used in EPA's documentation could also be reviewed irregularly. Users can catch up with the recent trend in academic literature and revise the price list if necessary.
    - Interest rate (EPA and academic literature): Interest rates used in EPA's documentation could be changed irregularly. Users can follow the recent trend of social discount rates in academic literature and revise the list if necessary.
    - City of Pittsburgh Climate goals (energy, carbon emissions): Users should update target values as City reviews its goals periodically.
- Occasional update (if necessary)
    - Carbon intensity of direct steam (U.S. nationwide): Users could use updated figures from Energy Star Portfolio Manager though the authors do not recognize its periodic update.
- No modification is necessary
    - Retrofit installation year: Automatically update based on the present date. Users can choose one among the five years from now as the retrofit construction year.
    - Optimization Priority Index: The multipliers for the optimization in Dynamic Accounting Sheet are set linearly, and users do not necessarily need any update.

Energy sheet

- Annual update
    - Annual electricity cost ($): Users should update annually based on the summation of twelve monthly electricity bills. The current data is 2017 due to limited access to data.
    - Annual electricity use (kWh): Users should update annually based on the summation of twelve monthly electricity bills. The current data is 2018.
    - Annual natural gas cost ($): Users should update annually based on the summation of twelve monthly gas bills. The current data is 2017 due to limited access to data.

- Annual natural gas use (Mcf: thousand cubic feet): Users should update annually based on the summation of twelve monthly gas bills. The current data is 2018.
    - Annual direct steam cost ($): Users should update annually based on the summation of twelve monthly district heating bills once any facility starts to use it. Currently, no HALCs use direct steam.
    - Annual direct steam use (kLbs): Users should update annually based on the summation of twelve monthly district heating bills once any facility starts to use it. Currently, no HALCs use direct steam.
- No modification is necessary
    - Other columns of the *Energy* sheet: All columns except the six above are calculated automatically.

Carbon sheet

- Occasional update (if necessary)
    - Carbon sequestration per tree: Average annual carbon sequestration in street trees in Pittsburgh (4.4M lbs C per 33498 trees) is currently used.[51] Users could use another value if necessary.

Stormwater Management sheet

- Occasional update (if necessary)
    - Annual precipitation per sqft: Average annual precipitation in Pittsburgh during 1981-2010 (38.1 inch) is currently used.[52] Users could use another value if necessary.
    - Average max retention rate at percel: Maximum rainwater retention rate on average of the parcel is set to determine the potential reduction in rainwater runoff because achieving no runoff (100% retention rate) seems unlikely with any additional retrofits. Currently, 90% retention rate is set as a ceiling for the potential reduction. Users can modify the rate if necessary.

Air Quality sheet

- Occasional update (if necessary)
    - Mortality rate: Increase in mortality by 0.685 per a million people with the increase in one microgram of PM2.5 per cubic meter is currently used based on academic literature.[53] Users could use another value if necessary.

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[51] Davey Resource Group, “Pittsburgh I-Tree Ecosystem Analysis” (City of Pittsburgh, Pennsylvania, July 2015), https://waterlandlife.org/wp-content/uploads/2018/02/i-Tree-Eco-Pittsburgh.pdf.
[52] National Oceanic and Atmospheric Administration, “Pittsburgh Historical Precipitation Totals 1836 to Current,” National Weather Service, accessed May 6, 2020, https://www.weather.gov/media/pbz/records/hisprec.pdf.
[53] W. J. Fisk and W. R. Chan, “Effectiveness and Cost of Reducing Particle-Related Mortality with Particle Filtration,” *Indoor Air* 27, no. 5 (March 6, 2017): 909–20, https://doi.org/10.1111/ina.12371.

Temperature sheet

- Annual update
    - Annual days in average temperature less than 10 °F, between 10 and 20 °F, and over 90 °F: Users should update annually based on the recent temperature data available at NOAA database.[54] The current data is a five-year average between 2015 and 2019.
- Occasional update (if necessary)
    - Mortality rate: Increases in mortality by 0.3438 per a million people in age 65 or above with the average temperature below 10 °F, 0.2408 between 10 and 20 °F, and 0.5219 over 90 °F are currently used based on academic literature.[55] Users could use another value if necessary.

VI. Climate Change: Future Trends

The following section outlines how future climate change will affect and exacerbate the projections and recommendations given by this tool. As these environmental changes become a reality the usefulness of this tool will also increase.

6.1 Temperature

- It is predicted that Pittsburgh's temperatures will resemble the historically observed temperatures in the Baltimore-Washington area from year 2041 to 2070. The CMIP5 model mean change would increase by 2.7-3.2 °F.[56]
- In the next 60 years, Pittsburgh's temperature will increase about 10.6 °F. Pittsburgh will have drier summers and 46.8% wetter winters. As a result, more floods and landslides may occur and Pittsburgh's climate will be similar to that near Jonesboro, Arkansas.[57]
- There may be an increasing number of extreme temperature days. On average, 4.5 days annually from year 2020 to 2029; 5.2 days annually from 2045 to 2055; and 5.9 days

[54] National Oceanic and Atmospheric Administration, "Pittsburgh Historical Precipitation Totals 1836 to Current," National Weather Service, accessed May 6, 2020, https://www.weather.gov/media/pbz/records/hisprec.pdf.
[55] Olivier Deschênes, Michael Greenstone, and Joseph S. Shapiro, "Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program," *American Economic Review* 107, no. 10 (October 2017): 2958–89, https://doi.org/10.1257/aer.20131002.
[56] Vicens, Natasha, and Nora Mattson. "Data: Stats You Should Know about Climate Change in the Pittsburgh Area." PublicSource, September 19, 2019. https://projects.publicsource.org/pittsburgh-covering-climate-change-now-data/.
[57] What will climate feel like in 60 years? University of Maryland Center For Environmental Science. Accessed April 20, 2020. https://fitzlab.shinyapps.io/cityapp/.

annually from 2090 to 2099. However, the number of extreme cold days may reduce due to the general tendency of warming.[58]

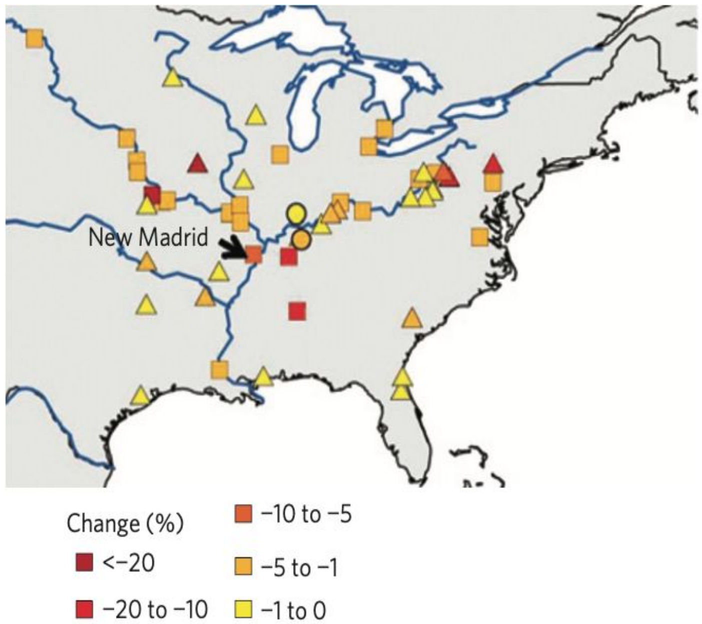
6.2 Energy and energy-related carbon emissions

Increase in temperature described above is likely to impact on energy use in several ways. First, rising temperature affects energy consumption. People in Pittsburgh would consume more energy in summer, primarily for cooling, and less in winter due to the decrease in heating needs. It is unclear if the overall energy consumption increases or decreases in Pittsburgh.

The second impact of temperature change is on electricity grids. Hot ambient temperature decreases transmission capacity which would result in more expensive retail electricity price.[59] According to Bartos et al, average capacity of transmission lines could decrease by 1.9% to 5.8% in the summer by 2040-2060 compared to the level during 1990-2010 while the peak electricity demand would soar by 4.2% to 15% due to the reason described above.[60]

Figure 27. Changes in usable capacity of thermoelectric power plants in the U.S.[61]

[58] Shortle, James, and David Abler. "Pennsylvania Climate Impacts Assessment Update," May 2015. http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=5002&DocName=2015
[59] Matthew Bartos et al., "Environmental Research Letters LETTER • OPEN ACCESS," *Environmental Research Letters* 11, no. 11 (November 2, 2016), https://doi.org/10.1088/1748-9326/11/11/114008.
[60] Ibid.
[61] Michelle T. H. van Vliet et al., "Vulnerability of US and European Electricity Supply to Climate Change," *Nature Climate Change* 2, no. 9 (September 1, 2012): 676–681, https://doi.org/10.1038/nclimate1546.



Moreover, the increase in temperature would influence the production at thermal power plants. As water temperature increases, cooling function degrades, and maximum power production rate decreases. In an extreme case, nuclear power plants had to shut down in France due to river water temperature rise under extreme heat waves in 2018.[62] Usable capacity of thermal power plants in the U.S. is estimated to decline by 12-16% by 2040, as Figure 27 indicates.[63] This change might lead to the increase in electricity price and carbon intensity since Pittsburgh heavily relies its electricity on nuclear power. In this regard, expanding renewable energy without thermal power generation would contribute to both greenhouse gas emissions and enhancing resilience against the impacts of climate change, as Bartos and Chester maintain.[64]

6.3 Precipitation

Annual precipitation in Pittsburgh is expected to increase. Figure 28 shows the projection of annual precipitation in Pittsburgh under RCP 4.5 and RCP 8.5 scenarios based on the Multivariate Adaptive Constructed Analogs (MACA) dataset.[65]

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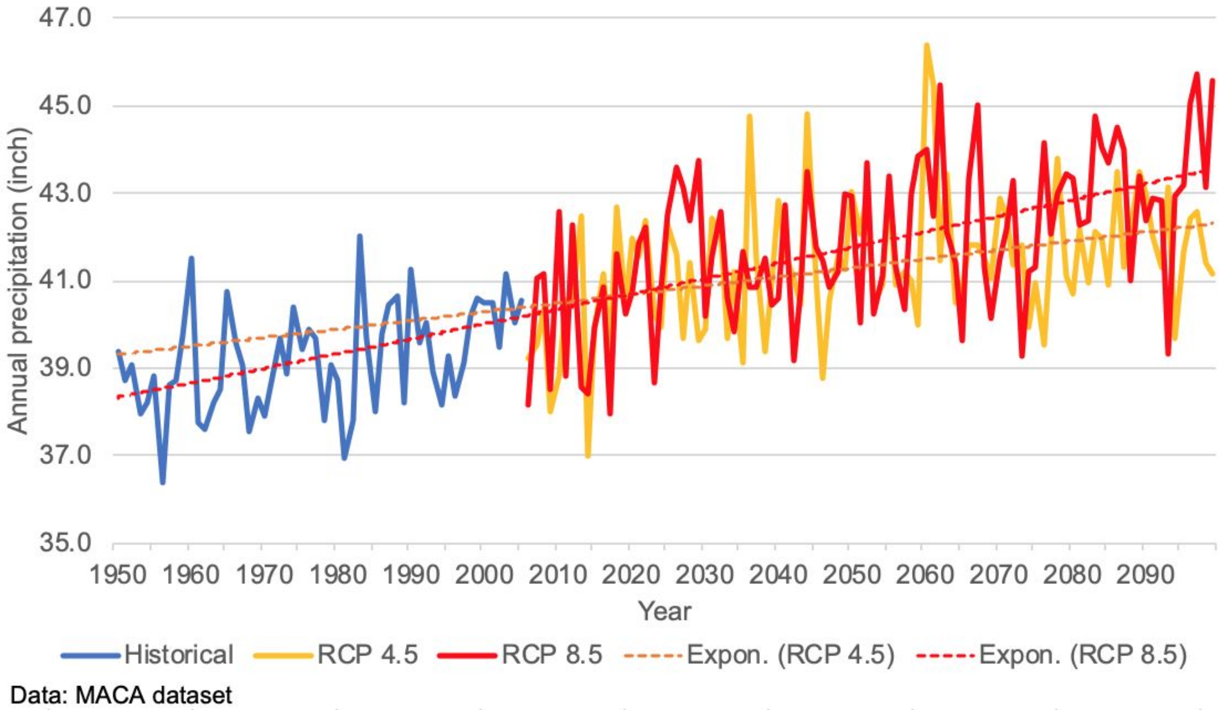
[62] Emily Shugerman, "Heatwave Forces France to Shut down Four Nuclear Reactors," The Independent, August 4, 2018, https://www.independent.co.uk/news/world/europe/france-nuclear-reactors-shut-down-edf-europe-heat-wave-a8477776.html.

[63] Michelle T. H. van Vliet et al., "Vulnerability of US and European Electricity Supply to Climate Change," *Nature Climate Change* 2, no. 9 (September 1, 2012): 676–681, https://doi.org/10.1038/nclimate1546.

[64] Matthew D. Bartos and Mikhail V. Chester, "Impacts of Climate Change on Electric Power Supply in the Western United States," *Nature Climate Change* 5, no. 8 (May 18, 2015): 748–52, https://doi.org/10.1038/nclimate2648.

[65] University of Idaho, "Multivariate Adaptive Constructed Analogs (MACA) Datasets," *Climate.Northwestknowledge.Net*, accessed May 6, 2020, https://climate.northwestknowledge.net/MACA/.

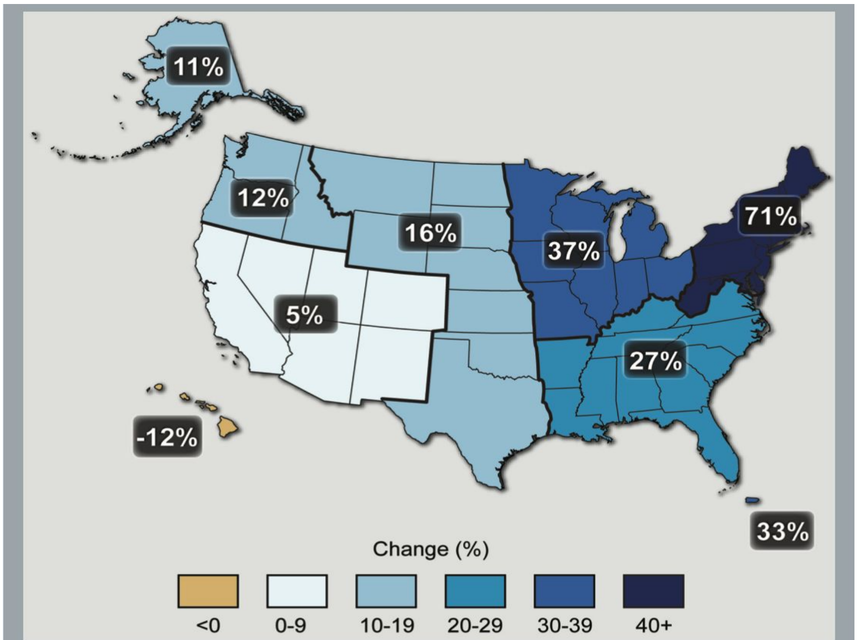
Figure 28. Projections for annual precipitation in Pittsburgh



Not only the total amount of precipitation, but also the intensity of rainfall is projected to increase. According to the third National Climate Assessment published in 2014, the amount of rainfall in a very heavy event in Northeast had increased by 71% in 2012 compared to the amount in 1958, as shown in Figure 29 below.[66]

[66] National Climate Assessment, "Climate Change Impact in the United States," GlobalChange.gov, May 2014, https://nca2014.globalchange.gov/.

Figure 29. Observed change in very heavy precipitation[67]



Percent changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012 for each region. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. (Figure source: updated from Karl et al. 2009[c]).

6.4 Air quality

Pittsburgh's air quality has been improving overall. As seen in the graphs below, compared to PM2.5 Concentration in 2003, there were more Good days, fewer Moderate days, and fewer Unhealthy days in 2019 (Figure 30).

Temperature inversion, however, is expected to become much more frequent as the temperature rises. Inversion will trap pollution and create stagnant air where PM2.5 is condensed and becomes increasingly unhealthy. As temperature is projected to increase for Pittsburgh, inversion is becoming more frequent, which leads to increase in PM2.5 spikes and super-pollution events.[68]

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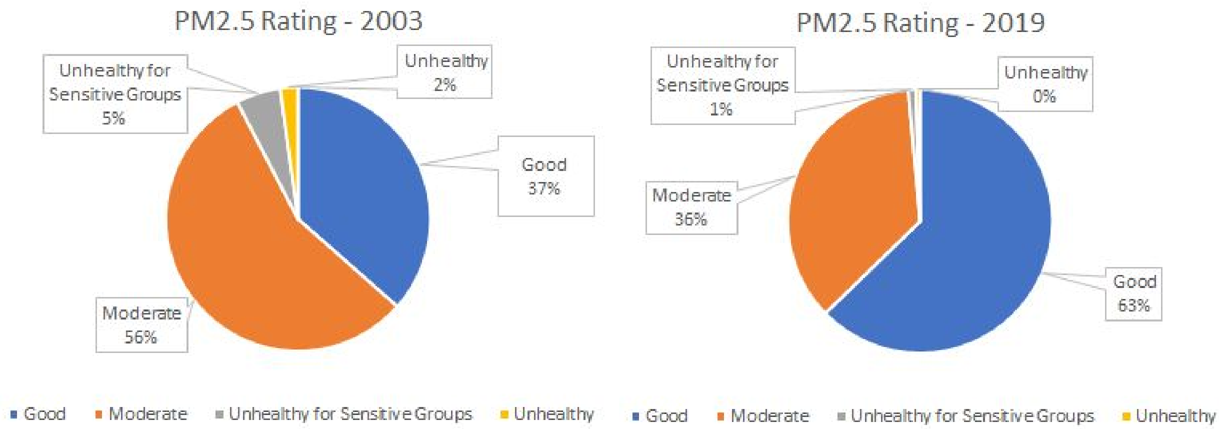
[67] Ibid.

[68] Marusic, Kristina. "Climate Change, Inversions, and the Rise of 'Super Pollution' Air Events." EHN. EHN, January 10, 2020. https://www.ehn.org/climate-change-inversions-and-air-pollution-2644464249.html?fbclid=IwAR2XTvS-g3CQ9TzuIkrwt6G0gJjt7pj6f2I2eohi-WNT8jFyC4Uxe5vIkMM

Fig. 30. Proportion of days by PM2.5 concentration rating for 2003 and 2019, respectively



6.5 Landslides

With the increased levels of precipitation that come with climate change, comes an elevated risk of landslides to areas of the state already prone to these issues due to their topography and land development. Unfortunately, as noted by the Department of Conservation and Natural Resources in 2019, it is currently impossible to track or predict landslide risks due to the lack of data.[69] Though the Pennsylvania Emergency Management Agency (PEMA) attempts to provide such data by tracking landslide occurrences, these reports are based on county reporting which poses a problem because counties may not always report these events. With no requirements to report landslide occurrences, or the monetary damage they have caused, and the lack of availability of landslide insurance, the surge in costs associated with these landslides can be expected to continue.[70]

6.6 Flooding

Many communities are at high-risk for flooding occurrences due to increased levels of precipitation and land development, as well as outdated stormwater systems. Like landslides, flooding can cause thousands of dollars in damage to the city's infrastructure. Unfortunately, also like landslides, flooding—especially flash flooding—can be difficult to predict and there is a lack of information regarding how flood planning should incorporate the effects of climate change.[71]

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[69] DePasquale, Eugene A. "Climate Crisis: The Rising Cost of Inaction." Pennsylvania Auditor General Special Report. 2019.
https://www.paauditor.gov/Media/Default/Reports/RPT_Climate_crisis_111219_FINAL.pdf

[70] Ibid.

[71] Ibid.

VII. Challenges and Limitations

During the course of the project, the team received numerous suggestions/critiques from our prospective end users and project advisory board. The team has integrated most suggestions into the product, and has encountered challenges and limitations when incorporating other changes, so compromises have been made. However, the tool was constructed with built-in flexibility so that it can be adapted by future teams or users if and when the following current challenges and limitations are now longer an issue.

As pointed out by the advisory board, instead of traveling to nearby HALCs, citizens would be safer staying at home under extreme air quality conditions, so the air quality-related retrofits might not have provided as much benefit as estimated by the tool. The team recognized that as a valuable critique, but was unable to specify the benefit under the new premise due to lack of HALC visitor data for each day. To produce reasonable estimates of retrofits' values under such limitation, the team specifies the coverage of a typical air purifier, and then uses HALCs' area to estimate how much mortality rate is reduced by a single air purifier in respective HALCs for a single person. This method makes sure that the number is not artificially bloated, but it will also potentially underestimate the benefits, as the number of HALC visitors is more than one person. Moreover, the benefit calculated is the expected benefit as mortality rate is now expressed as "probability of a person dying due to PM2.5 in HALC".

S&R expressed interest in seeing climate change's projected effects on each attribute. Although plenty of research and reports pointed out the importance of climate change projection, the team had limited time to parse out every interaction among each attribute. The tool, however, is designed to be flexible enough to incorporate these effects. Precipitation projection is included as a proof of concept. As the team prioritizes the tool's design, other projections are presented in qualitative fashion to inform users on how to interpret tool results.

As the team lacks the facilities' usage data, the team was unable to calculate the limits of additional benefits with retrofits. The tool uses an estimate of facilities' usage to calculate retrofits' benefits.

Flooding and Landslides were expected to be integrated into the tool. However, researches and reports suggest that it is impossible to track or predict landslide and flooding events due to lack of data. Therefore, the team presents a hazard map to display past events to give users a comprehensive idea of areas with high probability of flooding and landslides occurring. The tool also leaves space and templates for flooding and landslides, so they can be incorporated into the tool as soon as the data is available.

As pointed out by S&R, inversion events impact all age populations, not just 65+ populations. The team, however, prioritizes PM2.5's concentration's effects over inversion events as inversion events is one of the factors of air quality impacts. The team, therefore, focused on PM2.5's impact on 65+ people while providing a general trend of occurence of inversion events so that the calculation is not significantly biased, and the benefits provided by retrofits are not overestimated while still providing users a general idea when interpreting tool results. Moreover, the tool is flexible enough to include fluctuation and spikes in PM2.5 concentration due to inversion-like events, and templates are provided.

VIII. Recommendations for future work

The scope of this project was significantly limited by the time constraints under which we were operating. Similarly, the team is limited in the degree to which it is able to forecast the future condition of the thirty-five HALCs that were the focus of this study or specific retrofits that may eventually be considered. To compensate for these limitations, we offer the following three recommendations to guide future work and extensions of the project.

(1) Considerations for interoperability with Cartegraph (City's internal facilities management tool). Currently the tool is populated with static data retrieved from Cartegraph. A script to automatically update the data inside the tool using Cartegraph data will be useful.

(2) Updating and QA/QC of source data sets. The source data sets used by the team have been dated, and may not be accurate at current or future time. Updating the tool with the latest source data will improve its accuracy.

(3) Addition/update of retrofits with engineering expertise, including consideration of temperature effects in net-benefit calculation and future trends in temperature, air quality, and energy. Currently the tool only considers a typical retrofit in each category. To keep the benefits' calculation accurate, engineering expertise is a step to upgrade the tool.

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We would like to thank the many advisors that contributed to our project both directly and indirectly. We would also like to acknowledge the courses—and professors who taught those courses—that we pulled extensive knowledge and inspiration from. Special thanks especially to our advisor, Edson Severnini, who continuously provided much-needed guidance throughout the course of this project by way of useful data sources, feedback, and advice. Listed below are all the people and courses we owe many thanks too. Thank you.

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- Michelle Fanzo

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Appendix 1. Overview of Source Documents

1. CyPT Siemens Analysis - An analysis of carbon reduction opportunities and technologies for Pittsburgh conducted by Siemens using their City Performance tool (CyPT) tool. Good, brief overview of investment priorities for City and projected impact for each.

2. Benchmarking Report - Pittsburgh's first report on the new benchmarking ordinance, providing an overview of the ordinance and its importance to the city's carbon reduction goals. Also includes recommendations for early stage retrofit projects.

3. Climate Action Plan 3.0 - The third and most recent update to the City's climate action plan, specifying goals and timelines across 6 priority areas roughly mirroring the organizational structure of the Sustainability and Resilience Division

4. 2020 Capital Budget Prospectus (draft) - Recommendations on capital budget investments and policy changes based on Pittsburgh's climate action plan goals and timeline.

5. 2019 Capital Budget - 2019 capital budget requests broken down by department. Useful as reference point for cost/benefit analysis (see project description)

6. OnePGH Pittsburgh Resilience Strategy - Pittsburgh's overarching sustainability and resilience framework and agenda, modeled after the Paris Climate Agreement

7. OnePGH Investment Prospectus - An earlier attempt to align the City's investments with the OnePGH framework and goals

8. RMI Retrofit Priorities - A ranked list of city buildings prioritized for energy efficiency retrofits, conducted by the Rocky Mountain Institute consultancy group

9. Pittsburgh Buildings Portfolio Carbon Calculator

10. Massaro Report Facilities Optimization Plan - An in-depth report on the projected costs and impacts of retrofit projects for City-owned buildings

11. Benchmarking maps metanalysis (Excel) - an index of public benchmarking maps with links, comparisons of content and functionality, and other material for quick reference

12. Benchmarking Maps (PowerPoint) - a review of other city's public benchmarking maps with comparisons of content and functionality. Also includes recommendations for Pittsburgh's public benchmarking map

13. EV Task Force recommendations - Recommendations related to the development of EV infrastructure in Pittsburgh

14. Blackhurst, Michael. University of Pittsburgh. “Parcel Scale Green Infrastructure Siting and Cost Effectiveness Analysis: Recommended Siting of Green Infrastructure by Type in Allegheny County.” https://wetweather.pitt.edu/green/.

Appendix 2. Cost-Benefit Analysis of Retrofits

Calculation of each element

The authors prepared eight elements in each Retrofit Guide sheet for computing net-benefits of the retrofit. Values used in the sheet were the best available information under time and resource constraints. The City of Pittsburgh may revise the figures using its internal resources and past experiences.

- Capital expenditure:
  - Installation cost premium of the retrofit relative to the conventional one (e.g., green roof vs. black roof). If there is no alternative (e.g., install an air purifier or do nothing), use the whole initial costs.
  - It could include the replacement of a component of the retrofit in the middle of lifetime (e.g., replacement of an inverter at tenth years for a twenty-year solar power project). In that case, you should separate the initial and tenth-year costs to compute net present values.
- Operating expenditure
  - Typical annual costs to maintain the retrofit (e.g., prune cost of a tree, electricity cost to operate an air purifier, maintenance cost of pavement)
  - You could change different expenses among years if necessary. For instance, you can assume the operational cost inflates 3% per year. You can link whatever you need to each cell in *NPV of retrofits* sheet.
- Energy
  - Annual benefits of energy saving are estimated as the amount of energy saved by the retrofit times energy cost per unit (e.g., $/kWh). Examples of such retrofit are the introduction of high-efficient heating and lighting and less operation of AC due to tree shading or green roof.
- Carbon
  - Annual benefits of carbon emissions reduction are calculated as the amount of carbon emissions reduced times carbon price. The authors considered two types of carbon emissions reduction: CO2 reduction by energy saving and carbon sequestration by plants.
- Air quality
  - Annual benefits of air quality improvement is basically computed as the amount of pollutants removed times avoided mortality per unit times VSL. Because of the constraints in available study results, some retrofits consider the removal of more than one pollutant as benefits while others only have one pollutant or less. Calculation of the amount of pollutants removed may also differ among retrofits due to the same reason.
- Temperature

    - Although the authors could not find reliable resources to estimate annual benefits of retrofits in alleviating severe temperature, Retrofit Guide sheets hold room for temperature benefits so that users can include them in the tool in the future.
- Stormwater management
    - Annual benefits of stormwater management are estimated as the amount of reduced rainwater runoff times avoided cost per gallon to invest in an additional stormwater management system.
    - The amount of reduced runoff is estimated as annual precipitation in Pittsburgh times rainwater retention rate of the retrofit. Retention rate varies among retrofits, and you may find typical values of a particular type of retrofit online. As the authors mentioned in the earlier section, this estimate is coarse, and users might want to conduct an additional engineering study on a particular site to know more precisely the amount of reduced runoff.
    - The authors used a projection of future annual precipitation in Pittsburgh to calculate the amount of reduced runoff and avoided cost in each project year.
- Other values
    - Other benefits include aesthetic values of green infrastructure which improve property values. If you can find reliable research that shows the quantitative result, other benefits for facility users including health and productivity and broader societal values, such as the contribution to economic development of the city, could also be included.

<u>Net-benefit calculation</u>

Based on annual costs and benefits identified above as well as the project lifetime and the discount rate specified by users, net present value (NPV) of each element is calculated. Net-benefits of the retrofit are then computed by summing up NPVs of the eight elements. *NPV of retrofits* sheet conducts these computations.

<u>Sensitivity analysis</u>

Regarding the benefits of stormwater management, retention rate of rainwater significantly varies among locations and designs of bioretention measures as noted above. Therefore, the authors conducted sensitivity analyses of retention rate of green roof, rain garden, and permeable pavement.

The results in Table [x1-x3] show that retention rates are less likely to reverse the net benefits to net costs although the amount of net benefits with the retention rate of 40% might be significantly smaller than that with the retention rate of 80%. Only rain gardens would have net costs with the retention rate under 35%.

Table [x1-x3]. Sensitivity analysis of rainwater retention rate of green roof, rain garden, and permeable pavement

Retention rate of green roof	Total Avoided stormwater mgt cost	Total Net Benefit
5%	$0.32	$305.22
10%	$0.63	$313.49
15%	$0.95	$321.76
20%	$1.27	$330.02
25%	$1.58	$338.29
30%	$1.90	$346.56
35%	$2.22	$354.82
40%	$2.53	$363.09
45%	$2.85	$371.36
50%	$3.17	$379.63
55%	$3.48	$387.89
60%	$3.80	$396.16
65%	$4.12	$404.43
70%	$4.43	$412.70
75%	$4.75	$420.96
80%	$5.07	$429.23
85%	$5.38	$437.50
90%	$5.70	$445.76
95%	$6.02	$454.03
100%	$6.33	$462.30

Retention rate of rain garden	Total Avoided stormwater mgt cost	Total Net Benefit
5%	$0.32	-$57.13
10%	$0.63	-$47.72
15%	$0.95	-$38.31
20%	$1.27	-$28.90
25%	$1.58	-$19.49
30%	$1.90	-$10.08
35%	$2.22	-$0.67
40%	$2.53	$8.74
45%	$2.85	$18.15
50%	$3.17	$27.56
55%	$3.48	$36.97
60%	$3.80	$46.38
65%	$4.12	$55.79
70%	$4.43	$65.20
75%	$4.75	$74.61
80%	$5.07	$84.02
85%	$5.38	$93.43
90%	$5.70	$102.84
95%	$6.02	$112.25
100%	$6.33	$121.66

Retention rate of permeable pavement	Total Avoided stormwater mgt cost	Total Net Benefit
5%	$0.32	$6.59
10%	$0.63	$16.00
15%	$0.95	$25.41
20%	$1.27	$34.82
25%	$1.58	$44.23
30%	$1.90	$53.64
35%	$2.22	$63.05
40%	$2.53	$72.46
45%	$2.85	$81.87
50%	$3.17	$91.28
55%	$3.48	$100.69
60%	$3.80	$110.10
65%	$4.12	$119.51
70%	$4.43	$128.92
75%	$4.75	$138.33
80%	$5.07	$147.74
85%	$5.38	$157.15
90%	$5.70	$166.56
95%	$6.02	$175.97
100%	$6.33	$185.38