Policy Options to Achieve the City of Philadelphia’s Climate Change Goals

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Executive Summary

In 2016 the city of Philadelphia announced an ambitious climate goal; Mayor Kenney committed the city to an 80% reduction in citywide carbon dioxide equivalent (“CO₂e”) emissions relative to 2006 levels by the year 2050.¹ A year later, Philadelphia released the Powering Our Future report, outlining the policies and strategies the City plans to pursue to achieve this and other intermediate goals. Our client, the Clean Air Council, believes that the policies and strategies outlined in Powering Our Future are insufficient to achieve these goals.

We conducted a modeling effort to understand whether our client’s concern was warranted. The team relied upon the City’s proprietary emission projection model, with one critical aspect altered; we replaced an arguable underlying assumption that projected the carbon intensity of the electricity grid serving Philadelphia. Using a state-of-the-art integrated assessment model, GCAM, the team generated scenarios which represented a range of potential carbon intensity trajectories through 2050.

Our modeling suggests that the city will achieve somewhere between 27% to 38% CO₂e emission reductions in 2050, relative to 2006, through the Powering Our Future policies. This would constitute a sizable achievement gap on the order of 8 to 11 million metric tons (“MMt”) CO₂e between the net emissions and the reduction target of 3.7 MMt CO₂e in 2050. Thus, consideration of additional emission reduction policies is merited.

The city’s Office of Sustainability expressed interest in analysis of three potential new policies: a policy or programmatic response to enabling state legislation for community solar; a formalized offset program; and supplying renewable natural gas through the city’s municipally owned natural gas provider. Given the existing interest in these policies from city stakeholders, we explored these three policies using cost-benefit analyses, to assess whether any of these programs merit further consideration. The results of the cost-benefit analyses, cost-effectiveness analysis, and the estimated CO₂e reduction potential of these programs is numerated in Table ES-1.

A hypothetical community solar program was constructed, in which the City offered a municipal owned rooftop, located at the Curran-Fromhold Correctional Facility, at no- or low-cost to community solar developers. In this scenario, the City acts as an “anchor tenant” who mitigates the financial risk associated with programs oriented to serve low-income subscribers.² The program was found to be net beneficial but results in the fewest CO₂e emission reductions in 2050. In order to see sizable reductions, the City would likely have to repeat this project at several facilities.

A cost benefit analysis of two offset program options were explored; one in which the City purchases offset credits equivalent to 10% of net city-wide emissions each year from the voluntary market, and a second in which the City acts as a project developer to generate carbon offsets from the urban forest. The program in which the City purchases offset credits results in

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the most cost-effective strategy of all, as well as the greatest overall impact in terms of mitigating the city’s contribution to climate change. However, the offset program generates almost no local co-benefits. In contrast, the urban forest offset program yields comparatively little CO₂ reductions, but is associated with significant co-benefits for the city and its residents.

The renewable natural gas analysis considered capturing and refining fugitive methane emissions from state landfills. The program examines the value of the City establishing its own renewable natural gas facility, and assesses three project flow rate outcomes. The cost benefit analysis ultimately results in mid-level returns. The net present value is based largely in the benefit of capturing methane, and even then, the program does not have as great an emissions reduction impact as does purchasing offset credits. The project itself, as modeled, also yields a negative revenue stream for the utility in all facility options analyzed.

Table ES-1. Summary of Cost Benefit, Cost-effectiveness Analysis and Projected Emissions Reductions

<table>
<thead>
<tr>
<th>Policy</th>
<th>Cost-Benefit Analysis Net Present Value</th>
<th>Cost-Effectiveness Ratio ($/MtCO₂e avoided)</th>
<th>Emissions reduction in 2050 (MtCO₂e)</th>
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<tbody>
<tr>
<td>Community Solar Project</td>
<td>$1,200,116</td>
<td>$375</td>
<td>187</td>
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<tr>
<td>Offset Credit Purchasing</td>
<td>$1,505,564,870</td>
<td>$8.76</td>
<td>1,318,183</td>
</tr>
<tr>
<td>Urban Forest Offset Development</td>
<td>$7,460,597,005</td>
<td>$1,597</td>
<td>601</td>
</tr>
<tr>
<td>RNG Capture - medium flow facility</td>
<td>$253,466,501</td>
<td>$1,074</td>
<td>478,037</td>
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</table>

The transportation sector also presents an untapped opportunity for reducing emissions. Our model projects that emissions from the transportation sector in 2050 will constitute roughly 2 MMtCO₂e. At present though, the City has no plans for policies to meaningfully address transportation sector emissions. We modeled the emission reduction impact of two transportation policies: a congestion pricing scheme in the Greater Center City and a city-wide parking reduction policy. In 2050, based on our model, these policies would have the effect of reducing emissions by 99,293 and 891,852 MtCO₂e, respectively.

Finally, we conducted a landscape analysis to synthesize for our client what policies other cities around the world are implementing. Many of these policies are not possible in Philadelphia today given legislative limitations in Pennsylvania. This synthesis is meant to serve as a jumping off point for further policy consideration and analysis.

Ultimately, this analysis reveals that achieving an 80% emissions reductions target will be a challenging, monumental task. Policies available to cities have promise, but absent aggressive state- and federal-level policies, are somewhat stunted in terms of their impact. Moreover, implementing the many policies necessary to cumulatively reach emissions goals may not be feasible given resource constraints that may cities and municipalities face. However, based on our analysis, some of policies we explore could be deployed in Philadelphia that are both cost-effective and will augment Philadelphia’s ability to reduce emissions.
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<th>Abbreviation</th>
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<tr>
<td>AEPS</td>
<td>Alternative Energy Portfolio Standard</td>
</tr>
<tr>
<td>AEO</td>
<td>Annual Energy Outlook</td>
</tr>
<tr>
<td>BAU</td>
<td>Business as Usual</td>
</tr>
<tr>
<td>CAC</td>
<td>Clean Air Council</td>
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<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
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<tr>
<td>CCA</td>
<td>Community Choice Aggregation</td>
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<tr>
<td>CCSA</td>
<td>Coalition for Community Solar Access</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost Benefit Analysis</td>
</tr>
<tr>
<td>DOT</td>
<td>The Department of Transportation</td>
</tr>
<tr>
<td>DHA</td>
<td>Denver Housing Authority</td>
</tr>
<tr>
<td>EDC</td>
<td>Electric Distribution Company</td>
</tr>
<tr>
<td>EGS</td>
<td>Electric Generation Supplier</td>
</tr>
<tr>
<td>EIA</td>
<td>US Energy Information Administration</td>
</tr>
<tr>
<td>ELCC</td>
<td>Effective load carrying capability</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GCAM</td>
<td>Global Climate Assessment Model</td>
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<tr>
<td>ITC</td>
<td>Income Tax Credit</td>
</tr>
<tr>
<td>KWh</td>
<td>Kilowatt hour</td>
</tr>
<tr>
<td>LMI</td>
<td>Low- and Middle-Income</td>
</tr>
<tr>
<td>LMP</td>
<td>Locational Marginal Pricing</td>
</tr>
<tr>
<td>MACRS</td>
<td>Modified Accelerated Cost Recovery System</td>
</tr>
<tr>
<td>MSWLF</td>
<td>Municipal Solid Waste Landfill</td>
</tr>
<tr>
<td>MtCO₂e</td>
<td>Metric Ton of Carbon-Dioxide Equivalent</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>NREL</td>
<td>National Renewable Energy Laboratory</td>
</tr>
<tr>
<td>OOS</td>
<td>Office Of Sustainability</td>
</tr>
<tr>
<td>PEA</td>
<td>Philadelphia Energy Authority</td>
</tr>
<tr>
<td>PGW</td>
<td>Philadelphia Gas Works</td>
</tr>
<tr>
<td>PPA</td>
<td>Power Purchase Agreement</td>
</tr>
<tr>
<td>PPM</td>
<td>parts per million</td>
</tr>
<tr>
<td>PPUC</td>
<td>Pennsylvania Public Utilities Commission</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>REC</td>
<td>Renewable Energy Credit</td>
</tr>
<tr>
<td>RNG</td>
<td>Renewable Natural Gas</td>
</tr>
<tr>
<td>RPS</td>
<td>Renewable Portfolio Standards</td>
</tr>
<tr>
<td>SETPA</td>
<td>Southeastern Pennsylvania Transportation Authority</td>
</tr>
<tr>
<td>SCC</td>
<td>Social Cost of Carbon</td>
</tr>
<tr>
<td>WWTF</td>
<td>Wastewater Treatment Facility</td>
</tr>
<tr>
<td>80x50</td>
<td>The colloquial term for the city of Philadelphia’s climate goal to reduce emissions by 80% in 2050 relative to 2006 emission levels</td>
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1. Introduction

In 2016 the city of Philadelphia announced an ambitious set of climate change policies, beginning with Mayor Jim Kenney’s declaration of the city’s commitment to an 80% reduction in citywide carbon dioxide (“CO₂”) emissions relative to 2006 levels by the year 2050. Following the U.S. withdrawal from the Paris Agreement in June 2017, Mayor Kenney became the nation’s 100th mayor to sign Sierra Club’s “Ready for 100” campaign, pledging to transition Philadelphia to 100% renewable energy by 2050. In September 2017, the Office of Sustainability announced the City’s intention to purchase 100% renewable energy for all municipal operations by 2030, reduce the city’s built environment energy use by 20% by 2030, and reduce greenhouse gas emissions from the city’s built environment by 50% by 2030.

Urban environments are responsible for 70% of global CO₂ emissions and use two-thirds of the world’s energy. As such, cities have an important role to play in transforming their local energy, transportation and consumption systems to reduce emissions of carbon dioxide and other greenhouse gases into the atmosphere. City governments with the political autonomy and popular support to carry out reforms in favor of adopting policies to mitigate and adapt to climate change can make meaningful reductions in their greenhouse gas emissions. However, cities often have limited resources to explore and select the right combination of carbon reducing policies for their city. In light of these limitations, this project seeks to aid the city of Philadelphia’s effort to meet their ambitious climate and energy goals.

Our client is the Clean Air Council of Philadelphia (“CAC”), the city’s oldest environmental non-profit. CAC is an advocacy organization that envisions a future where the Mid-Atlantic region has the cleanest air and lowest carbon footprint in the country. CAC has consistently worked with Philadelphia’s Office of Sustainability (“OOS”) and the Office of the Mayor to encourage the city to adopt policies that improve air quality, promote sustainability, and protect public health. For example, our client informed us that CAC played a critical advocacy role in pushing for legislation that enabled the city to enter into solar power purchase agreements, which will enable the city to meet 22% of its municipal electricity demand with

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9 Clean Air Council, 2019.
renewable, local energy. CAC plans to continue to work with the city council to identify and enact strategies for meeting the city’s renewable energy and greenhouse gas reduction goals.

A year after announcing their ambitious climate and energy goals, Philadelphia released the *Powering Our Future* report, outlining potential policies and strategies the city and its residents could pursue to meet these goals. In the report, the policies and strategies are organized by five general categories: clean electricity supply, city wide solar, energy-efficient homes and businesses, low-carbon thermal energy, and low-carbon economy. The greenhouse gas reduction potential for each of these categories and the projection of their combined effect is shown in *Figure 1*. This waterfall chart implies that the city’s policies outlined in *Powering Our Future* will achieve the 80% reduction target from the built environment relative to 2006 levels. Even so, CAC was doubtful that these policies and strategies would be sufficient to make the depicted reductions a reality. For this reason, the project team was engaged to explore additional policies the city of Philadelphia could pursue to bolster the city’s chances of achieving this target.

*Figure 1 - CO₂ reduction potential for Philadelphia's policy strategies in 2050*

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12 OOS, 2018.
Opportunities to Augment Philadelphia’s Climate Planning

Upon closer examination of the Powering Our Future report, the project team saw several opportunities to add value to Philadelphia’s existing climate and energy policies and strategies.

The project team noted that many of the policies that will be most effective at enabling the City to reach its climate goals are not within the City’s authority to implement. In Powering Our Future, the City outlined advocacy activities for the city to conduct at the state level, for policies such as the Community Choice Aggregation programs, which are currently prohibited by the Commonwealth of Pennsylvania’s Public Utilities Commission, and strengthening the Alternate Energy Portfolio Standard, which can be updated by the governor. There are further policies outlined in Powering Our Future that are not even within the state’s purview to enact, but are dependent on private sector and market forces. These include expanding the 2030 District and encouraging large institutions to aggregate their renewable power purchasing strategies. Further, other policies outlined in the report that are highly dependent on the City acquiring additional resources to oversee their implementation, such as energy code compliance enforcement and PACE financing management. In sum, the Powering Our Future represents an impressive example of a city plan to reduce GHG emissions; however, many of the recommendations are not totally within the City’s authority to see enacted.

The project team also noted that in order to meet the 2050 emissions target, the Powering Our Future plan indicates that the city’s energy supply will need to come entirely from clean energy by 2050. Barring energy efficiency measures, the report calculates that this could result in a 5.1 MMt reduction of CO₂. However, the City acknowledges that it has limited authority and influence over the energy mix in the regional electricity grid and that local action through power purchase agreements, institutional renewable power aggregation, and consumer choice options, will not be sufficient to transition all of Philadelphia’s grid to entirely clean energy. Action at the state and federal level will be necessary to achieve further reductions, including joining the Regional Greenhouse Gas Initiative (“RGGI”), strengthening the state’s Alternative Energy Portfolio Standard (“AEPS”), maintaining existing nuclear generation, and lobbying for federal action on climate change. Many of the emissions reduction strategies outlined in Powering Our Future involve lobbying for policy action at the state and federal level, because the City lacks the authority to enact the particular legislation.

The project team also noted that the vast majority of the strategies outlined in Powering Our Future revolve around addressing emissions from the city’s building sector. This makes sense, as Philadelphia’s emissions profile is dominated by building energy consumption. The City’s 2012 GHG inventory indicated that roughly 80% of emissions came from buildings. However, we noted a lack of cohesive strategies to address transportation emissions, which

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13 OOS, 2018.
14 OOS, 2018.
15 OOS, 2018.
16 OOS, 2018.
17 OOS, 2018.
18 OOS, 2018.
19 OOS, 2018.
account for approximately 17% of the city’s emissions.\(^{20}\) In CONNECT: Philadelphia’s Strategic Transportation Plan, reducing emissions is only one strategic priority of many others. CONNECT’s only climate goals are focused on reducing emissions from transportation in the near term via transit mode shift and vehicle electrification, with no goals outlined beyond 2025.\(^{21}\)

We believe the transportation sector in Philadelphia represents untapped opportunity to achieved additional emission reductions owing to several reasons: the city has an extensive public transit system which likely possesses capacity to absorb higher rates of ridership; a sizable dent can be made to transportation emissions largely agnostic to what happens to the carbon intensity of the electricity grid; and finally, because it is an area over which the City may have more authority over and policy options within its disposal.

**Project Components**

In light of the precursory insights on the city’s existing plans, our project team sought to: (1) provide CAC with a more detailed evaluation on the effectiveness of the city’s existing strategy to reach their 80% reduction goal by 2050 (“80x50”); (2) explore the economic, social, and environmental merit of a set of three policies in which the City expressed interest; (3) explore three potential transportation sector policies; and, (4) provide a menu of additional emission reduction policy options pursued by other cities for consideration in Philadelphia.

The paper is divided into four primary sections. **Section 2** evaluates the City’s proprietary emissions projection model to understand the range of possible reduction outcomes between now and 2050. By altering one critical assumption in the model – the carbon intensity of the grid serving Philadelphia – we hypothesize that the city is unlikely to meet its 2050 climate goal with the Powering Our Future strategies alone. This analysis quantifies the magnitude of the city’s likely emissions gap, or “stabilization triangle,” representing the remaining emissions the City will need to address to meet their reduction target. This analysis highlights the need for additional policy action.

**Section 3** details an investigation into three policies in which the Philadelphia OOS indicated interest: community solar, a citywide carbon offsets program, and capturing renewable natural gas (“RNG”). The team designed hypothetical projects that the city of Philadelphia could implement and conducted cost benefit and cost-effectiveness analysess, and quantified the scale of potential emissions reduction for each.

In light of the dearth of existing plans or policies to address transportation sector emissions, **Section 4** discusses three transportation sector policies Philadelphia could implement and quantified their respective potential reductions. The policies explored include a sales tax to fund additional public transit infrastructure, congestion pricing, and a parking maximum policy.

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\(^{20}\) OOS, 2018.

Section 5 provides a literature review of some of the most promising climate and energy policies being executed by cities throughout the United States that could be considered for implementation in Philadelphia.

The results of this work support the case for further policy action in Philadelphia. We hope that the analysis herein will bolster advocacy efforts for more aggressive policies as well as provide initial directionality regarding which additional climate policies are economically, environmentally, and socially sound.
2. Philadelphia’s Emission Reduction Model

To evaluate the effectiveness of the city’s existing plan, the project team needed to establish an understanding of the city’s current emissions trajectory, as well as a more detailed understanding of the emission reduction potential of the strategies outlined in Powering Our Future. Philadelphia’s OOS shared a proprietary and rigorous model with the project team that the City developed with a consulting firm. The model helps the City simulate the emissions impacts of differing city policies and future scenarios. While the model is proprietary, it was shared with the project team to help inform this project’s analyses.22 The City’s model incorporates a detailed projection of citywide and municipal strategies, as outlined in Powering Our Future, and the effects of these policies on reducing city business as usual emissions through 2050.

In the model, emissions are forecasted for the residential and commercial/industrial sectors of the city, as well as varied sectors under the municipal purview. The model includes a business as usual (“BAU”) transportation projection through 2050 based on an analysis conducted by Drexel University researchers.23 The transportation projection does not include reductions from any explicit strategies undertaken by the City, which aligns with our initial observation that the City currently has no long-term plans to address transportation emissions.

In the version provided to the team, the model simulates a 2017-based city-wide BAU emissions trajectory, which projects 16.2 million metric tons of carbon dioxide equivalent (“MMt CO₂e”) in 2050. Through a combination of electric grid improvements, city strategies, and municipal strategies, the model predicts a 16.5% decrease in city emissions in 2050 relative to 2006 emissions, achieving 15.7 MMt CO₂e. This means that with the city’s current policies and projected changes to the electricity supply mix, the City expects that it will be emitting roughly 12.0 MMt CO₂e in excess of the 80x50 reduction target of 3.7 MMt CO₂e.

Though emissions are reduced overall, the model predicts an uptick in emissions in the decade following 2040, growing from 14 to 15.7 MMt CO₂e in 2050. The project team discovered that the intermediate decline, followed by an uptick in projected city emissions, observed in the model’s projection is attributable to the carbon intensity of the grid forecasted in the model. This assumption is examined further in the following section.

Model Assessment

The project team identified a fundamental risk associated with the City’s model. When examined closely, the team discovered that the forecast of carbon intensity for the electricity grid is an out of date and unrealistic projection.

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22 Information shared herein reflects only topline values and results from the model and only minimally discusses calculations and inputs related to the projection for grid carbon intensity. Any information published herein relating to the model was reviewed and approved for publication by the City’s Office of Sustainability.

The inputs that influence the model’s carbon intensity projections show growth in the quantity of electricity coming from fossil-fuel generation sources into the future. Table 1 shows the projection from the City’s model regarding the percentage of electricity generated by different sources. The percentages through 2040 were calculated based on the 2017 Annual Energy Outlook (“AEO”) Electric Power Projections for the RFC-East Region electricity market from the U.S. Energy Information Agency (“EIA”). For 2050, City modelers forced a 100% renewable energy mix. It’s upon these grid mix percentages that the model’s grid intensity projections are predicated.

<table>
<thead>
<tr>
<th>Adjusted Grid Mix</th>
<th>2016</th>
<th>2018</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>17.6%</td>
<td>18.2%</td>
<td>22.5%</td>
<td>23.0%</td>
<td>22.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0.0%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>38.0%</td>
<td>39.1%</td>
<td>38.9%</td>
<td>39.5%</td>
<td>45.9%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>40.5%</td>
<td>38.1%</td>
<td>33.4%</td>
<td>32.6%</td>
<td>27.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Pumped Storage/Other</td>
<td>0.0%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Renewable Sources</td>
<td>4.2%</td>
<td>4.2%</td>
<td>4.7%</td>
<td>4.5%</td>
<td>4.5%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

The City’s modeled projection for the grid carbon intensity based on the assumptions in Table 1 is demonstrated in Figure 2. The projection clearly reflects an intermediate net increase in output from fossil-fuel generation between 2020 and 2040, and then a drop to zero carbon intensity between 2040 and 2050 when the grid is served entirely by renewables.

Though the AEO is an authoritative source for projections, the EIA’s projections have changed considerably since 2017. The 2020 AEO presents a vastly different vision of the future. As synthesized in Table 2, the new AEO projects a 51% decline in output from coal compared to

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24 The Generation by Fuel type can be retrieved from [https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2017&region=3-9&cases=ref_no_cpp&start=2015&end=2050&f=A&linechart=ref_no_cpp-d120816a.5-62-AEO2017.3-9&map=&sourcekey=0](https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2017&region=3-9&cases=ref_no_cpp&start=2015&end=2050&f=A&linechart=ref_no_cpp-d120816a.5-62-AEO2017.3-9&map=&sourcekey=0)
a 9% increase from the 2017 AEO, and used by the City’s model. Though the 2020 AEO still projects an increase in natural gas, it is much more modest than 2017’s projection. There is also a less dramatic decline in electricity output from nuclear sources than previously projected. Finally, the updated projection for renewables growth is significantly larger than in the 2017 AEO.25

![Table 2 - Comparison of % Change Projected in the 2017 & 2020 AEO](image)

Though not pictured in the table, it is important to note that notwithstanding the high growth projection for renewables in the 2020 AEO, the projected output in billion KWh still only constitutes 25% of the output from all electricity generation sources in 2050.

Thus, the grid intensity forecasts used in the City’s model are problematic for two reasons: first, they are based on outdated projections for the electricity generation portfolio through 2040; and second, they force a growth in electricity output from renewables - from 4.5% in 2040 to 100% in 2050 – that is inharmonious with either the 2017 or 2020 AEOs. Thus, the trajectory of the carbon intensity of the grid used in the model is similarly flawed.

Not only is this trend no longer indicative of the most recent EIA projections, it is discordant with the decline in coal in recent years in the PJM market; since 2005, the carbon intensity in the 13-state region has decreased each year, and overall by 28%.26,27 Even Philadelphia’s regional transit authority SEPTA, in its own forecasts, projects an average annual 1.5% improvement in the grid’s carbon intensity from 2016 through 2021.28

The model’s trajectory for the carbon intensity is a point of concern because it is an underlying input to many subsequent, complex model calculations. Thus, a problematic grid

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25 This paragraph and Table 2 were calculated from data in the US EIA’s 2020 AEO, Table 54.10, Electric Power Projections by Electricity Market Module Region, Reference case for the: PJM / East region [https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-10&cases=ref2020](https://www.eia.gov/outlooks/aeo/data/browser/#/?id=62-AEO2020&region=5-10&cases=ref2020)


27 PJM is a regional transmission organization responsible for the management and coordination of a wholesale electricity market spanning 13 states across the Northeast and Mid-Atlantic regions. Pennsylvania is one of the states that participates in this market.

intensity projection renders similarly unlikely predictions for the BAU emissions projection, which in turn muddies the discourse of whether or not the city is on track to meet its goal.

Thus, it is important to consider alternative scenarios for how the carbon intensity of the grid serving Philadelphia might evolve. This will foster enhanced understanding of the range of the potential reductions achieved by the City’s planned reduction strategies, as well as the top line value of how much Philadelphia will be emitting in 2050 relative to its reduction goal.

The project team decided to devise three alternate scenarios in which grid intensity improvements represent a range of reasoned trajectories informed by a variety of potential policy outcomes. More about how these scenarios were derived and the impact of using them in the model is discussed after a brief introduction to the concept of wedge analysis.

Introduction to Wedge Analysis

The concept of the “stabilization triangle” was first introduced in 2004 by Pacala and Socolow in the journal Science. As then conceived, the stabilization triangle represented the difference between a global emissions trajectory that would limit atmospheric concentrations of CO₂ to being doubled, relative to pre-industrial levels, and a business-as-usual growth projection. The space on the graph between the two trajectories, as seen in Figure 3, represents the stabilization triangle, upon which, Pacala and Socolow overlaid seven “wedges” representing “an activity that reduces emissions to the atmosphere that starts at zero today and increases linearly until it accounts for 1 GtC/year of reduced emissions in 50 years”.

Since 2004, the scientific community’s understanding of what is required to avoid a doubling of atmospheric carbon concentrations has evolved substantially. It is now almost universally accepted that stabilization of emission at 2004 levels is inconsistent with achieving atmospheric concentrations at or below 500 parts per million (ppm) or a 2°C global temperature.

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change.\textsuperscript{32} However, what is important is that the concept of the stabilization triangle, and creating “wedges” that will help reduce the magnitude of the triangle, has become a ubiquitous tool for analyzing the potential of different combinations of technologies, policies, and strategies that can be deployed to achieve emission reduction goals.\textsuperscript{33}

In following section, we emulate the stabilization triangle concept to explore the difference between the interpolated 80x50 goal line for the emission trajectory, and three projected impact of three alternate scenarios for the carbon intensity on net emissions.

Crafting Alternate Scenarios for the Grid Carbon Intensity

As described previously, the City’s model uses outdated projections and makes an unsupported assumption between 2040 and 2050 regarding the carbon intensity of the grid (\textit{Figure 2}). Thus, we posit that the carbon intensity of the grid is unlikely to follow this trajectory, and that there is inherent benefit in considering a range of possible trajectories rather than just one. We also posit that the ramifications of a more realistic carbon intensity projections will yield insight into a range of total reduction that can be associated with the city’s current policies to reducing CO\textsubscript{2} emissions.

To craft a range of realistic alternate scenarios for the trajectory of the grid, the project team used the Global Climate Assessment Model (“GCAM”). GCAM is one of the leading integrated assessment models utilized by academia, researchers, and the U.S. Environmental Protection Agency. GCAM is an integrated tool for exploring the complicated dynamics of the human-Earth system and the response of this system to global changes. GCAM is maintained and distributed by Pacific Northwest National Labs and the University of Maryland. GCAM represents the interrelatedness and complex interactions between energy, water, agriculture and land use, the economy, and the climate.\textsuperscript{34}

Using GCAM, the project team modeled six scenarios in which a) New Jersey and Pennsylvania do not join RGGI, b) New Jersey and Pennsylvania do join RGGI and there are constant emissions after RGGI’s current 2030 “end-point,” and c) New Jersey and Pennsylvania join RGGI, and RGGI institutes a declining cap on emissions beyond 2030. For each of these three primary scenarios, an alternate scenario was run in which the default coal retirement assumptions inherent in GCAM were altered with a “coal fix” – created by the U.S. EPA’s Office of Research and Development – that better reflects recent trends in coal retirement.

The outputs from GCAM represent the tons of carbon emitted from Pennsylvania’s electricity sector through 2050 because GCAM does not have the functionality of modeling at a


\textsuperscript{33} Davis et al., 2013.

more granular unit than the state. These values were converted to MMt CO\textsubscript{2}e and then divided by GCAM’s projection for the quantity of electricity consumed through 2050.\textsuperscript{35}

Generally, the coal fix scenarios resulted in significantly lower CO\textsubscript{2} intensities in 2050 under the no-RGGI and RGGI with constant emissions post-2030 scenarios. For the declining cap beyond 2030 scenario, there was virtually no difference between the coal-fix and no coal-fix scenarios in 2050. However, there is a near and intermediate-term difference in the trajectories. The full spectrum of possible scenarios is presented in Figure 4.

![Figure 4 - Alternate Carbon Intensity Scenarios for Pennsylvania](image)

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>NJ &amp; PA Do not join RGGI*</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>SEPTA 1.5% Reduction Assumption Extended beyond 2021</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>NJ &amp; PA Do not join RGGI_coalfix*</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>2020-2030 NJ &amp; PA_constant emission level*</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>2020-2030 NJ &amp; PA_constant emission level_coalfix*</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>2020-2030 NJ &amp; PA_continued reduction beyond 2030_coalfix*</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>2020-2030 NJ &amp; PA_continued reduction beyond 2030*</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
<td>1.0E-07</td>
</tr>
</tbody>
</table>

*indicates that the scenario was the output of GCAM model runs.

Because it appears likely that Pennsylvania and New Jersey will end up joining RGGI, the project team decided to exclude the grid intensity scenarios in which they do not from the analysis.\textsuperscript{36} Instead, the team down-selected to the following three scenarios to incorporate into the City’s model as representatives of a conservative, moderate and best-case outcome: the continuous 1.5% reduction assumption used by SETPA and extended out through 2050, the RGGI constant emission post-2030 with coal fix, and the continued reduction beyond 2030, respectively. The team’s decision to use the continued reduction beyond 2030 scenario as opposed to the same one with the coal fix is due primarily to the fact that, though the coal fix scenario achieves more aggressive reductions in the near- and intermediate-term, the carbon intensity of the scenario without the coal fix is actually lower in 2050 than with the coal fix.

\textsuperscript{35} If desired, an excel based model depicting the calculations for grid intensity can be retrieved by emailing Dr. Betsy Albright at elizabeth.albright@duke.edu.

Grid Intensity Scenario Comparisons

When the alternate scenarios for grid intensity above are incorporated into the City’s model, there is a dramatic change to the 80x50 stabilization triangle. Figure 5 and Table 3 both demonstrate the ramification of the conservative, moderate, and best-case grid intensity scenarios on the magnitude of emissions not reduced over time and the difference between net emissions and the 80x50 target.

The best-case scenario yields a stabilization triangle that is two thirds the size of the city’s projection in 2050. It is also of interest that in all scenarios but the best-case, the magnitude of the stabilization triangle decreases initially and then rebounds in out years. This may be due in part to the best-case grid intensity scenario being the only one that decreases dramatically enough to counter other factors modeled by the City that may be upward drivers of emissions. Nonetheless, even if the carbon intensity of the grid follows the most ambitious projection, the city will only achieve a 38% reduction relative to 2006 baseline.37 Thus, the City

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37 This projection incorporates the policies currently in place or planned for the future, per the city’s proprietary model (v1.28.2020).
will likely need to identify and enact more impactful emission reduction strategies at the city level, or advocate strongly for them at the state and federal levels, in order to avoid an out-year increase in the magnitude of the stabilization triangle.

### Table 3 - Quantity of Emissions in Excess of the 80% Reduction Target (the Stabilization Triangle)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>GHG Emissions (MMt CO₂e)</th>
<th>% Reduced in 2050 relative to 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philadelphia's Grid Intensity Assumptions</td>
<td>0.61 3.58 6.86 11.95</td>
<td>16.5%</td>
</tr>
<tr>
<td>Conservative Grid Intensity Scenario</td>
<td>0.00 2.62 6.28 10.01</td>
<td>26.8%</td>
</tr>
<tr>
<td>Moderate Grid Intensity Scenario</td>
<td>0.00 1.93 5.61 9.42</td>
<td>30.0%</td>
</tr>
<tr>
<td>Best Case Grid Intensity Scenario</td>
<td>0.22 2.27 4.82 7.99</td>
<td>37.6%</td>
</tr>
</tbody>
</table>

Another insight revealed by this analysis is that the City’s current and planned strategies for reducing emissions yield the greatest reductions when the carbon intensity of the grid is at its dirtiest (Figure 6). Since a majority of the City’s current policies are focused on reducing building energy consumption, these interventions and programs yield fewer reductions as the grid becomes cleaner. However, a more aggressive scenario for grid intensity reduction is still preferable because the overall avoided emissions from a cleaner grid are substantial enough to make up for the fact that the City’s polices become less effective over time at avoiding emissions.

**Figure 6 - Reduction Strategy Efficacy**

The conservative and best-case intensity scenarios represent the possible upper and lower bounds on the range of carbon intensity outcomes for the grid serving Philadelphia. Based on
this model, these alternate grid intensity scenarios from GCAM, and the policies and programs
the City intends to implement between now and 2050, Philadelphia is projected to achieve
anywhere from a 27% to 38% emission reductions relative to 2006.

This quantity of reductions, if achieved, will be a significant accomplishment. However,
based on the city’s GHG inventory from 2016, the city has already reduced emissions by
approximately 26% relative to 2006. Thus, the potential reductions of 27% to 38% in 2050 are
less impressive. Regardless, the city will be anywhere from 8 to 11 MMt CO₂e away from
meeting its reduction target in 2050, leaving a significant achievement gap to be addressed via
other policies.
3. Cost Benefit Analyses

When the project team met with the city of Philadelphia’s OOS in September 2019, the project team posed the question: “if you had more resources to explore additional emission reduction policies, beyond those outlined in the Powering Our Future and other city plans, what policies would you start with?” Representatives from the OOS responded with several ideas. First among them was a question; what would the City’s role be if enabling legislation was passed at the Pennsylvania Legislature that legalized community solar in the state? The second concept of interest was regarding the capture of fugitive methane emissions throughout the city for use as renewable natural gas. The third concept related to the potential for carbon offsets.

With the goal of providing analysis and information that would be useful in vetting whether the City should further consider any of these policies and programs, the project team conducted a cost-benefit analysis (“CBA”) on each one. This section is dedicated to describing the context of each policy, summarizing other cities’ experiences with similar policies, describing the design of a hypothetical program for Philadelphia, and quantifying the societal benefits and Philadelphia that would result from these programs.

CBAs take a social perspective to determine the net weight of the tradeoffs from a potential project and quantifies the net present value (“NPV”) of the costs and benefit streams that may result from a project. If a project has a positive NPV, it is determined to be socially net beneficial for society. The project team used Crystal Ball software to conduct Monte Carlo sensitivity simulations that explored the probability of net beneficial outcomes given the range of potential values for each of the input parameters. 38

The final portion of this section is a cost-effectiveness analysis (“CEA”) that compares the costs of the three programs against one another for cost per metric ton of CO₂e reduced. CEAs have a narrower scope than CBAs and ignore other social benefits from projects. CEAs are designed to help decision makers pick interventions that deliver some result at lowest cost.

3.1 Community Solar

Introduction

Community solar, also known as shared solar or community solar gardens, is a form of distributed electricity generation that allows multiple people to own or lease portions of a typically offsite PV solar project. Community solar programs come in a diverse array of sizes and models. Projects in the United States range anywhere from a few kilowatts to several megawatts in size. As of July 2019, the total U.S. capacity of all community solar projects clocks in at 1.3 GW. 39

38 Crystal Ball is a software produced by Oracle. It is the leading spreadsheet-based application for predictive modeling, forecasting, simulation and optimization.
In its most basic design, a solar developer or utility constructs an offsite solar array. Program participants pay a participation fee to the developer, whether upfront or monthly, to own or lease a portion of the project. Program participants then see reductions on their electricity bill that are proportional to their share of the project. For example, if a household uses 1,000 kWh of electricity in a month and their share of the community solar project produces 300 kWh, then they will be charged for the use of 700 kWh at the end of the month rather than 1000 kWh. This process is known as virtual net metering, and mimics net metering, where residential owners of solar panels are able to sell their electricity back to the grid.

Unfortunately, no enabling legislation for community solar currently exists in the state of Pennsylvania. This section of the project (1) examines the advantages of community solar, in light of the City’s emissions targets and renewable energy goals, (2) provides state level policy design recommendations the City should advocate for, and (3) presents recommendations for how the City should respond in the event that enabling legislation is successfully passed, including a cost-benefit analysis on a hypothetical project involving city property.

Why should the city of Philadelphia consider community solar?

Within the City’s broader goals of reducing citywide GHG emissions to specific targets, there is a pair of additional goals related to clean energy: (1) transition the entire city’s energy use to carbon-free energy by 2050; and (2) meet municipal government electricity needs with 100% renewable energy by 2030. An important distinction between these two goals is that the municipal government’s 2030 goal relates only to electricity consumption and must be met with renewable energy, while the citywide 2050 goal applies to the entire energy system, including thermal energy systems which heat buildings, and can be met with “clean” energy. As of 2016, 40% of the electricity supplied to Philadelphia’s grid is from nuclear generation, which produces no GHG emissions and thus is considered “clean” though not renewable. However, one of Pennsylvania’s five nuclear power plants shut down in September and a second plant is scheduled to close in 2021. As of 2018, fossil fuels supply 56% of the regional grid’s electricity, and renewables supply 4% (Figure 7).

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40 OOS, 2018.
41 OOS, 2018.
43 OOS, 2018.
In light of the shifting generation portfolio that supplies Philadelphia with power, the City will need to invest in substantial renewable energy projects if it wants to meet its targets. The City is doing just that. In October 2019, the municipal government and the Philadelphia Energy Authority (“PEA”) signed a power purchase agreement (“PPA”) for a 70-megawatt (“MW”) photovoltaic (“PV”) array with Adams Solar, LLC. The project is expected to provide up to 22% of the municipal government’s electricity. As of 2019, 7% of the municipal government’s energy is supplied by renewables and the Adams Solar project is scheduled to come online in 2021. Barring additional renewable energy projects, that will bring the municipal government’s total renewable energy supply to approximately 29% by 2021. As noted previously, as of 2016 Philadelphia’s regional grid mix was only 4% renewables. Thus, the City will need to continue to seek renewable project opportunities for public investment while finding ways to encourage private investment in renewable energy projects.

Though cities have limited influence and authority over the energy mix of regional grids, they can encourage and incentivize the development of distributed solar generation projects among and for city residents. One way to encourage distributed solar generation is through the development of community solar arrays. On average, community solar arrays are 100 times larger than residential solar systems. The average community solar array is approximately 1,000 kW, compared to the average residential system of 6.1 kW. Community solar is unique in its

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44 OOS, 2018.
46 OOS, 2018.
ability to address three significant issues: the high cost of residential solar, the lack of suitable residential rooftops for solar, and the high energy burden of low-income households.

The high upfront cost of rooftop solar panel installation is a significant barrier to many households, with the average residential rooftop system costing anywhere from $15,000 to $28,000.\(^{48}\) Furthermore, approximately 75% of U.S. residential rooftop space is not suitable for solar panel installation, due to structural constraints or ownership issues.\(^{49}\) Community solar programs address both of these issues by allowing participants to receive the benefits of solar power generation without concerns about roof suitability, home ownership, or significant upfront personal investment. Participants thereby receive monthly or annual credits on their electricity bill that are proportional to the size of their subscription. This process mimics the mechanism known as net metering that owners of residential rooftop systems benefit from in many utility jurisdictions. Thus, by entering into a community solar agreement with others, the installation, operation and management cost of the array is distributed among members and the utility or other sponsoring host.\(^{50}\)

Community solar also represents a potential way that the city of Philadelphia can address distributional equity and reduce low-income residents’ electricity bills. As part of their “clean energy vision”, Philadelphia expressly wants to find ways to reduce utility bills of residents, particularly vulnerable Philadelphians, and address and eliminate inequities in the energy system.\(^{51}\) “Low- and moderate-income families pay a greater percentage of their income on utility bills than higher-wage earners. These customers will benefit the most from affordable solar power, allowing them to use savings from solar for other important necessities.”\(^{52}\)

While community solar has the specific advantage of increasing the accessibility of solar energy to a more diverse array of consumers, it also provides advantages associated with its status as a renewable energy source. Solar electricity production emits no harmful GHG, NOx and SO\(_2\) emissions compared to traditional fossil fuel electricity generation. Pollution from natural gas and coal plants cause approximately 2,300 premature deaths in Pennsylvania every year and are particularly bad for cities downwind from coal-burning plants, including Philadelphia.\(^{53}\) These air pollutants are also associated with a multitude of respiratory illnesses, including asthma and bronchitis.\(^{54}\)

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\(^{51}\) OOS, 2018, p. 7.

\(^{52}\) Southern Environmental Law Center, n.d.


Solar also provides benefits related to its status as a type of distributed generation. Community solar projects produce electricity close to the end use of the power compared to the traditional model of electricity generation that sources capacity away from population centers. Sourcing electricity generation close to its end use decreases losses along transmission and distribution lines, which in turn reduces the operating costs for existing sources of generation while simultaneously decreasing the volume of emissions from the grid’s fossil fuel fleet.\footnote{Environmental Protection Agency [EPA]. (2018). Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments. Retrieved from https://www.epa.gov/sites/production/files/2018-07/documents/epa_slb_multiple_benefits_508.pdf.} Distributed generation capacity also avoids future capital costs for expanding grid capacity, transmission, and distribution systems.\footnote{EPA, 2018.}

Community solar’s unique ability to expand access to clean, renewable energy while concurrently reducing certain costly burdens on the existing electricity grid provides a strong argument as to why Philadelphia should consider and support community solar in Pennsylvania. Unfortunately, no enabling legislation for community solar currently exists in the state of Pennsylvania. City representatives can and should lobby state representatives to advocate for enabling legislation for community solar. The following section outlines a framework with which the city of Philadelphia may approach supporting community solar at the state level.

State Level Policy Framework for Community Solar in Pennsylvania


To offer a framework with which to develop and advocate for an approach to community solar in Pennsylvania, the following section examines H.B. 531, a 2019 bill that would have established community solar in Pennsylvania by amending the state’s Alternative Energy Portfolio Standards Act (“AEPS”), in light of a diversity of approaches to community solar seen
elsewhere in the United States. The City should advocate for a statewide community solar policy that: (1) does not set a statewide cap for community solar, (2) sets a reasonable project cap for individual community solar projects so that developers and participants can take advantage of economies of scale, (3) allows for program administration flexibility, (4) expands the net metering policy for the state for distances greater than two miles, and (5) contains a low-and middle-income specific requirement.

Program Structure: Statewide caps, project capacity limits, and other design details

Some state community solar policies will put a cap on the total capacity of community solar or a net metering cap. For example, California has a statewide capacity cap for community solar of 600 MW, while Delaware, Vermont, and New Hampshire each have net metering caps. Many states have no cap at all. It is not clear if H.B. 531 would have established a cap. The bill would have amended P.L.1672, No. 213, which is the act that established the state’s AEPS. The AEPS establishes “alternative” energy targets for the state’s electric distribution companies (“EDCs”) and electric generation suppliers (“EGSs”). EDCs and EGSs must source 8% of their electricity from “solar PV, solar thermal, wind, low-impact hydro, geothermal, biomass, biologically derived methane gas, coal-methane, and fuel cell resources” by 2021. Of this 8%, 0.5% must be supplied from PV systems. As the expiration date for the AEPS is quickly approaching, Philadelphia must consider how any updates to this act will impact a community solar bill developed within the act. Some states establish community solar caps as a means to meet other state policy goals, as perhaps could be done with the AEPS. The Coalition for Community Solar Access (“CCSA”) recommends that states should establish a “permanent and uncapped” community solar program.

Other state’s community solar policies occasionally employ project capacity caps for individual community solar arrays. Vermont has the lowest project limit of all the states; community solar projects cannot exceed 500 kW, whereas California allows community solar projects as big as 20 MW. Generally speaking, developers of solar projects benefit from economies of scale, which lowers the price of solar for program participants. As such, capacity caps, when set too low, can be a hindrance for the growth of community solar projects.

Many states community solar caps are dictated by their net metering policies. H.B. 531 would have amended the section of the state’s law that established the net metering policy.

60 Cook & Shah, 2018.
62 Pennsylvania Public Utility Commission, 2020. Note: The AEPS also requires that EDCs and EGSs must supply 10% of their electricity by 2021 from new and existing waste coal, distributed generation, demand-side management, large-scale hydro, municipal solid waste, wood pulping and manufacturing byproducts, and integrated gasification combined cycle (IGCC) coal facilities.
63 Coalition for Community Solar Access, 2019.
64 Cook & Shah, 2018.
65 Southern Environmental Law Center, n.d.
Pennsylvania’s net metering policy has a 50 kw limit for arrays installed at residential sites and a 3,000 kw limit for “other customer service locations”, but H.B. 531 established a specific limit of no more than 5,000 kw for nonutility community solar projects. Community solar projects of this size will be able to take advantage of economies of scale and potentially offer savings customers. However, it is worth noting that some policymakers limit the size of projects so that they retain a “community” aspect or so that they can still qualify as distributed generation.

There are other detailed policy components that vary across states and affect the program structure of community solar projects: who is permitted to own and develop projects, who is the program administrator, and who administers bill credits. H.B. 531 would have allowed any entity to own or operate a community solar facility. The bill defined “community solar organization” as “an entity that owns or operates one or more community solar facilities”. Community solar ownership and operation in some states is limited to utilities, while other states also allow special purpose entities and nonprofits. Special purpose entities include LLCs, for-profit corporations, cooperatives, limited partnerships, and general partnerships. H.B. 531 sought to take advantage of Pennsylvania’s deregulated electricity market, allowing for either a utility or special purpose entity to sponsor a project. This would have had the effect of increasing competition and lowering costs for consumers.

H.B. 531 would also have allowed community solar projects considerable flexibility when determining who the program administrator would be. A program administrator, or “subscriber administrator”, “recruits and enrolls subscribers, administers subscriber participation in community solar facilities and manages the subscription relationship between subscribers and an electric distribution company”. The role of program administration for community solar can also be taken on by utilities, third parties, or other groups. Most often, utilities administer community solar programs, as they are uniquely experienced at administering complex energy systems. To increase transparency, the CCSA recommends that third party, independent administrators overseen by a state agency take on the responsibility of program administration. For example, Massachusetts’ MassACA is a third party administered application system that is not community solar specific, but helps manage projects seeking to partake in net metering capacity. If a community solar program seeks to target low-income households in particular, community solar developers may benefit from establishing program administrators outside their organization. “Programs are more effective when they coordinate with existing community

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61 Cook & Shah, 2018; Southern Environmental Law Center, n.d..
64 Coalition for Community Solar Access, 2019.
65 Coalition for Community Solar Access, 2019.
66 H.B. 531, 2019 Reg. Sess. (Penn. 2019), Section 9(a)(2), “A community solar organization may serve as a subscriber administrator or may contract with a third party to serve as a subscriber administrator on behalf of the community solar organization”.
69 Cleveland, 2017.
70 Coalition for Community Solar Access, 2019.
72 Cleveland, 2017.
73 Coalition for Community Solar Access, 2019.
support organizations, like local governments and community action agencies, to reduce the administrative burden associated with recruiting and managing low-income subscribers.”

H.B. 531 would have required electric distribution companies to administer the bill credits of community solar programs. This aligns with the CCSA’s recommended approach, as it streamlines the customer experience and simplifies the calculation, particularly in a competitive electricity market. The bill credits would have been applied monthly. H.B. 531 made no stipulations on the design of the participation fee structure for community solar projects, thus community solar developers, sponsors, and owners can design programs that best suit their project and the community. In general, community solar projects generally have two types of options for how customers can enroll: capacity offerings and rate offerings. Capacity offerings are the most popular, where participants pay an upfront fee to lease or own a set amount of panels and receive credit for their share’s electricity production. Capacity offerings offer the advantage of easy billing and a low financing risk for developers, but typically have a high upfront cost. Rate offerings allow participants to purchase kWh blocks of solar energy output to replace some of their home electricity use. Often the rate offering price is locked, which protects participants against future rate increases. While rate offering projects have low up-front costs for participants, they often have complex billing structures and a high financing risk for developers.

Compensation structure: subscriber eligibility, location requirements, and bill credits

All states with mandatory community solar programs require community solar subscribers to be located within the same service territory as the facility, and H.B. 531 was no different. Colorado, Minnesota, and North Carolina are even more stringent; subscribers must be within the same or adjacent county as the project. But strict geographic limits may disadvantage dense urban areas like Philadelphia, where finding available land large enough to support a project can be challenging and expensive. H.B. 531 would have altered the state’s net metering program by allowing multiple people to lease or own an array, but it would have left intact the two-mile limit of Pennsylvania’s net metering policy. The city of Philadelphia will want to pay close attention to future attempts to enable community solar to ensure that projects can be sited further than two miles away from subscribers.

82 DeShazo et al., 2015.
83 DeShazo et al., 2015.
84 DeShazo et al., 2015.
85 DeShazo et al., 2015.
86 Cook & Shah, 2018.
State policies also establish minimum subscriber requirements for projects to prevent the benefits from concentrating to a small number of primary customers.\textsuperscript{41} It is important that community solar projects are utilized by a variety of customers, including residential, commercial, and governmental, but developers are incentivized to pursue fewer, larger customers to reduce their financing costs.\textsuperscript{87} H.B. 531 set a minimum subscription size of two consumers, matching four other states’ policies.\textsuperscript{88} H.B. 531 also limited subscribers to projects larger than 1,000 kw to subscribing to no more than 50\% of facility capacity, which would have prevented large customers from taking the majority of outputs from facilities, with the exception of master-metered multifamily residential and commercial buildings.\textsuperscript{89}

As one of the key benefits of community solar projects, the value of the bill credit will have a significant impact on the success of the project. Bill credit amounts vary across states and projects, depending on how the state values electricity generation and how it treats renewable energy certificates (“RECs”). Many states use the retail rate of electricity as the basis for the bill credit. Colorado’s bill credit is valued at the aggregated retail rate, but excludes transmission and distribution charges, while Maryland’s bill credits are valued at the full retail rate.\textsuperscript{90} Participants of the program will receive savings on their electricity bills that are proportional to their share of the solar array, valued at the retail price of electricity. In some states, the RECs generated by community solar projects stay in the hands of developers, in other states they are passed onto subscribers. Pennsylvania’s AEPS program is set to expire in 2021, rendering consideration of how to treat RECs obsolete unless the program is extended.\textsuperscript{91}

H.B. 531 made no determination of the value of the bill credit for community solar, instead making it the responsibility of the Pennsylvania Public Utility Commission (“PPUC”) to determine the value of the bill credit for each electric distribution company that “allows for the creation, financing, accessibility and operation of community solar facilities to maximize customer participation”.\textsuperscript{92} For states where solar is a small portion of the electricity profile, the CCSA recommends that community solar participants receive bill credits equal to the retail rate of electricity, as is done with net metering in Pennsylvania.\textsuperscript{93} As distributed solar grows and develops within a state, creating a value-based credit, informed by an analysis of the long-term benefits of solar, is recommended.\textsuperscript{94}

\textit{Low-to-Moderate Income Households Consideration}

As of 2017, eight states with community solar programs had statewide stipulations establishing certain thresholds or requirements for lower income customer participation.\textsuperscript{95} Connecticut and Maryland created carve outs requiring 20\% and 30\%, respectively, of annual

\begin{itemize}
\item \textsuperscript{87} Cook & Shah, 2018.
\item \textsuperscript{88} Cook & Shah, 2018.
\item \textsuperscript{89} H.B. 531, 2019 Reg. Sess. (Penn. 2019), Section 2.
\item \textsuperscript{90} Cook & Shah, 2018.
\item \textsuperscript{91} Pennsylvania Public Utility Commission, 2020.
\item \textsuperscript{92} H.B. 531, 2019 Reg. Sess. (Penn. 2019), Section 10 (a)(4).
\item \textsuperscript{93} Coalition for Community Solar Access, 2019.
\item \textsuperscript{94} Coalition for Community Solar Access, 2019.
\item \textsuperscript{95} Cook & Shah, 2018.
\end{itemize}
community solar generation to benefit LMI households. Rhode Island took an alternative approach to encouraging LMI participation; public housing authorities are allowed to be subscribers to community solar projects, which then allows the developer of the community solar project to bypass other requirements, and ultimately allowing the developer to save money. If Pennsylvania extends its AEPS program, it could offer a low income community solar projects a higher REC rate, further encouraging low income participation and community solar program development.

H.B. 531 would have required the PPUC to establish specific community solar participation targets for low- and moderate-income customers, allowing for the use of additional funding to support their participation. The details of this requirement were never established, but CCSA recommends that states set overall program capacity requirements for LMI participation, rather than project-specific project requirements. However, the cost of community solar participation, whether through a one-time upfront participation fee or a monthly subscription, is a key challenge of providing LMI customers with access to community solar.

One of the best ways to address the financial challenges of LMI participation in community solar is a state level policy that allows the community solar market to grow quickly and increase competition. A community solar market that grows rapidly is in Philadelphia’s best interest for meeting their climate change and clean energy goals. A state level community solar policy that does not set a statewide cap for community solar, sets a reasonable project cap for individual community solar projects that allows developers and participants to take advantage of economies of scale, allows for program administration flexibility, expands the net metering policy for the state for distances greater than two miles will help to encourage a community solar market that can serve as many customers as possible.

If community solar enabling legislation is passed, the question of how the municipal government of Philadelphia should get involved in community solar projects arises. Given Powering Our Future’s clear goals relating to energy equity and justice and the PEA’s desire to invest in energy projects that improve air quality and social equity, the subsequent analysis explores how the city could potentially react to community solar enabling legislation, and explores whether a hypothetical community solar project that the municipal government could help implement is financially beneficial.

A Community Solar Strategy for Philadelphia

If enabling legislation passes at the state level, city governments throughout Pennsylvania can encourage and facilitate community solar in their cities through several strategies. Philadelphia could consider adding community solar targets to their climate and clean energy goals, particularly goals with low-income household participation thresholds. Philadelphia could also consider offering city property at no- or low-cost to community solar

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96 Cook & Shah, 2018.
97 Cook & Shah, 2018.
98 Heeter et al., 2018.
100 Coalition for Community Solar Access, 2019.
developers that have a low-income membership focus. Lastly, cities can offer financial security to community solar projects directed at low-income households by acting as an “anchor tenant”, subscribing to a large portion of the project’s capacity, which improves project economics, mitigates the financial risk associated with low-income subscribers and turnover, and further helps the city reach it’s renewable and clean energy goals.\textsuperscript{101}

Colorado in particular has been a leader in facilitating the development of community solar projects for low-income customers. In 2017, the Housing Authority of the City and County of Denver (“DHA”) launched the nation’s first community solar project that is entirely owned, developed, and operated by a housing authority.\textsuperscript{102} The project is 2 MW in size and all benefits of the project go towards low-income families and affordable housing developers. The project is expected to benefit between 500 to 700 families and will reduce their electricity bills by nearly 20\%.\textsuperscript{103}

To determine the extent to which Philadelphia would gain social benefits by actively participating in community solar projects, the project team calculated the costs and benefits associated with the City partnering with a solar developer to develop a community solar project dedicated to LMI customers, cited on City property. This analysis offers a precursory glimpse as to whether the municipal government should consider pursuing a project dedicated to LMI customers on City property from a social cost benefit perspective. The final NPV for this project is positive, suggesting that the project is socially net beneficial for society.

Scope of Community Solar Cost-Benefit Analysis

The municipal government of Philadelphia owns ample property throughout the City which could host potential rooftop community solar projects. The solar potential of each of these properties and the total rooftop area suitable for panels is available online through the City’s SOLARrooftops website, which used LiDAR imagery and solar radiation data to determine the solar potential of every building in Philadelphia.\textsuperscript{104} While the City could hypothetically carry out a wide range of varying sizes of community solar projects using municipal property, this analysis focuses on the potential cost and benefits of a single community solar project that is dedicated to low-income customers.

One of the City’s largest properties, the Curran-Fromhold Correctional Facility, was chosen as the host site for the hypothetical project. This location was chosen not only for its large, flat roof but its ample exposure to sunlight (\textit{Figure 8}). These characteristics would allow a potential developer to take advantage of economies of scale. The hypothetical project on the roof of this facility would be 992 kW and would provide bill savings to 333 low-income households in Philadelphia, with each household’s subscription totaling 8.5 panels.

\textsuperscript{101} Heeter et al., 2018.
\textsuperscript{103} U.S. Department of Energy, 2017.
\textsuperscript{104} City of Philadelphia (n.d.). SOLARrooftops. Retrieved from \url{https://phl.maps.arcgis.com/apps/MapSeries/index.html?appid=c1a5d30acec04aec8e4acfa4cc60a311}
The community solar project for this analysis is constructed and owned by private developers, rather than the City. By partnering with a private, taxable entity, the program will be able to take advantage of the federal investment tax credit (“ITC”) and the Modified Accelerated Cost Recovery System (“MACRS”). These incentive programs allow the business that installs, develops, or finances the project to claim reductions on their income taxes, ultimately allowing the entity to recover some of the costs of the project, and further increasing the affordability of the projects to their subscribers.106

The utility or solar developer that the City partners with would be responsible for all operation and maintenance costs. PECO, the electric distribution company that services Philadelphia, would be responsible for the billing costs associated with the community solar program. The Philadelphia municipal government would be responsible for all program administrative costs as they are likely best suited to recruiting, educating, and managing low-income subscribers. The program administrator could either be the Philadelphia Housing Authority or the PEA. The municipal government, or perhaps PEA, would also pay program participation fees on behalf of the low-income households, so as to encourage participation. Participants in the program receive monthly bill credits that are equivalent to the difference between their electricity consumption for the month and the amount of electricity produced by their share of the array, charged at the retail rate. In order to qualify for the program, total

105 The roof has total area of 157,140 ft² but approximately 120,000 ft² is suitable for rooftop panels. Conservative estimates suggest that a project taking advantage of this space could generate 8,000 kwh a day. Source: City of Philadelphia (n.d.). SOLARrooftops. Retrieved from https://phil.maps.arcgis.com/apps/MapSeries/index.html?appid=c1a5d30acec04aec8c4acfa4cc60a311
106 Solar Energy Industries Association. (2019). Solar Investment Tax Credit (ITC). Retrieved from https://www.seia.org/sites/default/files/2019-05/SEIA-ITC-Basics-Factsheet-2019-May.pdf; DeShazo et al., 2015. Note: The commercial ITC currently allows businesses a one-time 26% deduction of their solar investment costs for projects that began construction in 2020. The ITC will then step down 22% in 2021, and 10% in 2022. Tax-exempt organizations are unable to take advantage of these incentives, but if the program administer partners with a taxable entity – they will be able to use them by proxy.
household income must fall below the federal government poverty threshold, which varies depending on household size.\textsuperscript{107}

Standing in this analysis is granted to the utility/solar developer, PECO, the municipal government of Philadelphia, Pennsylvania residents, and society at large (due to avoided CO\textsubscript{2} emissions). Costs are accrued by the utility/solar developer, PECO, and the municipal government of Philadelphia. Benefits are accrued by utilities, PECO, community solar program participants, Pennsylvania residents, and society at large.

Typology of Costs and Benefits

The major costs of the projects are the capital expenditures associated with solar panel installation, fixed annual O&M costs, and program billing. The municipal government bears the program administration costs. Most of the benefits of distributed solar generation come in the form of avoided costs to the utility and society. A summary of the calculated costs and benefits can be found in \textit{Table 4}.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|}
\hline
\textbf{Benefits} & \textbf{Description} \\
\hline
\textit{Climate & Public Health} & \\
Avoided CO\textsubscript{2} emissions & The benefits to society in avoided damages associated with the carbon emissions that would have been produced to create an equivalent amount of electricity on PA’s grid. \\
Avoided morbidity and mortality from air pollutants & The benefits to society of avoided health impacts from the NO\textsubscript{x} and SO\textsubscript{2} emissions that would have been produced to create an equivalent amount of electricity on PA’s grid. \\
\textit{Power Generation & Electricity Grid} & \\
Avoided costs from displaced energy & Avoided fuel and variable O&M costs from existing generators. \\
Avoided costs in generation capacity expansion & Project’s ability to reduce costs based on its ability to replace or defer capital investments in power generation or transmissions and distribution capacity. \\
Resiliency value & The reliability benefit to the host and direct consumer of the electricity provided by the community solar project. Refers to the value lost during a potential black out. \textit{Not monetized}. \\
Net revenue from electricity sales & The net revenue created by the sale of the project’s electricity. Priced at the difference between the retail rate and the levelized cost of electricity. \\
\hline
\textbf{Costs} & \\
\hline
\textit{Direct Costs} & \\
Installation Expenditures & Includes the price of modules, inverters, hardware, installation labor, and other soft costs. \\
Operations & Management & Includes module cleaning, system checkup, inverter servicing, wear and tear repairs, and monitor and meter calibration.\textsuperscript{108} \\
\textit{Administrative Costs} & \\
Program Administration & Customer acquisition and engagement, marketing, and education materials. \\
Program Billing & Costs to the distribution company to provide bill credits to program participants. Typically involves new software and trained staff. \\
\hline
\end{tabular}
\caption{Summary of Community Solar Program Costs and Benefits}
\end{table}

Notably, the impacts of the program subscription cost, the tax credit deductions, and the bill credit savings are not included in the typology of costs and benefits. These are considered “transfers”, which are transactions where no new economic benefits are created but money moves from one stakeholder to another. These costs are considered in the distributional analysis but have no impact on the final net present value (“NPV”) of the project.


Assumptions of Analysis

Several assumptions were made to conduct this analysis. First and foremost, the project assumes that the Pennsylvania General Assembly passes enabling legislation to allow for the creation of community solar projects, particularly ones designed like the hypothetical project, which allows for virtual net metering and alternative program administrators.

One assumption is that the rooftops of the facility are structurally suitable to support solar arrays. Experts would need to scout potential host cites on City property to determine the physical eligibility for rooftop solar on top of the facility, but this analysis assumes that the data collected from LiDAR on the SOLARrooftops website is sufficient.

Another assumption is that the panels on the roof of the facility are 350 W commercially sized fixed solar panels installed with ballasted racking, which individually have an area of 21.2 ft², the average for panels of this type. Solar developers may want to consider alternative types of panels, which ultimately have different capacities, costs, and production potential depending on the host site location. For example, if vacant City land was used to host a community solar project, developers could use ground mounted fixed or tracking panels.

The project team also assumes that the project is developed and constructed in less than a year and that the community solar program maintains 100% customer participation throughout the project’s lifetime of 25 years. To calculate the benefits of the electricity revenues generated by the project, the team assumed that the average solar radiation for Philadelphia for each month would serve as a reasonable basis from which to calculate the project’s total electricity generation.

To calculate the benefits from avoided carbon dioxide, NOx, and SO₂ emissions, the project team assumed a moderate rate of decarbonization for the state of Pennsylvania. The team used the emission intensity values generated by the “Moderate Rate of Decarbonization” trajectory developed by the team through GCAM, as summarized in Section 2 of this paper. This trajectory represents a scenario in which New Jersey and Pennsylvania join RGGI after 2030, there are constant emissions, and a speedier retirement of coal facilities. The team also assumed that every kWh of energy produced by the community solar project replaces a kWh and its associated carbon dioxide, NOx, and SO₂ emissions rate.

Results of CBA

Table 5 below represents the results of the analysis, using the base case parameters. With a positive NPV, this project passes the decision criterion for CBA, and suggests that the City should further consider the implementation of community solar projects on municipal property.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided CO₂</td>
<td>$272,187</td>
</tr>
<tr>
<td>Avoided NOx</td>
<td>$349,488</td>
</tr>
<tr>
<td>Avoided SO₂</td>
<td>$298,173</td>
</tr>
<tr>
<td>Avoided Electricity Generation</td>
<td>$840,730</td>
</tr>
</tbody>
</table>
Avoided Capacity Expenditures $243,247
Net Electricity Revenues $1,277,862

Subtotal $3,281,690

Costs

Capital $1,105,250
O&M $309,903
Program Administration $409,502
Billing $256,917

Subtotal $2,081,574

Total Net Present Value $1,200,116

Sensitivity Analysis

The Monte Carlo analysis for this project reveals that the NPV for the Curran-Fromhold community solar project as designed in this analysis has an 82% probability of being positive. Given 10,000 trials, the distribution of possible outcomes ranged from approximately -$597,500 to $3,930,000.

The NPV is most sensitive to the value of the retail rate of electricity, followed by the locational marginal pricing (“LMP”) of electricity. O&M costs, program administration costs for the first three years, and the amount of electricity generated by the project were the second, third, and fourth most influential variables respectively, but are ultimately negligible.

The retail price of electricity exerts the most influence on the NPV of the projects because it dictates the degree to which project developers are able to cover their costs and generate a profit. As the retail price of electricity approaches the project’s levelized cost of electricity (“LCOE”), the profit margin shrinks, thus significantly impacting the project’s NPV. In response to this finding, the team also ran a Monte Carlo analysis on the project using a commercial retail rate of electricity, held at $0.06/kWh (compared to the residential rate base case value of $0.14). Commercial rates are typically lower than residential rates. The Monte Carlo analysis found that the project has a 20% probability of a positive NPV using commercial electricity rates. This large discrepancy highlights the importance of generating revenue from the project.

The LMP exerts the second most influence on the NPV. The LMP is the market clearing price for electricity sold in PJM, and is used in this CBA to quantify the value of avoided fuel and variable O&M costs for those units that run on the margin in the PJM territory, and thus the units that would be displaced by this project. LMP is a constantly changing value, and typically varies with respect to the time of day and season. LMP is higher during peak demand hours, and even higher during peak demand hours during the summer. The LMP range tested for this CBA included the average LMP for 2018 as the base case value with a range that is approximately reflective of the average peak winter and peak summer LMP for the PJM territory, for which there can be significant range (Figure 9).
The tornado chart revealed that LMP has the biggest influence on NPV with a price that approximated the summer average, but a low LMP would still not drive towards a negative NPV. To see the tornado charts and Monte Carlo analyses for community solar, see Appendix A.

Implications and Discussions

Beyond considering whether the benefits of the project outweigh the costs, it is important to understand who stands to experience the biggest gains and losses. Community solar projects require careful design to be financially viable for all project participants. Thus, beyond considering whether total benefits outweigh total costs, it important to consider who stands to experience the biggest gains and losses from this project.

A distributional analysis examines additional stakeholders, costs, and benefits not examined by the cost benefit analysis, including the project participants, U.S. taxpayers, and additional benefits to the utility. Many exchanges of money occur throughout this project, known as transfers, preventing their inclusion in the cost benefit analysis. Transfers included in the distributional analysis include the bill savings accumulated by the program participants and subsequent losses to the utility from these savings, tax credits and deductibles for the solar developer, and program fees paid by the municipal government to the solar developer. An undiscounted summary of these net impacts is presented in Table 6 below, and also include the impacts of the costs and benefits described earlier.

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Table 6 - Summary of distributional analysis for Community Solar

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Losses</th>
<th>Gains</th>
<th>Net Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>($4,780,732)</td>
<td>$4,473,037</td>
<td>($233,294)</td>
</tr>
<tr>
<td>PECO</td>
<td>($337,280)</td>
<td>-</td>
<td>($337,280)</td>
</tr>
<tr>
<td>Low-income</td>
<td>-</td>
<td>$10,776,973</td>
<td>$10,776,973</td>
</tr>
<tr>
<td>participants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEA</td>
<td>($2,227,040)</td>
<td>-</td>
<td>($2,227,040)</td>
</tr>
<tr>
<td>US taxpayer</td>
<td>($893,705)</td>
<td>-</td>
<td>($893,705)</td>
</tr>
</tbody>
</table>

Nationally, low-income households spend a greater portion of their income on energy. The energy burden for low-income households in PA is between 8-10%. Thus, the electricity bill credits were calculated with an additional distributional weight, to reflect that dollars received by low-income persons has a greater weight than dollars received by high-income persons. The distributional weight calculations can be seen in Appendix A. Thus, low income households see the biggest gains from this project, outweighing the losses to all other stakeholders.

The city of Philadelphia may decide that the impact on low income households makes the project valuable enough to continue. The losses experienced by the utility reflect the capital costs, operation and maintenance, billing costs, and lost revenue from the participants’ bill credits. PECO would also see losses associated with administering the program’s billing. Under the draft of H.B. 531, the electric distribution companies are able to “recover reasonable costs…to administer a community solar project”. While not included in this distributional analysis, billing costs could be covered by spreading the costs over all ratepayers in the distribution territory.

There may also be financing options available to the developer of the community solar project beyond the Philadelphia Energy Authority, further softening the developer’s losses. The Denver Housing Authority’s community solar project dedicated to low income households partnered with GRID, National Housing Trust, Enterprise Community Loan Fun and Monarch Private Capital to develop an innovative financing structure, and the solar developer for the project, Xcel, was able to secure a higher value for the RECs generated from the project. DHA also received $500,000 from the U.S. Department of Energy. A detailed explanation of the losses and gain computations can be found in Appendix A.

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3.2 Offsets

Introduction

An offset represents one metric ton of verified carbon emissions ("MtCO$_2$e") that are avoided or reduced as a result of a discrete, external project. The certification confirming the emissions reduced or avoided can be sold allowing the purchaser to claim the reductions as their own, netting out or “offsetting” carbon emissions for which the purchaser is responsible. Offsets are often used for meeting voluntary commitments when it is not feasible, either for technological or economic reasons, to lower direct or indirect emissions.

There are a variety of types of carbon offset projects: renewable energy, biological carbon sequestration (i.e. afforestation, reforestation, carbon density enhancement, and avoided deforestation), energy efficiency, methane capture and combustion, and industrial gas mitigation. While there is plenty of opportunity to generate offsets of all these types within Philadelphia, this CBA focuses exclusively on the costs and benefits for biological sequestration via urban reforestation within the city-limits and is compared to a program where offsets are purchased on the voluntary market.

Offsets are a frequently employed mechanism by cities because they can serve a variety of potential public objectives: offset programs can be a quick way to reduce emissions in the short-term; they can also serve as a reinforcing feedback strategy for the medium-term by using the proceeds from an offset program to finance future investments in long-term direct emissions reduction initiatives; and finally, offsets can be a last resort in the long-term to reduce residual direct emissions that hitherto could not be reduced or avoided (Figure 10).

![Figure 10 - Guiding Motivations for Offset Programs](image)

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116 The standard unit for carbon offsets is one metric ton of carbon-dioxide equivalent (MtCO$_2$e).

117 Barreto et al., 2018.

118 Barreto et al., 2018.

119 Barreto et al., 2018.
Cities across the world are employing the use of carbon offsets to help them accomplish their emissions reduction goals: London, Melbourne, Copenhagen, Berlin, San Francisco, Boulder, Cambridge, Seattle, Palo Alto, and Austin, just to name a few.\(^{120}\)

Austin is an example of a city employing urban forest offsets. In 2007, Austin committed to achieving net carbon neutrality for municipal operations and fleets by 2020.\(^{121}\) Between then and 2016, the City reduced its municipal emissions by 75% from 2007 levels via two primary strategies: subscribing to 100% renewable energy sources for municipal electricity demand and by fuel-switching to biofuels for the City’s motor fleet. While working on emissions reductions through a combination of other activities, the City recognized that 100% reduction of emissions would not be possible for technological and economic reasons.\(^{122,123}\) Thus, carbon offsets were identified as an important component of the City’s strategy to reach net-zero. The Austin Community Climate Plan of 2015 allows for up to 10% of the city’s annual emissions to be offset.\(^{124}\)

In 2013 the City began purchasing offsets to reduce annual emissions by 5% each year – roughly equivalent to 5,000 MtCO\(_2\)e reduced, annually.\(^{125}\) The first department to purchase offsets was the Austin Convention Center, with the intention that by 2020, all departments within the city would be responsible for purchasing offsets for its remaining emissions.\(^{126}\) The City devised a scoring matrix, that prioritized the purchase of offsets (from verified registries) from projects that are located close to Austin so that the city and its residents would reap any added co-benefits from the offset projects.\(^{127}\) As of 2018, the city’s Office of Sustainability released a memorandum to the Mayor and City Council indicating that the city was on track to meet its 2020 goal of net-zero emissions from municipal operations pending the procurement of carbon offsets to “neutralize” the remaining emissions. They estimated then that this would cost the city a cumulative minimum of $200,000 (40,000 tons at $5 per ton) to as much as $900,000 (60,000 tons at $15 per ton) over the successive three years.\(^{128}\)

Additionally, the city of Austin’s Office of Sustainability, Department of Parks and Recreation, and Watershed Protection Department, as well as Travis County are partnering with a local tree education and conservation organization, TreeFolks, and City Forest Credits to

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120 Barreto et al., 2018.
122 Climate Action Reserve, 2017.
125 Climate Action Reserve, 2017.
126 Climate Action Reserve, 2017.
develop local forest offsets. The partnership is planting trees to create riparian forests, or trees that constitute a buffer along more than 900 miles of creeks and streams. All of the offsets generated by trees planted as part of this program will generate carbon offset credits that will be purchased by the City to help meet the city’s 2020 carbon neutrality goal. The proceeds from the City’s purchase of the offsets will go to TreeFolks for administration of the program and to finance the planting of additional trees.

Additional information on approaches employed by other cities’ offset programs is provided in Appendix B.

Why Urban Forest Sequestration as a Climate Solution for Philadelphia?

There are several reasons why an urban forest offset project would be uniquely beneficial in the city of Philadelphia. First, the city of Philadelphia has established a 30% tree canopy cover goal for all of its neighborhoods. However, recently the City released a report that revealed the city is far from reaching its goals. According to the 2019 Philadelphia Tree Canopy Assessment, during the 10-year period of 2008-2018, Philadelphia lost 1,095 acres of tree cover – the equivalent of 1,000 football fields – representing a 6% overall decline. Much of this decline occurred in the form of street tree loss – trees that exist within 50 ft of a city street and perform valuable ecosystem services such as noise dampening, rainfall interception, and temperature cooling effects. The city saw a 13% decline in street trees over the period.

Establishing an urban forest offset project now would also dovetail with the City’s urban forest planning efforts. In December 2019, the city of Philadelphia announced the start of year-long urban forest strategic planning process. The process will result in a 10-year strategy to increase and conserve Philadelphia’s tree canopy, “...and set forth new ways of working with residents to combat climate change.” Dubbed “The Future of the Urban Forest,” this process is likely to lead to the largest ever multi-year tree planting effort the City has undertaken. Thus, a program that could track these plantings and verify and ensure their long-term existence, as well certify carbon sequestration, will reinforce the City’s tree planting and conservation priorities.

Moreover, the significant tree planting and conservation effort that is likely to result from the Future of the Urban Forest planning effort will likely require substantial financial investment. Establishing a carbon offset program may open avenues for creative private-public financing.
structures that may not otherwise be available and will help the City finance its tree canopy cover and climate goals more speedily.

The project team homed in on the potential for an urban forest climate solution for Philadelphia due to the substantial co-benefits associated with urban forests. Table 7 synthesizes many of the varied urban forest co-benefits from the literature that accrue to residents, businesses and cities. Many of these co-benefits were estimated and monetized in the process of conducting the cost-benefit analysis for a hypothetical urban forest program in Philadelphia.

<table>
<thead>
<tr>
<th>Table 7 - Benefits Associated with Urban Forests</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>o removal of harmful air pollutants (e.g. NO2, O3, SO2, PM2.5)</td>
<td></td>
</tr>
<tr>
<td>o sequestration of carbon dioxide</td>
<td></td>
</tr>
<tr>
<td>o precipitation interception</td>
<td></td>
</tr>
<tr>
<td>o increased property values</td>
<td></td>
</tr>
<tr>
<td>o tourism revenues</td>
<td></td>
</tr>
<tr>
<td>o urban heat island effect mitigation</td>
<td></td>
</tr>
<tr>
<td>o reduced energy consumption (for cooling)</td>
<td></td>
</tr>
<tr>
<td>o reduced emissions from energy production</td>
<td></td>
</tr>
<tr>
<td>o habitat for wildlife</td>
<td></td>
</tr>
<tr>
<td>o noise reduction</td>
<td></td>
</tr>
<tr>
<td>o decreased crime</td>
<td></td>
</tr>
<tr>
<td>o increased community cohesion</td>
<td></td>
</tr>
</tbody>
</table>

The co-benefit pertaining to the removal of harmful air pollutants was of particular importance for the project team when considering which policies to examine as part of this project. As one of the oldest environmental advocacy organizations, the Clean Air Council of Philadelphia celebrates its long-held fight to protect the rights of everyone to breathe clean air. The project team surmised that the complement of purposes and goals that would be served by a locally enhanced urban forest would be of heightened interest to an organization that is focused on both reducing air pollution as well as fighting climate change.

Finally, an urban forest offset program could be a mechanism to facilitate the correction of environmental justice disparities in Philadelphia. There is a well-documented correlation between the legacy of the 1930s “redlined” neighborhoods and a dearth of environmental amenities today, such as tree canopy. This correlation has very real and worsening ramifications in the form of higher land surface temperatures. Extreme heat is the foremost driver of summertime morbidity and has heightened impacts on populations with pre-existing


140 Clean Air Council, 2019.

health conditions, as well as those with limited access to resources, the elderly and children. Furthermore, extreme heat events in urban areas are becoming increasingly common due to anthropogenic climate change as well as the urban heat island effect, which already renders urban contexts warmer relative to sub-urban contexts. 

A paper published in the journal *Climate* found that 94% of 108 urban cities studied have land surface temperature disparities of as much as 7°C between formerly redlined and not-redlined neighborhoods. This study found that these discrepancies generally tended to be the largest in the southeast and the western U.S. regions, but the discrepancy is still alarming in Philadelphia, where the average land surface temperature of redlined neighborhoods is 5.21°C greater than in neighborhoods that were given a “Best” rating in the 1930s. The targeted planting of trees in neighborhoods that were formerly redlined, both in parks and along streets, via an urban forest offset program, could go a long way toward rectifying this horrible temperature disparity and environmental injustice in Philadelphia.

**Offset Program Design Alternatives**

If Philadelphia were to initiate an offset program, there are a variety of design decisions and trade-offs to be explored. These alternatives amount to choices between developing and buying, and if developing, whether the project will be publicly managed or contracted out, whether to diversify the portfolio of offset types, and whether to allow for private investment and/or purchase of offsets. These alternatives are each briefly discussed in the following paragraphs.

*Develop v. Buy*

The first and most foundational decision that must be made is whether to pursue an offset program in which offsets are purchased on one of the accredited voluntary offset registries, or whether to take on the role of project developer. One benefit of purchasing offsets on a voluntary market registry is that relatively little additional resources and capacity are necessary beyond the funds necessary to conduct the credit purchase transaction.

If the City were to purchase the offsets, it has less control over what types of projects are generating the offsets it is purchasing (e.g. offsets from fugitive emissions, waste handling, coal mine methane, fleet efficiency, livestock, landfill gas or forest projects). One way to exert some influence over the types of projects the City purchases offsets from is to prioritize the purchase of offsets within a certain radius of Philadelphia, similar to Austin’s approach, in order to maximize the potential localized effects, such as job creation. It is worth noting that Austin is pursuing a combination approach; we infer that the quantity of offsets purchased is a function of

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143 USDA Forest Service, 2018.

144 Hoffmann et al., 2020.

145 Hoffmann et al. Supplementary materials table s-1 Retrieved from: [https://www.mdpi.com/2225-1154/8/12/s1](https://www.mdpi.com/2225-1154/8/12/s1)

146 Climate Action Reserve, 2017.
annual emissions minus the quantity of offsets generated via their urban reforestation program mentioned above.\textsuperscript{147}

There are three highly respected voluntary market registries from which Philadelphia can purchase or list any locally developed offsets: American Carbon Registry, Climate Action Reserve, and Verified Carbon Standard.\textsuperscript{148} As of October 2019, there were 1.2 million offset credits issued by these three registries that were generated in Pennsylvania, of which only 109 thousand were issued by forest carbon projects.\textsuperscript{149} The only registry to list offsets generated by forest carbon projects in PA is the American Carbon Registry. If the City were to purchase all the offset credits generated in PA, it would constitute approximately 9.2\% of Philadelphia’s city-wide emissions for 2020.

Developing an offset program can take considerable time and resources. According to the Duke Carbon Offset Initiative, developing an offset program adhering to any one of the pre-established protocols could take up to two years and cost tens of thousands of dollars.\textsuperscript{150} The City may need to hire new or identify existing staff resources that would be responsible for identifying project locations, coordinating tree planting, ensuring protocol compliance, organizing partnerships, and facilitating the verification and retirement of offsets, among other activities.\textsuperscript{151}

The decision alternatives listed next each assume an urban forest offset development approach.

\textit{City Managed v. Contracted Out}

Philadelphia would not necessarily have to assume the role of offset project developer and owner. Philadelphia has the option to contract with local organizations or experienced offset project developers to take on the role of project development and offset verification on behalf of the City. The benefit of working with contractor(s) is that much of the administrative burden can be offloaded to a party with pre-existing expertise of how to develop urban forest offset projects. The benefit of working with local organizations is that it can support civil society to do the work of siting and developing the projects, and then claim the offsets and retire them against the city’s municipal or city-wide emissions.

The city of San Francisco uses a similar model to facilitate the generation of local offsets through its carbon fund without engaging directly in project development itself. The San Francisco Carbon Fund was first established in 2009, and thus, claims to be, “the first truly local

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{147} Treefolks, n.d.
\item \textsuperscript{149} Parajuli et al., 2019.
\item \textsuperscript{150} Arsenault, Mathew. (2020, January 31). Telephone interview.
\item \textsuperscript{151} Arsenault, Mathew. (2020, January 31). Telephone interview.
\end{itemize}
\end{footnotesize}
carbon offset program.”

The City established the carbon fund to support meeting its climate targets by making investments that, “mitigate GHG emissions from visitor, business, resident, and city government activities.” The fund prioritizes supporting the activities of neighborhood and community groups that act as guardians of the urban forest. The City awarded local organization, Friends of the Urban Forest, a grant to plant and provide care for 200 trees under the Urban Orchard Project, which are expected to sequester 150 metric tons of CO\textsubscript{2} over 15 years.

**Private purchase of Offsets v. Public Retirement**

A third design option the City can consider is whether or not to allow for private sector companies to purchase and retire offsets generated by the City’s offset program. This is similar to the approach utilized by King County, Washington, (discussed in more detail in Appendix B) where Microsoft purchased the rights to all offsets generated by the conservation of a specific parcel of rural forest in King County, and a local business has purchased offsets generated through urban forest conservation. Importantly, this model can serve as a means of revenue generation to fund the maintenance and care of the offset project, or for future offset project expansions.

Alternatively, the City can reserve the offsets entirely for retirement against municipal or city-wide emissions. The benefit of not selling the offsets generated by the program are that the City can opt for a lower-fidelity, and thus, less costly approach to verification in comparison to complying with rigorous protocols for the registries discussed above. A local university could provide the role of independent 3rd party verification as an applied learning opportunity for students.

**Diversifying the Offset Portfolio**

Finally, while urban forest offsets are the focus of this analysis, a more diversified portfolio of carbon offset generation is certainly feasible. For example, if the City were to pursue the capture of renewable natural gas or community solar development as described in other sections of this paper, it could equate avoided methane emissions and avoided emissions from electricity generation into carbon offset credits. The recently passed Philadelphia building tune-up program is yet another example of untapped potential for offset generation. Similar to the building efficiency standard program in Cambridge, Philadelphia can explore verifying avoided

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153 San Francisco Department of the Environment, 2013, p. 45.

154 San Francisco Department of the Environment, 2013. Note: Reports used to acquire information on the SF Carbon Fund were somewhat outdated – 2013 being the latest – and information on their website seems similarly old. The SF Department of Environment did not respond to email requests for information on the program, and thus, it is uncertain whether the Carbon Fund is still awarding grants to local organizations for the purpose of generating offsets.

155 King County. (9, May 2019). King County is the nation’s first local government to offer certified carbon credits that protects local forests. Retrieved from https://www.kingcounty.gov/elected/executive/constantine/news/release/2019/May/09-forest-carbon-program.aspx
emissions from efficiency programs that enable investment in efficiency upgrades that are otherwise not yet economic as carbon offsets.\textsuperscript{156}

Cost-Benefit Analysis

This CBA analyzes two approaches for acquiring carbon offsets as a strategy for reducing GHG emissions in Philadelphia: (1) purchasing offsets credits on the voluntary compliance market, or (2) cultivating offsets through a local urban forestry project. The analysis attempts to quantify and monetize changes in welfare for relevant cost and benefit categories over a project lifespan of 40 years.

Forty years is chosen as the project period because it is a common timeframe used in urban forest offset protocols. However, in alignment with the PAVER+ criteria for high quality offsets, permanence of the offsets associated with tree planting as part of this program is a foundational assumption.\textsuperscript{157}

The first approach analyzed is the purchase of carbon offsets through any one of the well-respected and highly vetted carbon registries. This approach would require the City to raise the funds (either through the City budget or via a creative financing mechanism) and purchase them from the market.

The development of urban forest offsets through re-forestation will require substantial effort on the part of the City in terms of resources and capital in order to plan, develop, certify, and maintain the offset project over time. A drawback of this approach is that it will take more time for the trees to mature, and for the sequestration potential of the trees planted to reach a substantial level. However, unlike the first, an urban forest project can yield a multitude of potential co-benefits. These costs and benefits are summarized in the following section.

There are two specific stakeholders whose perspectives are relevant to this analysis. One is the city government of Philadelphia, specifically the OOS, whom established the carbon emission reduction targets and is responsible for implementing emission reduction strategies at the behest of the Mayor and City Council. The OOS would likely be the responsible party for purchasing the offsets in the first scenario and collaborating with the Philadelphia Parks and Recreation department and TreePhilly to oversee the planting and care of trees in the second scenario. Philadelphians – as a microcosm of broader society – also have standing, given that climate change is a phenomenon that affects the entire planet, and carbon sequestered in Philadelphia accrues benefits globally.

Typology of Monetized Costs and Benefits

Establishing a carbon offset program in the city would result in a variety of benefits that are dependent upon the approach used to cultivate the offsets. The benefits can be grouped into four categories: financial, climate change, public health, and temperature benefits. \textit{Table 8}

\begin{itemize}
\item \textsuperscript{156} Read about the Cambridge Program in \textit{Appendix B}.
\item \textsuperscript{157} PAVER+ is an acronym commonly used in the offset industry that represents five criteria that, if met, help ensure genuine, high quality offsets. The letters of the acronym stand for Permanent, Additional, Verifiable, Enforceable, and Real.
\end{itemize}
describes each of the specific benefits pertaining to the aforementioned categories at a high-level. A more thorough description of each benefit and cost, and the literature underpinning them, are can be found in Appendix B.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic property value impacts</td>
<td>The increased value added to properties nearby or adjacent to trees.</td>
</tr>
<tr>
<td>Sequestration-abatement Cost Savings</td>
<td>The difference between the cost of offsetting emissions and the cost associated with direct emission abatement where the cost of abatement is economically impractical at present. Not monetized.</td>
</tr>
<tr>
<td>Avoided mortality from pollution removal mortality</td>
<td>The reduction in deaths associated with air pollution removal conducted by trees in an urban context.</td>
</tr>
<tr>
<td>Avoided heat stress morbidity and mortality</td>
<td>The reduction in morbidity and mortality associated with a reduction in the heat island effect in an urban context. Not monetized.</td>
</tr>
<tr>
<td>Climate &amp; Environment</td>
<td>The avoidance of climate change induced damages associated with the emission of an additional ton of elemental carbon. This is otherwise known as the social cost of carbon.</td>
</tr>
<tr>
<td>Precipitation Interception</td>
<td>The improvement to the urban water cycle provided by tree canopy that ultimately reduces runoff and pollution of local water sources. Not monetized.</td>
</tr>
<tr>
<td>Monetary Savings from Reduced Energy Consumption</td>
<td>The monetary savings caused by increased tree cover, which consequently reduces the electricity consumption for cooling and heating purposes.</td>
</tr>
<tr>
<td>Avoided CO₂ emissions from reduced energy consumption</td>
<td>The direct reduction in emissions from the generation of electricity due to decreased energy consumption from increased tree cover.</td>
</tr>
<tr>
<td>Equity Impacts</td>
<td>The potential impacts from targeting the benefits of enhanced tree cover in neighborhoods dominated by racial groups that have been found to be systemically underrepresented in terms of environmental amenity allocation, or more vulnerable to environmental disamenities. Not monetized.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Costs</td>
<td></td>
</tr>
<tr>
<td>Cost of Offsets</td>
<td>The purchase price associated with acquiring a given quantity of offsets on the voluntary market and retiring those offsets towards the City’s emissions.</td>
</tr>
<tr>
<td>Cost of Trees</td>
<td>Most similar to the CAPEX cost of infrastructure projects; represents the cost of purchasing trees.</td>
</tr>
<tr>
<td>Administrative Costs</td>
<td></td>
</tr>
<tr>
<td>Labor Costs</td>
<td>The salary and wages of additional staff necessary to design, manage, and track the progress of the program.</td>
</tr>
<tr>
<td>Operations &amp; Management (O&amp;M)</td>
<td>Regular care and maintenance activities such as watering, pruning, and mulching that help ensure tree survival, and when necessary, replacement of dead trees.</td>
</tr>
</tbody>
</table>

Assumptions of Analysis

Despite a significant amount of publicly available data on the voluntary offset market, tree sequestration, and other relevant parameters necessary to quantify the impacts of both
scenarios, many assumptions were made in the process of operationalizing this analysis. The paragraphs below briefly summarize many – though not all – of the assumptions of the analysis.

The first limiting parameter is the total available plantable space in Philadelphia. The Green2015 report indicated that there are approximately 1,043 acres of publicly owned vacant land in Philadelphia, and more than 1,365 acres of school yards city-wide.\(^{158}\) The project team summed these values to assume a baseline value of 2,408 total plantable space for an offset program tree planting. However, there is much greater potential space available if the City were to consider planting more than 3,000 acres of privately-owned vacant land or partnering with long-time institutions, such as universities. There is also considerably more plantable space if street-trees are a part of the offset program. Because there is a great range of potential determinations for the total quantity of space, a wide sensitivity range was included in the analysis.

The quantity of trees that could be planted as part of an offset project is a function of both the available land as well as the assumption made about tree-density. For this analysis, a conservative 120 trees per acre are assumed as baseline density; this value is a calculated average of the ideal spacing for the mature Northern Red Oak (species: \textit{Quercus rubra}).\(^{159}\) Since this tree (and many other species) can still thrive in more competitive densities, a sensitivity range of 89 to 153 trees per acre was utilized.

For simplicity, it is assumed that all trees planted as part of the offset program will be of the Northern Red Oak species. This species was selected for a variety of reasons that make it attractive. First, the Northern Red Oak already sequesters the most carbon in Philadelphia on an annual basis, given its relatively large average size at maturity, and because it is in the top 10 most prevalent species.\(^{160}\) Moreover, this species is a good street tree given its high tolerance for pollution and compacted soil.\(^{161}\) Information regarding the carbon sequestration and pollution removal rates are specific to this species and were derived from a combination of a report from the U.S. Forest Service\(^ {162}\) and the i-Tree Planting Calculator version 2.0.0.\(^ {163}\)

The average rate of tree planting is another limiting parameter on the total quantity of offsets that are possible to generate. The project team reached out to TreePhilly, the organization that organizes volunteering tree plantings, as well as maintains its own staff to coordinate and organize wide-scale tree planting to glean on average how many trees can be planted in an average year at max capacity. In a conversation with Erica Smith Fichman, Community Forest Manager at TreePhilly, she indicated that through a combination of street tree office plantings,


\(^{162}\) Nowak et al., 2016.

\(^{163}\) Accessed at https://planting.itreetools.org
volunteers and the tree give-away program, the tree planting capacity in Philadelphia is roughly 2,000 trees per year. This is the rate assumed in the analysis.

The values used to monetize the benefit of trees on private property values was borrowed from a pre-existing analysis that monetized the impacts of Philadelphia’s city parks from 2008. This analysis employs a conservative approach, assuming no increase to property values beyond annual inflation of 1.27% since the year 2008.

Tree costs are a reflection of the average cost for a Northern Red Oak sapling 3-4” diameter at breast height. The range used for sensitivity was corroborated by quotes and estimates shared by the Duke Carbon Offset Initiative. Labor costs were another large cost category and estimates for the hiring of three additional tree maintenance personnel and two operations and program managers to administer a carbon offset program were gathered from Philadelphia’s Office of Human Resources Job Class Specifications.

Through conversations with TreePhilly, the team learned of a meaningful difference between the maintenance costs associated with street trees versus non-street trees in Philadelphia. Street trees have approximately $500-800 worth of additional maintenance costs in the first year for pruning and other care measures, and there are additional costs throughout the life of the tree for pruning and removal. The first year cost differential was included in the analysis, but the long-term costs of pruning and maintenance were not. Though information on the first-year maintenance costs associated with non-street trees was not provided by TreePhilly, a ball-park value of $300 was assumed per tree to cover the range of different locations in which trees could be planted, and therefore, a range of different first-year maintenance costs. It was estimated for the analysis that approximately 30% of the trees planted through the offset project would be street trees.

For the project alternative where the City purchases offsets on one of the accredited voluntary offset registries, a cap on the quantity of annual emissions that could be offset was set at 10%. The average price per offset was gathered from Ecosystem Marketplace, the premier offset market observer. Given that the offset market is predicted to become a more competitive and supply-constrained market in the future, an offset compound annual growth rate of 3% is used in the CBA, with bounds of 1.5% and 5% for the sensitivity analysis.

Results of CBA

Table 9 - Net Present Value of Both Offset Program Scenarios

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Scenario: Purchasing Offsets</th>
<th>Scenario: Developing Urban Forest Offsets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Sequestration</td>
<td>$1,674,838,236</td>
<td>$605,893</td>
</tr>
<tr>
<td>Property Value</td>
<td>$7,493,231,733</td>
<td></td>
</tr>
<tr>
<td>Pollutant Removal</td>
<td>$637,180</td>
<td></td>
</tr>
<tr>
<td>Avoided Emissions</td>
<td>$1,088,334</td>
<td></td>
</tr>
<tr>
<td>Energy Cost Savings</td>
<td>$3,015,396</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>$1,674,838,236</td>
<td>$7,498,578,536</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offset Purchase</td>
<td>($169,273,366)</td>
<td></td>
</tr>
<tr>
<td>Cost of Trees</td>
<td>($967,653)</td>
<td></td>
</tr>
<tr>
<td>Labor Costs</td>
<td>($5,438,009)</td>
<td></td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>($25,801,222)</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>($169,273,366)</td>
<td>($32,206,884)</td>
</tr>
<tr>
<td><strong>Total Net Present Value</strong></td>
<td>$1,505,564,870</td>
<td>$7,460,597,005</td>
</tr>
</tbody>
</table>

Both scenarios for offsets programs yield a net beneficial result as demonstrated in Table 9. The urban forest scenario yields an NPV almost 5x the NPV of the purchasing offsets scenario. The largest driver of this discrepancy is the benefit associated with property values which significantly overshadow the rest of the benefit categories. This is despite the fact that property benefits in the model do not begin to accrue until 20 years into the project. Additionally, the public health benefits of air pollution removal grow over the life of the project to be roughly equally valuable as the benefit of carbon sequestration.

Purely from a carbon perspective, the purchasing program is more preferable to the urban forest program in terms of the ability to meaningfully offset emissions. Trees sequester increasingly more carbon each year as they mature. In the base case, given the constraints on planting, the urban forest offset project would result in 802 MtCO₂e sequestered in 2060, which represents less than 1% of projected emissions for Philadelphia in that year. Thus, the urban forest carbon offset program is admissible not for its climate related impacts alone, but for the cumulative value of all benefits provided by urban trees.

The NPV of purchasing offsets are similarly net beneficial largely due to the comparatively cheap purchase price associated with offsets on the voluntary market relative to the increasing value of the SCC as time progresses.

Sensitivity Analysis

Monte Carlo simulations revealed that the NPV of the urban forest program is always positive. Given 10,000 trials, 100% of the time, the NPV distribution was between $2-$12

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169 The net emissions projection used in the CBA was from the City of Philadelphia’s model with the moderate alternate scenario for carbon intensity.
billion. The NPV was most sensitive to the percentage of a property’s value that is increased by the presences of trees being on or near the property. The discount rate used for the overall project and the real value of properties within 500 feet of a park were the second and third most influential variables, respectively. Comparatively, all other variables in the analysis had negligible influence on the outcome of the project’s NPV.

The property value benefit exerts enormous influence over the range of possible outcomes for the project’s NPV. As such, we ran a Monte Carlo simulation of the NPV excluding this benefit to understand better whether the project would be net beneficial without monetizing the property value benefits. The results indicated that probability of the NPV being positive without the benefit of property values is 0%.

A tornado chart of the distribution of possible NPV outcomes excluding property benefits revealed that the planting rate capacity, or how many trees on average the City could plant in a given year, was the most influential parameter. The parameters for the cost of tree maintenance for street and non-street trees were the second and third most influential variables.

Finally, since offset programs are designed to neutralize the impact of emitting greenhouse gases, a Monte Carlo simulation was run to examine whether there was any possible scenario in which the NPV of the project would be net beneficial for the carbon dioxide benefits alone (CO₂ sequestration by the trees, and CO₂ emissions avoided by reduced energy consumption). The probability of a positive NPV is 0%.

The Monte Carlo simulation for purchasing offsets on the voluntary market revealed that it is not always net beneficial; the probability of the NPV being positive is approximately 60%. The tornado analysis revealed that the cost of offset credits and the compound annual growth rate for the cost of credits contributed the most to the variability of the NPV outcome. The inflection point for the cost of credits, beyond which, the NPV would no longer be net beneficial, is approximately $44.52.

Limitations

While this analysis leveraged data exclusively from rigorous peer reviewed scientific studies as well as official government sources, there is still significant room improvement in the analysis.

One of the primary limitations of the analysis is timeliness of the data used for parameterization, particularly for the forest development scenario. The analysis relied heavily upon a study by the U.S. Forest Service for many of the parameters. That study was conducted in 2016 using data from 2012 and 2011. Potentially, a great many changes have occurred since that time to the monetary parameters extrapolated from this resource – such as the removal value for each air pollutant. It is likely that the value of removal for each of these pollutants has changed since that time, due in part to changes in population, science’s improved understanding of the impacts to public health from PM2.5, and the quantity levels for these pollutants. The only modification made to these values was to update them to 2020 USD values.
While the values attributed to the property benefit category do seem high and have disproportionate sway on the NPV outcome for the offset development scenario, they are likely a conservative estimate for two reasons. First, the values were extrapolated from an economic valuation of Philadelphia’s parks in 2008.\textsuperscript{170} Second, while these values were updated to reflect inflation, we assumed no increase on property values, which is realistically unlikely. However, this method of benefit monetization is nonetheless a proxy at best; parks are not equivalent to trees, and there is likely a difference between the impact of trees and parks on property values. A subsequent analysis that monetizes the specific benefit of trees on properties in Philadelphia would be more ideal. For information on how the benefit to property values was treated see the Appendix B parameter table.

This analysis also assumes that all the trees planted under the offset program would be young saplings. Trees grow slowly, and as they grow, their sequestration capability increases proportional to their growth and size. This analysis is artificially capped at 40 years, which is young in the full lifespan of a tree. It is likely that the sequestration potential of the trees planted through this program would be significantly higher in the years of its life beyond the frame of this analysis. However, because these benefits are so far into the future, they were less meaningful in terms of the original intent of the program to help the City meet its greenhouse gas emission reduction targets. Moreover, it would be possible for the City to develop offset credits from the protection of forested properties that are at risk of being of developed, which would be a model that dramatically differs from the design analyzed in this CBA.

An urban forest program may be significantly more difficult to implement in reality than is suggested in this analysis. If the urban forest program were to be enacted as a new and separate program with a distinct stream of funding and dedicated resources, the potential of the program would be constrained by factors both internal and external to the City’s control, such as the availability of tree service contractors and the stock of trees from local nurseries.\textsuperscript{171} In order to meaningfully expand tree planting operations, reliable and consistent funding would need to be in place such that local contractors and nurseries would have confidence in increasing the scale of their operations to meet the city’s increased demand.

This analysis is also limited by the fact that only one tree species was selected to represent the full sequestration and pollution removal benefits. Other trees may be better than the Northern Red Oak for a variety of reasons that an urban forester is better suited to determine. It is unlikely that the City would invest in only one species for a program of this size; rather, species procured will likely vary depending on the site of planting, soil quality, available space, average size at maturity, attractiveness, ease of care, hardiness, and sequestration potential. Thus, the full benefits may be overstated or understated depending on the optimal portfolio of species planted.

This analysis was meant to be indicative of the benefits and costs associated with hypothetical offset programs in Philadelphia. It is intended to provide directionality on whether or not further consideration of an offset program of either type is worthwhile and was not intended to be used as a reference for a program budget.

\textsuperscript{170} The Trust for Public Land’s Center for City Park Excellence, 2008.
\textsuperscript{171} Smith Fichman, Erica. (2020, February 28). Telephone interview.
Implications

In this section, two offset program alternatives were examined to understand whether or not an offset program could yield net benefits to Philadelphia and help the City to achieve its 80x50 greenhouse gas emission reduction target. Both project designs yielded positive net present values, though sensitivity analysis revealed that the purchase offset credit scenario would not always be net beneficial depending on the price of offset credits and the rate of growth in the cost over time. Moreover, the develop urban forest offset credits scenario would not be net beneficial without the benefit attributable to increasing property values. However, the analysis used conservative estimates for many of the benefit parameters. Thus, it is likely that the positive NPV results are understated, and the probability of either project resulting in a negative NPV are overstated.

The NPV of an urban forest offset program, when only considering the climate change impacts, is not net beneficial. Moreover, an urban offset program only minimally helps the City to achieve its offset reduction goals. Due to the limited sequestration capacity of young trees, and resource constraints on the number of trees that can be planted, CO$_2$ offsets in the fortieth-year amount to less than 1% of the City’s expected emissions.$^{172}$ However, there are a variety of other benefits that urban trees provide that will accrue to Philadelphia that make the project a valuable investment. Moreover, there were several additional benefits that were not incorporated into this analysis, that if analyzed, would likely further increase the probability and absolute value of a positive NPV outcome.

Based on this analysis, the project team recommends that the City further consider implementing a carbon emission offset program of some type, be it an urban forest carbon offset program or an offset purchase program. If the City opts to further explore an urban forest program, it should contemplate the design alternatives mentioned earlier in this section, in particular, the potential value of combining it with additional offset project types, such as capture of renewable natural gas, and/or renewable energy credits from viable solar project designs.

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$^{172}$ The emission trajectory for the analysis is described in Section 3.5.
3.3 Renewable Natural Gas Capture

Introduction

Renewable natural gas (“RNG”) is the refined form of biogas. Biogas is the mix of methane and CO₂ emitted by decomposing organic material during anaerobic decomposition.\(^{173}\) It can be collected from farms dealing in livestock and sewage water treatment facilities, though is usually sourced from landfills. Biogas naturally contains about 40 to 60% methane, the rest of the compound being carbon dioxide, with trace amounts of water vapor and other gases.\(^{174}\) Captured biogas can be used to generate electricity. In fact, of national landfill biogas projects documented by the EPA Landfill Outreach Program (“LMOP”), about 72% currently capture biogas for electricity.\(^{175}\) Biogas that has been refined into RNG has an increased methane content of 96 to 98% at which point it can be injected directly into natural gas pipelines as a substitute for natural gas.\(^{176}\)

Refinement is a three-step process, including primary treatment to remove moisture and particulates, secondary treatment to remove contaminants and compress the gas, and advanced treatment to upgrade the gas to a pipeline quality fuel source (Figure 11). Secondary treatment is still necessary to distill biogas that can be used in generators to produce electricity. Biogas only becomes RNG after going through tertiary, advanced treatment. At that point, RNG is a flexible fuel source that can be compressed into a vehicle fuel or used for pipeline thermal applications.\(^{177}\)

\[\text{Figure 11 - Diagram of Landfill RNG Treatment and End Use}^{178}\]


\(^{174}\) EIA, n.d.


\(^{176}\) EPA, n.d.

\(^{177}\) EPA, n.d.

\(^{178}\) EPA, n.d.
RNG Development in the United States

Government policies, particularly the Renewable Fuel Standard (“RFS”), currently incentivize using RNG as a transportation fuel rather than building energy source. The RFS, along with the state of California’s own low-carbon vehicle fuel standard, are likely drivers behind the predominance of RNG projects in the country dedicated to vehicle fuel production, as documented by the EPA. However, motivated by increasing political and public concern regarding GHG emissions, utility companies still see the value in RNG’s thermal energy applications.

Southern California Gas Company (“SoCalGas”), the U.S.’s largest natural gas provider, services 21.8 million California customers who use natural gas for most heating needs. Yet natural gas is facing competition in California with thermal electrification. With the support of the California Energy Commission, six local governments in California set policies to limit or ban the use of natural gas in many new buildings, requiring entirely electric appliances and heating systems.

To remain competitive as a natural gas supplier amidst a growing call for electrified utilities, SoCalGas now seeks to provide a less carbon intensive product. SoCalGas’s solution is to incorporate RNG into its system and has committed to using 5% RNG by 2022 and 20% RNG by 2030. Replacing 20% of California’s natural gas with RNG holds the potential to reduce carbon emissions at a scale “equal to making every building in the state electric-only, but at half the cost.” Though sourcing RNG at the scale that SoCalGas needs to meet its system supply goals is a challenge, the benefits of RNG as a renewable fuel source and marketable energy option are notable.

In Pennsylvania, a number of landfills operate energy projects, as documented by the EPA LMOP database. Seneca Landfill outside of Pittsburgh, for instance, utilizes biogas in a closed-loop system to primarily fuel onsite vehicles. Additional biogas not stored at the landfill is injected into the local natural gas pipeline as a vehicle fuel for customers. The project generates credits under the Renewable Fuel Standard and received state funding totaling $800,000 toward facility construction, which incentivized the project and made it economically viable. In Kersey, at the Advanced Disposal Greentree landfill, methane emissions are captured, cleaned, and compressed to be inserted into the National Fuel Interstate pipeline. This

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184 SoCalGas, n.d.


biogas is sold as renewable electricity to power plants.\textsuperscript{187} None of the currently operational gas capturing projects in Pennsylvania convert methane emissions into renewable natural gas for building energy use.

Why should Philadelphia consider RNG?

The Philadelphia OOS comprehensively assessed built environment emissions, which includes emissions generated by waste production.\textsuperscript{188} Philadelphia also has a Zero Waste and Litter Plan, which calls for halting outgoing landfill waste by 2035.\textsuperscript{189} However, consideration still must be put toward the need to address existing waste, as well as planning for a future in which Philadelphia continues to generate outgoing waste. With RNG, the City’s waste reduction goals align well with the City’s concurrent interest in pursuing city-wide, low-carbon thermal energy options.\textsuperscript{190}

Currently, heating to Philadelphia buildings comes from oil, gas furnaces, or the natural gas-supplying Veolia steam loop.\textsuperscript{191} This heating is managed by Philadelphia Gas Works ("PGW"). PGW is the city’s natural gas supplier and the largest municipally owned natural gas utility in the country.\textsuperscript{192} The company manages about 6,000 miles of gas pipelines and serves about 500,000 customers in Philadelphia.\textsuperscript{193} Given the prominence of natural gas use in both Philadelphia and the state as a whole, a move entirely away from natural gas use is unlikely to succeed at this point in time. However, the OOS has expressed interest in the feasibility of diversifying PGW using low-carbon thermal energy options as a way to meet the City’s built environment goal.

\textit{RNG Potential for Philadelphia Gas Works}

RNG facilities provide notable GHG emissions benefits. By capturing methane elsewise emitted into the atmosphere, facilities help reduce the high global warming effects of atmospheric methane. For this reason alone, the OOS may reasonably be interested in PGW implementing an RNG project. However, the success of an RNG program depends as much, if not more so, upon the economic value of RNG to PGW as a company.

That said, the value of an RNG project is threefold. First, RNG can be considered a renewable resource. While Philadelphia produces landfill waste, an RNG facility is an asset which could provide a reliable source of gas to PGW far into the future. Second, RNG acts like natural gas, so after constructing the refinement facility, PGW would not need to change any existing infrastructure to begin processing RNG. Third, establishing an RNG facility allows PGW to capitalize on a new market.

\begin{footnotes}
\item OOS, 2018
\item OOS, 2018
\item OOS, 2018
\item OOS, 2018
\item PGW, n.d.
\end{footnotes}
In January 2020, the first renewable natural gas provider entered the Philadelphia natural gas market. The Energy Co-op, a nonprofit cooperative, has been supplying RNG to customers living outside the city through PECO since 2015, but in 2020 began supplying RNG to PGW as well. The Energy Co-op, though, sources RNG from outside the state. Establishing an RNG facility in Pennsylvania would allow PGW to provide a new product to its customer base, and generate a new revenue stream for the company, in a consumer market that has indicated an interest in the product.

Capacity for RNG

RNG comes from three primary sources: municipal solid waste landfills ("MSWLFs"), livestock manure farms, and wastewater treatment facilities ("WWTFs"). Pennsylvania contains a number of these sources.

MSWLFs are the most commonly assessed source of biogas. Under the Clean Air Act, MSWLFs already must collect and control landfill gas levels on site. Some landfills do so through flaring, by burning captured methane. Some landfills operate in a waste-to-energy recovery system, producing energy through waste material combustion, as well as through gas recovery, pyrolysis, and anaerobic digestion. In Pennsylvania, most MSWLF projects are dedicated to electricity generation. However, natural gas pipelines cross the entire state, providing ready access points for RNG transportation back to Philadelphia. As such, MSWLFs that are not currently practicing energy recovery are key sources of potential RNG moving forward.

Pennsylvania also has a number of cattle farms, from which manure can be processed in anaerobic digesters to create biogas. However, only 5% of farms in Pennsylvania are guaranteed to be large enough to handle an RNG program, following EPA recommended criteria. For PGW, cattle farms present an uncertain and likely costly source of RNG.

The EPA does not have official guidelines for biogas operations at WWTFs, likely because many WWTFs already incorporate anaerobic digesters into facility operations for internal use. Philadelphia currently collects biogas from its WWTFs, but not at large enough

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195 Jaramillo, 2019.
196 EIA, n.d.
197 EPA, n.d.
scales to support PGW’s operations. Thus, Philadelphia continues to seek low-carbon energy sources to support the city’s thermal energy consumption.

In short, Philadelphia has several options when considering RNG sources. Ultimately, however, landfill-sourced RNG is likely the most viable option for a scalable, cost-competitive emissions-reducing energy source that can be readily incorporated into PGW’s existing operations. Landfill-sourced RNG both offsets carbon emissions that the City waste sector generates and re-incorporates outgoing landfill waste back into the city energy market. MSWLFs will, as such, be the sole consideration of RNG sources in this analysis.

Scope of RNG CBA

The EPA LMOP database lists three criteria for RNG project candidate sites: be actively accepting waste or have been closed for five years or less; have no less than one million tons of waste; and not have an existing onsite RNG project. Currently, there are ten MSW landfills in Pennsylvania that meet these criteria (Table 10).

RNG facilities must also be able to connect to Pennsylvania’s pipeline system, to carry newly produced RNG to PGW’s factories. Pennsylvania has a robust network of gas pipelines running across the state, and all but two of the nine candidate sites are less than five miles from a pipeline (Figure 12). Since RNG can be mixed with natural gas and transported through the same pipes, once these sites have been connected to the existing pipeline infrastructure, transportation costs are essentially zero for the purpose of this CBA.

Table 10 - PA MSWLF RNG Project Candidates

<table>
<thead>
<tr>
<th>Count ID</th>
<th>Landfill Name</th>
<th>County Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rolling Hills Landfill</td>
<td>Berks</td>
</tr>
<tr>
<td>2</td>
<td>Western Berks Community Landfill</td>
<td>Berks</td>
</tr>
<tr>
<td>3</td>
<td>Wayne Township Landfill</td>
<td>Clinton</td>
</tr>
<tr>
<td>4</td>
<td>Advanced Disposal Services Sandy Run Landfill</td>
<td>Bedford</td>
</tr>
<tr>
<td>5</td>
<td>Advanced Disposal Chestnut Valley Landfill</td>
<td>Fayette</td>
</tr>
<tr>
<td>6</td>
<td>Evergreen Landfill</td>
<td>Indiana</td>
</tr>
<tr>
<td>7</td>
<td>Greenridge Reclamation Landfill</td>
<td>Westmoreland</td>
</tr>
<tr>
<td>8</td>
<td>Kelly Run Sanitation</td>
<td>Allegheny</td>
</tr>
<tr>
<td>9</td>
<td>Northwest Sanitary Landfill</td>
<td>Butler</td>
</tr>
<tr>
<td>10</td>
<td>Modern Landfill</td>
<td>York</td>
</tr>
</tbody>
</table>

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201 OOS, 2018.
202 EPA, n.d.
Methane capture from MSWLFs does not translate to a direct emission reduction in Philadelphia because the landfills are located outside of city limits, potentially even on the other side of the state. However, by sourcing biogas from MSWLFs, PGW is the reason that methane does not get emitted from the site. The benefits of the methane emissions reduction can get attributed the PGW’s use of the resultant RNG in Philadelphia. Furthermore, the city of Philadelphia measures waste emissions as part of its emissions inventory and includes waste emissions in its reduction strategies. Thus, it would be reasonable to apply methane captured from landfills outside the city toward reductions in Philadelphia’s waste sector. So, methane reductions at MSWLFs can be attributed as a social benefit supporting Philadelphia’s emissions reduction goals. Accompanying detailed quantitative analysis can be found in Appendix C.

Typology of Costs and Benefits for RNG

This assessment considers establishing an RNG facility at one of Pennsylvania’s candidate sites. Overall, typology is simple (Table 11). The focal costs encompass facility construction and operation costs, while the benefits are derived from PGW-facilitated sales revenue of RNG, as well as the social value of avoided methane emissions.
<table>
<thead>
<tr>
<th>Benefits</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Generation</strong></td>
<td></td>
</tr>
<tr>
<td>Revenue from Natural Gas Sales</td>
<td>The revenue generated from selling RNG through PGW.</td>
</tr>
<tr>
<td><strong>Climate &amp; Environment</strong></td>
<td></td>
</tr>
<tr>
<td>Avoided Methane Emissions</td>
<td>The social benefit derived from avoiding increases to atmospheric methane, valued as a dollar amount.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Facility Construction</td>
<td>The cost of constructing an RNG refinement facility, based on RNG capture and processing capacity of the facility.</td>
</tr>
<tr>
<td>Pipeline Connection</td>
<td>A base cost of establishing injection lines to connect the facility to existing pipelines.</td>
</tr>
<tr>
<td>Operations &amp; Management (O&amp;M)</td>
<td>The annual cost of maintaining facility operations, dependent on RNG capture and processing capacity of the facility.</td>
</tr>
</tbody>
</table>

**Assumptions**

Assumptions were required to estimate both facility costs and operational capacity. Concerning costs, specific equipment prices and construction costs are generally restricted from public knowledge, so this model does not allow for variations in equipment types or manufacture designs selected for the facility. Instead, bundled capital and construction costs were synthesized from national reports to build the cost estimates. The same is true for annual operational costs of the facility. Where details are limited, generalized costs of running the facility were pulled from public reports.

Capital costs are assumed to evenly distribute over three years, beginning in 2020. Once finished, the facility is assumed to shift into full operational capacity. From 2023 to the model’s end period of 2050, annual O&M costs are consistent each year.

The facility must be connected to an existing gas pipeline, to transport RNG. All but two of the candidate sites are similarly close to pipelines, so the interconnection cost of adding an RNG facility to the pipeline system is assumed to be the same for all project options modeled in this assessment. Conversely, capital and operational costs are not constant across project options, but are instead varied based on facility capacity to capture RNG and direct it to project use, called the facility flow rate.

Of Pennsylvania’s current biogas collection projects, recorded flow rate of biogas to project use can be highly variable and is not strongly correlated to the amount of methane measured to be otherwise emitted from the project site. Determining potential biogas project flow rate from Pennsylvania’s candidate sites is difficult to determine to great specificity. Instead, a high, mean, and low potential flow rate was determined based on the current methane emissions of the candidate sites, as well as generalized correlations between current project site methane emissions and project flow rates. The high and low flow rates clarify the likely upper and lower bounds of RNG that could be collected from a Pennsylvania facility established at a

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given candidate site. The higher flow rate facility also has the higher capital and O&M costs, as well as greater RNG generated for sales revenue.

The benefit generated from sales revenue is also based in some assumptions. Philadelphia provides very transparent information on the comparative pricing of natural gas suppliers for consumers. As such, natural gas pricing can be highly competitive. In addition to that, anticipating market changes in the emerging RNG sector is difficult. Therefore, it would be extremely challenging to model PGW’s realistic sales volume of RNG using the existing price of Philadelphia’s newly established RNG company, the Energy Co-op, especially through 2050, the extent of this CBA’s analysis. To ensure that all captured RNG is sold, RNG is instead priced at PGW’s current natural gas rate, rather than the Energy Co-op’s current RNG rate. This does make final profit margins a likely conservative estimate. However, it could be equally true that PGW may not be able to sell the entire volume of RNG captured by its facility every year at the higher RNG price, if consumer interest in RNG decreases or the higher price of RNG becomes a significant barrier to sales. By instead treating RNG as a replacement for PGW’s natural gas, the model can assume not only that captured RNG translates directly to sales revenue, but that the facility will have enough energy demands to justify consistent, annual operations. Assuming consistent operations has the added benefit of making valuation of the social benefit of avoided methane consistent. If facility operations are hampered by inadequate or inconsistent sales, then the value of avoided methane emissions becomes unreliable as well.

Finally, a leakage value is applied to facility operations and kept consistent across options, regardless of facility flow rate, the assumption being that a similar construction process would be applied to each facility with the same leakage risks. The assumption that RNG is comparable to natural gas carries through to this assumption as well. The leakage rate used is a mean value generated from published low and high estimates of natural gas industry leakage rates.

Results

The results, in terms of investment value, are mixed (Table 12). Total capital costs see the largest negative value. Depending on the report referenced as well as variations in regulations and permit laws across the country, the capital costs used in this analysis may even be a conservative estimate. Net revenue is negative as well. Revenue may also be a conservative estimate in this mode but doubling the revenue of RNG sales still only generates a positive net profit in the high flow rate option. At this point in time, given capital costs, RNG is simply not a feasible enough project to make the investment financially worthwhile.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Low Flow Rate</th>
<th>Medium Flow Rate</th>
<th>High Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided methane emissions</td>
<td>$155,722,591</td>
<td>$359,279,110</td>
<td>$1,259,437,491</td>
</tr>
</tbody>
</table>

Sales revenue | $ 5,698,323 | $ 13,147,030 | $ 46,086,319
--- | --- | --- | ---
Subtotal | $ 161,420,913 | $ 372,426,360 | $ 1,305,523,810
Costs
Capital costs | ($ 8,467,441) | ($ 17,318,168) | ($ 56,303,485)
O&M costs | ($ 6,647,223) | ($ 12,011,966) | ($ 20,427,110)
Subtotal | ($ 15,114,664) | ($ 29,330,113) | ($ 76,730,595)
Total Net Present Value | $ 107,816,324 | $ 253,466,501 | $ 909,208,686

Even so, the social benefits of RNG production are notable. Methane is a strong greenhouse gas with impactful atmospheric effects. Removing it from the air is highly valuable. Even the lowest flow rate option, with the lowest associated avoided methane benefits, sees massive returns in social benefits. Capturing even a fraction of the methane modeled in this analysis, while making the costs of establishing an RNG program even less cost effective, still guarantees a net positive return on social benefits. Furthermore, when RNG is burned, it releases the same chemicals that burned natural gas does. Since an RNG facility reduces methane emissions from a previously unmanaged emissions site and does not change or add emissions to operations on the consumer end of the production line, the value of reducing methane emissions on site can be taken at whole value.

Sensitivity Analysis

The analysis is most sensitive to changes to market assessment of the future. The analysis uses a discount rate of 10% when calculating the net present value, a standard rate taken when assessing projects with social benefits. However, the nature of methane as a greenhouse gas makes overall impacts of methane reduction highly dependent on the time period of risk considered. Since methane’s global warming potential can be over 30 times that of CO₂, methane lasts for about a decade in the atmosphere but absorbs more energy than CO₂ does over its lifetime.²⁰⁷ Compared to CO₂, removing methane from the atmosphere can be extremely valuable. As a result, varying the discount rate can have great effects on the total benefits gained by capturing methane. To a lesser extent, the analysis is increasingly sensitive to changes to the sales price of RNG (more details in the Appendix C). Given that a positive revenue stream is hypothetically achievable if RNG unit price increases, as modeled in this CBA’s high flow rate scenario, sales revenue is an important variable to carefully consider. Similar to the net present value discount rate, changes in the market price of RNG over the next 50 years will greatly determine the feasibility of implementing an RNG facility project.

Comparatively, shifts in the values of other variables involved in the analysis have minimal impact on potential outcomes. This project will likely not generate revenue through operations alone. The net benefits of this project are driven by and dependent upon the social benefits gained through methane capture. As such, changes in the total volume of gas collected or market price of RNG is not as impactful on the end value of this project.

Limitations

This CBA has constructed a model around a largely hypothetical project, in a comparatively new field of renewable energy. As a result, this assessment is most limited by the assumptions made in order to create a cohesive model. Cost information is based on a literature review of limited data, largely published by consulting firms. As a result, costs and methodology deriving cost values are extremely high level. This model would benefit greatly from more granular cost information, perhaps as facility information disaggregated by equipment or manufacturer, or as fine scale Pennsylvania biogas site cost information. O&M costs have been derived in the same way, and would benefit as well from more granular cost data.

The RNG pricing assumptions are the other great limitations of this model, which have fewer clear solutions. Until the RNG market is more well established, pricing trends over time will remain uncertain. Outside of a detailed RNG market scenario forecast, pricing options will remain highly dependent on assumptions.

On a different note, landfills produce biogas so long as they are open and receive solid waste. This model projects normal operations of a landfill through 2050. The facility landfill must receive a constant amount of solid waste each year for this model’s assumptions to hold, when in reality that is not certain. Furthermore, this model caps operations in 2050 because that is the year at which the EPA’s social cost of methane projections end. In theory, the facility has no reason to cease operations in 2050, so this model may not have captured the full costs and benefits of an RNG project. Conversely, the facility landfill may close before reaching 2050, depending on the success of the biogas project as well as waste generating trends in Philadelphia, in which case this model again would not accurately reflect full costs and benefits of an RNG project.

Overall, this CBA is limited most by the uncertainty surrounding many aspects of the model’s construction. Some uncertainties can be removed with more detailed data. Some limitations are dependent on inherent market uncertainties of the future.

Implications

As a municipally owned utilities company, PGW is presented with an interesting opportunity in the form of RNG. PGW has already indicated an interest in supplying RNG to Philadelphia by partnering with the Energy Co-op. Beyond that, though, lies an opportunity to bring RNG more fully into the Pennsylvania energy market. A private company would not likely take on an RNG project of the scope assessed in this model, based on the costs of this analysis’ options.

However, the City-supervised company of PGW may see the value in the social benefits of reducing methane as a worthwhile venture. As the city of Philadelphia has set ambitious goals to reduce its emissions from the built environment, being able to claim the captured emissions of an RNG project could be useful to the City reaching its reduction targets. Pennsylvania also maintains funding opportunities that could offset the financial cost of an RNG program. In 2019

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alone, the Commonwealth Financing Authority funded 11 renewable energy projects across Pennsylvania through the Alternative and Clean Energy Program, totaling $12 million in state funding.\textsuperscript{209} Other existing projects in Pennsylvania receive credit and financing for producing renewable vehicle fuel specifically.\textsuperscript{210} While vehicle fuel and thermal energy remain competitive end products for RNG, PGW may see value in establishing biogas refinement facilities that take advantage of the current RNG vehicle fuel market, either in addition to thermal energy or as an alternate path to diversifying PGW’s products.

This analysis has only touched the surface of Pennsylvania's RNG capacity. Though the costs modeled here of an RNG program are not encouraging, the social benefits certainly are. Methane capture is valuable on its own, but also a key potential strategy to achieve emissions reductions for Philadelphia by 2050. A government supported utility company may be an ideally placed candidate to break into the RNG sector in Pennsylvania.

### 3.4 Cost Effectiveness Analysis

Cost effective analysis (“CEA”) is an approach comparing the costs of different projects based on a single outcome. CEA is often used in the economic evaluation of public health interventions and results are expressed as a ratio, dollars spent per year of life gained or death prevented.\textsuperscript{211} CEA can be understood as an approach that attempts to assess which policy has the “biggest bang for the buck”. It can be a useful decision tool for parties that want to pick policies that deliver one particular result at lowest cost. Notably, CEA ignores the other economic and social costs and benefits that result from a policy intervention and narrows the analysis to a single benefit.

The project team applied the methodology of CEA to the hypothetical community solar, carbon offsets program, and renewable natural gas projects to compare the projects solely in terms of their ability to reduce or avoid CO\textsubscript{2}e emissions. The methodology of CEA levelizes project time frames and scales so that the projects can be compared on an even playing field with regards to their ability to reduce or avoided emissions at lowest cost. All of the costs listed in the typologies for the CBA for each project were included in the CEA analysis. The result of the CEAs are summarized in Table 13.

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost-Effectiveness Ratio ($/Mt CO\textsubscript{2}e avoided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community solar</td>
<td>$375</td>
</tr>
<tr>
<td>Carbon offsets program – purchased offsets</td>
<td>$8.76</td>
</tr>
<tr>
<td>Carbon offsets program – urban forestry program</td>
<td>$1,597</td>
</tr>
<tr>
<td>Renewable natural gas</td>
<td>$1,074</td>
</tr>
</tbody>
</table>

\textsuperscript{210} DEP. (n.d.). Alternative Fuels Incentive Grant Program. Retrieved from https://www.dep.pa.gov/Citizens/GrantsLoansRebates/Alternative-Fuels-Incentive-Grant/Pages/default.aspx
Solely from a cost per unit of carbon dioxide equivalence reduction perspective, purchasing offsets on the market has the “biggest bang for a buck” value of the projects. However, this value is based on the assumption of a low growth rate in the price of a carbon offset between now and 2050. Furthermore, there is no guarantee or precedent that an entity can purchase offsets at a scale large enough to benefit the city and would require the City to spend millions without generating any localized benefits.

Community solar has the second lowest ratio of the projects. However, community solar is currently not authorized in the state of Pennsylvania. The combined results of this analysis and the CBA should encourage the municipal government of Philadelphia to continue to advocate for community solar at the state level, not only for its ability to avoid CO₂ emissions and expand the City’s renewable electricity profile, but also for its distinct potential to improve access to renewable energy benefits to low income communities.

RNG the third lowest cost-effectiveness ratio of the three projects. As the landfills that could be viable candidates for RNG are located outside the city of Philadelphia, it is unclear how capturing methane from these facilities would translate to emissions reductions on the City’s GHG inventory. The captured methane could count towards reductions in Philadelphia’s waste sector emissions inventory, but as of now that possibility remains uncertain. As noted in the discussion of the RNG CBA, further research should be considered to determine more granular and site-specific capital costs for constructing the necessary equipment to capture methane from landfills. While there is a substantial amount of emissions to be captured from landfills, the City should be cognizant that beyond capturing methane and potentially generating additional revenue for PGW, RNG offers few other localized benefits for the city.

Lastly, a carbon offsets program through an urban forest has the highest cost-effectiveness ratio. This is partially because the timeline of the urban forestry program in this analysis was limited to 2050, in light of Philadelphia’s penultimate emissions’ target deadline. Trees are able to capture greater amounts of CO₂ as they mature and increase in diameter, so the greatest benefits from an emissions reduction perspective would likely come in the decades following 2050. While an urban forestry offsets program might not result in the “biggest bang for buck” in GHG reductions in the short term, it does offer substantial localized benefits: increasing property values citywide, providing energy cost savings to households as the trees mature and provide shade, removing harmful pollutants from the air, and more.

3.5 Carbon Impacts of Programs Analyzed

As discussed in Section 2, the City will likely have a sizeable quantity of emissions in excess of their 80% reduction goal in 2050 unless additional action is taken. Figure 13 depicts the emissions reduction “wedges” from the three CBA policies added to the City’s and municipal strategies and the magnitude of the diminished stabilization triangle. The data labels quantify the magnitude of each wedge in 2050. The most effective policy of the three is the RNG capture program, which would offset roughly 3.8% of emissions in 2050. The community solar project and urban forest offset projects combined would yield only six thousands of one percent of the
reductions in 2050. A multitude of community solar projects, while not analyzed in this project, would lead to greater cumulative emissions reductions.

Notably, Figure 13 does not show the “reduction” potential of an offset credit purchasing program, whereas Figure 14 does. If implemented as designed in this paper, the offset purchasing program has the greatest effect in terms of helping the City reach its goal. The high level of influence of this program is driven by two factors: the purchasing cap of 10% and the projected net emissions through 2050. If the City failed to continue driving down net emissions, and set a high cap on the offset quantity, then the implications of an offsetting program would be even more significant than modeled.
The avoided emissions from the electricity serving Philadelphia shifting toward cleaner sources of generation will likely far outweigh the impacts of any policies the City can implement. However, the City’s own policies and programs, in place as well as planned, will have a great impact if they are as effective as predicted by the City’s model. The cities policies will achieve just shy 10% of the emission reductions necessary to reach the 80x50 goal in 2050.
4. Transportation Policies

The emissions projection analysis in Section 2 and the potential emissions reduction impacts of the community solar, carbon offsets, and RNG projects in Section 3.5 highlight that the City’s existing strategies in Powering Our Future, combined with the additional policies they are considering, will not be sufficient to meet their 80x50 target. The project team identified the transportation sector as a potential arena with which the City could pursue additional emissions reductions.

The transportation sector is a currently underestimated opportunity to reduce GHG emissions and minimize the gap between projected emissions and the 2050 goal. Philadelphia has dedicated considerable resources to assessing strategies for limiting building emissions, to marked projected success. The majority of strategies outlined in Power Our Future revolve around addressing emissions from the city’s building sector, which represents roughly 80% of the city’s total emissions. However, we noted a lack of cohesive strategies to address transportation emissions, which account for approximately 17% of the city’s emissions. Relatedly, the project team noted that the City’s model has an underdeveloped projection of transportation emissions through 2050 when compared to the model’s built-environment predictions. The transportation emission projections in the model are based on a report by Drexel University researchers that forecasted the business as usual emissions for the transportation sector in 2050 to be 1.97 Megatons (equivalent to 1.8 MMt CO₂e). The values for 2020, 2030 and 2040 transportation emissions were interpolated from this value and the 2012 GHG inventory estimate.

The City’s model not having a thorough component dedicated to transportation emissions may be attributable to the lack of prioritization that the city of Philadelphia has given towards reducing emissions from the transportation sector. However, in the event that the city’s electric grid does not achieve zero emissions by 2050, the City may need to implement other strategies to help reduce or stave off a continued growth in emissions.

The project team has no reason to doubt the accuracy of the transportation emission projections from Drexel. Rather, the project team created its own model to project emissions from transportation by mode of transit through 2050 which yielded a very similar result to the Drexel figure (1.93 MMt CO₂e). The reason for creating a model for transportation emissions was to enable the exploration of various potential transportation emission reduction policies and whether such policies could play a valuable role in furthering the city towards its ultimate reduction goals. Details on the transportation model developed by the project team can be accessed in Appendix D. The model is publicly available and can be retrieved by emailing Dr. Betsy Albright at elizabeth.albright@duke.edu.

CO₂ mitigation strategies in the transportation sector can take numerous forms. However, the most effective emission reduction transportation policies are most often targeted at moving

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212 OOS, 2018.
213 OOS, 2018.
215 The model is publicly available and can be retrieved by emailing Dr. Betsy Albright at elizabeth.albright@duke.edu.
people out of their personal vehicles and into public transit. To provide an idea of how Philadelphia might tackle transportation sector emissions, we have considered three transportation strategies that Philadelphia might utilize. Where possible, we modeled impacts of these policies on the transportation sector and its emissions.

Important to note, however, is that the electric grid feeds into not only the built environment but the transportation sector as well. We therefore incorporate our grid intensity scenarios into our transportation sector baseline model, for consistency across analyses (Figure 15). We use the Moderate Scenario for grid intensity when assessing the impacts of our selected transportation policies on emissions projections.

![Figure 15 – BAU Projected Emissions from Transportation Sector](image)

Sales Tax and Public Transit Financing

Personal vehicles are an ongoing source of major GHG emissions. The best way to manage these emissions is by encouraging people to use public transit. In fact, studies show that people with access to public transit will use it, even if they have a car. To increase use of public transit though, public transit projects must continue to be developed and maintained. Financing, then becomes a crux of sustainable public transit development.

Sales taxes have contributed to public transit funding for decades. Base sales tax rates are set by the state, and range from about 2% to 6% across the United States, though cities can


adopt sales tax additions to generate city funds. Cities across the U.S. have implemented sales tax policies that directly fund transportation infrastructure. In 2015, through a ballot measure, Phoenix, Arizona raised the sales tax by 0.3% and dedicated the additional revenue exclusively to transit projects, which essentially doubled the amount of funding dedicated to transit in the city. The City used the additional funds to improve its bus service, expand the light rail, and improve city sidewalks and bike lanes. As a result of this policy, the City saw a 6.1% increase in bus ridership in 2017, and a 2.7% increase in public transit ridership as a whole. Phoenix is not the only city to implement a sales tax increase to the benefit of its public transit system.

Despite the benefits, voter approval of transit funding through sales tax increases is mixed. In 2019, following the compromise of a reduced income tax, Cincinnati, Ohio voters approved a 0.8% sales tax increase to help finance the city’s Metro bus service. In Henry County, Georgia, a local option sales tax was approved with the prediction that over $92 million funding would be generated for regional transportation projects. Meanwhile, Larimer County, Colorado rejected a half-cent sales tax increase predicted to raise nearly $1 billion over the next two decades, while Osceola County, Florida rejected a one-cent sales tax meant to fund road repairs. The success of a proposed sales tax increase is highly dependent on the tax increase, the recipient project of the new funding, and public understanding of the funding benefits.

Pennsylvania's sales tax is 6%, though Philadelphia’s current combined tax is higher at 8%. As a result, opponents may argue that another sales tax increase will disproportionately hurt low income Philadelphians. While this may align with conventional wisdom, the literature presents a contrasting theory: the degree to which the sales tax increase will be regressive to economically disadvantaged persons is dependent upon how those funds are spent or redistributed. What matters is, who benefits, which projects are funded, where projects are located, and when investments occur. Furthermore, according to the Victoria Transit Policy Institute, “overall equity impacts depend on how revenues are used and the quality of travel

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choices. If revenues are used to benefit lower-income households and there are good travel alternatives to driving … taxes can be progressive overall.” As long as the revenues from the tax increase are used to enhance and expand public transit and infrastructure for alternative modes, as is suggested, the funds will likely yield benefits for the low-income population.

Acknowledging, though, that an increased sales tax is still a political and social hurdle, Philadelphia has other financing options. Cross-sector taxes could be adjusted minimally to pool resources for a public transit fund. New York for instance, has instituted a cannabis tax, whose funds will be combined with revenue from New York City’s upcoming congestion pricing scheme to fund subway operations. Philadelphia could also consider implementing a parking performance pricing system. Though a relatively new strategy, trial projects have been implemented in San Francisco and Boston, to adjust street parking meter prices based on the availability of parking spaces in the surrounding area. San Francisco’s ongoing performance pricing scheme increases street meter parking in high demand areas to encourage people to move their street parking to under-utilized streets. Boston, after completing their two 2017 trial schemes, reported a $5.7 million increase in meter revenue from their 2016 numbers in their first trial area, and a $350,000 increased revenue at their second trial area.

The cost of public transit projects is extremely varied, and the ramifications of these financing projects on public transit ridership are difficult to model. However, public transit needs funding not only to maintain operations, but also to expand and encourage people to leave private vehicles and shift into public transportation. When strategizing for future transit development, these are potential financing avenues for the City to consider.

Congestion Pricing

Congestion pricing schemes are another policy option that Philadelphia can consider to reduce emissions from transportation. Congestion pricing encapsulates a range of pricing actions meant to reduce traffic through an area. They are built around managing demand for personal vehicular travel. The price setting itself can be fixed, or a variable fee based on the time of day or dynamic user demand. Some congestion pricing schemes are aimed at interstate travel, such as toll roads and express lanes which give drivers the option to pay a fee to avoid traffic on the main road. More often though, congestion schemes are aimed at intercity travel, wherein a highly trafficked area of a city requires a fee for personal vehicles to enter. Intercity congestion pricing schemes are most commonly known as cordon pricing.

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Congestion pricing schemes have been used in cities all over the world, including:

1. Singapore, 1975
5. New York, expected 2021

Congestion pricing is a concept with a long conceptual history but short applied history. Though Singapore implemented its cordon pricing scheme in 1975, most development in the field has happened since the turn of the century, as cities apply and evolve cordon pricing schemes to best fit their citizenry’s lifestyles. Appendix D contains more details on the history of cordon pricing schemes. That said, though each of these cities had varying reasons for implementing a congestion pricing system, some similarities thread through every design. Namely, adaptive fee systems were applied to avoid creating overly restricted zones and public transit systems were always improved in tandem with a scheme’s implementation, to avoid stifling city travel.

We modeled the impact on emissions of a hypothetical cordon scheme around Philadelphia’s Greater Center City. Greater Center City is a central hub for commuting and travel within Philadelphia and promises to continue developing in the future. The cordon scheme was designed to capture commuter travel into and out of the downtown area over the course of a workday; cordon schemes force a reduction in the number of personal vehicles used in a population. This model assumes a 25% reduction in commuter traffic through the cordon zone as a result of the scheme. That relationship is based on similar scheme designs from other cities currently implementing cordon zones, particularly London and Milan (Appendix D contains model more detailed model assumptions).

For Philadelphia, since public transit infrastructure connecting Greater Center City is robust, the team assumed that any commuters dissuaded from using personal vehicles under the policy will easily shift to public transit, without undo lag or strain on the system. The scheme is modeled to capture long distance commuters, so riders moving out of personal vehicles are modeled to move into train, regional rail, and bus public transit modes. Impacts on final city emissions are not significant. The congestion scheme results in a 34% reduction in emissions from 2018 levels by 2050, a 5% improvement in emissions reduction from the baseline projection of emissions in 2050.

Though the direct impacts of a cordon scheme on emissions reductions is minimal as modeled, several key factors must be kept in mind when evaluating the full potential of a cordon scheme. First, the modeled impacts are based solely on commuter data, rather than overall

234 Lehe, 2019
intracity travel, and so offer a conservative estimate of impacts. Second, cordon pricing produces a new revenue stream which the City would be able to dedicate to its public transit system. Maintaining and improving the efficiency of the city’s public transit can encourage people to choose public transit over personal vehicles, without any direct forcing on personal vehicle use. Finally, the efficacy of a cordon pricing scheme only improves as a city’s downtown area expands. As the Greater Center City continues to develop, more people will be drawn to traveling to and from the district, which would magnify the future impacts of a Greater Center City cordon zone beyond what has been modeled here. Overall, a cordon pricing scheme is a flexible tool for traffic and emissions control that the City may find worthwhile to consider when looking forward.

Maximum Parking Standard

Another approach that cities are using to decrease their emissions from transportation is to implement maximum parking standards. A maximum parking standard is a policy that establishes an upper limit on the quantity of parking space allowed in an area. They can be applied at variable scales, from specific apartment complexes to whole cities. Parking maximums can help public planners achieve a variety of goals: increase tax revenue through parking redevelopment, improve pedestrian safety in a downtown area, mitigate the effect of the urban heat island, and reduce stormwater runoff. Parking maximum policies make most sense in concentrated urban contexts where there is a high supply of public transit options, attractive pedestrian environments, and dense businesses areas. Areas that meet these characteristics, such as Philadelphia, can withstand the competitive disadvantage that may come from the loss of parking space.

Parking maximums also reduce car ridership. Abundant and low-cost parking encourages driving and engenders urban sprawl. The relationship is strong enough that some transportation scientists have argued that it is empirically causal. Using a widely-accepted epidemiological method to determine causality, and data going back to 1960 from nine U.S. Cities, a study found that a 0.3 parking space per person increase results in a 23% increase in personal vehicle mode share.

As of 2018, Philadelphia has 2.2 million parking spaces, which equates to roughly 3.7 spaces per household, or 1.4 spaces per person. As argued above, if the City wants to meaningfully decrease the share of its residents that use personal vehicles, the quantity of


236 Metropolitan Area Planning Council (MAPC), 2010.

237 Metropolitan Area Planning Council (MAPC), 2010.

238 Metropolitan Area Planning Council (MAPC), 2010.

239 Metropolitan Area Planning Council (MAPC), 2010.

240 Victoria Transportation Policy Institute, 2018.


242 McCahill et al., 2016.

parking space the City currently possesses works counter to their goals. Instead, reducing the quantity of parking spaces in the city is likely a viable way to shift drivers out of cars and into alternative modes of transportation. Moreover, the reclaimed parking spaces can be repurposed into public land uses the City needs more of, such as parks, sidewalks, protected bike lanes, and affordable housing. Appendix D contains a greater exploration of parking standard barriers, benefits, and city implementations.

We modeled the impact of a hypothetical parking maximum policy with the goal of reducing parking spaces from 1.4 to 0.9 per person. We applied the linear relationship found in the above parking space causality study to determine annual reductions in city parking spaces over a 25 year period, from 2025 to 2050. To achieve our space reduction goal, the City would need to eliminate about 625,000 parking spaces in the city, translating to a 25,000 space annual reduction. Such a reduction impacts the number of people who continue to use personal vehicles (assumption details in Appendix D). Annually, the mode share of Philadelphia’s population using personal vehicles decreases 0.014, so that final mode share of personal vehicles decreases from the baseline’s 0.6 to 0.2 in 2050.

People moving from personal vehicles are assumed to move into public transit. The model absorbs new ridership into trains, trolleys, and buses, to account for the assumed need for both long distance commuting and easy downtown travel. With these shifts into less carbon intensive transportation modes, the city sees a significant improvement in final emissions. The parking maximum standard achieves a 63% reduction in emissions from 2018 levels by 2050, which is a 47% improvement from the baseline 2050 projection.

Unfortunately, parking authority within Philadelphia actually resides with the state, rather than the city. The City cannot enact a maximum parking standard independently, but instead, must advocate to the Commonwealth. In addition, the topic of parking in Philadelphia is highly contentious. Debates have long been held concerning parking prices and availability. Needing to advocate for the standard already reduces the City’s project control. Advocating for a standard involved in such a polarizing issue is only another barrier to successful project implementation.

Discussion

In terms of greenhouse gas emission reduction, Philadelphia is missing a potentially high value "wedge" by placing so little emphasis on the transportation sector. In terms of city improvement strategies, the policies recommended here are ones targeted not only to reduce city emissions, but also improve daily transportation in Philadelphia. Either in tandem or alone, each transportation policy this team has recommended has the potential to benefit the city in more ways than just emission reduction.

244 McCahill et al., 2016.
Even so, with regards to emissions reduction goals, some strategies must be more effective than others. As modeled, the maximum parking standard sees much reductions to greater sector emissions than does the congestion pricing scheme (Figure 16). Furthermore, when both policies are implemented in the same projection, overall emissions reductions improve by only 1%. The parking scheme is simply extremely effective at curbing personal vehicle use and, in turn, sector emissions.

Both policies are still worth considering, however, as they bring new strategies into Philadelphia’s emissions reduction toolset. Implementing transportation sector strategies which center around personal vehicle use will balance out existing built environment strategies which focus on energy efficiency improvements. This will become increasingly valuable as the electric grid intensity improves moving forward, and energy efficiency strategies becomes decreasingly impactful. In short, while the City remained focused solely on built environment strategies, the transportation sector will remain an untapped resource for emission reduction.

Figure 17 shows the of the modeled emission reductions from these transportation policies in the context of city-wide emissions projected between now and 2050. If implemented in tandem with the policies examined in the cost-benefit analysis section, the model shows the city achieving a 64.8% reduction related to 2006 emission levels. This would mean the city is still emitting 6.63 MMt CO₂e in excess of the 2050 reduction goal.
The modeling efforts undertaken in this paper are by no means an indication of what will happen, nor is there any ability to tie probability to any of the modeled outcomes, should the City implement any or all of the policies examined. Rather, the modeling effort is meant to be illustrative of what could happen, given current known factors.

What this effort illustrates, is how difficult it will be for the city of Philadelphia to meet its goals through their actions alone. This is not to say that there are not more policies that the City could implement beyond what is currently in place or planned; to the contrary, one of this project’s goals is to highlight the potential of several policies and programs the City could enact that would have the effect of reducing CO$_2$ emissions. However, implementing all of these policies will not ensure the City achieves its 80x50 reduction goal. State and federal action will be necessary to reach 80% reduction in emissions relative to 2006 by 2050.

However, there are still numerable policies that other cities across the world are enacting that differ from what the city of Philadelphia is doing and has planned. The following section synthesizes many of these city-level policy and programs as a reference for subsequent analysis and study.
5. Additional Policy Options and Examples from Other Cities

Around the world, major cities have developed and implemented climate action plans to curb carbon emissions and increase the share of renewable energy. This section outlines a set of policy options that can be potentially adopted by the city of Philadelphia in order to reach its 2030 and 2050 carbon emissions and renewable energy goals. The policies are divided into the three main categories that are under consideration for the city of Philadelphia – buildings, energy and transportation - with examples of successful policies that the city of Philadelphia can use as reference and potentially implement in the future.

The policies selected for this analysis have been implemented by cities that belong to the C40 Climate Leadership Group. This organization is composed of major global cities across the world, all with significant economic and environmental influence at a global scale.

While Philadelphia has already given details of its climate action plan in the Powering Our Future report, we believe that there is more room for improvement in terms of higher policy standards and new alternatives do be discussed. This is especially true in the transportation sector, which has a considerable amount of potential for carbon reduction and is not directly addressed in the report. This analysis aims to provide more information on an array of policy options that other cities are implementing to reduce emissions.

Global Context

Climate action is being addressed by major cities worldwide with a wide range of policies to reduce carbon emissions and improve efficiency in sectors such as buildings, energy and transportation. The C40 group aims for collaboration between cities to tackle climate change and reduce the urban impact on the environment through policy action. The city of Philadelphia, as well as other major cities in the U.S., are part of this group.

Amongst the work done by the organization is annual global reporting and tracking of the Paris Agreement climate change goals, including policy action and recommendations for cities to take in order to reduce their emissions. We have looked at the organization’s reports and recommendations in order to pinpoint the main policy trends that are relevant to our project and that can add complementary value to our previous wedge and CBA analysis.

According to the organization’s most recent report, the 84 cities members of the C40 group were responsible for 240 MtCO\(_2\)e emissions in 2015,\(^\text{246}\) a significant amount when compared with the global yearly emissions of approximately 36,000 MtCO\(_2\)e.\(^\text{247}\) This number reflects the importance of action that must be undertaken in cities and urban areas within the global context of climate change.

While cities are responsible for large amounts of greenhouse gas emissions, they also have the possibility to be drivers for change. Due to their concentration of resources and human capital, they are able to move forward with technological and political solutions in a faster way than sparsely populated areas. According to research by the C40 group, 51% of the emissions reductions needed for C40 cities to be compliant with the Paris Agreement can be achieved through policy actions where local city governments have influence\textsuperscript{248}. Major cities within the C40 group have begun to take significant steps in shifting in the way that urban transportation, building and energy policies are planned and developed in order to achieve considerable greenhouse gas emission reductions.

Similarly to Philadelphia, other cities have set targets for reducing emissions reductions, as well as improving energy efficiency and consumption. Just to mention a few examples, the city of Boston aims to reduce its carbon emission 50\% by 2030 and 100\% by 2050, using 2005 as a baseline year. On a municipal level, carbon emissions are aimed to be reduced by 60\% in 2030 and 100\% by 2050, effectively becoming carbon neutral. In the case of New York City, it is aiming to reduce its carbon emissions 80\% by the year 2050, using 2005 as the baseline year\textsuperscript{249}. Lastly, the city of Washington DC, under the District of Columbia’s governance, aims to reduce both its greenhouse gas emissions by and energy consumption by 50\%, as well as increasing its share of renewable energy use by up to 50\%.\textsuperscript{250} All three of these policy cases will be further expanded below, as well as other cities from within and outside the U.S. Local governments in these three cities, as well as in others in the U.S. and worldwide have also pledged to commit to the Paris Climate Change Agreement and lead efforts to keep global warming under 1.5 degrees Celsius\textsuperscript{251}.

Building Policies

Most major cities in developed nations possess high rates of building energy consumption and carbon emissions. In Philadelphia, building emissions account for 79\% of the citywide emissions\textsuperscript{252}. Other major cities have similar percentages and have started developing strategies and policies that will enable them to produce significant carbon emission reductions. While the *Powering Our Future* report addresses these issues, looking at and potentially implementing other cities’ standards and policy implementations can help reduce emissions in this sector even further.

**Regulation for Reduced Carbon Emissions in Large Buildings**

\textsuperscript{248} C40 Cities, 2018, Deadline 2020.
\textsuperscript{252} OOS, 2018.
As part of the Climate Mobilization Act, the city of New York passed new legislation for all buildings larger than 25,000 square feet in 2019. This act aims to reduce the carbon emissions footprint of buildings by 40% by 2030, when compared to 2018, or face financial penalties. The real estate in the city represents a fraction smaller than 2% in New York City, but accounts for half of the city’s emissions from energy consumption.

This law is the first made by a U.S. city to impose emission restrictions produced by, in addition to economic sanctions if the set standards are not met. It is expected that these new legal incentives will encourage further building energy retrofitting and investments in renewable energy sources for building usage. This is especially true when considering the high costs of building maintenance and energy utilities in the city of New York.

Zero Net Carbon and Energy Standards for Municipal Buildings

Zero Net Carbon Standards for buildings require that their construction and operation produce net zero carbon emissions. This is achieved by measures such as high-efficiency climate and lighting systems, efficient enclosures, and reduced consumption of energy generated by fossil fuels. Zero net carbon buildings can potentially run on 100% renewable energy if the resources are available, bringing their carbon emissions entirely to zero.

In the case of Boston, 17,000 metric tons of annual carbon emissions are expected to be avoided from municipal activities following the implementation of these standards. This will also translate into improved air quality in and around the buildings leading to better and healthier environments.253 Because municipal buildings account for large amounts of carbon emissions from local municipal operations, higher standards for building energy performance are essential to reach the City’s carbon emission goals. Building on existing resources and tools, the city of Boston will expand its green building requirements to a zero-net carbon standard between 2019 and 2020 in order to accelerate towards the City’s 2050 carbon neutrality goal. This is expected to result in a 19% reduction in total annual building emissions from a business as usual scenario with no policy implementation by the year 2020.254

In Colorado, the city of Boulder has set the ambitious target of 80 percent reduction in greenhouse gas emissions below 2005 levels by 2050. To accomplish this goal, the City developed and started implementing its own zero net energy standards, developed in collaboration with the Rocky Mountain Institute. These standards apply not only to all existing industrial and commercial buildings but also to residential ones. In addition, the Building Performance Ordinance requires new constructions to comply with the zero net energy standards. This applies to existing buildings with a size of 20,000 square feet or larger, new buildings that are equal or larger than 10,000 square feet, and city-owned buildings 5,000 square feet and larger.255

253 City of Boston, 2019.
254 City of Boston, 2019.
The buildings currently complying with these standards represent 50% of the total City-owned and private commercial and industrial square footage in Boulder. Annual energy savings account for 467,000 MMBtu, and carbon savings total 94,000 metric tons. Energy savings in particular, translate to considerable economic savings by building owners and tenants.\(^{256}\)

Philadelphia can potentially adopt similar types of programs starting with new building constructions in the residential sector, and progressively moving forward with industrial, commercial and state-owned buildings. This will increase its current construction standards even further and reduce larger amounts of building energy consumption and emissions.

Energy Policies

To accomplish its climate goals and reduce carbon emissions, the city of Philadelphia must be able to diversify its grid with an increased share of renewable energy. To accomplish this, the City has set renewable energy targets, which will take major policy action to achieve. This is especially true given the present low penetration of renewable energy in the City when compared to other major cities, and the high standards set by Philadelphia in its climate action plan.

**Implement and Expand Community Choice Aggregation**

As mentioned in our previous CBA section, many states throughout the U.S. have enacted Community Choice Aggregation (“CCA”) legislation and are implementing renewable energy programs into their cities’ grid service. Due to the fact that the state of Pennsylvania does not currently permit CCA programs, this information can also help the city of Philadelphia can learn from other states.

The state of California has enabled the creation of CCAs since 2002, when the State Legislature passed Assembly Bill 117. This bill allowed CCAs to form in the service territories of the state’s utilities and allowed customers to enroll in them, with the option of opting out after a 120 day period.\(^{257}\)

Due to the continued support of CCA programs at the state level, cities such as San Francisco have been able to integrate utilities with high rates of renewable energy generation in their mix, in collaboration with regional investor owned utilities. CleanPowerSF is managed by the city of San Francisco’s Public Utilities Commission since 2016 and is the City’s flagship CCA program.

Residents of San Francisco have the option to choose from their electricity being delivered by either their local utility, PG&E, or by CleanPowerSF. PG&E is currently at 39% in renewable energy sources, while CleanPowerSF offers Green and Super Green services. These


contain 48% and 100% renewable energy respectively. These ambitious policies have helped the City stay on track to meeting its 50% renewable energy target by 2020, which is a decade ahead of the 2030 state target of the same percentage. It is key for the city of Philadelphia to look into these practices and advocate for them on a state level in order to increase its percentage of energy consumed from renewable sources and meet its 2030 and 2050 deadlines.

**Increasing Renewable Portfolio Standards**

Renewable Portfolio Standards ("RPS") are policy targets used by states nationwide in order to encourage increases in renewable energy production and cleaner energy grids. These policies require compliance by the regulated utilities within the states and vary in terms of their time frame and production goals.

In state of Pennsylvania, 18% of the total electricity supply must be generated from qualified alternative energy resources by 2021. As of 2018, the renewable energy supplied 14.7% of the electricity in the state. In the *Powering our Future* report, the city of Philadelphia expressed interest in increasing the state RPS to promote more renewable energy generation to more closely match other state’s standards and the policy results achieved.

The neighboring state of New Jersey currently has an RPS of 50% by 2030. One of the main policies it is implementing to achieve this goal is to offer a flat 15-year price for its Transition Renewable Energy Certificates, giving the industry price certainty and incentives to develop more projects within the state.

Similarly, new standards adopted in 2016 require District of Columbia to have 50% of its grid made up of renewable energy for 2032. These standards also require that 5% of all electricity consumed to be supplied by local solar systems.

An increase in state RPS, in addition to incentives for solar and other renewable energy forms’ development can help the City further increase its share of renewable energy and lower its emissions. Although it is clear that these policy measures must be taken on a state level, the City can look at these neighboring states to make a strong case for raising the state of Pennsylvania’s standards.

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Greenhouse Gas Intensity Limits for Electricity Supplied

In addition to the RPS standards, city governments are working on designing legislation to gradually raise the standards for energy intensity and emissions in conventional power generators (i.e., emission limits per unit of energy). These regulations will also require generators and utilities to provide information of their electricity supply sources.

Complementary to the RPS, Washington D.C. is shifting its procurement of electricity away from large GHG. This is aimed at reducing emissions to achieve the City’s 2032 GHG reduction target. These measures apply to all electricity supplied to the city (both new and current generators), but is aimed at the large emitters of GHG per unit.\(^\text{264}\)

While it might not be within the city of Philadelphia’s authority to legislate over these greenhouse gas standards, the necessity for climate action and meeting the emissions targets can help the OOS and CAC advocate for state legislation that supports higher greenhouse gas emission standards. This in turn can incentivize the generation of electricity from renewable energy sources.

Renewable Natural Gas

As we have previously described in our CBA, RNG technology has potential for implementation in Philadelphia to help provide the City with its energy needs in a more sustainable, carbon reduced way. Numerous cities and states have already started implementing policies and regulatory frameworks to ensure the growth of this energy alternative over traditional fossil fuel sources.

The State of Oregon has passed legislation in order to incentivize financial development in the renewable natural gas sector. Oregon’s largest utility, NW Natural Gas, is expected to invest $30 million a year in a bid to replace 5% of fossil gas by 2024.\(^\text{265}\) NW Natural Gas aims to become 100% carbon neutral for the gas in its system, with recent studies showing that biogas could reduce 10 to 20% of Oregon’s current natural gas use.\(^\text{266}\)

Renewable natural gas as a fuel source can also provide energy to the transportation sector. The city of New York has partnered with Clean Energy Fuels Corp, a renewable natural gas producer to open renewable natural gas refueling stations. Vehicles fueling with renewable natural gas see their carbon emissions reduced by at least 70% when compared to diesel or gasoline as fuel sources.\(^\text{267}\)

\(^\text{266}\) van der Voo, 2020.
Philadelphia could benefit from this energy source by promoting legislation that enables investments in both its energy and transportation sectors. This is especially true when considering the social benefits of renewable natural gas by decreasing carbon emissions and air pollution within the city.

Transportation Policies

As seen previously in our wedge analysis and transportation policy options to address the gap, there are several steps that the city of Philadelphia can take to make its transportation cleaner and more efficient, as well as encouraging healthier and more affordable options for everyday commuting. The following policies are currently being implemented in several cities and can further improve Philadelphia’s action.

The top five transportation programs recommended by the C40 report impact include: bus services; travel demand management; a low emissions private vehicles program; a low emissions truck program; and a freight systems improvement program. It is estimated that in 2030, there would be an offsetting of 340 MtCO\textsubscript{2}e, and by 2040, this number would rise to 640 MtCO\textsubscript{2}e if major cities were to successfully implement these measures.\textsuperscript{268}

The policies implemented in the upcoming years will aim to reduce vehicle miles traveled and carbon emissions from transportation. In most cities such as Philadelphia, Boston and New York, transportation accounts for nearly a third of total carbon emissions, most of that from private vehicles that run on gasoline.\textsuperscript{269} In addition, cities draw thousands of daily commuters from surrounding regions so it is in their interest to shift commuters out of personal vehicles, as well as switching the remaining vehicles on the road to zero emission vehicles, such as electric vehicles to reduce carbon emissions and urban air pollution. Complementary to this, progress is being made towards developing infrastructure for electric vehicle charging and promoting policies for increased ridesharing transportation.

Modernization and Expansion of Public Transit

One of the key aspects in reducing emissions in the transportation sector is to incentivize the shifting from cars and personal vehicles to more efficient and cleaner public transportation. The city of Philadelphia has already a robust transportation system already in place that can be further improved and benefit its citizens with least access to mobility options. Some of the successful policy cases discussed below provide guidance on this.

Starting in 2019, the city of Boston’s public transportation system is undergoing new developments, especially in marginal neighborhoods in the city. These policies include increasing the number of bus priority lanes and updating the existing regional rail and local rail services. New transit hubs are also being created at different strategic points throughout the city to improve connectivity and reduce commuting times. It is expected that these projects will

\textsuperscript{268} C40 Cities, 2018, Deadline 2020.
\textsuperscript{269} City of Boston, 2019.
reduce annual carbon emissions by 55,000 metric tons and reduce vehicle miles traveled per vehicle by 7%\textsuperscript{270}.

New York has begun developing the Brooklyn-Queens Connector, a streetcar line planned to connect residents to work areas that don’t have proper transportation access. In addition, the Citywide Ferry Service was launched in 2017 to attempt to provide additional options to users of the current lines. The City will also continue to fund this expansion through a $2.5 billion investment\textsuperscript{271}. This will support the second phase of major avenues and station reforms, and expansion of communications-based train control, which will allow for more people traveling in less amounts of time\textsuperscript{272}.

New York is also planning to expand its regional rail services, including the trans-Hudson rail service and subway system. In the latter case, new investments are aimed at updating the fare payment system and including new subway cars to increase the current capacity. These improvements are aimed at increasing the use of public transportation, especially by those residents with limited access\textsuperscript{273}.

*Increase Mode Share of Biking and Walking*

In addition to traditional modes of public transportation, other alternatives such as biking and walking are being developed by cities. This is not only done as an effort to reduce city emissions but also provides residents with better use of public space by reducing motor vehicles and improving air and sound quality in urban centers.

The city of Philadelphia’s current percentage of biking and walking are at 2% and 8% respectively\textsuperscript{274}. The City is planning on implementing policies such as expanding pedestrian and biking space, as well as launching the bike sharing program Indego 2.0. It can be useful to Philadelphia to look at other case studies from cities with robust biking and walking transportation systems in order to implement them more efficiently. Below are some good examples of these policy implementations.

New York aspires to have 80% of its modes of transportations used with low carbon impact by 2050. Of this 80% sustainable mode share, the City aims to have 10% made up of bicycle transportation\textsuperscript{275}. The city of New York already has a robust bicycle infrastructure in place which is continuing to expand, having constructed 75 miles of networks in 2016. This includes 18 miles of protected lanes, and an accelerated annual target of at least 10 miles of protected lanes. The City’s Department of Transportation is currently developing a continuous pathway around the entirety of Manhattan that will drastically improve bike mobility. By the end of 2017, the City had added 12,000 bikes and 700 stations to the current network, in partnership with various developers. It is also aiming to build connections across bridges and is advancing

\textsuperscript{270}City of Boston, 2019.
\textsuperscript{271} The City of New York, 2016.
\textsuperscript{272} The City of New York, 2016.
\textsuperscript{273} The City of New York, 2016.
\textsuperscript{274} City of Philadelphia, 2018.
\textsuperscript{275} The City of New York, 2016.
efforts to create a continuous greenway loop around the entirety of Manhattan that will dramatically improve cycling connectivity.\(^{276}\)

The City’s Department of Transportation is also expanding the bicycle network access by increasing the number of parking options near transit hubs and allowing the option for on-street bicycle parking in selected corrals. In addition, the New York State Legislature is developing legislation that will permit the use of electric bicycles. New York is also planning to expand sidewalks and areas that allow the more frequent use of walking, encouraging pedestrian use over cars and other vehicles.\(^{277}\)

Looking at the city of Amsterdam and its policies, one of the key points that can be taken as an example from the city is the coordination between biking and public transportation. Many of the bike racks and parking options available in the city are strategically located near public transportation options such as trams and regional trains. This allows more efficient movement for residents without the need for private vehicles.\(^{278}\)

An additional program named “Park and Bike” allows commuters to bike their way into the city center after parking their vehicles on the outskirts of it.\(^{279}\) This reduces congestion within the city as well as air pollution and emissions. This policy also responds to the restricted options for vehicle parking within the city’s center, as well as the lack of options for private vehicle access in certain downtown areas.\(^{280}\)

**Financial Incentives for Electric Vehicles**

Financial incentives for Electric Vehicles (“EVs”) are key in order to increase their share in the urban space, replacing fuel-based vehicles. These incentives can be used to help EV manufacturers expand their business and reach thousands to millions of users. They also serve as an opportunity for improved vehicle access and autonomy for low income residents through payment plans and other flexible options. Most of these incentives come in the form of tax credits or rebates, which are regulated on a state or federal level. There is a limit to how far the city of Philadelphia can go in terms of moving forward with this policy, but it can advocate to its implementation by using cases from other states in the country.

At the State level, California offers the Clean Vehicle Rebate Program, which provides consumers with rebates to reduce the initial costs of purchasing a plug-in hybrid electric vehicle, battery electric vehicle, or a fuel cell electric vehicle. These can be accessed by residents that

\(^{276}\) The City of New York, 2016.
\(^{277}\) The City of New York, 2016.
\(^{279}\) Buheler and Pucher, 2010.
fulfill the financial requirements and are interested in buying or leasing a vehicle. The program can provide up to $7000 per vehicle.281

Another incentive for qualified electric vehicles and plug in hybrid vehicles is the eligibility for tax credits. The state of Colorado offers new buyers the option to claim a $5,000 credit on their income tax return for the purchase of an electric car and $7000 for an electric truck.282

Research has shown that rebate and tax incentives can contribute to a 4.8% increase in electric vehicle sales, making these policies a useful tool to increase electric vehicle usage and reducing emissions.283 These incentives have promoted the growth in electric vehicles and plug-in hybrid vehicles in Colorado, making it the fourth-highest nationwide state for electric and plug-in-hybrid sales compared to all auto sales at 7,051 vehicles in 2018.284

Supporting Electric Vehicle Infrastructure

Providing electric vehicle users with the appropriate infrastructure is key to ensuring the success of higher electric vehicle usage in cities.

Seattle City Light, the city of Seattle’s public utility, has begun to install fast-charging stations for electric vehicles. These have a capacity of 80 miles of range 20 minutes of charge time. This is part of the “Drive Clean Seattle” program, aimed at decreasing the traditional fuel powered vehicles in the city. 285 Additionally, private companies have also begun installing their own EV charging stations in the city.

Boston is another city that plans to prioritize deployment of electric vehicle charging infrastructure in municipal lots and other publicly owned locations. With these measures, the City projects to have public charging infrastructure available in every Boston neighborhood by 2023. Up to 400,000 tons in annual carbon emissions are expected to be reduced, in addition to 3,400 kg PM2.5, 39,000 kg NOx and $300 savings in each vehicle for maintenance purposes.286

In the city of Barcelona, 40% of transportation is done by public means, while the private sector represents 27% and other options such as walking and biking add up to 33%. In addition

286 City of Boston, 2019.
to its robust public transport system, the city is also providing infrastructure incentives to accelerate the transition to EVs, with 350 charging stations already in place, of which 230 are for electric motorbikes.287

**Parking Lot Requirements**

Circling the destination surroundings in search for a parking spot is a common cause of increased GHG emissions in urban areas. Cities such as Washington D.C., plan to set up policies that consider the minute-to-minute parking demand in different city areas and set parking prices accordingly. This means that the price of parking space will change during the day according to the demand of commuters. It will be higher in peak transit hours and lower during less busy times of the day. As a result, vehicle miles travelled will be reduced and emissions will be further lowered from private vehicles. The Park Rite DC study concluded that parking usage and supply are heavily correlated to parking price.288

Washington DC is basing this policy action from looking at the experiences in cities such as New York, where space used for parking must account for at least 20% of their area designated to EV charging stations in them. DC is progressively requiring parking spaces to include EV charging stations as well. This is subject to how large said area represents but is within the 6% to 12% range.289

The city of Philadelphia has seen limited success with its Electric Vehicle Parking Space program, which is currently suspended and might be completely eliminated in the near future.290 A replacement program that encourages increased electric vehicle usage, such as the one in Washington D.C. could be a good alternative for Philadelphia.

**Car Sharing**

Another policy being implemented to reduce the number of personal vehicles in cities is the promotion of car sharing. This concept allows people to rent an available vehicle through a mobile phone app and park it when finished for other residents to use it.

Paris has been developing this form of transportation with ZITY, a car sharing company, which has a fleet of 500 battery electric Renault ZOEs. The company offers per minute and fixed time rates that are adapted to needs with no registration or subscription fees. ZITY also makes it possible to keep the vehicle when needing to park for a short time without incurring extra costs. In addition, and an algorithm that constantly analyses vehicle use helps identify the areas where the car-sharing demand is highest and can intelligently reposition vehicles in the city after servicing, so that users can easily find a vehicle.

---


According to the car manufacturer Renault, the trend in Paris is that 20% of the city's inhabitants will use car-sharing in the near future.\textsuperscript{291} This translates not only into less vehicle congestion but also less citywide emissions and improved air quality. The city of Philadelphia can potentially complement its electric cars and fleet incentives with the inclusion of car sharing to further reduce personal vehicles travelling within the city.

Key Takeaways

There are many lessons to be learned by the city of Philadelphia when looking at what other cities are doing to reduce their impact of climate change. While the City has done a great amount of work so far, there is clearly more progress to be made, especially in the transportation sector. The most important cities around the world are approaching the traffic, air quality and climate change problem through innovative solutions, while at the same time taking bold action in cleaning their grids and making their buildings more efficient in energy and emissions.

The city of Philadelphia has a great opportunity to adopt the analyzed policies to further decrease its emissions and promoting the use of renewable energy. Much like in the CBA section, this policy section has also shown that there are many additional benefits to the policy options that we have presented, outside of the 2030 and 2050 goals. The City can not only meet its climate change mitigation commitments, but also greatly improve its transportation network, making it cleaner, safer, more efficient and accessible to more residents. At the same time, it can improve its energy grid, making it more resilient, clean and empower its citizens with informed choices. Finally, it can make its buildings more environmentally efficient, reducing costs and attracting investors for more sustainable real estate development.

The social, economic and environmental benefits that these policies can bring could potentially help Philadelphia become not only a referent city in climate change action but also in positive modern urban development.

5. Conclusion

The city of Philadelphia has done substantial work in terms of identifying its climate change mitigation goals and establishing a roadmap to achieve them. The *Powering our Future* report is a testament to the City’s commitment to the environment and addressing carbon emissions reduction needs. Beyond that, the report shows the City’s dedication to choosing energy policies that will benefit its citizens and improve city operations. However, given only the policies outlined in the report, the team was unable to model a scenario in which the City successfully achieves its 80% carbon emission reduction goal for 2050. In order to fully realize its goals, the City may need to consider more diverse sector strategies.

To that end, we hope that the Office of Sustainability can use the results of the cost benefit analyses to determine which, if any, of the programs of interest to the City warrant further consideration. We also hold that the transportation sector has meaningful potential for emission reductions and offer the transportation policies discussed herein as a starting place for policies that the City may consider.

This project highlights how difficult it will be for the city of Philadelphia, and likely many other cities, to meet ambitious climate targets absent similarly ambitious targets at, and additional authority granted by the state of Pennsylvania. As such, we recommend that the Clean Air Council continue to advocate for additional policy enactments within the city of Philadelphia. If none of the policies analyzed herein are suitable, we hope that the city policy synthesis can serve as a jumping off point for subsequent policy deep dives. We also suggest that the Clean Air Council work in tandem with the City to identify strategies for joint advocacy at the state policy level. Though current policies may not be sufficient to meet the City’s goals, Philadelphia is well positioned to identify and implement additional strategies that will continue to chip away at the stabilization triangle, reinforcing the City’s standing as a global leader in climate policy.
# APPENDIX

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Appendix A. Community Solar

Costs and Benefits

Costs

Installation Expenditures

The largest expense of the community solar project is the capital expenditure associated with installing the solar panels on the rooftop of the facilities. This cost was calculated by multiplying the project’s capacity by the $/Watt for commercial solar.

To determine the project’s capacity, the analyst used the National Renewable Energy Laboratory’s PVWatts Calculator tool.\(^{292}\) The tool has a function that allows someone to configure a hypothetical rooftop solar project on existing buildings, using satellite imagery. The tool is then able to determine the capacity of a project at this site, along with expected annual electricity generation using local climate data. Using this tool, the analyst was able to develop a configuration on the roof of the Curran-Fromhold Correctional Facility that could support a 992 kW PV system.

NREL publishes yearly cost benchmarking reports, and the price per Watt of commercial solar in 2018 for systems over 1 MW in size was $1.72 per Watt DC (Wdc).\(^{293}\) The project in this analysis is over 1 MW, but this analysis used a price of $1.60 per Wdc which removes the 7% profit charge that is included in the price provided by NREL. The price provided by NREL is inclusive of the capital cost of modules, inverters, interconnection, hardware, installation labor, and other soft costs.\(^{294}\)

This yielded a gross capital cost of approximately $1.5 million.

Operation and Maintenance

The O&M costs associated with the project are the fixed annual costs. O&M costs for solar arrays typically vary based on the capacity of the project, with smaller solar projects having higher O&M costs than larger projects.\(^{295}\) This solar project benefits from economies of scale and has low fixed O&M costs compared to smaller community solar projects. The cost to the utility for the operation and maintenance of the community solar array is only a function of the generation capacity of the project and the O&M cost-per kW per year, which NREL published data on in 2017, at approximately $16/kw-year.\(^{296}\)

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\(^{294}\) Ran Fu et al., 2018.


\(^{296}\) National Renewable Energy Laboratory, 2017.
Program Administration and Billing

Program administration is a crucial part of the success of community solar projects, and includes the cost of customer acquisition, marketing, education, and record keeping. Program administrative costs are a function of program size and maturity. Administrative costs are highest in the initial years of a program but decline after the program becomes more established and enrollment is complete. Using proxy data from Arizona community solar programs, the program administrative costs are $0.05/W-year for years 1 through 3 of the projects. Administrative costs steadily decline for community solar after the initial enrollment period. Based on the modeling from DeShazo et al., this analysis assumes that administrative costs drop to $0.03/W-year for years 4 through 11 and drops again to $0.01/W-year for years 12 through 21.

There are also costs to the distribution company associated with setting up a new billing system to provide community solar participants with their bill credits. Using data from Arizona’s community solar program, billing costs are $0.04/W-year for years 1 through 3 of the project, and then similarly to administrative costs, drop to $0.01/W-year for the rest of the program’s lifetime.

Benefits

Avoided CO₂ Emissions

The social cost of carbon values used for the CBAs in this report were developed by the EPA as a way to quantify the economic damages associated with climate changing, including changes in “net agricultural productivity, human health, property damages from increased flood risk, changes in energy system costs…[but]it does not include all important damages”. The values used for this analysis encompass both domestic and nondomestic damages from climate change.

While the SCC quantifies the long-term damages associated with CO₂ emissions, the value of the damages depends on the discount rate used for the price of carbon. High discount rates will decrease the value of damages in the future, while lower discount rates reflect higher values for future damages. Regardless of the discount rate selected, the social cost of carbon increases every five years into the future to reflect the increasing damages that every ton of carbon causes, as more carbon accumulates. The analyst used the social cost of carbon at a 3%
discount rate beginning in 2020 as the base case value for this analysis. A 3% discount rate was used throughout the rest of the CBA as well.

The analyst calculated the benefit of avoided CO₂ emissions by multiplying the social cost of carbon by the amount of electricity generated by the project and the carbon emission intensity of Philadelphia’s grid. All three variables (social cost of carbon, the amount of electricity generated overtime, and the carbon intensity of Philadelphia’s grid) changed over time.

The analyst used the electricity generation outputs provided by NREL’s PVWatts Calculator, which found that the project would produce approximately 1.3 MWh of electricity in Year 1. The analyst then used a 0.75% panel degradation rate to determine the electricity output for the project from Year 2 through Year 25.

The analyst used the carbon emission intensity values generated by the “Moderate Rate of Decarbonization” trajectory developed by the team through GCAM, as summarized in Section 2 of this paper. These emission intensity values are summarized in Table A1 below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mt CO₂/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>0.345</td>
</tr>
<tr>
<td>2025</td>
<td>0.293</td>
</tr>
<tr>
<td>2030</td>
<td>0.236</td>
</tr>
<tr>
<td>2035</td>
<td>0.194</td>
</tr>
<tr>
<td>2040</td>
<td>0.178</td>
</tr>
</tbody>
</table>

The analyst assumed that all of the solar project’s generation would be avoided electricity generation from units that would have the approximate emissions intensities above. A more rigorous analysis could determine a more precise value for the avoided electricity generation from dirtier units, using marginal emissions rates and examining Philadelphia’s load demand curve compared to the load profile of the project.304

**Avoided Toxic Air Pollutants**

Solar energy improves local air quality by avoiding toxic emissions such as NOx and SO₂, which are produced by fossil fuel electricity generating plants. Pollution from natural gas and coal plants cause approximately 2,300 premature deaths in Pennsylvania every year, and are particularly bad for cities downwind from coal-burning plants, including Philadelphia.305 These air pollutants are also associated with a multitude of respiratory illnesses, including asthma and bronchitis.306 While these pollutants also provide climate cooling benefits, the net cost of these pollutants still find that the damages outweigh the benefits.307

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305 PSE Healthy Energy, June 2016.
Avoiding NOx and SO₂ emissions provides savings in avoided health impacts, and is a function of the Mt of NOx and SO₂ released per MWh by Pennsylvania’s grid, the electricity generated by the community solar project, and the cost per kWh of NOx and SO₂ emissions.

The analyst used the same electricity generation data described in the procedures for calculating the benefits from avoided CO₂ emissions, from NREL’s PVWatts Calculator tool. The analyst used grid NOx and SO₂ emission intensity values generated by the “Moderate Rate of Decarbonization” trajectory developed by the team through GCAM, as summarized in Section 2 of this paper. These emission intensity values are summarized in Table A2 below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mt NOx/MWh</th>
<th>Mt SO₂/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>0.00026</td>
<td>0.00025</td>
</tr>
<tr>
<td>2025</td>
<td>0.00019</td>
<td>0.00028</td>
</tr>
<tr>
<td>2030</td>
<td>0.00014</td>
<td>0.00026</td>
</tr>
<tr>
<td>2035</td>
<td>0.0001</td>
<td>0.00021</td>
</tr>
<tr>
<td>2040</td>
<td>0.00008</td>
<td>0.00012</td>
</tr>
</tbody>
</table>

Using data from a paper by D.T. Shindell, the analyst found the values for avoided NOx emissions to be $21/MWh, and the value of SO₂ emissions to be $18.69.³⁰⁸ The analyst calculated the benefits in avoided pollutants by multiplying the project’s electricity generation by the pollutant emissions intensity values of the grid and by the Shindell values for avoided NOx and SO₂. Like the avoided CO₂ emissions benefits calculation, the analyst assumed that all of the solar project’s generation would be avoided electricity generation from units that would have the approximate emissions intensities above. A more rigorous analysis could determine a more precise value for the avoided electricity generation from dirtier units, using marginal emissions rates and examining Philadelphia’s load demand curve compared to the load profile of the project.

**Avoided Electricity Generation – Variable Fuel, Operation, Maintenance, and Transmission Losses**

The electricity generated by the community solar array will most likely replace generating units that are “on the margin” in the PJM territory. The value of this benefit captures the avoided costs associated with fuel, variable operation and maintenance, and losses of electricity through the transmission system.³⁰⁹ The electricity generated by this project is used either nearby or directly on the site, thus avoiding the losses that occur along transmission lines as electricity travels from the point of generation to the distribution network.

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³⁰⁸ Shindell, 2015.
³⁰⁹ EPA, 2018.
In order to meet electricity demand at any given time, generators are typically dispatched in order of variable costs from lowest to highest. Base load units typically have low variable costs, such as nuclear power plants, and cannot be easily ramped up or down to meet changes in demand. Natural gas or hydro units can be ramped up or down quickly to meet changes in demand and are often used to help meeting the changes in load. PV can displace units other than natural gas, however, including coal- and oil-fired generators. To capture the variable avoided costs associated with ramping up or down existing generators to meet demand, this analysis uses the LMP; the average market price for electricity in the PJM market. The LMP captures the operational value of PV that displaces the generators on the margin. Philadelphia is part of PJM, a restructured electricity market in which generators bid into the market daily with their various costs and performance characteristics. Generators are selected and paid to provide electricity at their respective bids based on cost effectiveness, and the market clearing price for a day represents the marginal cost of the last generator. This is the generator that the PV array will be replacing. The value of this benefit is a function of the average LMP for the PJM territory and the amount of electricity generated by the project.

**Avoided Costs in Additional Capacity**

The community solar projects also provide value in their ability to defer or replace capital investments in generation or transmission and distribution in the future. A significant portion of ratepayers’ electricity bills are associated with constructing additional capacity for generation, transmission, and distribution. PV’s ability to offset these costs is a function of the system’s capacity credit and the capital costs of additional capacity. Capacity credit, also known as the effective load carrying capability (“ELCC”), refers to the fraction of an array’s capacity that can be reliably used to offset traditional generation. PJM has published data on the average ELCC for solar systems in their territory. To translate the project’s ELCCs into monetary values, this analysis uses values from PJM’s capacity market, known as the Reliability Pricing Model. As a restructured electricity market, PJM’s capacity market seeks to ensure grid reliability over the long term by forecasting expected electricity demand growth and project the additional capacity required to meet it. Participants in this market bid to provide future supply and reduce demand. Similar to the value provided by the LMP, the capacity auction clearing price represents the value of the marginal cost of investment in additional capacity and is provided on a $/MW-Day basis. The value of this benefits calculated as a function of nameplate capacity of the solar project, the 2022/2023 capacity auction clearing price for PECO, and the ELCC of solar in the PJM territory, and the number of days that the capacity would clear.

**Electricity Sales Net Revenue**

311 Denholm et al., 2014.
312 Denholm et al., 2014.
313 Denholm et al., 2014.
The utility is able to sell the electricity generated by the solar array to the market and make a profit on the investment. The profit is a function of the amount of electricity produced by the project, the market residential electricity rate, and the levelized cost of electricity (“LCOE”). The LCOE is the minimum price per kilowatt hour the electricity would need to be sold to cover costs.

\[
LCOE = \frac{\sum_{i} (\text{annual capital cost} + \text{O&M costs} + \text{program admin costs})}{\sum_{i} (\text{project capacity after degradation})} \cdot \frac{1}{(1 + r)^t}
\]

**Distributional Analysis**

*Electricity Bill Credits*

One of the biggest draws for solar projects, whether commercial or residential, is the cost savings they can provide to ratepayers. In the case of these projects, participants receive monthly credits on their bill that are equivalent to their share of the solar array. This project was designed to allow 333 households to participate, with each household’s subscription size totaling 8.5 panels. Over the 25-year lifetime of the project, each household’s subscription generates approximately 77,500 kWh.

The bill credits given to each household is a function of each subscription’s annual electricity generation multiplied by the residential retail electricity rate. Each participating household saves $10,800 over the project’s lifetime, totaling approximately $3.6 million in savings across the low-income households. To reflect the social impact of the lessening the energy burden of low-income households, the analysts calculated a distributional weight for the households that would participate in the community solar project. A distributional weight reflects the notion that dollars received by low-income persons has a greater impact than dollars received by high-income persons. The weight value was calculated with the following equation:

\[
\text{Distributional Weight} = \left( \frac{\text{Median Household Income}}{\text{Weighted Average Income of 3 Lowest Income Brackets}} \right)^{\frac{1}{2}}
\]

Philadelphia’s median household income is $40,649, and the weighted average of the three lowest income brackets (that would qualify for the community solar program) is $16,355. The 1.2 in the equations represents the marginal utility of income, and was taken from a paper by Layard, Nickell, and Mayraz. This equation determined a distributional weight of 3. The bill savings calculated earlier were multiplied by the distributional weight to get a value of $10.7 million.

*Tax Credits*

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The utility does not ultimately bare the total cost of the capital expenditures associated with solar panel projects, as the federal government has several tax credit and cost recovery programs that solar developers can take advantage of. The solar investment tax credit (“ITC”) provides a 30% tax credit on the capital costs of solar. The solar tax credit is slotted to decrease in future years, at 26% for projects that begin construction in 2020, and 22% projects that begin construction in 2021. However, projects that begin construction before 2021 can still qualify for the 30% credit if they are running before December 31, 2023. For the purposes of this analysis, the project assumes that the community solar begin construction in 2020 and is operational the same year, thus qualifying it for the 30% credit. The cost to the federal government, and subsequent savings to the utility, happens in the first year of the project, is 30% of the total project cost, totaling approximately $476,000.

The second tax consideration involved in this project is the MACRS, or Modified Accelerated Cost Recovery. The MACRS allows the utility to recover some of the project capital cost over a five-year period. If a project has already been granted the ITC, then the MACRS is one-half the value of the 30% ITC. The MACRS is also a function of the federal corporate tax rate, the state business tax rate, and the total capital installation costs. The federal tax savings occur in the first year, and the utility can recover 100% of the depreciable basis of the total cost. The utility can also recover 20% of the depreciable basis of the capital cost during this first year, based on Pennsylvania’s corporate tax rate of 9.99%. The equation for these savings is below, and totaled $378,000. The federal corporate tax rate is set at 21%.

\[
\text{Year 1 MACRS} \quad = (\text{total system cost} \times 0.85 \times 0.21) + (\text{total system cost} \times 0.85 \times 0.099) \\
\times 0.2
\]

The utility can also recover costs over a five-year schedule through the state corporate tax rate of the depreciable basis. The state depreciation schedule for the next five years is 32%, 19%, 11.52%, 11.52%, and then 5.72%. In total, the solar developer recovers approximately $417,000 from the MACRS.

By taking advantage of these two tax programs, the utility ultimately recovers an enormous portion of their initial capital investment, totaling $893,700. Thus, while the federal government spends $1.19 million on the project, the utility’s true cost of installation is

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approximately $926,000. With a project lifetime of 21 years and a discount rate of 3%, the annualized cost of capital is $60,075.

Revenues to Utility/Developer

Similar to how the electricity revenues were calculated for the full CBA, the distributional analysis uses LCOE to determine the utility’s margin of profit. Unlike the CBA calculation, however, this analysis took into consideration the impact of the federal tax credits and deductions when calculating the annualized capital cost of the project. The LCOE for the project was determined to be $0.08/kWh. With the retail rate for residential electricity in Philadelphia at approximately $0.14/kWh, the net revenue electricity rate is $0.06/kWh. The analyst then multiple this rate by the project’s generation over its lifetime, taking into consideration a 0.75% annual panel degradation rate.

Program Fees

Traditional community solar programs usually require participants to pay either an annual or one-time subscription fee, which ultimately helps the utility recover some of their costs. This project was designed so that the PEA pays the developer or utility the program fees, rather than the program participants, as high upfront program costs can be a significant barrier for low-income household participation in community solar. Designing a community solar program to benefit low-income subscribers can be challenging, but many programs for low-income households will often use on-bill financing through the participants electric bills. For the purposes of this analysis, the program fees are paid for by the PEA. A full financial analysis was not conducted to determine the optimal program fee structure, and would be necessary in the future. The program fees were a function of the project capacity, and the full $/W price point provided by NREL at $1.72/Wdc, without the profitability margin removed as for the CBA analysis. Program fees totaled approximately $1.7 million.

If desired, the full model depicting the calculations for the community solar CBAs is publicly available and can be retrieved by emailing Dr. Betsy Albright at elizabeth.albright@duke.edu.

Sensitivity Analysis Figures

Figure A1 below is the Monte Carlo analysis of the NPV of the Curran-Fromhold Correctional Facility community solar project. This analysis shows the project has an 82% probability of resulting in a positive NPV.

Figure A1 - Monte Carlo Analysis with Residential Retail Rate

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324 Coughlin. et al. 2010.
325 Heeter et al., 2018.
326 Heeter et al., 2018.
Figure A2 below is the second Monte Carlo analysis that the analyst ran, in which the electricity rate was held at Philadelphia’s commercial rate of $0.06/kWH, unlike the previous analysis which used a base case electricity rate of $0.14/kWh. If the community solar project must utilize an electricity rate of $0.06/kWH, the project has a 18% probability of resulting in a positive NPV.

Figure A2 - Monte Carlo Analysis with Commercial Retail Rates

The tornado chart below reveals the influence of the various parameters utilized in the analysis on the project NPV.

Figure A3 - Tornado Chart of Parameters Influence on NPV
### Parameters for the Community Solar Analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Low</th>
<th>Base</th>
<th>Hi</th>
<th>Description/Calculation</th>
<th>Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel Price</td>
<td>$/W</td>
<td>$1.69</td>
<td>$1.72</td>
<td>$1.83</td>
<td>$/Wdc for commercial rooftop panels.</td>
<td></td>
</tr>
<tr>
<td>Program administration costs years 1-3</td>
<td>$/kW-year</td>
<td>$0.03</td>
<td>$0.05</td>
<td>$0.08</td>
<td>The program costs listed by this source include the billing costs, which were removed for the values for this parameter.</td>
<td>Smart Electric Power Alliance. (2018). <em>Community Solar Program Design Models</em>. Retrieved from <a href="https://www.leg.state.nv.us/App/InterimCommittee/REL/Document/12290">https://www.leg.state.nv.us/App/InterimCommittee/REL/Document/12290</a>.</td>
</tr>
<tr>
<td>Program billing costs years 1-3</td>
<td>$/W-year</td>
<td>$0.02</td>
<td>$0.04</td>
<td>$0.06</td>
<td>Billing costs are higher for programs that are administered by utilities, rather than third parties. These prices were extracted from the total administrative costs found at in the source listed previously. Includes marketing and billing costs. Median for the first year for SEPA. Low is price for programs that have capacity &gt; 1 MW. Medium is for programs that have capacity &lt; 1 MW, and high are for programs that are utility administrated.</td>
<td>Smart Electric Power Alliance. (2018). <em>Community Solar Program Design Models</em>. Retrieved from <a href="https://www.leg.state.nv.us/App/InterimCommittee/REL/Document/12290">https://www.leg.state.nv.us/App/InterimCommittee/REL/Document/12290</a>.</td>
</tr>
<tr>
<td>Retail electricity price</td>
<td>$/kWh</td>
<td>$0.11</td>
<td>$0.14</td>
<td>$0.19</td>
<td>Base case value is Pennsylvania's average price of electricity in September 2019. The high value is New York's September 2019 price and the low value is Texas.</td>
<td>Table 5.6.A from EIA from Monthly Form EIA-861M (formerly EIA-826) detailed data (1990 - present); <a href="https://www.eia.gov/electricity/data.php#sales">https://www.eia.gov/electricity/data.php#sales</a>.</td>
</tr>
<tr>
<td><strong>LMP Average for PJM</strong></td>
<td>$/MWh</td>
<td>$26</td>
<td>$38</td>
<td>$76</td>
<td>The base case value is the 2018 average LMP for the PJM territory. To reflect the swings in LMP based on season, the analyst included a standard deviation of the 2018 LMP data set for the low and high values.</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td><strong>PJM Capacity Auction clearing price</strong></td>
<td>$/MW-day</td>
<td>$140</td>
<td>$171</td>
<td>$200</td>
<td>The base case value reflect the market clearing price for new capacity in ASTI. The low value reflects the clearing price for new capacity for the rest of the RTO, and the high value reflects the clearing price for BGE.</td>
<td></td>
</tr>
<tr>
<td><strong>ELCC of solar</strong></td>
<td>0%</td>
<td>45%</td>
<td>50%</td>
<td>Data on the ELCC for solar in PJM is varied. 45% represents the average ELCC of solar in PJM’s territory, while 0% represents the typical ELCC of solar in PJM’s territory for December and January. ELCC goes up for smaller projects.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Capacity clearing days</strong></td>
<td>Days/year</td>
<td>90</td>
<td>183</td>
<td>365</td>
<td>The base case assumes that capacity clear half the days of the year, while the low value assumes that the capacity only clear for the summer months, and the high value assumes that the capacity clears for the entire year.</td>
<td></td>
</tr>
<tr>
<td><strong>PECO distribution loss ratio</strong></td>
<td>0</td>
<td>0.05</td>
<td>.1</td>
<td>The base case value was calculated using PECO’s reported losses. The high value is based on the national average.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Project generation</strong></td>
<td>kWh/year</td>
<td>1,255,981</td>
<td>1,307,497</td>
<td>1,357,966</td>
<td>The low and high values were calculated by PVWatts Calculator and reflect the year to year variation in solar radiation that an area experiences.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B. Carbon Offsets

Offsetting Programs in Other Cities

An example of a city employing the reinforcing feedback strategy is Cambridge, Massachusetts. Like Philadelphia, 80% of Cambridge’s emissions come from building energy consumption. The city is highly motivated to invest in direct emission reduction locally, and so it established a program of energy standards that become stricter over time, with different tiers for residential, commercial and industrial buildings.

To meet the standard in place for their building, owners have the option of either investing in energy-saving retrofits or upgrades, or buying “offsets” in the form of contributing to the city-established carbon-fund. A third-party organization administers the carbon fund to invest in high cost, high return energy efficiency investments within the building stock through subsidization, enabling these retrofits and upgrades to become economical before they would otherwise do so. Offsets generated through these projects are only viable from the time period in which they become active through the time at which the investment would have been economical on their own without the subsidization from the carbon fund. The program is designed such that as certain offset projects expire, new offset projects must be funded in order to comply with ever-tightening emission standards, thus increasing the cost of purchasing offsets through the carbon-fund option. Eventually, Cambridge intends to phase out the offset-purchase option entirely.

Cambridge’s offset program is just one example of many different types and variants of offset programs. Other cities, such as Austin, TX and King County, WA have chosen to implement offset programs that biologically sequester carbon through trees on urban and adjacent rural lands.

King County has committed itself to carbon neutrality and is employing forest carbon sequestration – specifically, conserving lands at risk of conversion to non-forest through residential or commercial building development – as a mechanism to help achieve this goal. Launched in 2019, the county began quantifying and selling offset credits for carbon sequestered by county public lands acquired since 2015. King County boasts that it is the first local government to create a certified carbon credit program for local forest preservation. The so-

327 Barreto et al., 2018.
328 Barreto et al., 2018.
329 Barreto et al., 2018.
330 Barreto et al., 2018.
named Forest Carbon Program offers offsets independently verified to voluntary standards by a 3rd-party to local companies seeking to offset a portion of their carbon emissions. Microsoft has already committed to purchasing 100% of the rural forest offsets generated by the project in the first year.

There are two crediting streams for the Forest Carbon Program: urban and rural. On the urban side, King County has engaged with City Forest Credits – a Seattle-based non-profit that specializes in urban forests – to use their protocol. In 2018, an independent verifier issued the program’s one parcel of 20 acres of urban forest 3,025 (MtCO₂e emissions) offsets. The rural credits represent the protection of larger forested-areas in the county and will be verified using the Verified Carbon Standard, a well-established voluntary protocol that is used for most rural forest carbon projects globally. Verification of the rural credits of the program are still underway, but are expected to be approved and for sale in 2020.

The Forest Carbon Program dovetails effectively with the county’s already existing land conservation initiative. Revenues from the Forest Carbon Program represent the first private revenue stream for the initiative, which has a goal of, “protecting 65,000 acres of King County’s last remaining and most vital conservation lands and ensuring that all the county’s residents have access to greenspace.” Thus, this program, similar to the offset program in Cambridge, fulfills a medium-term oriented reinforcing feedback program.

Description of Costs & Benefits

Benefits

Financial Benefits

*Aesthetic benefits to property value.* Tree coverage is widely considered to be a desirable and valuable characteristic contributing to property values. Many studies have found that good coverage of yard and street trees in a neighborhood can increase property values by as much as 7% on average, though the full range of can be anywhere from 3% to 15%. Increasing tree coverage throughout the city from carbon offset planting program may increase the value of properties proximal to offset project planting sites.

In the analysis, only “mature” trees – defined here as trees measuring greater than 10 inches diameter at breast height (d.b.h.) – have an impact on property values. Thus, this benefit is a function of starting d.b.h. at time of planting, annual growth rate, median property values, and the quantity of properties “impacted.

Public health benefits

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335 King County, 2019.

Reduction in Mortality from pollutants. Air pollution is linked with negative impacts to human pulmonary, cardiac, vascular, and neurological systems.\textsuperscript{337} There is also a connection between urban green space and a myriad of public health benefits including increased longevity, decreased rate of childhood asthma, decreased rates of cardiovascular-related mortality, improved mental health, and relief from attention fatigue and ADHD symptoms.\textsuperscript{338}

\textit{Table B1} demonstrates the quantity and economic value of pollution removal by the urban trees already existing in Philadelphia as found by the USFS.\textsuperscript{339} The economic value of pollutant removal was estimated as the “avoided human health impacts (i.e. cost of illness, willingness to pay, loss of wages, and the value of a statistical life),” and was determined by using the U.S. Environmental Protection Agency’s Environmental Benefits Mapping and Analysis Program.\textsuperscript{340} In the analysis, the resulting health benefits are a function of average quantity of each pollutant removed by a tree in a year, for each pollutant, multiplied by the economic value of removing a ton of each pollutant.

\textbf{Table B1 - Pollutant Removal Value}

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Value associated with removal in 2012 (millions, USD)</th>
<th>Quantity removed in 2012 (tons)</th>
<th>$/ton removed in 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>O\textsubscript{3}</td>
<td>3.9</td>
<td>332</td>
<td>11,747</td>
</tr>
<tr>
<td>N\textsubscript{2}O</td>
<td>.174</td>
<td>109</td>
<td>1,596</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>.028</td>
<td>48</td>
<td>583</td>
</tr>
<tr>
<td>PM\textsubscript{2.5}</td>
<td>14.9</td>
<td>24</td>
<td>620,833</td>
</tr>
</tbody>
</table>

Climate Benefits

\textit{Carbon damages avoided}. For every carbon offset credit, there is a cancellation of damages associated with the emission of a ton of carbon dioxide. A credit represents the social damages that are prevented by cancelling out a ton of carbon.\textsuperscript{341} The economic value of sequestration is determined by the amount of carbon sequestered, the social cost of carbon, a discount rate, and the change in the SCC.\textsuperscript{342}

In this analysis, the benefits of offsetting Philadelphia’s carbon emissions are a function of the 3\% discount rate social cost of carbon, the quantity of trees planted minus an assumed rate of 1.5\% tree mortality, multiplied by the average annual rate of CO\textsubscript{2} sequestration per tree. An 0\% annual rate of change in the price of carbon is assumed, which indicates that the value to society of carbon sequestered in the future is the same as today; in other words, the value does not change.\textsuperscript{343}

\textsuperscript{339} Nowak et al., 2016.
\textsuperscript{340} Nowak et al., 2016.
\textsuperscript{342} Natural Capital Project, n.d.
\textsuperscript{343} Natural Capital Project, n.d.
Temperature benefits

The existence of trees in urban contexts is associated with cooling that mitigates the intensity of the heat island effect. The cooling effect of trees can be significant, but varies significantly across the day, between seasons, and from neighborhood to neighborhood.344

Building Energy Cost savings. The cooling effect from trees can decrease building energy consumption for electricity in city buildings. Based on average energy costs in 2012 from the U.S. Energy Information Administration, the USFS estimated that the existing trees in Philadelphia reduce energy costs for residential buildings by $6.9 million each year.345 To operationalize this value for the analysis, the total estimated savings was divided by the total number of trees in Philadelphia to derive an average per tree monetary impact on building energy usage with an estimate error value of ± %10 for sensitivity analysis.

Avoided Building Energy Emissions: Given that trees can reduce the energy consumed by buildings, there is an avoided emission from electricity generation associated with the increased efficiency of energy use. The USFS also estimated that the existing urban forest provided $1.4 million each year by decreasing the quantity of GHGs emitted by fossil-fuel power generation; this constitutes a direct reduction of 39,000 tons of CO₂ emitted in 2012.346 To monetize the impact of avoided carbon emissions in this analysis, we divided the quantity of tons avoided by the quantity of trees in Philadelphia to derive an average per tree CO₂ reduction. We then multiplied this estimate by the quantity of trees planted and the social cost of carbon.

Cost Categories

The costs associated with either of the offset project options are straightforward. The approach in which the city purchases offsets would accrue only the direct cost of the offsets; there would be negligible programmatic costs as the role of once annual purchase and retirement of offsets can likely be assumed by existing staff resources within the OOS. The forest offset development approach will incur non-negligible programmatic costs.

Cost of offset credits on the market: The costs of purchasing offsets through an accredited offset registry on the voluntary market will have an average cost per credit to purchase and retire the credit.347 Unlike compliance markets, where offsets typically sell at a relatively stable price, offset prices on voluntary carbon markets can range dramatically.348 Average prices can range between $3 and $6 per ton of CO₂e, but actual prices can vary much more: from under $0.1/ton

344 Nowak et al., 2016.
345 Nowak et al., 2016.
346 Nowak et al., 2016.
347 Retirement is when the end buyer claims the emissions reductions represented by offsets purchased against their own emissions, and the offset is no longer available for trading or selling.
CO$_2$e to just over $70/ton$.$^{349}$ For the purpose of this analysis, I assume a price of $4.50 per offset, with high and low values of $3$ and $6$ for sensitivity analysis.

Several factors could impact the future growth of and price of offsets in voluntary markets. New international agreements, such as the Carbon Offset and Reduction Scheme for International Aviation, could lead to an increase of credit demand.$^{350}$ It is also probable that increasing damages associated with disasters exacerbated by climate change will generate an uptick in demand. These forces combined will likely lead to an increase in the price of offsets on voluntary markets.

*Labor Costs.* There are administrative labor costs associated with starting a City-run offset program; additional staff resources may be necessary to identify project locations, process tree procurements, schedule plantings, and manage ongoing care and maintenance of the trees. These staff will also be responsible for establishing and managing a relationship with a university partner to serve the (hopefully) pro-bono role of independent rating agency: to validate and verify the offsets generated by the project.

*Operations & management costs.* A subset of the administrative costs pertains to the ongoing operational management costs associated with maintaining urban forests offset projects. The trees will need to be monitored to ensure health, existence, and best practices management throughout the life of the offset project. Furthermore, trees will die over the course of the project, and replacing dead trees will be an ongoing cost.

Non-monetized Costs and Benefits

There are additional benefits and costs that, for the reason of being too difficult to monetize, were excluded from the analysis, but are described here to inform broader understanding of the total potential value associated with developing an urban forestry offset programs and/or purchasing offsets.

*Cost savings.* Money can be saved from purchasing or cultivating offsets for units of emission where the cost of abatement exceeds the costs associated with offsetting, either purchased or developed. It is likely that the cost of purchasing and/or developing offsets will be cheaper than the cost of direct emission abatement for certain types of emissions. Thus, there is a savings associated with both approaches analyzed here. Broadly, the cost savings are equal to the cost of *abating* 1 ton of carbon dioxide equivalent (tCO$_2$e) minus the cost of *offsetting* 1 tCO$_2$e.

*Equity benefits.* There is also an equity dimension to the health benefits associated with trees removing pollutants from urban neighborhoods. Minority and low-income populations have been found to be more sensitive to the health benefits associated with increased green space

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access than white populations.\textsuperscript{351} A better distribution of green space could be a valuable tool to combat income-related health disparities in segregated urban areas.

Further, areas of poverty and low tree density are often plagued with high rates of crime and violence and, while these are complex issues, trees have been linked to improved quality of life and reduction in crime. Research has shown that there is an inverse relationship between tree canopy and levels of certain types of crimes - particularly robbery, burglary, theft and shootings; one study conducted in Baltimore, Maryland found there was a 10\% increase in tree canopy to be correlated with a 12\% decrease of these crimes.\textsuperscript{352,353} Thus, an urban forest offset program may yield beneficial results if first targeted towards low-income neighborhoods to attempt to address some of these inequities. However, teasing out the monetary impacts associated with an equity focus with any level of accuracy is too difficult for the purpose of this analysis, and thus, it is omitted.

\textit{Temperature benefits on human health.} There are benefits associated with the cooling effect of trees. As such, there is likely an economic value associated with reduced morbidity and mortality due to heat stress, and this is a value that will likely increase over time as the planet continues to warm. However, the monetary impact on human health impacts from reduced heat stress that is attributable to trees was too complex for inclusion in this analysis, but worthy of mention.

\textit{Rating agency.} Offsets that are certified and entered into registries or sold on any market must be certified as genuine. Traditionally, a third-party is commissioned to provide these certification services on an annual basis. This analysis assumes that the offsets generated by projects under the purview of the city will not be sold on a market, but instead will be used to offset the city’s emissions, procuring a costly rating agency can be avoided. Instead, this analysis assumes that Philadelphia enters into a partnership with a local university who can provide these services for free or at a reduced fee and offer it as a learning opportunity to students of forestry and climate

\section*{Sensitivity Analysis Figures}

\textit{Figure B1} shows the results of the Monte Carlo analysis for the scenario in which the city purchases offset credits equal to 10\% of its emissions. Given the high and low values for parameters used in the model, this project would yield a positive NPV roughly 60\% of the time. \textit{Figure B2} demonstrates the influence of certain parameters on the NPV outcome, as discussed in Section 3.2.

\footnotesize
\begin{itemize}
\item \textsuperscript{351} Jennings et al., 2012.
\item \textsuperscript{353} Troy, Grove, & O’Neil-Dunne, 2012.
\end{itemize}
Figure B1 - Monte Carlo Analysis for Offset Purchase Scenario

Figure B2 – Tornado Analysis of Offset Purchase Scenario Monte Carlo Analysis

Figure B3 shows the probability distribution for the range of NPV outcomes for the scenario in which the city develops its own offset credits through an urban forest program. Given the high and low values for parameters used and benefits included in the model, this project would yield a positive NPV 100% of the time. Figure B4 demonstrates the influence of certain parameters on the NPV outcome, as discussed in Section 3.2.

Figure B3 - Monte Carlo Analysis for Urban Forest Offset Program

Appendix - 20
If desired, the full model depicting the calculations for the carbon offsets CBAs is publicly available and can be retrieved by emailing Dr. Betsy Albright at elizabeth.albright@duke.edu.
## Parameters for the Offset Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Low</th>
<th>Base</th>
<th>Hi</th>
<th>Description/Calculation</th>
<th>Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount rate</td>
<td>%</td>
<td>0.025</td>
<td>0.03</td>
<td>0.05</td>
<td>Assumption made by analyst. 3% was chosen as base rate in alignment with the SCC discount rate.</td>
<td>NA</td>
</tr>
<tr>
<td>Density</td>
<td>trees/acre</td>
<td>88.5</td>
<td>120.7</td>
<td>152.8</td>
<td>The upper and lower bounds represent the minimum space needed by large trees to thrive in competition and open space. The base value is the average of the two densities.</td>
<td>Southern Research Station of the U.S. Forest Service. (n.d.). Quercus rubra L.; Northern Red Oak. Retrieved from <a href="https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_2/quercus/rubra.htm">https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_2/quercus/rubra.htm</a></td>
</tr>
<tr>
<td>Max Trees Planted</td>
<td>trees</td>
<td>132,805</td>
<td>290,620</td>
<td>764,211</td>
<td>Trees = Density * Plantable Space</td>
<td>NA</td>
</tr>
<tr>
<td>Planting Rate</td>
<td>trees/year</td>
<td>1500</td>
<td>3000</td>
<td>5000</td>
<td>Represents the maximum number of trees that can be planted by the city given current resources.</td>
<td>Base value derived from Fichman, Erica Smith. (2020, February 28). Telephone interview.</td>
</tr>
<tr>
<td>Annual sequestration</td>
<td>MtCo2/year/tree</td>
<td>0.006</td>
<td>0.008</td>
<td>0.010</td>
<td>Represents the average carbon removal rate for a Northern Red Oak in 1 year.</td>
<td>i-Tree planting calculator (v2.0.0)- 99 year lifespan for a Northern Red Oak in Philly, PA for a dbh 3</td>
</tr>
<tr>
<td>Cap on Offset Quantity</td>
<td>%</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>Upward bound on the total quantity of offsets that can be retired each year as a % of total City emissions. Assumption made by analyst.</td>
<td>NA</td>
</tr>
<tr>
<td>Annual urban tree Mortality</td>
<td>%</td>
<td>0.0073</td>
<td>0.0146</td>
<td>0.0292</td>
<td>Base value provided in literature for trees &gt;3 dbh, lo value represents half the base, and hi represents double the base value.</td>
<td>Nowak, D. J., &amp; Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. Environmental Pollution, 116(3), 381–389. doi:<a href="https://doi.org/10.1016/S0269-7491(01)00214-7">https://doi.org/10.1016/S0269-7491(01)00214-7</a></td>
</tr>
<tr>
<td>Buffer Pool</td>
<td>%</td>
<td>0.15</td>
<td></td>
<td></td>
<td>The buffer pool is the % of gross offsets generated by the project that are not counted in the net offset calculation (attempts to account for leakage and verification errors).</td>
<td>The Duke Carbon Offsets Initiative. (2018, July 19). Urban Forestry Carbon Offset Protocol 2.2. Retrieved from <a href="https://sustainability.duke.edu/sites/default/files/UrbanForestryProtocol_v2.2.pdf">https://sustainability.duke.edu/sites/default/files/UrbanForestryProtocol_v2.2.pdf</a></td>
</tr>
<tr>
<td>Value of O3 removal</td>
<td>$/ton</td>
<td>7,809</td>
<td>13,369</td>
<td>18,930.25</td>
<td>The value of removing 1 ton of Ozone from the air in terms of public health. The base value is from Nowak et al; the low value 2008 Trust for Public Land; and high value an equal % difference between base and low.</td>
<td>Nowak et al. The urban forests of Philadelphia. (2016). Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. Retrieved from <a href="https://www.nrs.fs.fed.us/pubs/53315">https://www.nrs.fs.fed.us/pubs/53315</a></td>
</tr>
<tr>
<td>O3 Removed by project</td>
<td>tons O3/yr/tree</td>
<td>0.000006</td>
<td>0.000007</td>
<td>0.000008</td>
<td>The average quantity of O3 removed in a year by a single tree of the Northern Red Oak species.</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Value of NO2 removal</td>
<td>$/ton</td>
<td>1,816.81</td>
<td>4,813</td>
<td>7,809</td>
<td>The value to public health from removal of one ton of nitrogen dioxide. Lo value determined from Nowak et al; for hi, used 2008 trust for public land, and base value equals an avg of two.</td>
<td></td>
</tr>
<tr>
<td>NO2 Removed by project</td>
<td>tons N20/yr/tree</td>
<td>0.000002</td>
<td>0.000003</td>
<td>0.000003</td>
<td>The average quantity of NO2 removed in a year by a single tree of the Northern Red Oak species.</td>
<td></td>
</tr>
<tr>
<td>Value of SO2 removal</td>
<td>$/ton</td>
<td>664</td>
<td>1,288</td>
<td>1,912</td>
<td>The value to public health from removal of one ton of sulfur dioxide. Lo value determined from Nowak et al; for hi, used 2008 trust for public land, and base value equals an avg of two.</td>
<td></td>
</tr>
<tr>
<td>SO2 removed by project</td>
<td>tons s02/yr/tree</td>
<td>0.000029</td>
<td>0.000034</td>
<td>0.000039</td>
<td>The average quantity of SO2 removed in a year by a single tree of the Northern Red Oak species.</td>
<td></td>
</tr>
<tr>
<td>Value of PM 2.5 removal</td>
<td>$/ton</td>
<td>529,935</td>
<td>706,580</td>
<td>883,225</td>
<td>The value to public health from removal of one ton of particulate matter 2.5. Base was calculated by dividing the total value of the pollutant removal in Philadelphia by the quantity of the pollutant removed to derive a value per ton. The value was updated to 2020$. hi and lo represent +/- 25%.</td>
<td></td>
</tr>
<tr>
<td>PM2.5 removed by project</td>
<td>tons PM2.5/yr/tree</td>
<td>0.000001</td>
<td>0.000001</td>
<td>0.000001</td>
<td>The average quantity of PM2.5 removed in a year by a single tree of the Northern Red Oak species.</td>
<td></td>
</tr>
<tr>
<td>Property Value</td>
<td>$</td>
<td>13,169.2</td>
<td>39,857</td>
<td>17,558.9</td>
<td>Represents the “real” value of properties within 500 Feet of “Average Parks” in Philadelphia. This benefit was not calculated until 20 years into the project. A modest 4.5% increase to property values in the intervening years was assumed (between 2007 and 2041). Lo and Hi values represent +/- 20% of base value.</td>
<td></td>
</tr>
<tr>
<td>Price Increase</td>
<td>%</td>
<td>0.03</td>
<td>0.05</td>
<td>0.07</td>
<td>The value of a house that is attributable to the presence of trees. The average increase from studies is 7%, and 3%-35% is given as the range from studies. Erred on conservative side.</td>
<td></td>
</tr>
</tbody>
</table>


i-Tree planting calculator (v2.0.0)- 99 year lifespan for a Northern Red Oak in Philly, PA for a dbh 3

Nowak et al. (2016) & The Trust for Public Land’s Center for City Park Excellence. (2008)

Nowak et al. (2016)


<table>
<thead>
<tr>
<th>Monetary Savings from Reduced Energy Consumption</th>
<th>$/year/tree</th>
<th>2.02</th>
<th>2.69</th>
<th>3.36</th>
<th>The report estimated $6.9 million savings from reduced energy consumption in 2012. For the base value, this was converted to 2020$, and then divided by the # of trees in Philadelphia (2.9 million in 2012) to get an average energy savings per tree. Hi and low values assumed +/- 10%.</th>
<th>Nowak et al. (2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Avoided from Reduced Energy Consumption</td>
<td>metric tCO₂/year/tree</td>
<td>0.009</td>
<td>0.012</td>
<td>0.015</td>
<td>The report estimated 39,000 tons CO₂ avoided in 2012 from the urban trees in Philly. This value was used for the base case by converting to metric tons, then divided by the # of trees in Philadelphia (2.9 million in 2012) to get an average avoided emissions per tree. Hi and low values assumed +/- 10%.</td>
<td>Nowak et al. (2016)</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree Cost</td>
<td>$/tree</td>
<td>7.95</td>
<td>16.95</td>
<td>39.95</td>
<td>The range of costs of Northern Red Oak saplings.</td>
<td>Willis Orchard Co. (n.d.). Northern Red Oak Tree. Retrieved from <a href="https://www.willisorchards.com/product/northern-red-oak-tree#.Xp0hPi2ZOCR">https://www.willisorchards.com/product/northern-red-oak-tree#.Xp0hPi2ZOCR</a></td>
</tr>
<tr>
<td>Labor Costs</td>
<td>$/year</td>
<td>260,478</td>
<td>285,767</td>
<td>311,055</td>
<td>The summed min and max salary for five employee classes were used as high- and low-end values. The the base value was a sum of the average for all 5 classes.</td>
<td>The City of Philadelphia Office of Human Resources. (n.d.). Job Class Specifications. Retrieved from <a href="https://www.phila.gov/personnel/Specs.html">https://www.phila.gov/personnel/Specs.html</a></td>
</tr>
<tr>
<td>Other Tree Maintenance Costs</td>
<td>$/tree</td>
<td>200</td>
<td>300</td>
<td>400</td>
<td>Represents the cost of planting and maintenance care for trees at planting that are not street trees. Analyst’s estimate</td>
<td>NA</td>
</tr>
<tr>
<td>Share of Project that is street Trees</td>
<td>%</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>Represents an arbitrarily determined portion of the overall project that would be comprised of street trees compared to non-street trees. Analyst’s estimate</td>
<td>NA</td>
</tr>
<tr>
<td>Carbon Offset Price CAGR</td>
<td>%</td>
<td>0.015</td>
<td>0.03</td>
<td>0.05</td>
<td>Represents the potential rate of growth of the cost of offsets credits over time due to increased demand for offsets and worsening climate conditions.</td>
<td>Analyst’s estimate</td>
</tr>
</tbody>
</table>
Appendix C. Renewable Natural Gas

RNG Quantitative Assessment

Ideally, this analysis would be broken down explicitly by cost of RNG facility components. However, most RNG facilities do not release detailed capital and operating costs. Therefore, costs have been synthesized from a literature review of existing analysis reports on RNG plants in the United States. Pennsylvania specific information has been drawn primarily from the EPA’s Landfill Methane Outreach Program.

Interestingly, the amount of waste in a landfill does not appear to be clearly correlated with the flow of landfill gas from the site, according to EPA LMOP data. Furthermore, the flow rate to existing projects, tends to be variable. Therefore, it is difficult to predict precisely how much biogas each of the candidate landfills will produce once facilities are fully operational. Of the Pennsylvania landfills participating in RNG projects specifically, the proportion of the flow rate of gas directed to an RNG project compared to the gas collected on site, as documented by the EPA LMOP database, is variable across landfills. However, project gas flow tends toward half of gas collected, across the sites considered (Figure C1). In this analysis, it is assumed that project gas flow is half of the gas collection capacity of a facility.

![Figure C1 - PA Operational Site Flow Rates](image)

Table C1 - Candidate Site Flow Rates

<table>
<thead>
<tr>
<th>Site Flow Capacity</th>
<th>Gas Collected on Site (scfm)</th>
<th>Gas to Project (scfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>610</td>
<td>305</td>
</tr>
</tbody>
</table>

Ultimately, a low, mean, and high gas collection value was derived from the Pennsylvania candidate site data, half of which is assumed to contribute to actual facility project end use (Table C1).
Capital construction and O&M cost estimates were synthesized from a literature review of construction and operating costs of RNG facilities. The numbers available from these reports are aggregate costs, which, as discussed in the RNG Assumptions section, limits the scope of cost estimates to high level assessments. Out of the literature review, low, mean, and high costs to facilities built were pulled for three levels of landfill gas flow capacity. Since the cost data was in per unit values, from this data, costs were estimated for larger facility sizes, necessary to match the estimated flow rate capacities of the candidate facilities (Table C2).

<table>
<thead>
<tr>
<th>Gas Flow (scfm)</th>
<th>Facility Capital Cost ($/scfm)</th>
<th>Rate of Change</th>
<th>Rate of Rate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>$2,589</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>$1,538</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>$1,114</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>$791</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>$722</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>$680</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>3500</td>
<td>$653</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>$636</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>4500</td>
<td>$624</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>$616</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas Flow (scfm)</th>
<th>Facility Operational Cost ($/scfm)</th>
<th>Rate of Change</th>
<th>Rate of Rate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>$153</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>$119</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>$108</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>$103.58</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>$101.89</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>$101.20</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>$100.92</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>3500</td>
<td>$100.80</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>$100.75</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>4500</td>
<td>$100.73</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>$100.72</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Table C2 – Estimated Facility Costs Based on Flow Rates
Final facility costs were then scaled to the flow rate estimates when determining total capital construction and O&M costs. Flow rates and associated costs were scaled up to total facility and annual costs, in order to model facility operations for NPV values. Three project options were assessed, considering one facility with a low, medium, and high flow rate, in order to compare the range of potential final values of an RNG facility project.

To convert methane estimates to CO\textsubscript{2}e estimates, the EPA’s Greenhouse Gas Equivalencies equations were referenced (Table C3).\textsuperscript{354} Methane captured was ultimately converted to a CO\textsubscript{2}e to better compare project impacts to the other policies considered through CBAs in this paper. A global warming factor of 25 was used when scaling the impacts of methane to CO\textsubscript{2}e values.

<table>
<thead>
<tr>
<th>Conversion: MMBtu to metric tons CO\textsubscript{2}e</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 mmbtu &gt;&gt; 1 therm</td>
</tr>
<tr>
<td>1 mmbtu &gt;&gt; 14.43 kg C</td>
</tr>
<tr>
<td>44 kg CO\textsubscript{2} &gt; 12 kg C</td>
</tr>
<tr>
<td>1 metric ton &gt;&gt; 1000 kg</td>
</tr>
<tr>
<td>0.005291 metric tons &gt;&gt; 1 therm</td>
</tr>
<tr>
<td>361,398 MMBtu/yr &gt;&gt; 3,613,980 therm</td>
</tr>
</tbody>
</table>

### Sensitivity Analysis Figures

These tables support the conclusions explored in the main RNG CBA section on sensitivity analysis. The first table shows the comparative impacts which a change in variable value would have on the final net present value (Figure C1). Changes to the discount rate result in the greatest variation to final NPV, so uncertainty surrounding the discount rate poses the greatest risk to the accuracy of the model’s conclusions. All other variables exert much weaker influence over NPV in comparison. The other anticipated most impactful variable of this model was actual facility flow rate, but variable sensitivity to this variable was modeled out in the three facility options, rather than assessed as part of the final sensitivity analysis. The variable with the next most impact to model results is sales revenue. The actual scale of impact which a change in the revenue variable would see is less notable than the ranking of the revenue variable as the next most sensitive variable. Though the project as modeled does not make a net positive profit, the sensitivity of the revenue variable would indicate that the RNG market should be monitored moving into the future. As prices increase, the project may be worth revisiting. However, these variable drivers should all be carefully considered when assessing or reassessing this project because, as the Figure C3 Monte Carlo chart depicts, the overall NPV of this project is more likely to result in a low rather than high value. There is some risk associated with overvaluing the projected NPV in in this modeled if drivers are not reviewed carefully.

Figure C2 - Tornado Chart Mapping NPV Sensitivity to Variable Changes

Net Present Value - Sensitivity to Variable Changes

<table>
<thead>
<tr>
<th>Discount Rate (%) · Mean</th>
<th>Revenue ($/MMBtu) · Mean</th>
<th>Leakage (%) · Mean</th>
<th>Interconnection costs · Mean</th>
<th>High flow rate (1,752 mmscfy) · Mean (C14)</th>
<th>High flow rate (1,752 mmscfy) · Mean</th>
<th>Interconnection costs annual · Mean</th>
<th>Low flow rate (105.85 mmscfy) · Mean</th>
<th>Medium flow rate (912.5 mmscfy) · Mean</th>
<th>Low flow rate (105.85 mmscfy) · Mean (C12)</th>
<th>Medium flow rate (912.5 mmscfy) · Mean (C13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0</td>
<td>$500,000,000</td>
<td>$1,000,000,000</td>
<td>$1,500,000,000</td>
<td>$2,000,000,000</td>
<td>$318,750</td>
<td>$68,750</td>
<td>$2,218,064</td>
<td>$2,194,064</td>
<td>$67,948,895</td>
<td>$4,185.50</td>
</tr>
<tr>
<td>6%</td>
<td>$2.60</td>
<td>$0.023</td>
<td>$14%</td>
<td>$2.60</td>
<td>$0.023</td>
<td>$14%</td>
<td>$2.60</td>
<td>$0.023</td>
<td>$14%</td>
<td>$2.60</td>
</tr>
<tr>
<td>14%</td>
<td>$7.40</td>
<td>0.015</td>
<td></td>
<td>$7.40</td>
<td>0.015</td>
<td></td>
<td>$7.40</td>
<td>0.015</td>
<td></td>
<td>$7.40</td>
</tr>
</tbody>
</table>

Upside  Downside

Figure C2 - Tornado Chart Mapping NPV Sensitivity to Variable Changes
## Parameters Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Low</th>
<th>Base</th>
<th>High</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount Rate</td>
<td>%</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>A standard discount rate used for projects with a social benefit, particularly pertaining to GHG emissions impacts.</td>
<td>EPA. (n.d.) Renewable Natural Gas. Landfill Methane Outreach Program. Retrieved from <a href="https://www.epa.gov/lmop/renewable-natural-gas">https://www.epa.gov/lmop/renewable-natural-gas</a></td>
</tr>
<tr>
<td>Cost Category</td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
<td>Source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M Costs – Low Flow Facility</td>
<td>$1,280,060</td>
<td>$1,295,060</td>
<td>$1,310,060</td>
<td>Public Utilities Commission Of The State Of California. (2015). Decision Regarding The Costs Of Compliance With Decision 14-01-034 And Adoption Of Biomethane Promotion Policies And Program. Retrieved from <a href="http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M152/K572/152572023.PDF">http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M152/K572/152572023.PDF</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interconnection Capital Cost</td>
<td>$37,500</td>
<td>$52,500</td>
<td>$350,000</td>
<td>The capital construction cost of connecting a facility to an existing pipeline network.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interconnection Annual O&amp;M Cost</td>
<td>$3,805</td>
<td>$5,327</td>
<td>$7,610</td>
<td>The annual O&amp;M cost associated with maintaining a connection to an existing pipeline network.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sale Revenue</td>
<td>$2.60</td>
<td>$3.94</td>
<td>$7.40</td>
<td>Revenue gained from selling RNG on the Philadelphia gas market, based on PGW's costs of natural gas.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leakage</td>
<td>1.4%</td>
<td>2.0%</td>
<td>2.3%</td>
<td>A leakage rate accounting for methane lost to imperfect facility construction and transportation.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source:
Appendix D. Transportation Modeling

MP Team Transportation Baseline Model Assumption

Our model uses 2018 as our baseline year and projects transportation emissions through 2050. Our projection uses the KAYA equations adapted to transportation energy use and CO$_2$ emissions:

\[
\text{Energy} = \text{Population} \times \text{PMT/Pop} \times \frac{\text{VMT/PMT}}{\text{VMT}} \times \frac{\text{E/VMT}}{1}
\]

\[
\text{CO}_2 \text{Emissions} = \text{Population} \times \text{PMT/Pop} \times \left(\frac{\text{PMT/VMT}}{\text{VMT}} \times \frac{\text{E/VMT}}{1} \times \frac{\text{CO}_2/E}{\text{mode}}\right)
\]

The model considers the following transportation modes: walking, biking, personal vehicles, trains, regional rail, trolleys, On Demand passenger vans, and the public bus system. To create the 2018 to 2050 baseline, the model takes into account existing polices the City of Philadelphia has in place to reduce emissions. First, the City plans for a transportation mode shift in the population from personal vehicle use to walking, biking, and public transit use, translating to a total ridership increase of these public transit modes from 36% to 41% of the population. The model used here assumes an even distribution of ridership across walking, biking, trains, regional rail, trolleys, and buses when accounting for this mode shift policy.

Second, the Southeastern Pennsylvania Transportation Authority (“SEPTA”) has committed to adding 25 electric buses and 525 hybrid buses to its fleet by 2021. The model assumes that these vehicles will replace existing diesel buses in SEPTA’s 1,400 bus fleet, 25 electric buses being added in 2019, 262 hybrid buses added in 2020, and the final hybrid buses added in 2021. Third, SEPTA estimates that bus diesel fuel efficiency will improve by 0.09 miles per gallon by 2021, which is reflected in the diesel fuel efficiency and emissions levels of the diesel buses still in the fleet by 2021. The model assumes linear improvement in diesel fuel efficiency from 2019 to 2021.

Finally, the electrical grid is assumed to improve annually through 2050. SEPTA estimates a 1.5% grid improvement annually, though it considers only the years through 2021. However, grid improvement is highly dependent on shifting political and economic developments. We modeled our own projections of grid intensity improvement, distilling a Conservative, Moderate, and Best Case Scenario for grid improvement. We ultimately use the Moderate Scenario when moving forward with analysis of the transportation sector.

The other major policy we build into the baseline accounts for personal vehicle improvement over time. We use the CAFE policy guidelines, and assume that 4% of Philadelphia’s population buys a new car every year. Starting in 2019, a portion of the mode share of personal vehicle users switches into a CAFE compliant personal vehicle mode share. This new mode share consists of cars with slightly improves emissions values. Each year, another 4% of cars from the non-CAFE compliant pool of personal vehicles are exchanged for cars that meet the CAFE standards for that year. In the baseline, total personal vehicle mode share reduces to 55% by 2025 in response to City policies. Personal vehicle mode stays at 55%
through 2050 in the baseline, but of that mode, 40% of the mode falls under some CAFE compliance by 2050, so the overall personal vehicle mode emissions level improves over time.

To access the full excel model, please contact Professor Betsy Albright via email at elizabeth.albright@duke.edu.

Cordon Pricing Schemes Implementation History

Singapore was the first city to implement cordon pricing in 1975 with its Area License Scheme. Singapore cordoned off a 6.2 km² Restricted Zone around the city’s central business district which was active weekdays 7:00am to 10:00pm, from Monday through Saturday mornings. Drivers were required to purchase a $3 daily license to enter the CBD when the Restricted Zone was active. Enforcers at CBD access points would note the car plate of any vehicle entering the Zone without a valid license. Singapore’s Area License Scheme was reformed frequently over its 20-year lifespan – extending the weekday Restricted Zone hours, raising and dropping the license price, changing which vehicle types were exempt from requiring licenses – as Singapore broke ground on this new model of urban traffic control. In 1998, following additional global studies into congestion pricing and technological advancements, Singapore automated its pricing system, changing from its Area License Scheme to an Electric Road Pricing scheme. Now, computer readers at entry points to the CBD scan in-vehicle smart cards and charge the vehicle directly, based on the scheme’s variable pricing system. A central control system manages charges, violation notices, and system errors. Singapore’s cordon pricing scheme continues to be in place today.

In 2003, London implemented its own cordon pricing scheme, based in part on Singapore’s electronic pricing design. The London Congestion Charge requires vehicles to pay a daily fee for travel into or within the 22 km² Congestion Charging Zone that covers London’s historic and commercial districts. Unlike Singapore’s card readers, London installed Automatic Number Plate Recognition cameras to read vehicles within the zone. Vehicles have until midnight to pay the zone fee to the central system, either online or through a payment machine. Otherwise, the central system will send a violation notice to the owner of the vehicle plate recorded by the plate recognition cameras. London closely monitored its pricing program from 2003 to 2008 and documented an immediate impact to its traffic flow. After implementation, entry by cars into the congestion zone dropped 33% and remained at that lower rate through the monitoring period. Overall, the city saw a 25% reduction in congestion, and bus ridership increased by 38%.

Stockholm, in 2007, and Milan, in 2008, are the other two major cities to have implemented a cordon pricing scheme. Stockholm designed a time-variable toll for cars to pay when entering or exiting central Stockholm. Before trial implementation of the Stockholm

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357 Lehe, 2019.
Congestion Tax, public polls were strongly against implementing any congestion scheme. However, after the trial started, public opinion turned favorable, as the scheme worked to curb traffic. After a successful trial, Stockholm put careful attention to improving through-traffic tunnels, and later, using revenue generated from the congestion scheme to finance a new city metro tunnel. Overall, traffic fell about 20% from pre-scheme levels, and Stockholm saw a 7% increase in public transit ridership. Milan started a congestion pricing scheme specifically to control air pollution in the city. The scheme uses a camera-enforcing daily license system similar to London, with a sliding fee depending on the standard, residential, or service status of entering vehicles. However, Milan also specifically banned high-emissions vehicles from the cordon zone and exempted many renewable fuel vehicles.

After the congestion scheme was introduced in Milan, traffic decreased by about 31%, particulate matter decreased 18%, and carbon emissions decreased by 35%. Milan temporarily suspended their congestion scheme in 2012, revealing interesting data. Immediately following the scheme suspension, average congestion spiked back up to pre-scheme levels, then dropped down again once the pricing scheme was reinstated. However, the commuter routes close to public transportation experienced a smaller increase in traffic, compared to the city average increase, during the pricing suspension, where people continued taking public transportation regardless of the scheme. Overall, Milan’s congestion program controls congestion well and compliments the city’s public transportation system.

New York is currently in the planning phase of implementing a congestion pricing scheme to be enacted in 2021. A congestion pricing plan has been under discussion since 2007, proposed as part of New York City’s PlaNYC 2030 sustainability document. Since then, the proposal has been debated and stalled several times until 2019 when New York’s governor and NYC’s mayor agreed upon a congestion pricing model whose revenue would be dedicated to New York City’s Metropolitan Transportation Authority. As it currently stands, the pricing scheme will consist of a cordoned zone encompassing Manhattan south of 61st Street and use variable-time pricing through an electronic tolling system. The pricing scheme, proposed to generate funding for the transportation sector more than to curb personal vehicle congestion, is currently being assessed by the federal government, but NYC plans to have the pricing scheme in place for the start of 2021.

360 Lehe, 2019.
362 Lehe, 2019.
364 Jaffe, 2015.
Philadelphia Cordon Pricing Model Assumptions

Commuters from the Great Center City to suburbs outside of Philadelphia were not considered, as these commuters likely cannot transition easily from personal vehicles to public transit options. Commuters between districts outside of the Greater Center City were also not considered, as they likely do not enter Greater Center City over the course of a work day, and so would not cross the cordon zone. Finally, this team understands that the impacts of this modeled cordon scheme will be a conservative estimate of real cordon zone forcings, as this model does not capture anyone other than commuters moving through the Greater Center City over the course of a day. This model also assumes stationary proportional growth between districts, assuming that the same proportion of commuters will come from each district each year through 2050, when in fact some districts may grow more quickly than others, changing the proportion of commuters that district is contributing to the scheme.

The model assumes that commuters shifting from personal vehicles will move equally into either buses, trains, or regional rail, as the next most convenient transit options. The model structures a cordon zone similar to that of London or Milan, and assumes comparable results regarding a personal vehicle mode shift of 25% of vehicles currently commuting moving into public transit.

Parking Maximum Standard Barriers and City Implementations

While parking maximums are an effective mechanism for reducing personal vehicle use and encouraging public transit alternatives, imposing these policies can be challenging for a variety of reasons. First, determining the limit on parking spaces is an analytically intensive exercise that requires precise projections of demand. Second, removing centralized parking lots may lead to spillover effects, such as increased use of street and neighborhood parking. The use of resident permits can help mitigate these effects. Third, getting parking maximum policies passed can be quite difficult. The developer industry may fight back against parking maximums due to fears that the long-term marketability of their properties will be reduced, threatening their financial returns. However, if the policy is broadly applied across a large area, then it is less concerning to developers because there is little differential in the competitive advantage of developing in one part of town, or another; all areas of the city would be facing the same constraint.367

Cities that have implemented parking maximum policies include Portland, San Francisco, and Seattle. Portland’s policy goes as far back as 1975, when an overall limit of 40,000 spaces was set for the downtown area. Though this cap has increased over time, the city attributes a significant share of the public transit use to this and other progressive policies. San Francisco’s policy is a bit more nuanced. Parking can only constitute a maximum of 7% of a building’s gross square footage and new developments must get their parking plan approved before they can receive occupancy permits. In comparison, Seattle limits parking on a rate basis: one parking space for every 1,000 square feet of office space in downtown.368

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367 Victoria Transport Policy Institute, 2018.
368 Victoria Transport Policy Institute, 2018.
Boston is an example of just how potent maximum parking policies can be. In the late 1970s, Boston suspended the growth of commercial parking that could be used by the public, but commercial parking within office buildings that were dedicated to companies’ use was exempted. The number of commercial parking spaces remained the same while the quantity of exempted spaces increased by 26% between 1984 and 1987. This increase corresponded to a time where the city experienced a dramatic uptick in traffic on major city corridors.\textsuperscript{369}

Maximum Parking Standard Model Assumptions

The relationship between parking space numbers and personal vehicle mode share which this model uses was pulled from McCahill et al’s paper on the “Effects of Parking Provision on Automobile Use in Cities: Inferring Causality.”\textsuperscript{370} The paper establishes that an increase from 0.2 to 0.5 parking spaces per person available in a city results in a personal vehicle mode share increase from 60% to 83%. We extrapolated from that relationship the linear line’s slope and y-intercept, so that we could use the same linear relationship to project mode share changes in Philadelphia. We assume that the number of parking spaces in Philadelphia does not change from 2018, where we having parking space count data, to 2025, when we start implementing a parking standard. With a starting parking spaces per person of 1.3 and end goal of 0.9, and using the linear relationship, we calculate mode share at each parking space per person value in order to find change in mode share when reducing parking spaces from 1.3 to 0.9 spaces per person. That is converted to an annual change which is then cumulatively applied to the baseline personal vehicle mode share from 2025 through 2050.

With a parking standard, final mode share of personal vehicles reduces to 20% by 2050. Not only that, but working with the baseline CAFÉ Standard mode share forcing, by 2045, it is modeled that no non-compliant cars are on the road anymore. This joint forcing out of non-CAFÉ compliant personal vehicles from the city personal vehicle pool results in a very impactful decrease to total emissions for the city.

\textsuperscript{369} Victoria Transport Policy Institute, 2018.
\textsuperscript{370} McCahill et al., 2015.