URBAN SOLAR ROOFTOP POTENTIAL:
Technical and Economic Analysis of Rooftop Solar Generation in Wilmington and Newark Delaware

SECOND YEAR REPORT MAY 2018

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EXECUTIVE SUMMARY

This report describes the work conducted from September 2017 – May 2018 for the 2017-2018 Science, Engineering and Technology (SET) Services Program. The research detailed below follows a research effort performed last year to evaluate the sustainability profiles of the Delaware municipalities of Wilmington and Newark by implementing the Sustainability Tools for Assessing and Rating (STAR) framework with the title "Measuring Urban Sustainability Through Common Indicators and Peer City Benchmarking in Delaware" (Byrne et al. 2017a).

The STAR framework offers a menu-based system for enabling cities to build more inclusive, equitable and accountable investment paths. It is a leading framework for assessing and promoting sustainability performance of cities and communities. In the first-year's research (2016-2017), we examined the potential benefits and challenges associated with using the STAR framework, especially its twenty-one leading metrics to assess the sustainability profiles of Wilmington and Newark. Among the metrics analyzed were safe wastewater management, climate adaptation, renewable electrical energy supply, environmental justice, business development, housing and transportation, and food security (Byrne et al., 2017a: 14). The first-year report also identified baseline foundational sustainability assets and platforms of the two cities (Byrne et al., 2017a: 20), including developing renewable electricity sources like solar and wind, energy efficiency initiatives, recycling, public transportation systems, community contributions and many more.

In this second-year report, we selected one of the twenty-one metrics—renewable electrical energy supply – for further evaluation. More specifically, we set out to analyze technical and economic solar energy generating potential for flat rooftop buildings in both Wilmington and Newark. Across the entire rooftop space of Wilmington, about 1.5 million square meters can be considered suitable for PV system deployment – equal to just over 194 MWp of solar capacity. For the public buildings owned by the City of Wilmington, about 2.3 MWp is available. The electricity generation provided by this system is preliminarily estimated at 18.9% of annual electricity consumption for the public buildings owned by the City of Wilmington. The same approach used for the City of Newark yields about 661,000 square meters or 83 MWp of system capacity for its flat rooftops. For the public buildings owned by the City government, about 480 kWp of capacity could be installed on its flat rooftops, sufficient to generate about 13.7% of estimated annual consumption or, in April, about 28% of daylight hour consumption. To illustrate, such an installation level can be contrasted against the currently installed *statewide* solar capacity in Delaware of 106 MWp. In other words, the technical potential of flat rooftops across the entire city of Wilmington and Newark is larger than the current total statewide installed capacity.

A critical focus for any municipality interested in improving its sustainability profile are opportunities to advance sustainable energy deployment within city boundaries; i.e investing in its own capacity. In particular, to advance sustainability, a municipality should consider pursuing accelerated and large-scale deployment of sustainable energy technology options, like solar photovoltaic (PV), wind, sustainable transportation, or energy efficiency among others. To guide the implementation of policy efforts to advance the sustainability profile of Delaware's municipalities, the research presented in this report evaluates the technical potential to deploy rooftop solar PV across the flat rooftops of public buildings for both Wilmington and Newark. [1] The technical evaluation of the potential provided in this report represents a first-order approximation of possible sustainability contributions by rooftop solar PV. By focusing on flat rooftops owned by public agencies, it provides a practical and actionable understanding for future policy direction. In particular, flat rooftops allow for easy rooftop solar deployment and rooftops owned by public agencies can serve as a test-bed for such strategies.

An important driver of the research conducted is to conceive municipal rooftop 'real estate' as a pool of possible project sites available for aggregation. In other words, rather than viewing the PV installation potential for flat, public rooftops on a project-by-project basis, the research outlined here specifically focuses on the entire pool of rooftops – a portfolio-based approach. This strategy garners important benefits, most notably economies of scale that could reduce critical cost components and at an investment-scale

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1 To clarify, "technical potential" refers to an evaluation that does not incorporate economic or policy considerations – it only makes use of technical criteria to define the potential. Other commonly used terms for assessments that do include policy or economic dimensions are "economic potential" or "achievable potential".

that can negotiate important concessions from investors, installers, and other participating stakeholders.

This portfolio-based approach, when regarding city-wide installation of rooftop solar PV, is oftentimes called a "solar city" strategy (Byrne, Taminiau, Kurdgelashvili, & Kim, 2015). Evaluation of the "solar city" potential is conducted in three stages: a) a technical potential assessment, b) an economic assessment, and c) a policy scenario assessment (Byrne, Taminiau, Kim, Lee, & Seo, 2017). This report focuses on the technical and economic potential assessment. Subsequent analysis during 2018-2019 will provide deeper insight into the financing options and policy scenario assessments.

The results of the analysis indicate a significant potential for rooftop solar PV deployment across both Wilmington and Newark. Direct purchase options for Newark and Wilmington indicate feasible PV system deployment at 10.87 cents/kWh and 8.601 cents/kWh, respectively. The Sustainable Energy Utility (SEU) loan option and municipal bond financing is explored as well. If the system is deployed, it represents a substantial net revenue generator depending on assessment inputs and could hedge against price volatility.

SECTION 1. INTRODUCTION

Sustainability improvement opportunities are widely available to the municipalities in Delaware. Policy strategies to improve sustainability profiles could benefit from including efforts to advance the deployment of sustainable energy technologies within city boundaries like energy efficiency, smart mobility, and solar and wind energy. Focusing on rooftop solar PV, the potential for such efforts is preliminarily evaluated in this report for both Wilmington and Newark.

Impetus for urban energy economy change is provided by the international agreement to mitigate climate change agreed upon in Paris in December 2015. The 2015 "Paris Agreement" motivates actors around the world to address climate change and cities are no exception (e.g. Bulkeley & Castán Broto, 2013). In fact, in the wake of the U.S. withdrawal from the Paris Agreement announced by President Trump, many cities and states have redoubled their efforts – this "We Are Still In" movement encompasses at least 41 states and 125 cities. This has led some to conclude that a "polycentric" paradigm is emerging in energy and climate change – this new paradigm emphasizes the role played by local and other sub-national actors such as municipal governments (Jordan et al., 2015).

To assess the sustainable energy improvement potential in Wilmington and Newark, the research effort presented here implements a three-stage analysis. First, an analysis is conducted to determine the solar electricity generating potential for flat rooftops owned by public agencies in both Wilmington and Newark. Next, an economic analysis is conducted to translate this technical potential into investment terms. Finally, a policy scenario analysis is produced to provide actionable and useful policy recommendations for Wilmington and Newark to follow. The technical potential assessment and the beginnings of an economic assessment are included in this report.

In terms of the technical potential analysis, this stage of the research effort is bolstered by widespread findings of significant opportunities to redesign urban energy economies. For instance, a U.S.-wide study estimated the electricity generation potential for rooftop photovoltaic (PV) technology to be sufficient to cover almost 40% of the 2016 total U.S. electric-sector sales (Gagnon, Margolis, Melius, Phillips, & Elmore, 2016; Margolis, Gagnon, Melius, Phillips, & Elmore, 2017). Even high-density, vertical cities contain sufficient space to deliver large-scale solar electricity. For example, a study of Seoul, South Korea, estimated the city's solar PV capability to be sufficient to cover its entire load during favorable moments of the year (Byrne et al., 2015). Analysis of financial feasibility of city-wide deployment also found opportunities for this "solar city" concept: evaluation of New York City, Tokyo, Seoul, London, Amsterdam, and Munich found that most could deploy solar city strategies under both existing conditions (Byrne, Taminiau, Kim, Seo, & Lee, 2016) and under various risk profiles (Byrne et al., 2017). A recent literature review and analysis shows that the concept of the "solar city" appears feasible not only from a technical perspective but could also satisfy market, finance, and policy constraints (Byrne, Taminiau, Seo, Lee, & Shin, 2017). Findings like these have lead other researchers to conclude that solar energy's capability to mitigate climate change is frequently underestimated (Creutzig et al., 2017).

Second, the selection of rooftop solar PV is strategic. According to the U.S. Energy Information Administration (EIA), the capacity of U.S. small-scale solar PV (also known as distributed solar as opposed to centralized utility scale solar power plants) increased by 8.6 gigawatts peak (GWp) from 2015 to 2017. This resulted in an increase in generation from U.S. small-scale solar PV electricity from 14.1 terawatthours (TWh) in 2015 to 24.1 TWh in 2017, an increase of 70% in two years. Similar trends can be observed worldwide. An important driver to this development pattern is the rapid price declines observed for solar PV. For instance, commercial PV system prices in 2010 stood at \$5.36/Wp (2017 USD) while Q1 2017 benchmarks now put system prices at \$1.85/Wp – a compound annual price drop of 12.8% per year or a total price decline of over 65% (Fu, Feldman, Margolis, Woodhouse, & Ardani, 2017). This falling cost profile has significantly improved the economics of (rooftop) solar electricity – in other words, the investment case for widespread solar energy deployment is now much more attractive to investors, particularly when a portfolio-based approach is offered.

Finally, much of the growth in the U.S. solar market has been made possible through diverse policy efforts to push the implementation of solar energy forward. The State of Delaware has regulations in place to support PV market development. For example, Delaware was one of the early adopters of 'net metering' which has been in place since 1999. This allows PV system owners to get full credit on their electric bill for any power they produce. As a result, the state was ranked seventh per capita for cumulative solar installations in 2013 (Schneider & Sargent, 2014) and Wilmington was ranked 22nd among cities nationwide for solar capacity per capita according to a 2018 report by Environment America Research & Policy Center (Bradford & Fanshaw, 2018). In addition, the state's net metering law allows third-party solar financing and shared solar, supporting the distributed solar market. County level policy support further shapes the investment case for solar energy in Delaware: New Castle County is considering to double the state's solar energy capacity by building a solar-panel array on 400 acres of farmland in southern New Castle County (Wilson, 2017).

1.1. Project Context and Purpose

The purpose of this second year of the three year research project is to assess the technical, financial, and policy dimensions of solar rooftop potential in of the City of Newark and the City of Wilmington. Combined with first year and future third year results, the research project as a whole will outline a policy vision for how these two cities could improve their sustainability profile by relying on existing sustainability assets. The research project, as such, presents a valuable reference source for state and city government officials, policymakers, and planning authorities for capitalizing on areas of opportunity and to respond effectively by developing realistic sustainability goals.

As a first approximation of the solar energy potential, the stage of the research effort included in this report focuses on flat rooftops owned by public agencies. In other words, this is a (small) subset of the total potential. However, identifying this potential allows for the formulation of a practical and actionable strategy in technical, economic, and policy terms – public buildings could be seen as a test-bed target for city-wide solar energy deployment and, by limiting the analysis to flat rooftops, many potential complications for such deployment are eliminated.

1.2. Overview of Research Approach

In brief, the research project seeks to answer two key research questions:

- What is the potential for rooftop solar energy deployment on the flat rooftops of the selected public agencies in Wilmington and Newark?
- Can this flat rooftop potential be economically developed using a portfolio-based approach?

In an effort to address these questions, a three-stage approach was used. The approach consists of three modules and was first applied by researchers from the Foundation for Renewable Energy and Environment in an evaluation of the technical, economic, and policy potential of New York City, Seoul, Tokyo, London, Amsterdam, and Munich (Byrne et al., 2015). Separated into technical, economic, and policy analysis modules, the three modules each deploy several different research and analytical methods. The approach is visualized in Figure 1.

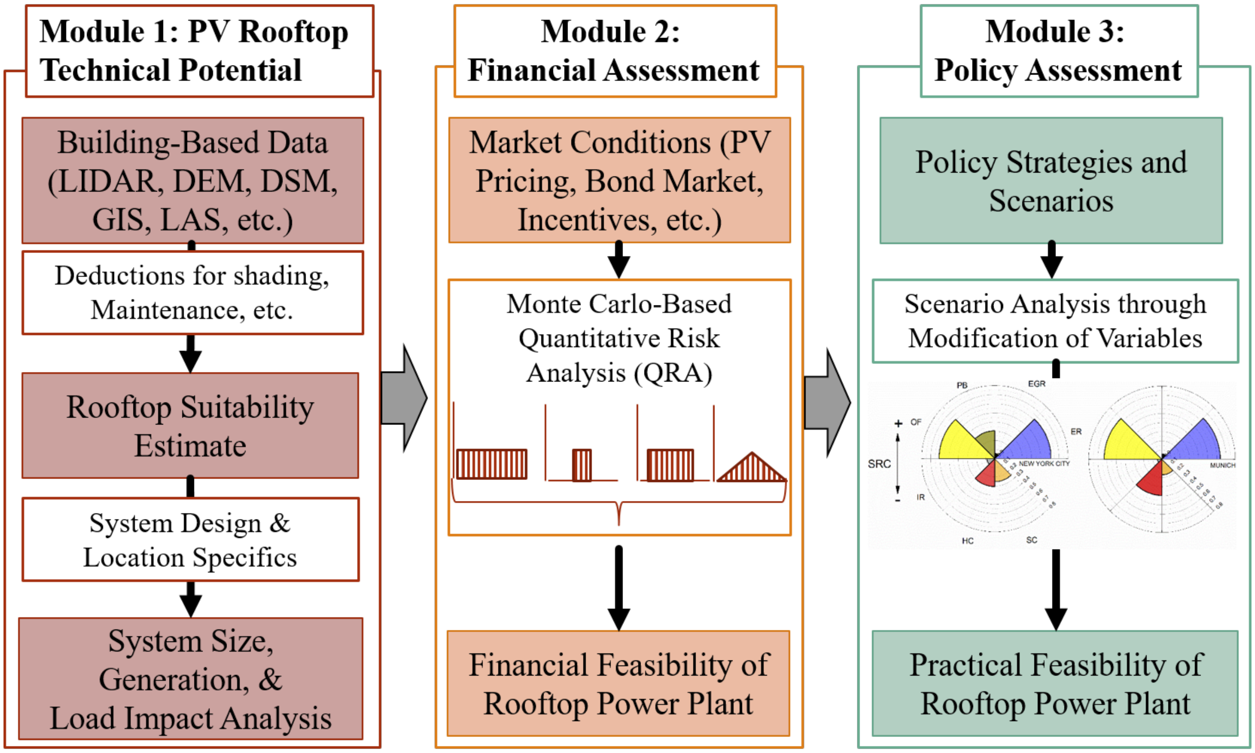

Figure 1. A three-stage research approach to detail the rooftop solar PV opportunity in Newark and Wilmington. Developed by the Research Team of the Foundation for Renewable Energy and Environment

Module 1: PV Rooftop Potential

The first stage of the research approach evaluates the solar electricity-generating potential of urban rooftops. Assessing the potential of a city to deploy rooftop solar energy systems relies on a series of datasets that together provide insight into the city's morphological and meteorological conditions. To conduct the assessment, a range of methodological approaches have been suggested each with varying complexity and computational requirements (Byrne et al., 2015; Melius, Margolis, & Ong, 2013).

Motivation for the method selected here is described in Section 2 in detail. It relies on Geographic Information System (GIS) assessment of the morphological and meteorological conditions of both Wilmington and Newark. A key component of the analysis is the use of Light Detection and Ranging (LIDAR) data – a 3D dataset generated through remote sensing of the morphological conditions of both cities using lasers. This data was collected by the United States Geological Survey (USGS). In brief, the method used here includes methodological components to:

- *Determine rooftop morphology*: the method yields a categorization of rooftop forms ('flat' being defined as < 9.5° tilt vs sloped > 9.5° tilt) by orientation (e.g. north-facing or south-facing).
- *Determine the influence of shading*: varying the position of the sun throughout the year yields a detailed understanding of how shading affects the solar energy yield on the city's rooftops. Rooftops with insufficient yield are subsequently excluded from the analysis.
- *Limit the analysis to buildings owned by the city of Wilmington and Newark:* using GIS-based datasets, the buildings owned by public agencies are identified and selected for analysis.

Next, using a series of established guidelines, the installation and generation potential is calculated from the suitable rooftop area derived from the three steps listed above. This step of the assessment makes use of System Advisor Model (SAM) software, developed and supported by the National Renewable Energy Laboratory (NREL) and widely used by the solar industry.

Module 2: Financial Assessment

Identifying the market conditions for rooftop solar, including investment cost, system cost, electricity yield, etc., the next stage of the research effort defines the economic potential of developing the resource identified in the previous step. A component of this analysis, in addition to relying on market data, is the use of Monte Carlo-based techniques to conduct a Quantitative Risk Assessment (QRA). This assessment technique incorporates potential uncertainty related to market changes in order to provide a robust estimate of the economic viability. The methodological components of this QRA analysis include a capability to:

- *Estimate the risk profile associated with all the relevant variables*: risk conditions are captured in the analysis using Monte Carlo-based techniques. For each length of financing, at least 10,000 simulations are conducted.
- *Determine the number of simulations that yield financial metrics sufficient to attract investment*: For example, selecting a threshold value of 80% of simulations to be included in the analysis would indicate that, for a particular length of financing, 80% of the simulations yield financial metrics in line with the expectations of the investment community, and thus should be capable of attracting the investment necessary to develop the solar energy project.

Module 3: Policy Assessment

To advance the financial feasibility of a city-wide solar energy rooftop project, city and state policy makers have a variety of policy tools at their disposal. This last step of the analytical approach used here incorporates these tools in a series of policy scenarios and recommendations that delineate possible practical and actionable strategies for the cities of Newark and Wilmington in particular and the State of Delaware in general. The methodologies incorporated in this analysis help to:

- Determine the influence of various policy drivers on the financial feasibility of a city-wide rooftop solar energy project.
- Formulate a range of policy scenarios and identify their contribution to the financial feasibility of the project.
- Extract a range of policy recommendations that could be deployed by local and state policy makers to accelerate the rooftop solar energy market in Newark, Wilmington, and the State of Delaware.

1.3. Limitations of this Analysis

As with any research effort, there are limitations regarding the data and assumptions. While the research team took care to identify the most up to date and accurate data, limitations regarding the accuracy of the data remain. Three limitations are of particular relevance:

- **Quality of the LIDAR data:** a quality control assessment of the LIDAR data used here established a vertical accuracy of ±16.2 cm and horizontal accuracy of ±38 cm. In other words, the 3D representation of the both cities' morphological conditions has a (relatively small) built-in error term that is carried through throughout the analysis.
- **Temporal coverage of the data:** the LIDAR assessment was conducted during a particular time (winter 2013 and spring 2014) and any changes since then are not included in the analysis.
- **Building perimeter data:** as described in more detail below, building perimeter footprint data is used as a key filter to reduce the computational load of the analysis. This data was obtained from New Castle County's GIS Data Viewer. However, no clear indication as to the specific accuracy of the data is provided in the metadata – any error in the building perimeter footprint data, as such, is included in the analysis presented here. We conducted a detailed visual one-by-one investigation of all the buildings owned by the City of Newark and by the City of Wilmington to counteract this limitation.

SECTION 2. DATA AND METHODS

2.1. Study area and input data

The analysis focused only on the area within the municipal boundary of either city – buildings outside of the municipal boundaries were excluded. The GIS "shapefile" (a file type specific to GIS software) that outlines the municipal boundaries was obtained from FirstMap Delaware (http://firstmap.delaware.gov/). Relevant GIS-based data was also obtained from the New Castle County GIS Data Viewer (https://gis.nccde.org/gis_viewer/). The municipal boundary for Wilmington and Newark is illustrated in Figure 2.

Figure 2. Municipal boundaries used for Newark (left) and Wilmington (right). Note that the two images are not represented in the same scale.

The LiDAR data used in our analysis was created by the USGS and obtained from the National Oceanic and Atmospheric Administration (NOAA) data viewer (https://coast.noaa.gov/dataviewer/#/). The LiDAR assessment conducted by USGS took place in Winter 2013 and Spring 2014 when there was no snow on the ground and rivers were at or below normal levels. A calibration process was performed by USGS and to assure quality. A third party (a company called Quantum Spatial) evaluated the data and performed independent quality control procedures. The LiDAR data was collected at a nominal pulse spacing of 0.7 meter. The LiDAR assessment was based on USGS National Geospatial Program Base LiDAR specifications, version 1. Further technical and specific details are available via the NOAA data viewer access portal.

Building footprint data and other relevant GIS based data, in particular information regarding building ownership, were obtained from the two GIS portals from FirstMap Delaware and New Castle County GIS Data Viewer. Weather data was obtained from the National Solar Radiation Database (NSRDB) from NREL as provided through their SAM software platform. The solar irradiance was obtained from Typical Meteorological Year (TMY) data. For our analysis we selected a TMY3 data file for New Castle County as a whole.

2.2. Methods to identify rooftop solar potential

Urban solar potential assessments have focused heavily on the development of various methodologies – many articles introduce variations of methodological approaches which can broadly be categorized into three groups (Byrne et al., 2015; Melius et al., 2013). An analysis by the National Renewable Energy Laboratory classified these categories as: a) constant value methods, b) manual selection methods, and c) methods based on Geographic Information Systems (GIS) (Melius et al., 2013) (see Table 2).

A constant value application was used by Byrne et al. in their estimation of the solar resource potential of New York City, Seoul, Tokyo, London, Munich, and Amsterdam (Byrne et al., 2015; Byrne et al., 2016). This method allows for rapid assessment of the total solar resource and does not rely on GIS or other visualization software. Drawing from typical rooftop configurations, this method effectively relies on "rule-of-thumb" assumptions determining the proportions between total rooftop space and suitable rooftop space (Byrne et al., 2015).

A manual selection method relies on the one-by-one identification of rooftop morphology, typically using aerial photography. Rooftops that appear especially suitable for PV installation, such as flat or south-facing roofs with low levels of shading, can then be selected for further analysis. This was the analytical approach used by an earlier study by CEEP on Newark, Delaware, aided by Google Earth (Byrne et al., 2009).

The final methodological category is represented by GIS-based methods, which have increasingly become the norm for this type of analysis. The major difference between this method and the previous two categories is the use of computer models to determine areas of high suitability for PV deployment – these computer models together fall under the general category of GIS-based models but can rely on a variety of data sources and can use distinctive software applications. The analytical approach is more responsive to context-specific conditions as it relies on direct data from the area under investigation. In addition, the method can be automated for quicker, more reproducible, analysis. The category is typically seen as a more accurate way to estimate rooftop solar suitability (Byrne et al., 2015; Melius et al., 2013). The method has been applied in many investigations (e.g. Jakubiec & Reinhart, 2013; Santos et al., 2014; Wong et al., 2016).

Table 1. Overview of three categories of assessment methods. Source: (Melius et al., 2013)

Approach	Advantages	Disadvantages
Constant value methods	Quick and easy to compute	Generalized result. Difficult to validate estimate
Manual selection methods	Detail-specific and allow for context-specific assumptions	Time intensive and hard to replicate across different jurisdictions
GIS based methods	Detail-specific and applicable across jurisdictions. Can be automated.	Time intensive and computer-resource intensive

The analysis presented throughout this section of the report will rely on what is known as the "NREL method" – this is a GIS-based approach to determine rooftop suitability in a jurisdiction and has been applied for 128 U.S. cities (Gagnon et al., 2016; Margolis et al., 2017). Intended to replicate industry best practices and standards, the NREL method provides a series of core guidelines (Gagnon et al., 2016) which are detailed below.

2.3. Method based on NREL analysis

To estimate flat rooftop suitability for PV installation in both Newark and Wilmington, the analysis applies a robust analytical method as outlined and evaluated by a research team from the National Renewable Energy Laboratory (NREL). This "NREL method" has been described in detail by Melius et al. (2013), Gagnon et al. (2016), Margolis et al. (2017) and, to some extent Ko et al. (2017). The method relies on LiDAR (Light Detection and

Ranging, a remote sensing technique) and building footprint data to conduct a rigorous and validated GIS analytical method. In addition to GIS software, the other key software component used in this analysis is NREL's System Advisor Model (SAM) to determine yearly PV electricity generation based on location-specific TMY3 data.

Effectively, the NREL method can be divided into three key phases. First, the analysis aims to determine the effect of shading on rooftop illumination. Using a 3D model derived from the original LiDAR data, the shading patterns are calculated and includes rooftop shading effects from nearby buildings or other nearby structures (in particular, vegetation) or from obstructions on the rooftops themselves casting a shadow (for example, air conditioning units). Next, the analytical approach is used to calculate the slope of each rooftop. By calculating height differences between pixels, the approach determines which sections of rooftop area can be considered "flat" (as mentioned, up to 9.5 degree slope is considered "flat") or sloped. Finally, the analysis determines the orientation or azimuth of each rooftop segment. This step further classifies the rooftop real estate into east, southeast, south, southwest, northwest, north, or northeast facing rooftops. This final step is useful for creating a full inventory of Newark and Wilmington's opportunity but, as mentioned, this report does not document the sloped rooftop result.

To operate this process, the LiDAR point cloud is converted to a digital surface model (DSM) or reflective surface model. Next, the three GIS tools of hill-shade, aspect, and slope are applied to the data. This process is provided in Figure 3.

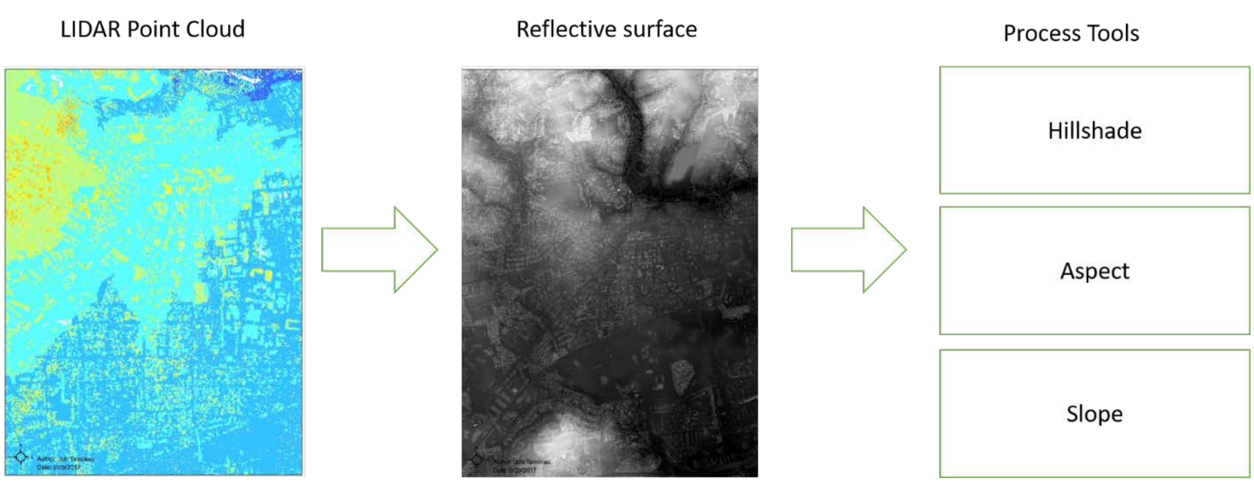

Figure 3. Overview of the initial stages of the analysis. Shown here is (a section of) Newark's LiDAR point cloud, color coded for elevation (left), followed by

a representation of the reflective surface or DSM (middle) and the application of the three main GIS tools (right).

2.3.1. Shading Assessment

The analysis begins with a simulation of shading patterns for daylight hours for a selection of four days of the year each representing one quarter. These four days have a unique relation to the position of the sun and are:

- Spring equinox, March 21st;
- Summer solstice, June 21st;
- Fall equinox, September 21st; and
- Winter solstice, December 21st.

The shading simulation makes use of altitude and azimuth of the sun to model the shading patterns throughout the sunlight hours for each of these days using the GIS Hill-shade tool in the Spatial Analyst extension in ArcGIS (Desktop version 10.5.1.).

For each of the four days, a threshold illumination value is applied which determines whether a pixel (i.e. each square meter) is “shaded” or “unshaded”. The threshold for March was taken to be 60%, for June, it was taken to be 70%, for September it was taken to be 60% and for December it was taken to be 50%. These values are taken from NREL method guidelines.

The number of sunlight hours received each day was then combined with the shading data to determine the daily sunlight availability for each individual month. A summation of sunlight hours for the four months are then computed and averaged to estimate the annual average sunlight availability for each square meter.

This process is visualized in Figure 4.

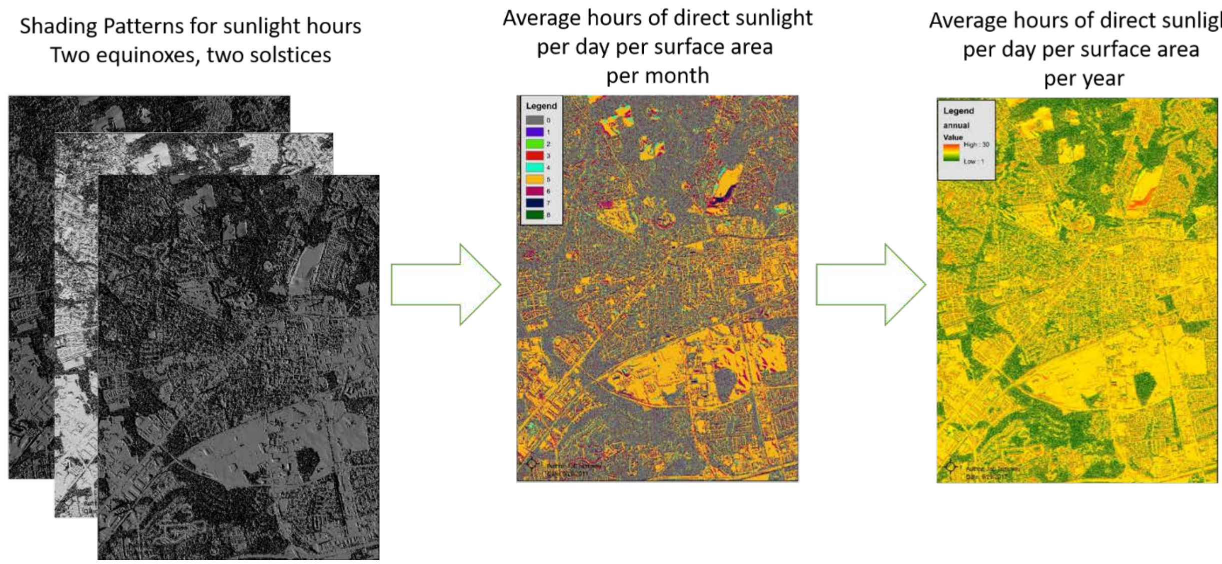

Figure 4. Overview of the assessment to determine shading. Shown here are the shading patterns for three moments in the day for Newark (left), the average hours of sufficient sunlight for a PV system as defined by the NREL method for each square meter per day for a full month in Newark (middle), and the annual average hours of direct sunlight sufficient for a PV system as defined by the NREL method per square meter (right).

2.3.2. Roof Orientation and Slope

The tilt analysis was done using the slope tool in ArcGIS. The analysis is limited to the building footprint data to allow for faster processing – in other words, any LiDAR data outside of the building footprint was ignored for this part of the analysis. To be consistent with PV installers' criteria in the region, we define flat roofs as roofs with a tilt less than 9.5 degrees and include this in our analysis and consider all other roofs with a tilt greater than 9.5 degrees to be sloped roofs. Figure 5 illustrates the calculation process.

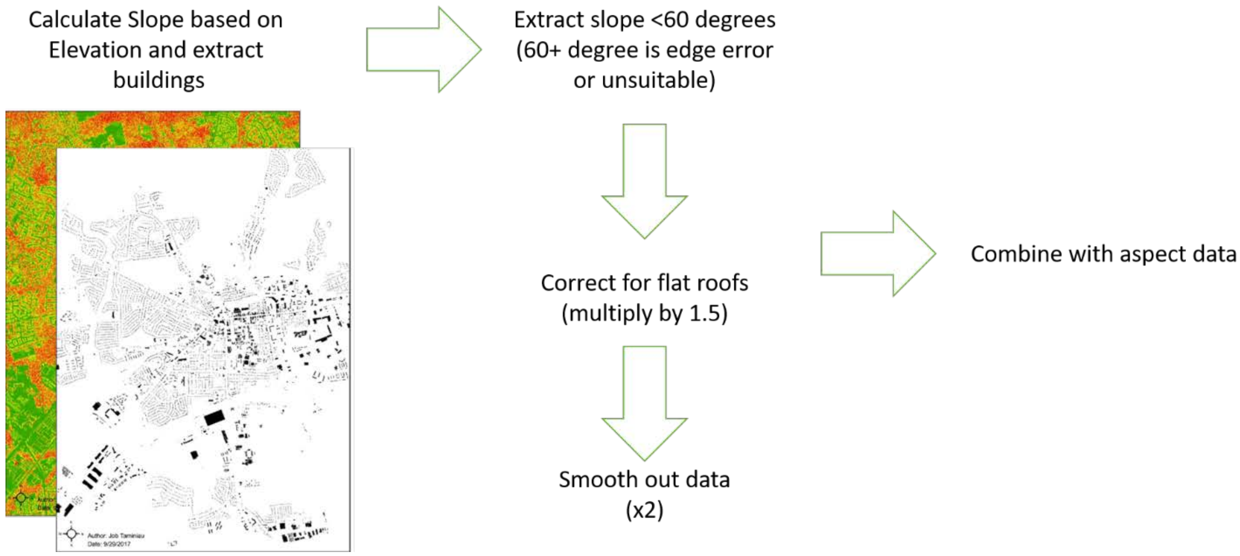

Figure 5. Overview of the slope calculation process.

2.3.3. Application of minimum (10 m^2) contiguous area threshold

We also excluded rooftop areas that did not have a minimum amount of contiguous roof area of ten square meters. This requirement ensured that there is at least enough area to install a 2.0 kW PV system (assuming a 20% module efficiency). To corroborate this threshold of ten square meters, consider NREL's database of U.S. PV installations which shows that over 96% of PV systems have a capacity beyond 1.6 kW.

2.3.4. Aggregation of results

The findings of the analysis are subsequently aggregated to levels of interest. For example, the data can be parsed out by zip code to evaluate the solar energy opportunity in relation to U.S. census data. For the analysis presented here, the data is aggregated by ownership – buildings are assigned to their associated owner. We focus especially on the public buildings owned by the City of Wilmington and the City of Newark.

2.4. Simulation of PV productivity on suitable rooftop area

Having determined the total suitable flat rooftop area by excluding rooftop areas that did not meet the requirements for shading, azimuth and a minimum area, the next step is to determine the electricity generation capacity of the suitable flat roof covered public buildings that have been classified by their ownership. This calculation requires the formulation of several assumptions as technical performance of PV systems varies due to equipment and design choices. First, a power density corresponding to a 20% efficient module is used. This type of module is now available in the market. An additional dimension to consider is inverter efficiency. This was assumed at 98.3% weighted average efficiency. The DC-to-AC ratio was assumed at 1.2 which is the literature value for the optimum size of inverters to minimize the cost of PV generated electricity. For flat roofs, the ratio of module area to roof area was chosen to be 0.63 to accommodate row spacing, maintenance access, and other dimensions related to system operation (such as fire codes and safety standards) (Byrne et al. 2015). These and other assumptions are covered in Table 2.

Table 2. PV System input used in SAM simulation

PV System Characteristics	Flat Roofs
PV System Installation Tilt	5 degrees
Ratio of Module area to roof area	0.63
Azimuth	180 degrees (facing south)
Module efficiency	20%
Inverter efficiency	98.3%
DC-to-AC ratio	1.2

2.5. Economic analysis

The economic analysis presented throughout this section is based on the SAM (System Advisor Model) version 2017. 9. 5. r2. provided by NREL, which is a performance and financial model that is capable of estimating a solar project's upfront and lifecycle costs and helps decision makers in the renewable energy industry. SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that user can specify as inputs to the model.

2.5.1. Components of the SAM model and simulation

The inputs of the photovoltaic commercial model include location and solar resource, module and inverter type, system design, shading and snow losses, lifetime, battery storage, system costs, financial parameters, incentives, electricity rates, and electric load. With all of these parameters, SAM creates cash flows for every year of the project and its net present value (NPV). We consider a portfolio-based project "feasible" when it meets two key conditions:

- **A positive Net Present Value (NPV):** essentially, this means that, in today's dollars, the project generates more value over the lifetime of the PV project (20 years) than it costs.
- **Net positive cash flow for each year of operation:** considered a critical threshold in order to attract low-cost financing, a project is feasible only when it has no years where cash flow is negative.

Project feasibility is tested along three possible economic scenarios:

- **Outright purchase:** we model the cost and benefit profile of a portfolio-based approach to solar system deployment in both Wilmington and Newark when the city governments use their own funds to directly purchase the system.
- **Low-cost sustainable energy loan:** The Delaware Sustainable Energy Utility (DE SEU) has a low-interest loan program available for projects of this kind. We model the system economic performance when using a 20-year, 2% loan from the DE SEU.
- **Municipal bond financing (Wilmington only):** municipalities in the U.S. can access the municipal bond market if the project reaches sufficient scale. Considering the Newark project is too small to access the municipal bond market at attractive terms, we model this economic scenario only for Wilmington.

2.5.2. Location and Resource, Module, Inverter and System design

SAM provides NREL National Solar Radiation Database (NSRDB) weather files based on 30 year historical data. In this report, we use "USA DE Wilmington New Castle Cnty AP (TMY3)" for both cities since this model Wilmington and Newark largely share climatic conditions. For each of the given scenarios above, the same general design was used. In SAM this means the same input values were used for the Location, Module, Inverter, and System Design tabs. The system sizing determines the number of modules in the system, string configuration, and number of inverters in tclimaticearhe system.

The SAM inputs are tabulated below (Table 3):

Table 3. System Design Parameters.

System Component	Parameter	Value
Location	TMY weather file	USA DE Wilmington New Castle Cnty Ap (TYM3)
Module	Solar Panel Module	20% efficient
	Mounting Standoff	Rack Mounted
	Array Height	Two Story Building or Higher
Inverter	Inverter	98.3% weighted efficiency
System Design	Desired Array Size	System size from technical potential assessment
	DC to AC ratio	1.2
	Tracking and Orientation	Fixed
	Tilt	5 degrees
	azimuth	180 degrees
	GCR	0.63

2.5.3. System Cost

System cost data was obtained from NREL benchmark reports for the region and crosschecked by system cost estimates published by the U.S. Energy Information Administration (U.S. EIA). Our SAM inputs for system cost are tabulated in Table 6 below. A different cost profile is used for Wilmington compared to Newark due to the different system size.

Table 4. *System cost parameters obtained from NREL and US EIA. Note that Newark and Wilmington have identical costs per Watt installed except for inverter cost and Engineering and Developer overhead both due to Wilminton's larger size.*

Parameter	Value	
	Wilmington (Utility Size)	Newark (Commercial Size)
Module Cost	$ 0.35 /Watt	$ 0.35 /Watt
Inverter Cost + Warranty ($0.01/Watt)	$ 0.07 /Watt	$ 0.11 /Watt
Balance of System Equipment	$ 0.32 /Watt	$ 0.32 /Watt
Installation Labor	$ 0.17 /Watt	$ 0.17 /Watt
Installer Margin and Overhead	$ 0.18 /Watt	$ 0.18 /Watt
Contingency	4%	4%
Permitting and Environmental Studies	$ 0.12 /Watt	$ 0.12 /Watt

Engineering and Developer Overhead + Profit & Grid Interconnection	$ 0.47 /Watt	$ 0.53 /Watt
Land Purchase	$ 0.00 /acre	$ 0.00 /acre
Sales Tax	0%	0%
Operation and Maintenance Costs + Insurance	$ 16.00 /kW	$ 16.00 /kW
O & M Escalation Rate	0%	0%

2.5.4. Financial Parameters

In addition to technical aspects and hardware and software cost profiles, a critical element in economic analysis is the financing approach used. As mentioned above, we apply three scenarios, and apply the financial parameters as listed in Table 5.

Table 5. Financial Parameters.

Parameter	Outright Purchase	DESEU Loan		Municipal Bond
		Newark	Wilmington	Wilmington
Debt Percent	0%	100%	50%	100%
Loan Term (years)	0	20	20	20
Loan Rate	0%	2%	2%	4%
Inflation Rate	2%			
Real Discount Rate	3%			
Federal Income Tax Rate	0%			
State Income Tax Rate	0%			
Insurance Rate	0%			
Net Salvage Value	0%			
Property Tax-Assessed Percentage	0%			
Annual Decline	0%			
Property Tax Rate	0%			
Federal & State Depreciation	No Depreciation			
SREC contract price	$45/MWh for years 1-10			
	$35/MWh for years 11-20			

2.5.5. Data Request to City of Wilmington and Newark

Additional supporting data requests have been submitted to both the City of Wilmington and the City of Newark. In particular, no public data is available regarding the electricity charges both city governments incur or how these prices have changed over time. In addition, the rate charged by the City of Newark's municipal utility is needed to establish a firm estimate of the profitability of the system from the perspective of both the City and the City's customers. This data has been requested and will be used in future research.

SECTION 3. TECHNICAL SOLAR POTENTIAL OF WILMINGTON AND NEWARK

The combined use of the NREL method using GIS software and the SAM PV system design software yields insight into the PV technical potential and generation profile. These are outlined below for both Wilmington and Newark.

3.1. Solar City Wilmington

Our analytical method identifies 1,540,828 square meters of suitable flat rooftop space across the entire city of Wilmington (i.e. including residential, commercial, and all other building types). Using the data and assumptions outlined in the previous section of this report, this amount of suitable rooftop space can house just over 194 MWp of solar PV capacity. Under full deployment, such a system could generate 224,880,384 kWh in the first year of operation. Separated by property class, our estimate suggests that the commercial sector (32.3%), followed by the public (30.6%) and residential sector (28.4%) together account for most of the flat rooftop space that is available to solar system deployment.

In terms of City of Wilmington buildings – i.e. public buildings owned by the City of Wilmington per our database downloaded from New Castle County GIS Data Viewer – we identify a total flat rooftop system size opportunity of 2,300 kWp. To arrive at this total system size, we carefully inspected each data point one-by-one to ensure the analysis results are accurate. For example, Wilmington owns many residential buildings as part of the Land Bank – these were excluded from the analysis. This inspection has increased the accuracy of our estimate since the interim report.

When fully deployed, this system generates 2,651,848 kWh in the first year of operation. Using SAM, we can calculate the hourly estimated system generation. To illustrate, we apply this hourly solar electricity generation profile to an *illustrative and preliminary* load profile of the City of Wilmington. As documented above, we don't currently have the necessary data to make a load profile of the City of Wilmington buildings so, instead, we used an estimate of annual electricity consumption based on city budgets and scaled it per a Department of Energy benchmark office building. Future research will verify the actual load consumption when data is obtained from the City of Wilmington. Our estimated load profile enables an estimate of the solar PV contribution to the City's load (Figure 6).

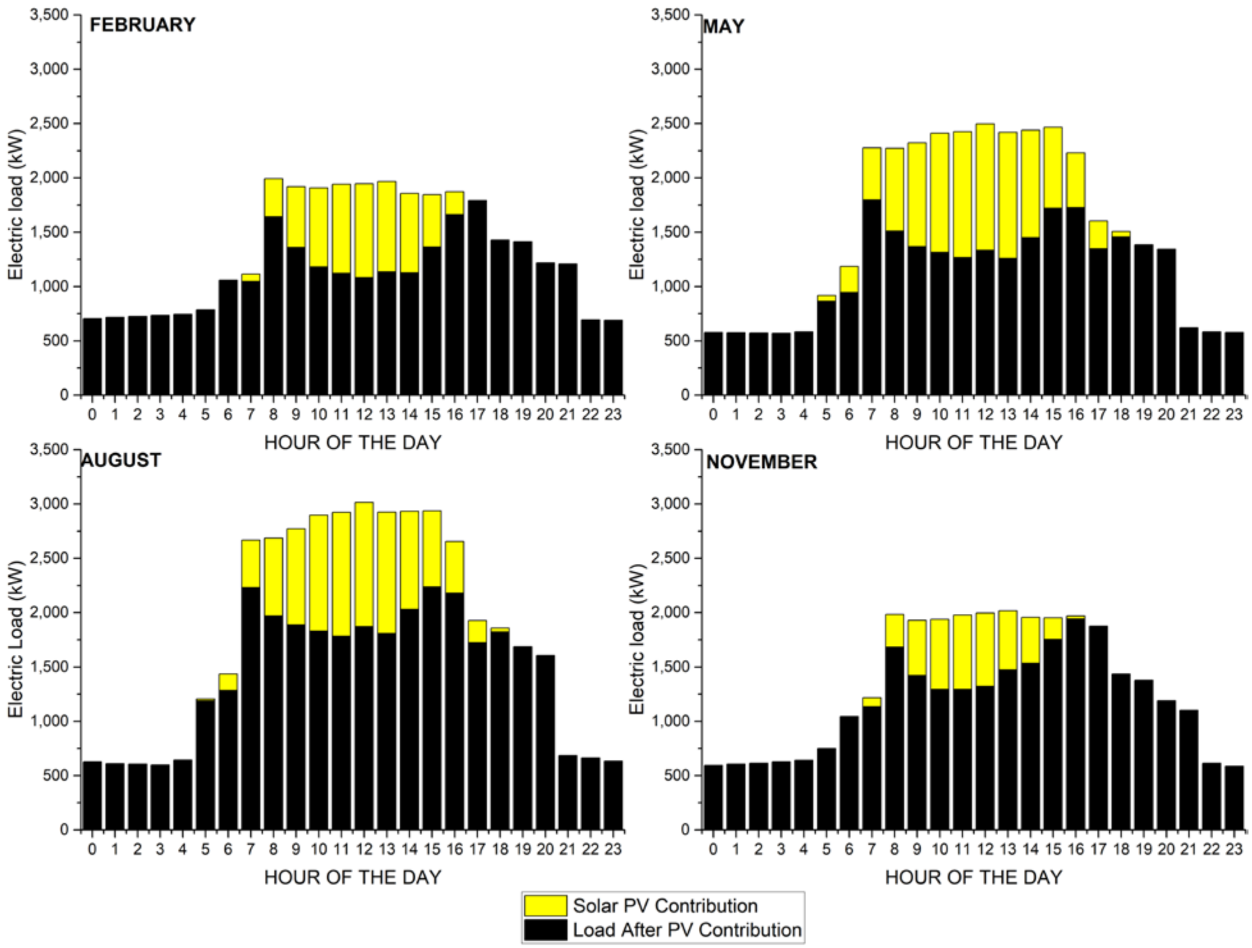

Figure 6. Average Wilmington load profile and solar PV contribution for each hour of the day in four select months.

Note: graph created using estimated annual City of Wilmington electricity consumption of 13 million kWh and scaled according to a DOE benchmark office building.

Based on the data presented in Figure 6 – again, preliminary and constructed using benchmark data as opposed to actual use data – the City of Wilmington, on average, could expect to cover about 17.5% of the daily electricity consumption in February and about 21% in August. However, looking only at the daylight-hours (which is when the PV system actually operates), the City of Wilmington could expect to cover about 31% of the August daytime electricity consumption. Indeed, there are hours of the day during certain times of the year where the City would produce more than it consumes (not illustrated in Figure 6).

3.2. A Newark Solar City

The same approach was applied to the City of Newark as a whole and for the City owned building specifically. Our estimate yields a total 661,434 square meters of flat rooftop space that is suitable per NREL method guidelines. This rooftop space could be home to about 83,341 kW of PV. Such a system at full deployment could generate about 96,531,912 kWh in the first year of operation. Separated by property class, our estimate suggests that the public sector (38.6%), followed by the commercial (29.4%) and industrial sector (24.9%) together account for most of the flat rooftop space that is available to solar system deployment. In terms of the public sector accounting for such a large share – our data bears out that this is primarily due to the high share of buildings that are owned by the University of Delaware.

In terms of City of Newark buildings – i.e. public buildings owned by the City of Newark per our database downloaded from New Castle County GIS Data Viewer – we identify a total flat rooftop system size opportunity of 480 kWp. To arrive at this total system size, we carefully inspected each data point one-by-one to ensure the analysis results are accurate. For example, while we couldn't include new construction in our analysis due to 2013-2014 LIDAR database used, we were able to exclude some buildings that have since been demolished. This inspection has increased the accuracy of our estimate since the interim report.

The 480 kWp system can generate 546,658 kWh in its first year of operation. Applying the same process to Newark – using a preliminary and illustrative load profile generated from an annual consumption level of 4,000,000 kWh – we can estimate the City of Newark solar PV contribution. Annually, the system generation should be sufficient to cover about 13.7% of consumption. In April, the system can cover about 28% of daylight-hour consumption.

Due to the fact that we estimated the load profile using benchmark building data from the DOE, the load profile shape of Newark is the same as that of Wilmington. As such, rather than showing a very similar image for the load profile, we illustrate below

Newark's estimated load duration curve. The load duration curve shows the entire year (8760 hours) but ranked from highest level of consumption to lowest level of consumption. The hourly solar PV contribution from SAM is included in the graph to illustrate the share of the load covered by solar PV. The load duration curve shows that there are several low-consumption hours (far right end of the graph) with high solar electricity generation (Figure 7).

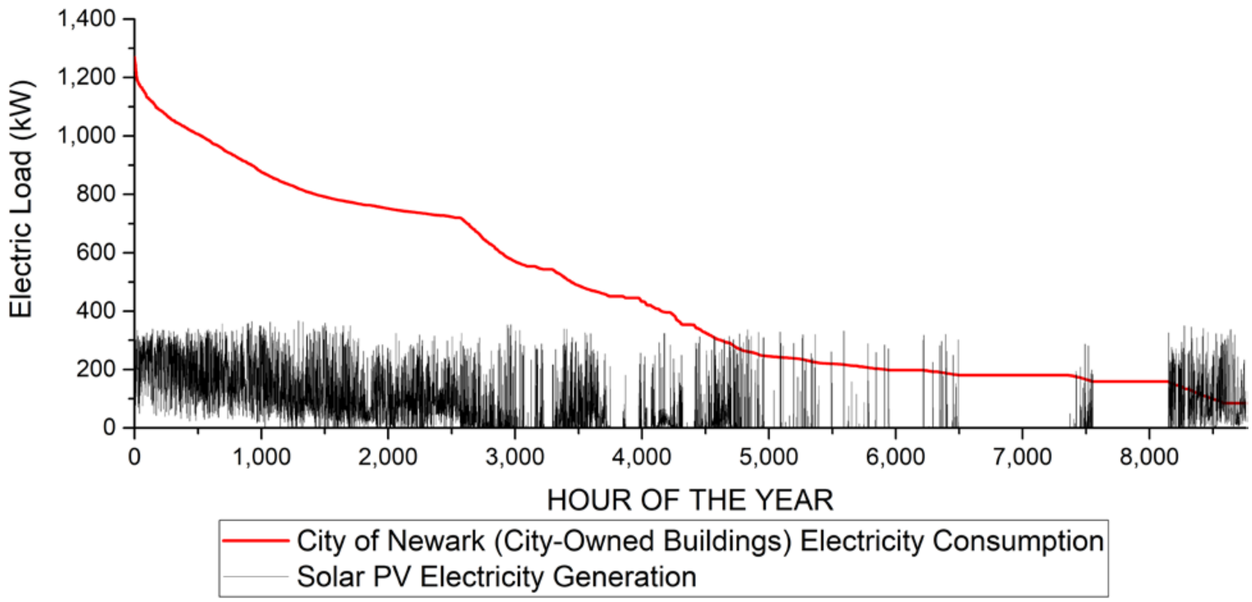

Figure 7. Annual load duration curve (red line) with solar PV electricity generation (black line).

SECTION 4. ECONOMIC VIABILITY OF NEWARK AND WILMINGTON SOLAR CITIES

Using NREL's SAM model, we test the economic feasibility and viability for both the Newark Solar City and the Wilmington Solar City options. As introduced during the data and methods section above, several financing pathways are available for each city and, critically, each financing method offers different advantages and disadvantages. In particular, three financing pathways are evaluated:

- *Outright Purchase:* The city purchases the solar panel system and its installation with money from their own budget.
- *Delaware Sustainable Energy Utility Loan:* A loan from the DE SEU is used to fund the purchase of the system and installation. Loan conditions, supported by direct communication with a DE SEU official, are that each city has access to a up to $2 million dollar loan for 20 years at 2% interest.
- *Municipal Bond:* Newark and Wilmington both have access to the municipal bond market. Based on data from the Electronic Municipal Market Access Database (EMMA), we estimate that the City of Wilmington could secure capital for 20 years at 4% interest. We don't include this option for Newark as the PV system size is too small to warrant the offering.

The financing scenarios used for the two cities differ and are tabulated bellow along with their respective system sizes and total installed cost. Based on these installed cost data, Wilmington can acquire a system at about $1.71/W while Newark, due to its smaller system size, can acquire a system at approximately $1.81/W.

Table 6. Scenarios with given system sizes and financing methods

City	System size (kW)	Estimated Installed Cost	$/W	Financing Method
Wilmington	2,300	$3,959,425	1.72	Outright Purchase, DESEU Loan, Municipal Bond
Newark	480	$867,000	1.81	Outright Purchase, DESEU Loan

Estimating the break-even point for a PV system can be done by iterating for a solution where the Net Present Value (NPV) is equal to zero. Effectively, this approach determines at what point the system makes exactly sufficient return to warrant the investment, but no more than that – no profit is calculated in this regard. This is a suitable approach for both the cities of Newark and Wilmington as they do not have a mandate to generate a profit. The approach also overcomes the data limitation that we do not know the actual electricity rate either city has contracted for with their supplier.

4.1. Economic Feasibility Testing for Wilmington

Wilmington's 2,300 kWp system or almost $4.0 million investment can be financed in three primary ways: direct purchase, SEU loan, or municipal bond. For each of these three approaches we calculate the break-even point for PV. The results are captured in Table 12.

Table 7. Net savings in year 1 with given scenarios for Wilmington.

Financing Method	Cost Per Kilowatt-Hour (cents/kWh)	NPV	Discounted Payback Period (years)	Net Savings in Year 1 (i.e. after-tax value of energy generated by system)
Outright Purchase (0% Debt)	8.601	$0	18.5	$ 228,086
DESEU Loan (50% Debt, 20 years, 2% Interest)	9.445	$0	19.37	$ 250,467
Municipal Bond (100% Debt, 20 years, 4% Interest)	12.14	$0	19.98	$ 322,000

On an annual cash flow basis, each of these three financing pathways looks slightly different. Two primary inflows of cash represent the revenues of the system. First, there is the savings on the electricity bill – this is the value of the electricity that is generated by the system as it avoids the use of electricity from the grid. Second, the solar renewable energy credits represent a revenue stream as well. Based on current market conditions, the credits could reasonably be expected to be fixed at at $45/MWh for the first 10 years and $35/MWh for the last 10 years. The value of SRECs represents a risk in the assessment as the market conditions fluctuate – in other words, a City of Wilmington solar PV system bidding at $45/MWh might not be awarded this credit depending on market conditions. Primary negative pressure on the cash flow comes from loan and interest payments and operating and maintenance cost. Also, it should be noted that the average solar panel system will last for 25 years, providing for more value after the 20 year mark.

4.1.1. Direct Purchase for Wilmington

Direct Purchase: If Wilmington has the funds available to purchase the almost $4 million system outright, it would achieve a NPV of zero when the value of each kWh generated by the system is set at 8.601 cents/kWh. In other words, if the City of Wilmington currently pays more than 8.601 cents/kWh for its electricity, the City could install a PV system as proposed here for the same operational cost. However, critical benefits accompany a PV system that are likely not currently available to the City, including:

- We model the PV electricity price level here as a constant – no escalator is enabled. In other words, the City would know exactly for 20 years what its electricity price is.
- Considering electricity rates typically inflate over time, the fixed price level for PV likely results in a larger and larger delta between the electricity rates charged to the City of Wilmington and the fixed rate at which the system produces value. This is a considerable risk management hedge against future price increases and volatility.

The result is illustrated in Figure 8.

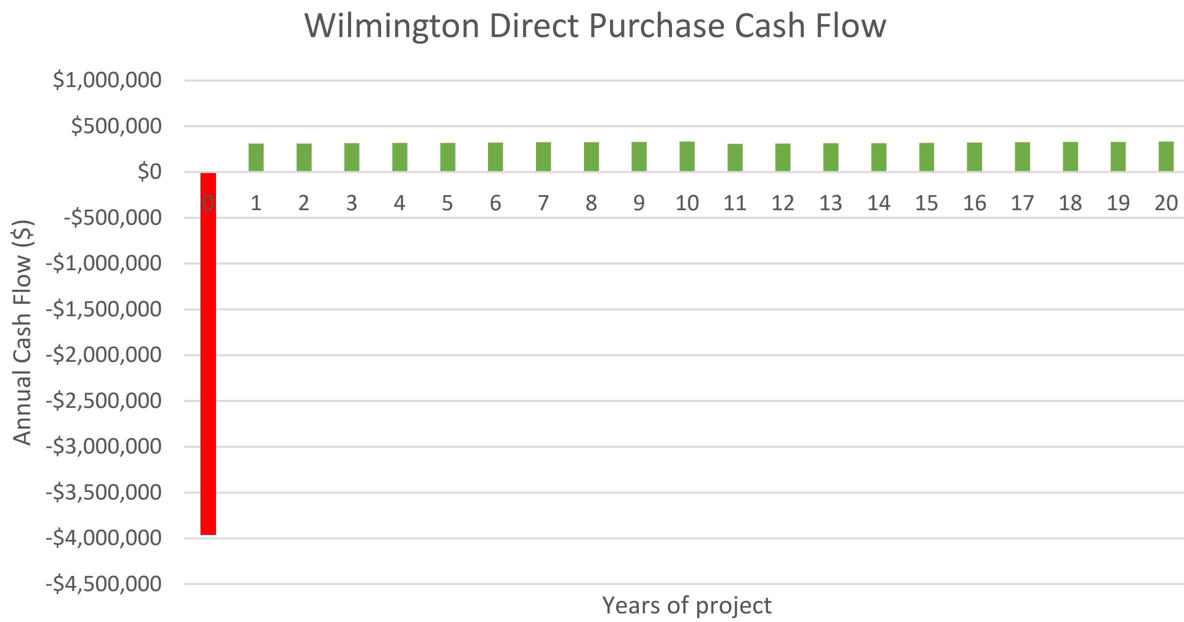

Figure 8. Annual Cash Flow for Wilmington – Direct Purchase Financing Pathway

4.1.2. DESEU Loan for Wilmington

DESEU Loan: The City of Wilmington could elect to make full use of the 20-year low-interest loan program provided by the Delaware SEU. Making use of the DE SEU loan relieves pressure of City of Wilmington's own capital budget as half the project cost could be covered by this loan program. The other 50%, under this scenario, is covered by the City of Wilmington. Due to the added cost of the interest on the loan, the City of Wilmington could achieve a NPV of zero when the value of each kWh generated by the PV system is set at 9.445 cents/kWh.

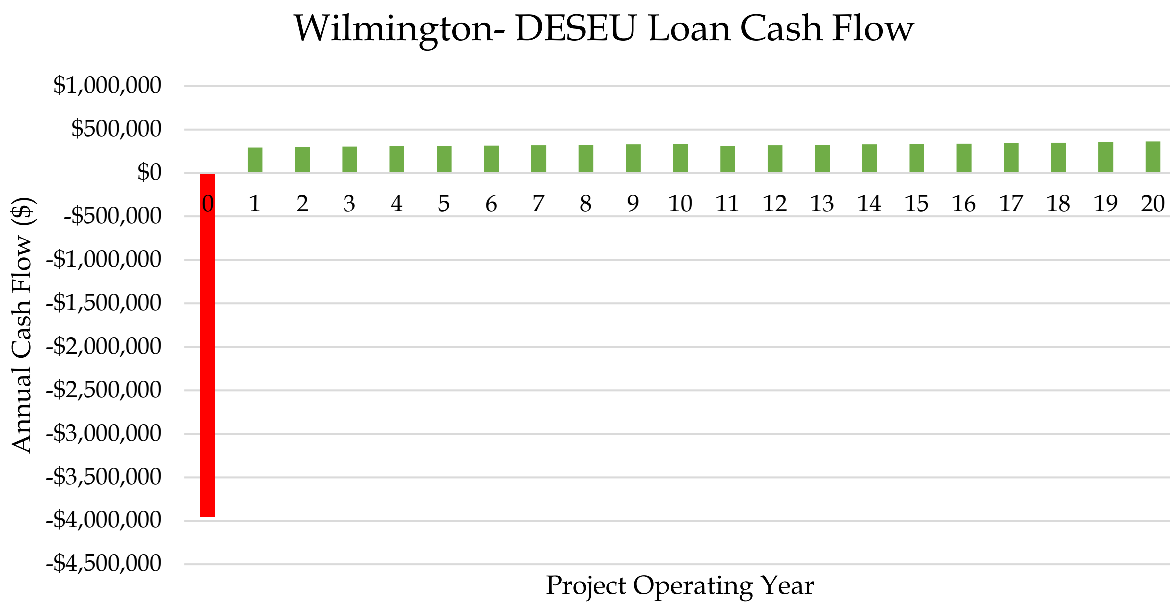

Figure 9. Annual cash flow for Wilmington – DE SEU Loan.

4.1.3. Municipal Bonds for Wilmington

Municipal Bond: With a municipal bond, the City of Wilmington could cover the entire capital cost with debt. However, the debt comes at a higher interest rate compared to the DE SEU loan. The 4% interest represents a cost, and as such, the City of Wilmington would need to value the electricity generated by the system at 12.14 cents/kWh to break-even. This financing approach essentially represents a full use of the City's operational budget – to pay back the debt – and no use of the City's capital budget as the entire installed cost is borrowed.

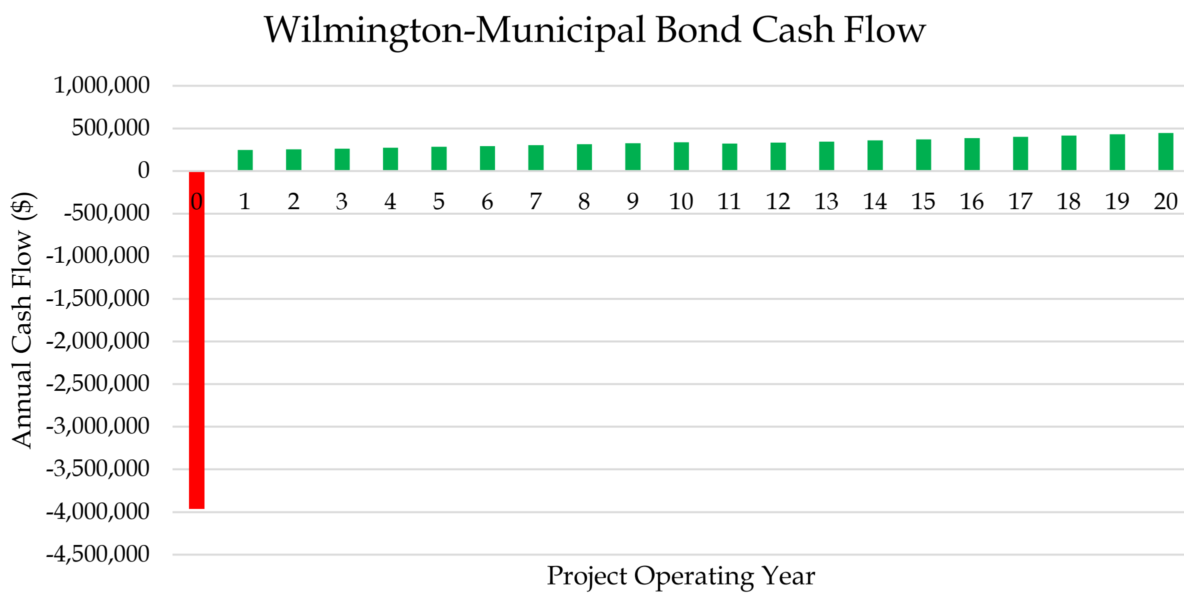

Figure 10. Annual cash flow for Wilmington – Municipal Bond.

4.2. Economic Feasibility Results for Newark

For Newark, we considered only two of three financing options, outright purchase and the DSEU loan. A municipal bond model was not considered because of the project's low cost. Newark has a slightly higher installed capital cost compared to Wilmington. This difference leads to a higher value that needs to be placed on the electricity generated by the PV system in order to break even. The results of our assessment are provided in Table 16.

Table 8. Net savings in year 1 with given scenarios for Newark.

Financing Method	cents/ kWh	NPV	Discounted Payback Period (years)	Net Savings in Year 1
Outright Purchase	10.87	$0	20	$59,170.00
DSEU Loan	12.98	$0	20	$53,314.00

4.2.1. Outright Purchase for Newark

Direct Purchase: Like with the scenario assessment for Wilmington, Newark could elect to cover the entire installed costs from its own budget. Considering the total installed cost is considerably lower than for the City of Wilmington, this option should be feasible for the City of Newark. We calculate that, if the city values the electricity generated by the PV system at 10.87 cents/kWh or more, the system represents an feasible investment. The projected cash flow, under the assumptions outlined throughout this report, is provided in Figure X.

While no detailed electricity rate data is as of yet available to the research team – this hopefully will be part of the research effort next year – we note that, from a cursory evaluation of residents, residential electricity rates are well above the 10.87 cents/kWh. This creates the opportunity to either lower electricity rates to the Newark municipal utility customers by means of solar PV or to value the system's electricity value at a higher level to hedge against uncertainties. For example, SREC values of $45/MWh are used here for the first ten years. However, if the system's electricity generation is valued at a higher rate, the City could bid into the SREC market at an even more competitive value thus improving the probability that SRECs will be awarded to support the project.

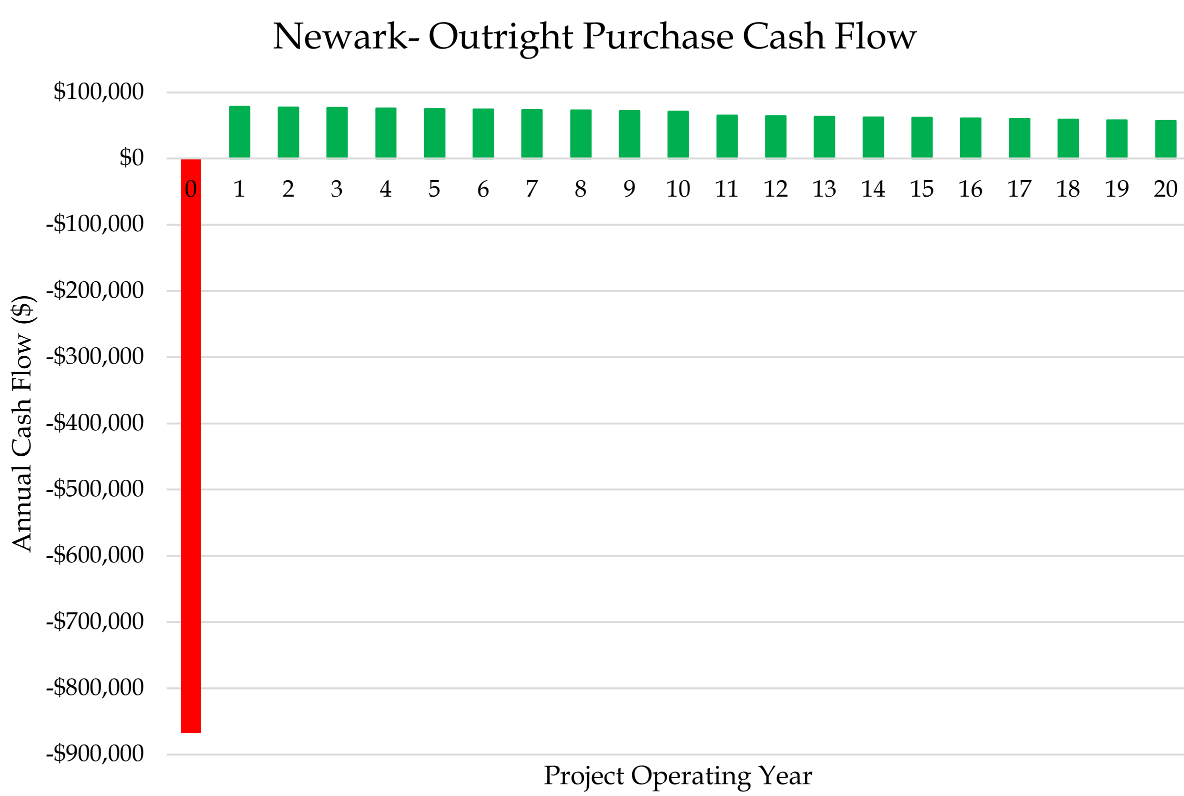

Figure 11. Annual cash flow for Newark – Direct Purchase

4.2.2. DSEU Loan for Newark

Borrowing the full capital cost of the system enables the City of Newark to rely fully on its operational budget (as opposed to its capital budget) for this project. Because of the low interest rate, the City of Newark would have the benefit of not having to affront the entire installed cost immediately. If the city sells the electricity at a rate of 12.98 cents per kilowatt-hour, the project is able to cover the debt service costs and interest costs by generating enough value to break-even.

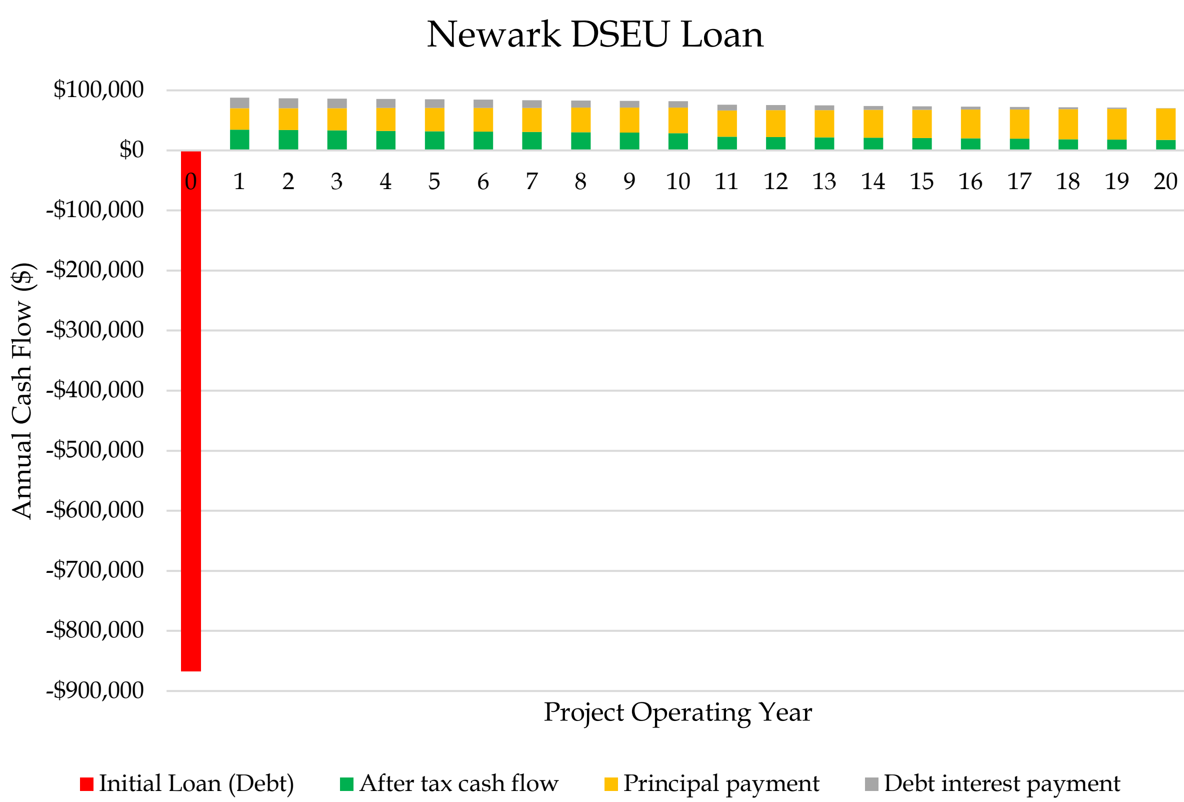

Figure 12. Annual cash flow for Newark – DE SEU Loan

SECTION 5. CONCLUDING REMARKS AND POTENTIAL FUTURE STUDY

The findings reported in this second-year installment of the three-year research effort indicate significant solar potential across both the City of Wilmington and the City of Newark. We estimated for both cities the flat rooftop city-wide solar PV potential and the PV potential for Wilmington and Newark's city-owned infrastructure. The research findings indicate that Delaware could embark on a sustainable energy pathway that exceeds current obligations outlined under the statewide Renewable Portfolio Standard (RPS) and set the state on track towards a significant improvement in its overall sustainability profile. In particular, municipal leadership exhibited by, for instance, Newark and Wilmington could propel other actors in the state to participate in the vision.

The city fabric represents an often underestimated opportunity to advance the urban energy economy. As reported throughout this second-year publication, both the City of Wilmington and the City of Newark have a substantial opportunity to reduce their energy use and improve the sustainability of their cities. Using the portfolio-based strategy applied here, these cities have the opportunity to rely on self-financing, asset-backed investment that generates consistent and stable value for over 20 years. The idea of city-wide solar PV installation appears out of reach at first sight but consider that Seoul, South Korea recently embarked on a 1 gigawatt (GWp) "Solar City" strategy, investing $1.5 billion over the next five year. Closer to home, the City of Philadelphia, New York, and Pittsburgh are actively exploring their urban rooftop solar energy options.

The research of the third year will more fully develop the solar PV potential for both Newark and Wilmington. In particular, the following lines of research can be considered for 2018-2019:

- **Detailed Analysis of Financing Options:** The economic analysis conducted in this report provides a preliminary insight into the financing opportunities to both the City of Wilmington and the City of Newark. Looking forward, a more detailed analysis can be implemented, considering both additional financing options and expanding the analysis on the three financing pathways evaluated here. In particular, the research can explore the use of power purchase agreements (PPA), a popular financing option for solar PV that could yield attractive benefits to the city.

- **More detailed mapping of rooftop potential:** The analysis presented here focused explicitly on the flat rooftop potential of the two cities. A follow-up investigation could explore the sloped rooftop potential as well to provide a more thorough overview of the entire opportunity.
- **Evaluation of solar PV opportunity by building type:** We have focused on the flat rooftop space of city-owned buildings but future research could expand to other building types (e.g. commercial, residential) as well.
- **Investigation of partnership opportunities:** expanding the portfolio of PV rooftop installations can reduce transaction costs, lower system costs, attract more beneficial financing terms, etc. For example, the University of Delaware is a major owner of infrastructure in the City of Newark. Various partnership modalities are available to the City of Newark to engage with the University of Delaware. For instance, the City of Newark could lease rooftop space from the University or they could co-finance a large-scale PV system.

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