Cocreating Property Value and Energy Justice: A Framework to Leverage Investor Self-Interest to Overcome the Renewable Energy Split-Incentive in Rental Property

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Cocreating Property Value and Energy Justice: A Framework to Leverage Investor Self-Interest to Overcome the Renewable Energy Split-Incentive in Rental Property

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A Thesis in the Field of Sustainability

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Abstract

Renewable energy deployment over the past two decades has been undeniably successful in many facets of the national economy. Its mass deployment can create positive economic, environmental, and energy justice impacts. In the built environment, which accounts for up to 40% of the U.S. greenhouse gasses, renewable energy has made significant inroads in adoption. Unfortunately, the benefits have not been evenly shared among all economic demographics and in all property types. Specifically, renters in existing multifamily workforce apartments are lagging far behind single-family homeowners in access to photovoltaic solar renewable energy as apartments currently have adoption rates below one percent. A primary reason cited for this stubbornly low adoption rate is the existence of the split-incentive where landlords must make the financial investments, but tenants receive the benefits of the energy systems.

The ramifications of this situation manifest themselves in economic, environmental, and health outcomes that are demonstrably worse for residents of workforce multifamily rental housing. The negative impacts are most acutely experienced in socioeconomically marginalized communities, but the effects can extend beyond local and state borders and have far-reaching negative consequences.

This study evaluated the financial and environmental benefits available with photovoltaic solar when deployed on a large scale on multifamily properties in various locations across the country. I therefore created a model to quantify the financial return and decarbonization potential of installing photovoltaic solar systems on multifamily

apartments. I correlated these results with energy burden data across seven U.S. cities to create a geographic index for property owners and policy makers to understand how to develop and implement measures to incentivize increased renewable energy adoption.

The results of the study demonstrated that positive economic results can accrue to landlords after making photovoltaic solar investments in the form of both increased annual net income and property values beyond the value of the initial system investments. The property value increases were available in almost all geographic jurisdictions studied and reached above an eight-fold increase over the system cost in Lahaina, HI. Similarly, the annual cash flow enjoyed by the investors attained over a four-fold increase in the best-performing city, Lahaina, HI. These financial results were buttressed with significant positive environmental outcomes in many states when a reasonable photovoltaic solar adoption rate was modeled. Over half a million metric tons of CO_2e could be avoided annually in six states, and in Texas, over two million metric tons of GHGs could be eliminated annually.

The study hopes to facilitate renewable energy adoption in rental housing in a wide variety of locations by providing the information necessary for property investors to determine the financial outcome of making renewable energy investments. Additionally, by using the three-dimensional index developed in the study, regulators could incentivize private property owners to unleash the financial and environmental results identified in the study by targeting policies to the locations that offer the best opportunities. This public-private schema could have the effect of allowing a private market mechanism to address both environmental and energy justice challenges creating a virtuous system where landlords, tenants, and community interests are all simultaneously promoted.

Frontispiece

Replication of Relief of Akhenaten and Nefertiti worshiping the Aten (sun god), The Egyptian Museum (Bildagentur, 2021)

Author's Biographical Sketch

Anthony Keslinke is an ALM candidate at the Extension School at Harvard University studying Sustainability and Environmental Management. He received a bachelor's degree from the Illinois Institute of Technology in Metallurgical Engineering and Materials Science and a master's degree from the University of California at Berkeley in Materials Science and Engineering. He has been awarded the Harvard Innovation Lab's Social Impact Fellowship and named as a semi-finalist in the Harvard University's President's Innovation Challenge.

He is interested in discovering new ways to apply his experience in the built environment that provides safe and healthy spaces to strengthen communities and empower residents to realize their highest outcomes. He hopes to contribute to a body of work that creates a discussion around a new archetype to inspire other decision-makers to implement these enriching methods in their locales.

Dedication

“I can do all things though Him who gives me strength.”

Phil 4:13

This work is dedicated to the Father and the grace of the vertical relationship He provides that creates the foundation and stability that allows me to build lasting and meaningful horizontal relationships. Personally, my deep appreciation goes to my wife and son who motivate me to put my sincerest efforts forward to make positive contributions to create a legacy that will endure. Finally, this is dedicated in memory of the sacrifices of a mother who committed her solitary and sustained efforts to give direction and love to two irrepressible boys and always managed the best she could. I love you, Noreen.

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Acronyms and Abbreviations

AEC: average electricity consumption

AGI: annual gross income

ASA: assumed solar adoption

AUR: average utility rate

BC: benefit-cost

BCA: benefit-cost analysis

CO_2e: carbon dioxide equivalent

DOE: Department of Energy

EB: energy burden

EIA: Energy Information Administration

FERC: Federal Energy Regulatory Commission

GHG: greenhouse gas

IRA: Inflation Reduction Act

kW: kilowatt

kWh: kilowatt-hour

kWp: kilowatt peak

LEAD: Low-Income Energy Affordability Data

LCOE: levelized cost of electricity

MDU: multifamily dwelling unit

MFU: multifamily units

MWh: megawatt-hour

NOI: net operating income

ΔNOI: change in net operating income

NREL: National Renewable Energy Laboratory

O & M: operating and maintenance

PEA: project emissions avoided

PV: photovoltaic

PVI: property value increase

PVS: photovoltaic solar

RECR: real estate capitalization rate

ROI: return on investment

SD: standard deviation

SF: square footage

SFC: system financing cost

SFD: single-family dwelling

SREC: solar renewable energy certificate

WRI: World Resources Institute

ZE: zero energy

Chapter I

Introduction

There are many opportunities in the built environment to reduce the carbon impact of the various building sectors. In the multifamily sector, significant efforts by building professionals to decarbonize buildings in recent years have been evidenced by the results in new construction projects with dramatically lower energy use intensity (EUI) coefficients (Fabris, 2023; Hannas et al., 2017). This has been accomplished with a multidisciplinary approach across the different aspects of building construction. These approaches include energy efficiency improvements in HVAC, water heating, improved building envelopes, electrical equipment, and especially the use of renewable energy primarily employing photovoltaic solar (PVS). These efforts are creating a viable pathway toward zero energy (ZE) status in new multifamily dwelling units (MDUs); MDUs are typically defined as condominium or apartment buildings with five or more units (Langner et al., 2020).

However, these advances to decarbonize the built environment are not evenly distributed within the different building types, or across socioeconomic strata. Existing MDUs continue to contribute a disproportionally large percentage to the overall building sector's GHG emissions, and it is estimated that 70% of the existing building stock in the United States will still be in service by 2040 (Säynäjoki et al., 2012). To achieve the Paris Agreement's goals, the existing built environment must cut its ongoing emissions from operations by 65% by 2030, and reduce them to zero by 2050 (Architecture 2030, 2022; Silva, 2020). Therefore, while it is important to develop and use novel technologies and methods to decarbonize the entire built environment, intense efforts must be made to address the decarbonization and renewable energy gap present in legacy MDU properties, if a just energy transition is to be achieved.

The existence of the disparity of PVS adoption among property types leaves some communities unable to take advantage of the renewable energy benefits which include lower electricity rates, enhanced grid resilience, and reduced air pollution; leading to significant energy and environmental inequalities. Historically, disadvantaged communities with higher percentages of low-income residents and minorities have experienced higher rates of environmental injustice and energy burden (Lukanov & Krieger, 2019; Pivo, 2014; US DOE, 2023). The higher energy cost burden is therefore falling on the residents in existing MDUs that are statistically in lower-income minority households (Airgood-Obrycki, 2022; Brown et al., 2020). Also, power generation plants in these communities create both higher levels of GHGs and localized air pollution in communities near the plants in the form of fine particulate matter below 2.5 ($PM_{2.5}$) microns in size (Declet & Rosenberg, 2022). These particles cause detrimental health impacts and can lead to death in health-impaired residents in the communities near the power generation sites (Bowe et al., 2019; Machol & Rizk, 2013). Hence, reducing the dependence on electricity generated from fossil fuels, and thereby decarbonizing existing MDUs in at-risk communities, could have substantial positive social, health, and environmental benefits.

The introduction of renewable energy to existing MDUs could reduce the energy justice gap; however, owners of MDUs may not possess the information necessary to perform a rational analysis to determine if their properties are good candidates for renewable energy investments. Complications in the investment decisions arise because many local factors affect the financial viability of the investments, preventing an across-the-board solution. These include solar irradiance PV output, average electrical power consumption, local utility power rates, and real property capitalization rates. Therefore, a benefit-cost analysis (BCA) employing the factors that affect the payback period of PVS investments in multifamily properties will enable property owners in different geographic areas to make rational decisions to de-risk renewable energy investments.

Research Significance and Objectives

This research formed the foundation to construct a framework for property owners to assess the economic benefits of making an investment in renewable energy for their MDUs. It provides the information necessary to enable investors to determine the economic and environmental implications of developing PVS systems on their properties specific to their geographic location. The BCA model I constructed can be applied to a wide variety of situations with vastly different solar irradiance, electricity rates, annual electricity consumption amounts, real estate capitalization rates, and carbon emissions rates from electricity generation. The BCA model uses these location-dependent variables as the operational variables that affect the return on investment and environmental impacts of PVS systems installed on MDUs. The results of the BCA model allow an analysis in 70 major cities across the United States and facilitate the examination of meaningful comparisons and trends.

The research is important because it gives property owners the required information to quantify the economics of PVS systems and address the split-incentive barrier that has heretofore prevented them from investing in renewable energy and deploying PVS to any meaningful degree (Raziei et al., 2016). It also quantified the reduction in carbon equivalent emissions at both the project and state level that these systems could have by their incorporation on MDUs.

The main objectives of the research study were:

- To build a model that incorporated the operational independent variables that determine the financial viability of PVS in MDUs
- To use the model to perform a BCA of PVS investment in MDUs across major U.S. cities and rank the cities based on their financial results
- To perform statistical analyses to determine which factors are dominant in determining the economic return of PVS systems in MDUs
- To perform sensitivity analyses that demonstrate the influence that the primary variables have on the economic return of PVS systems in MDUs

Background

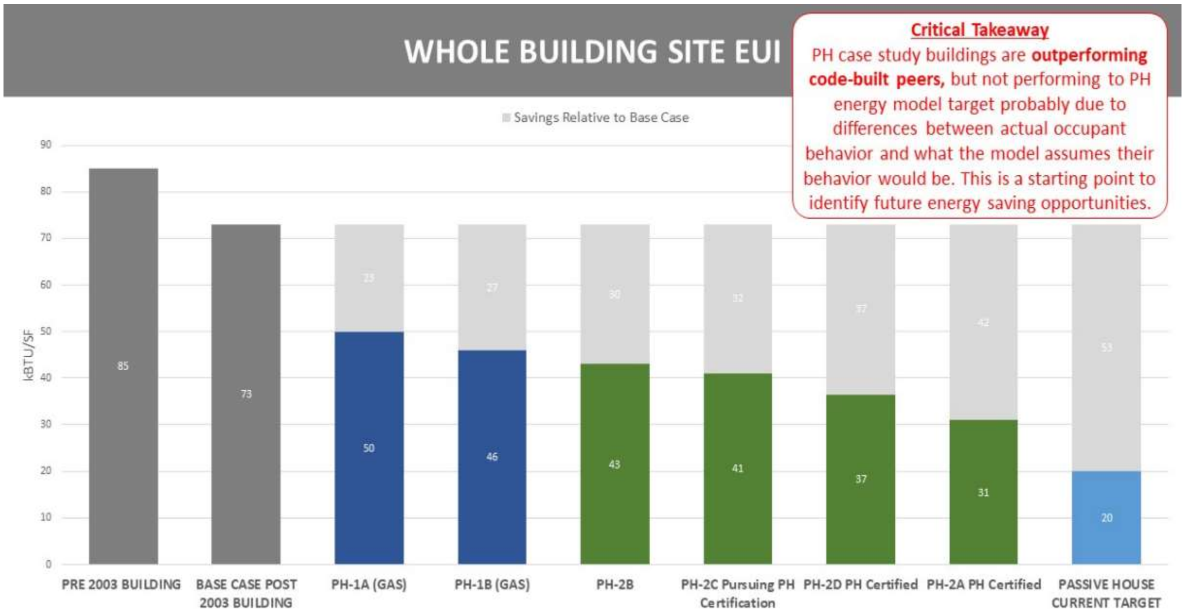
The built environment contributes up to 40% of the total U.S. greenhouse gas (GHG) emissions annually and consumes up to 39% of overall U.S. energy production. It has a larger impact than both the industrial and transportation sectors (U.S. Energy Information Administration, 2022). A looming challenge to reaching the Paris Agreement's climate targets continues to persist with existing structures because ongoing building operations during the use phase account for up to two-thirds of the emissions, and the vast majority of that is from energy consumption (Delmastro, 2022). The technologies to virtually eliminate these emissions exist and are rooted in energy efficiency and incorporating on-site renewable energy; however, they are being adopted at vastly different rates in different building sectors.

The variation of deployment rates may be most stark across the different facets of residential real estate. Multifamily properties lag single-family renewable energy installations by a ten-fold factor. Single-family PVS installation rates have reached the low double digits in some states while existing multifamily PVS installations remain woefully small at less than 1% (Dillon, 2022; St. John, 2022). This difference is significant as the residential building sector in the United States accounts for 53.7% of the total built environment energy consumption (U.S. Energy Information Administration, 2021).

New Construction vs Existing Construction Energy Use

To lower their GHG emissions and energy consumption, new construction projects are employing techniques that are having dramatic impacts on reducing the building energy use per square foot. Over the relatively short period of a dozen years, innovative techniques and standards, such as Passive House, have had the effect, in some jurisdictions, of lowering the EUI of new construction from approximately 85 kBTU/SF to a current target of 20 kBTU/SF (Figure 1) (Winter, 2020). This target for new residential construction is almost 80% lower than the current energy intensity estimate of existing MDUs, at 84.3 kBTU/SF in certain regions of the United States (Hu et al., 2022).

The number of existing U.S. multifamily properties is significant at approximately 44 million units, representing roughly 20% of the total residential building



Critical Takeaway

PH case study buildings are **outperforming code-built peers,** but not performing to PH energy model target probably due to differences between actual occupant behavior and what the model assumes their behavior would be. This is a starting point to identify future energy saving opportunities.

Figure 1. EUI trend in residential new construction pre 2003 to present.
New construction EUI has declined from 85 to 20 in the past 20 years (Winter, 2020)

Stock; therefore, the massive performance difference between new construction and existing structures must be overcome if this sector is to constructively contribute to the Paris Agreement's decarbonization goals (Desilver, 2021). While new construction continues to make substantial progress in reducing its energy use, and the corresponding electrical grid GHG emissions, the emissions load from the existing multifamily building sector continues to create a significant annual impact. Based upon the EPA's eGRID emissions factors, and average multifamily annual electrical usage, existing multifamily units may account for up to 18 MM metric tons of CO_2e annually in the United States (US EPA, 2020).

Barriers to Multifamily Sector Renewable Energy Deployment

Understanding the existing barriers to renewable energy deployment in the multifamily sector could lead to solutions to increase the low PVS adoption rates in

MDUs. A main impediment to multifamily renewable energy adoption has been the split-incentive dilemma. Rental property owners must make the capital investment necessary to retrofit the properties with renewable energy systems, but they cannot benefit economically from the reductions in grid-provided energy; only tenants receive the savings benefit of the lower utility bills (Raziei et al., 2016). Energy-sharing models have been proposed for multifamily properties to overcome the friction created by the split-incentive, but unfortunately, these solutions require complicated new behaviors and group cooperation for success (Fleischhacker et al., 2019).

Other barriers to multifamily solar adoption include the property owners' lack of technical knowledge to design, permit, install, and maintain systems on a long-term basis. Also, the complexity of integrating on-site renewable energy generation, in combination with local utility grid-provided energy, creates large technical and accounting challenges that landlords are unwilling and unable to overcome. These factors, combined with an uncertain return on investment, create an unstable environment for property owners to commit significant investment amounts in renewable energy for their properties (Hammerle et al., 2023).

The complexity of the multi-stakeholder relationships continues to impede the adoption of renewable energy and inhibit society's ability to fully address the challenges created by fossil fuel-generated electricity. Complications arise from the lack of clarity of the aims and solutions supported by the various stakeholders and the interwoven policy, environmental, investment, technology, and infrastructure challenges (Haukkala, 2019; Rittel & Webber, 1973). Much work has been attempted to shed light on how to approach and solve these types of societal dilemmas, and have led to suggestions of change profiles and other frameworks to institute progress (Waddell, 2016). The results promote the prototyping of solutions and provide ample information and examples for decision-makers to have a rational basis for making transformational change (Ayoub et al., 2009). Without readily available information and solutions that will drive renewable energy adoption increases, many harmful effects will continue to be experienced.

Health Effects of the Electrical Grid and Energy Injustice

An area of impact from central power generation that may not be generally understood is the link between grid-tied electrical power and the associated air pollution leading to negative health impacts and premature death in the surrounding communities (Dedoussi et al., 2020). These outcomes have been linked to the presence of nitrogen oxides (NO_x), sulfur oxides (So_x), and fine particulate matter, $PM_{2.5}$. Power generation plants also pollute the surrounding areas with heavy metals and mercury (Li et al., 2017; Saljnikov et al., 2019). These plants are more likely to be located in marginalized communities that disproportionately bear the associated health and economic burdens (Cranmer et al., 2023). The impacts can be staggering, evidenced by a premature death rate which has been reported to be as high as 30,000 deaths annually in the United States (Schneider, 2000).

Although the negative effects of power generation may be most severely felt in localized areas near plants, the effects can also transcend state borders and have negative effects over extended distances. Schneider (2000) found that 41-53% of air pollution-related to premature mortality was from sources outside of a state’s borders, with the majority of this due to electricity generation. Therefore, reducing the demand for electricity generated by high polluting fossil fuels not only has significant implications for energy justice in marginalized communities, it also has much wider environmental and health consequences.

Policy and Tariffs

Both policy and tariffs can have significant impacts on all aspects of power generation, distribution, and availability. However, these items are very localized as policies, regulations, and tariffs vary dramatically between states, and even between utility providers.

Policies

Electrical deregulation has been gaining momentum since 1999 when the Federal Electrical Regulatory Commission (FERC) issued order 2000 that promoted competitive power markets (Trehan & Saran, 2004). However, individual states have approached the deregulation mandate differently, leading to a wide variety of policy outcomes. These disparate policies also lead to very different local and regional market conditions.

In California, based on a 1921 State Supreme Court ruling and a 2008 state law, landlords are legally allowed to sell utilities to their tenants; however, the rate must be at or below the local utility rate for the utility (Energy311, 2023; Ivy Energy, 2022). In other jurisdictions, landlords are precluded from this practice, although there may be indirect methods to recoup the investment expense for installing renewable energy on MDUs (Caceres, 2019). Thus, the fragmented policy landscape requires specific knowledge and informed interpretation to determine when renewable energy solutions are allowed and advantageous in the MDU sector.

Tariffs

The shifting landscape of electrical tariffs, or the total fees charged for electrical generation plus associated delivery fees, further aggravates property owners' renewable energy investment decisions. Policymakers in many jurisdictions have considered and are implementing changes to renewable energy rate structures that will dramatically alter the economics of such projects and introduce further risk into the investor decision process. As solar energy installations have become more prolific, many of the early incentives are being reduced or eliminated. In California, the Public Utility Commission voted in 2022 to dramatically reduce the value of excess site-generated energy being sent to the grid from distributed renewable energy sites (CA PUC, 2023). These policies may have a chilling effect on solar adoption rates; however, as these nascent policies have yet to be fully implemented, their long-term consequences have yet to be quantified. Hence, it appears that the heretofore positive policy environment undergirded by a favorable net metering treatment may inevitably be reduced or altogether eliminated. However, ambiguities in the overall solar market forecasts persist in light of incentives designed to promote and expand solar systems provided by local and federal programs such as the Inflation Reduction Act (IRA) (SEIA, 2023).

Not only do the changing tariffs create investment uncertainty, but tariff rates vary wildly across the country and even between neighboring jurisdictions. The U.S. national average rate is \$.15/kWh, however, these amounts can be as low as \$.081/kWh in Idaho and as high as \$.55/kWh in certain circumstances in California (Nebraska Department of Environment and Energy, 2022; Nikolewski, 2018; Pressler, 2023). With such widely varying rates that directly impact the economic viability of renewable energy investment decisions, it is imperative for investors to have the information required to assess these dramatically different pricing and policy structures.

Variables of Economic Viability of PVS Systems

Although studies have identified more than two dozen variables that could impact the economic feasibility of PVS system investments, many of these factors are relatively constant or not relevant to a national review of renewable energy investments in MDUs. The most significant variables have been identified to be the PV production factor, energy tariff, and electricity consumption (Azevêdo et al., 2020). When considering the impact on the property’s net operating income (NOI) and overall asset value, then the real estate capitalization rate is also among the most impactful economic variables (Frew & Jud, 2003).

The relative difference in these variables is significant as energy tariff rates can differ by almost an order of magnitude, while the other variables may change only by a maximum of approximately 50% (D’Alessandro et al., 2021; *Global Solar Atlas*, 2023; Nebraska Department of Environment and Energy, 2022; U.S. Energy Information Administration, 2022). The massively outsized variation in the energy tariff, when compared against the variance of the other factors, then indicates that it likely has the greatest opportunity for the most significant impact on overall BCA results.

Factors Influencing Investment Decisions

These foregoing factors create difficulty for property owners when facing decisions to invest in energy efficiency and renewable energy solutions for their properties due to unknown or uncertain outcomes. Studies have found that under these conditions, owners do not behave as rational agents and instead are led by an informal self-perceived economic model focused on the initial cost commitment. Further, they discount the collective environmental and long-term benefits (Gichia, 2014). Gichia's work, based on the tenets of Prospect Theory developed by Kahneman and Tversky (2012) suggests that many of these sustainable investment decisions are typically emotionally based and rooted in loss-aversion mechanisms. In these situations, the potential investors feel the pain of the perceived losses from sunk costs with no investment returns much more than the potential gains available by making a productive economic investment in renewable energy. These factors then prevent investors from moving forward with making decisions to adopt renewable energy solutions for their properties.

Some researchers have therefore attempted to provide tools such as design frameworks to introduce more certainty to aid property owners in the decision-making process. These efforts strive to increase the rate of sustainable upgrade investments by reducing the decision barriers faced by stakeholders (Nauman et al., 2021). Others have attempted to increase sustainable investments by modeling the optimal time and conditions to make investments in renewable energy; however, these have been limited to single-family dwellings (SFDs) and have not broached the more complicated circumstances encountered in MDUs where multiple stakeholders interests must be taken into account (Vargas & Chesney, 2023).

Benefit-Cost Analyses

A method that would provide additional information to MDU property owners weighing renewable energy investments is a benefit-cost analysis (BCA). Unfortunately, studies in the U.S. on MDUs have centered around the cost-effectiveness of energy efficiency retrofit measures and have not provided true BCA treatments (Cluett & Amann, 2015; Samarripas, 2017). The few studies that have performed BCAs on apartments have been performed in international locations and are becoming outdated. Further, they do not address the factors impacting investment decisions on domestic PVS systems (Balaras et al., 2000; Ramadhan & Naseeb, 2011; Ren et al., 2019). While these studies do provide a rationale and the methods to inform a U.S.-based BCA on MDUs, they do not address the rapidly changing landscape of the technology and economics of renewable solar energy for residential properties.

Value Increase as Motivation to Invest

One important criterion for all property owners when making economic decisions is the effect on the ultimate asset value as a function of any additional investment in their properties. With regard to renewable energy investments, little is known about the creation of value from the addition of renewable energy systems. A study in Hawaii on SFDs found that a 5.4% value increase was expected with the addition of PVS systems (Wee, 2016). This type of information, if widely available and considered economically impactful, could heavily influence a market participant’s decision to make a renewable energy investment. However, because current studies only relate to single-family homes, little is known about the increased value expected from the addition of PVS on MDUs.

For investment property, the economic impact is even more significant as investors have very specific methods for understanding and valuing real property. In MDUs, the most commonly used valuation method is the income value approach. This approach converts a future net income stream for a property into an indication of market valuation using a capitalization rate (Baum et al., 2017). These rates can vary significantly by market and are used to convert the NOI of a specific property into a current market value.

The net income of a property is related to its market value through the real estate capitalization rate (RECR). The capitalization rate incorporates an average capital cost in a given market and is an accepted method to calculate the value of a real estate asset. The RECR is a ratio of the expected NOI, the net property income remaining after all expenses have been deducted, to the market value of the property (Frew & Jud, 2003). The higher the NOI of a property from any income source — rent, late fees, laundry, or energy services — the higher the overall value of the underlying asset. Therefore, any additive net income from a renewable energy system will have a corresponding effect on the project market value.

Therefore, if a landlord makes an investment in a PVS system and is able to monetize the power and sell the site-generated energy to its tenants at retail rates, the increase in the NOI could be a significant factor in the overall asset value. Unfortunately, the literature has not employed methods to model the economic results expected with the addition of PVS systems to MDUs. A case can then be made to create a model to determine if MDU values are significantly impacted by the addition of PVS systems.

There are various avenues available to landlords to monetize their investments in PVS systems. These pathways can result in dramatically different return on investment (ROI) results and vary significantly by jurisdiction. They are also highly dependent upon the local and regional regulations and tariff environments where the properties are located.

Some of the monetization opportunities include offsetting the common area and house electrical expenses, although these may be minor in comparison to the overall electrical usage of the entire project. Power generated in excess of the needs of the project where it is installed could be sold to the local utility company. The compensation rates for these sales typically are paid at a wholesale electricity rate that is much lower than the local retail rate and may not be much higher than the levelized cost of electricity (LCOE) generation of the system. In some jurisdictions, the landlord may be able to transfer electricity credits among their own properties or can earn solar renewable energy certificates (SRECs) that can be sold for a profit (Rich, 2022). Additionally, landlords may be able to benefit from local, state, and federal subsidies and incentives for renewable energy upgrades to their properties; however, these are very fluid and may change rapidly with time.

The highest and best economic use of a PVS system occurs as the site-generated power value approaches the local retail electricity rate. Certain states have passed legislation to permit these transactions at these rates as exemplified by California in state law AB 2863 which was passed in 2008 (CA Assembly, 2008). As a result, landlords can sell site-generated power directly to their tenants at or below the local retail electricity rate. While these different models result in different ROIs for the landlords as a result of their investment in the PVS systems, each of them allows for the monetization of the renewable infrastructure.

The monetization of site-generated energy has a positive effect on NOI and property value for a wide variety of properties. However, the incentive to monetize PVS systems is likely higher in older workforce housing than in newer construction owning to the fact that older properties are often less energy-efficient (Samarripas, 2017). The inefficiency leads to higher utility payments, as compared to rent, which can deliver a higher proportional increase in NOI and property value when monetizing the electricity payments with on-site PVS systems. This variation in the change in NOI creates a unique opportunity for property owners of workforce housing to have a positive impact on their private investment portfolio value while simultaneously generating positive environmental and energy justice outcomes for their communities and tenants.

Research Questions, Hypotheses, and Specific Aims

This study addressed the following question: How does the addition of PVS systems affect the investment economics of MDUs in different cities across the United States? Specifically, how do the benefit-cost ratios of the PVS system investments vary in different locations and what impact do the systems have on the real property values and environmental impacts of the MDUs?

The study examined the following hypotheses:

- Based upon local capitalization rates, the additional revenue resulting from the new PVS system will increase the value of the real property asset by greater than 15%, independent of the geographic location. This hypothesis assumes the landlord can monetize the site-generated electricity from the addition of a PVS system on a multifamily property at the local retail electricity rate.
- The prevailing local electrical tariff will be the largest determinant of the benefit-cost ratio. Each operational variable including the local solar resource, local electrical consumption, local electrical tariff, and applicable real estate

capitalization rate was examined to determine which has the largest effect on the benefit-cost ratio when investing in a PVS system.

- Assuming a 25% installation rate for PVS systems on existing multifamily properties, the statewide CO_2e emissions from the residential sector would be reduced by greater than 3% with the PVS systems.

Specific Aims

The achieve the specific aims of this research, the following items were performed:

1. Develop an Excel BCA model that incorporates the independent location-dependent operational variables that determine the economic return of the investment in PVS systems in MDUs.
2. Determine the relative influence of the primary variables of the BCA model and determine which variables have the largest effect on the economic viability of the PVS systems for the cities.
3. Describe specific policy initiatives that could promote greater adoption of PVS in MDUs

Chapter II

Methods

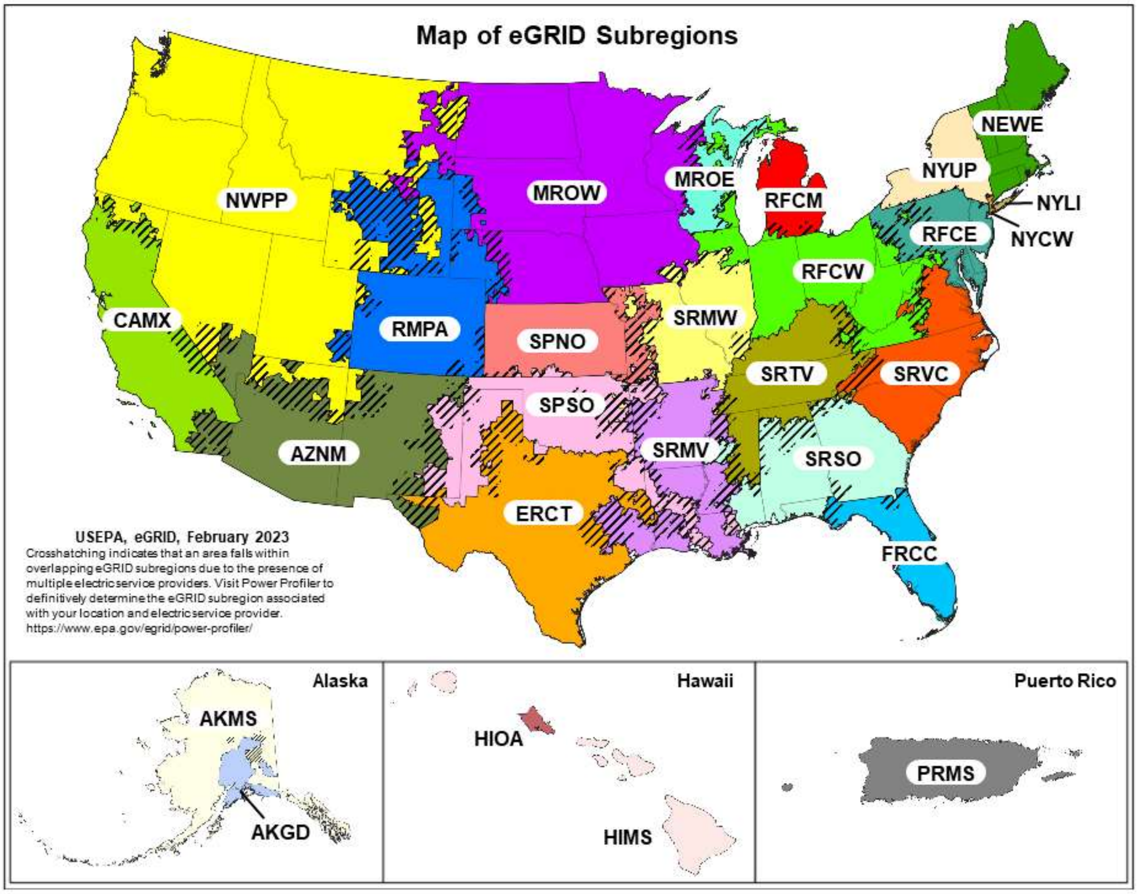
The objective of the research project was to determine the financial impact and decarbonization potential that PVS systems can have when incorporated in MDUs in a set of U.S. cities that are geographically disparate and have significantly different location-specific parameters for the relevant economic and environmental inputs. Energy justice implications were also examined by considering the energy burdens of different populations as compared to baseline measures. The research was designed to examine the metrics arising from the PVS systems including the property NOI, property value increase, and the GHG avoided emissions from the displaced grid-tied electricity. The objectives included providing a relative ranking of the cities based on each category and an overall blended scoring model was developed to incorporate the economic, environmental, and energy burden dimensions into one overall result.

The research questions and hypotheses were addressed with a research design that defined a standard PVS system for a model MDU and incorporated the location-dependent operational variables that determine the economic viability of the system. A comprehensive list of cities was chosen to be representative of most jurisdictions and conditions within the United States. Analyses were conducted to determine the project-level financial impact of introducing the PVS systems on the MDUs in both a cash investment and loan-financed model. A benefit-cost analysis that accounted for all expected system revenues and costs was used to rank the economic performance of the different cities. The environmental impacts of adding the PVS systems were calculated in all locations and the energy burden implications were studied and quantified. An expanded explanation of each approach is provided below.

For the financial modeling, the change in the NOI resulting from the addition of the PVS system to each MDU location was determined by calculating the additional annual gross income generated by the system, and then subtracting the total annual expenses of the system. To perform the calculations, it was assumed that all site-generated electricity by the PVS system was used to offset the annual MDU consumption with no net export of electricity to the grid. This assumption would allow electricity transfer to and from the grid but would result in no electricity billing from the local utility company as it is assumed to be completely offset by the addition of the PVS system. Typically, this would only be possible with a full net metering treatment by the local utility, which is unlikely to be available in all locations. Alternatively, smaller system sizes or on-site power storage could enhance the self-consumption ability of the sites. Although these techniques would have a diminishing effect on the project's net operating income (NOI), they are outside the scope of this study.

NOI was used to calculate each MDU's property value increase from the PVS system using an income value approach by applying the appropriate RECR to the resulting NOI increase for each location. It was also used for the BCA for the cities.

The decarbonization potential of the PVS system was calculated by determining the project emissions reductions in each MDU location and these results were extrapolated to a statewide reduction amount for each state studied, predicated on a projected MDU solar adoption rate. The regional emissions factors for each MDU location were derived from the EPA's eGRID database for the local electricity grid, as seen in Figure 2, and were used to determine the carbon dioxide equivalent (CO_2e) emissions avoidance calculations under the World Resources Institute's (WRI) Green House Gas Protocol (GHG Protocol) (Barrow et al., 2013; USEPA, 2023). The overall organizational process that was followed for the study is displayed in Figure 3. The diagram displays the three areas studied, economic, environmental, and energy burden, and illustrates the flow of the variables and constants in the calculations and analyses. It also demonstrates the interrelation of the three areas of study.


Map of eGRID Subregions

USEPA, eGRID, February 2023
Crosshatching indicates that an area falls within overlapping eGRID subregions due to the presence of multiple electric service providers. Visit Power Profiler to definitively determine the eGRID subregion associated with your location and electric service provider.
https://www.epa.gov/egrid/power-profiler/

Figure 2. Emissions regions as categorized by the EPA eGRID database.
(USEPA, 2023)

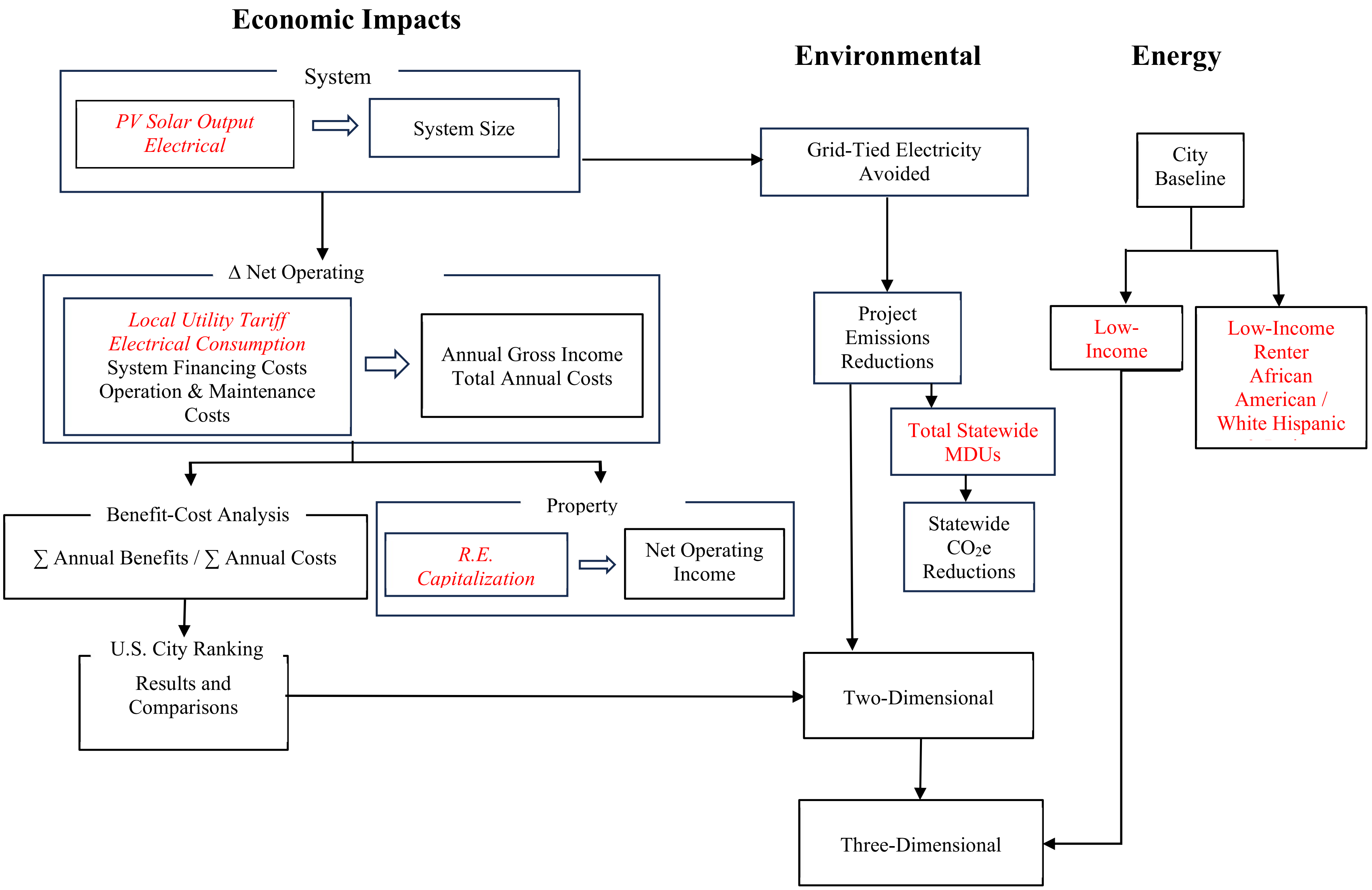


Figure 3. Organizational process of the study.

Inputs listed in ***red*** *are the location-dependent operational variables and inputs listed in* ***black*** *are constant across all locations*

Location-Dependent Operational Variables

The primary location-dependent variables that were used to calculate the NOI, property value increase, BCA, and the avoided emissions to determine the impact of the addition of a PVS system are listed below:

- PV production factor (PVPF): Data from the Global Solar Atlas database was used as the source for the PV solar resource factors for the selected U.S. cities. Each value from the Global Solar Atlas is displayed in Table 11, Appendix 1, with its corresponding city. The production factors in the atlas are listed as PV output specific to each geographic location and are given in annual generation of kilowatt-hours per the overall kilowatt peak capacity of the installed system (kWh/kWp) (Global Solar Atlas, 2023). The atlas uses a model designed to account for local solar radiation and air temperature and includes derating factors for terrain and other shading, as well as losses due to snow, soiling, and other environmental factors. It does not account for PV module degradation over time.
- Average electrical consumption (AEC): The values for the average electrical consumption per individual residential unit per year were taken from the U.S. Energy Information Administration's (EIA) database containing the average electrical consumption for a multifamily unit in each region of the United States (U.S. Energy Information Administration, 2021). The appropriate values for the selected cities were recorded and included in Table 11 in kWh. The consumption values provided by the EIA are listed by U.S. geographical regions, so consumption for each selected city was determined by its location within its respective region.

- Average utility rate (AUR): The average utility rate for each city was collected from the Energy Information Administration's Electric Power Monthly database which provides average residential electricity costs for each state (U.S. EIA, 2023). The electricity rates for each selected city were drawn from the EIA state date and are listed in cents/kWh in Table 11, Appendix 1.
- Real Estate Capitalization Rate (RECR): The values for the real estate capitalization rate were drawn from industry sources and the values from the Cap Rate Index were used as the primary source (CapRateIndex, 2023). These values are included in Table 11 with their corresponding city.

The PVPF and AUR variables were found to have the most significant effect on the BCA and were tested using the Excel what-if sensitivity analysis function to determine the relative influence of each variable.

Models, Calculations, and Analyses

To determine the overall economic, environmental, and energy burden impacts of the PVS systems on MDUs, a series of models, calculations, and analyses were carried out using the data from the location-dependent operational variables in the selected cities.

Individual Unit PV System Size

To design a PVS system capable of theoretically producing an amount of electricity consumed annually by an average apartment unit, a size for the individual PVS system required per apartment was calculated in each city location based on the EIA average annual consumption values for the region. The PV system unit size required when operating under a net metering scheme for the individual apartments was calculated by dividing the average annual consumption per unit, AEC, by the local site-specific annual system power output, PVPF, and multiplying by 110% to account for typical excess system margin capacity, as seen in equation (1):

$$System\ Size\ per\ Unit = AEC\ /\ PVPF \times 1.1 \qquad (1)$$

The system oversizing of 10% was provided to accommodate for growth in demand as electrification increases and for any unaccounted derate losses the systems may encounter over time. This total capacity was assumed to be below any limits on system sizing placed by local utility providers (Depner, 2019).

A secondary assumption built into the electricity demand-driven sizing model is that sufficient roof space is available for the required PV modules for each system. To test this assumption, a roof coverage analysis was performed in three cities. These cities represented the largest, smallest, and average PVS system sizes required to meet the MDU consumption demand of the residents.

Roof Coverage Analysis

The calculated PVS system size for an individual apartment unit was used to test if sufficient usable roof area was available on the model configuration of the MDUs in various city locations. An analysis of the usable roof area available for both a one-story and a two-story apartment configuration was performed.

Actual roof square footage often greatly exceeds the ground floor apartment square footage for a variety of factors including; extended roof areas over common spaces such as stairs and walkways, roof areas of eaves projecting beyond the conditioned floor space of an apartment, and pitched roofs with square footage considerably greater than the flat roof projection required for an apartment. However, a conservative value of roof square footage equal to an average apartment size was used for the study and no further consideration was given to alternative PV solar installation areas that may be available such as on top of carports or over other open and common areas resident in typical apartment complexes. These methodological assumptions ensured the most constrained square footage scenario would be considered in the roof analysis.

To perform the usable roof area calculations, an average apartment size of 800 square feet was used and it was assumed that 80% of this area was available for PV solar installation, the remaining 20% area being left open for setback requirements, egress, and common roof obstructions. It was further assumed that a 335-watt panel would be installed that had an 18-square-foot area per panel. The roof area required for each apartment was calculated by dividing the individual unit system size determined in (1) by panel wattage and multiplying by the panel area (equation 2):

$$PV\ Roof\ Area/Apt = (System\ Size\ per\ Apt/Panel\ Capacity) \times Panel\ Area \quad (2)$$

Both system size and panel capacity are expressed in watts. The panel area is in units of square feet. The result of (2) was then divided by the net usable roof area, after accounting for the 20% obstruction factor, for apartments with both a one-story and two-story configuration. The results were presented as a percentage of net usable roof space occupied by the PV system. For the two-story configuration, a complete stacking of one unit over another was assumed, which is common for pre-2000 walk-up apartments. This stacking results in two-story configurations having 50% less roof space available for PVS systems than one-story MDUs.

MDU Project PVS System Cost

The overall system cost for each entire apartment project was determined by expanding the individual apartment unit PVS system size in each city location to the standard 50-unit MDU model by multiplying the individual unit PVS size by 50. The overall project PV system requirement was then multiplied by a dollar cost per watt factor that represented all upfront installation and commissioning costs for a system, exclusive of any system financing expense. This project-level system cost then represented the entire investment necessary for an individual owner in any city location required for a complete 50-unit PVS system necessary to meet the annual consumption needs of the apartment residents.

Because the results of the roof coverage analysis indicated that in one and two-story configurations there is sufficient roof space available for PVS systems, except when examining the highest demands in the most extreme example, it was assumed that roof space was not a limiting factor when sizing the systems to meet total consumption demand of the units in all locations. The model project will be assumed to be a standard 2-story walk-up project because it has been shown to be capable of reaching reasonable environmental and economic feasibility in a wide variety of climate zones (McKittrick & Henze, 2021). As mentioned, a standard project size will be defined at 50 residential units for all cities, and a standard cost per watt for commercial-sized systems will be used (Noel, 2023).

An NREL survey documented various system costs in different residential, commercial, and utility-scale PVS projects and documented ranges of installation costs and trends (Ramasamy et al., 2023). Although the documented installation costs can vary based on many factors including the size of the system and location, a standard value of \$1.83/watt was seen to be a reasonable estimate for this study based on the NREL information. Projects have been seen to be completed both above and below this cost factor as noted in the NREL photovoltaic system cost benchmark analysis (Ramasamy et al., 2023) This installation amount accounts for the total capital expense of a standard system that includes all costs associated with the design, permitting, labor, and acquisition of the necessary equipment and supplies for the initial installation. To account for differences in installation costs that could be encountered based on temporal and geographical differences, a sensitivity analysis was performed in the two study cities that represent the highest and lowest BCA performance to understand the extent of the impact of installation costs on the economic results.

The total system cost in dollars was calculated by multiplying the system size per apartment, in watts, by the standard number of 50 units for each MDU project, and by the installation cost per watt (equation 3):

$$MDU\ System\ Cost = \ System\ Size\ per\ Unit\ \times \ \#Units\ \times \ Installation\ Cost\ (3)$$

Annual Gross Income

To determine the overall financial impact a PVS system would have when installed on an MDU, first, the annual gross income (AGI) needs to be calculated. The AGI is the total income the system would generate assuming that all site-generated electricity is consumed by the project residents at the local retail utility rate without the need for any net imported electricity. To calculate the AGI, the system size was multiplied by the PV solar output, PVPF, and the electricity rate, AUR, across all 50 units of the model MDU (equation 4):

$$AGI = System\ Size \times PVPF \times AUR \times \#Units \qquad (4)$$

Net Operating Income

Net operating income is a fundamental consideration for a real estate investor because it customarily determines the long-term economic viability of an investment property and it also forms the basis of the value determination of an income-producing property. Therefore, it is an important economic parameter to examine when evaluating the impact of incorporating a PV solar system on an MDU. To understand the effect of the anticipated increase of the NOI on the MDUs in the selected cities, the base line project NOI was first modeled for the cities, and then the projected NOI increase due to the PV solar system was determined for each location.

To calculate the base net operating income, Base NOI, prior to the PVS installation, for each property, a value for the average MDU monthly rent per square foot for each selected city was collected from industry sources and organized with its corresponding city in Table 12, Appendix 2 (Zumper, Inc., 2023). The Base NOI for the 50-unit project for each location was calculated according to (5):

$$Base\ NOI = \ Rent \times Apt\ SF \ \times \#Units \times Months \ \times (1 - Exp)(5)$$

The Rent was provided in monthly $/square foot/month and the Apt SF was held constant at 800 square feet for the study. The #Units for the study was defined as 50 and Months represent the 12 rental months in the year. Exp is the generally accepted expense factor which is determined by the class and age of an investment property. It is designed to include all expenses that would be expected when operating an investment property for profit and includes, real estate taxes, property insurance, landlord-paid utilities, repairs and maintenance, janitorial, management fees, and general and administrative expenses, among others. Because the properties studied are assumed to be of older vintage, a factor on the higher end of the accepted range of values of 40% will be used to represent all property expenses (Bullpen Editorial, 2021).

The change in the overall project NOI (ΔNOI) from the addition of the PVS system was determined by assuming that all on-site generated power was sold to tenants at the local prevailing retail electricity rate with no net electricity consumption from the grid due to the benefit of an assumed 1:1 net metering tariff structure. The assumed net metering obviated the need to consider on-site power storage or the impact that the chosen system size has on the economics of the study. The ΔNOI was calculated by using the PVS system's AGI, as described above, and then subtracting the annual operating and maintenance (O&M) costs.

The ΔNOI was then calculated from the AGI and O&M (equation 6):

$$\Delta NOI = AGI - O\&M \qquad (6)$$

A figure of $21.46 /kW/year was used for the O&M figure and was derived from a blending of the range of figures provided by NREL in their model of O&M costs for photovoltaic systems (Walker et al., 2020). In the study, rates as low as $12/kW/year and as high as $30/kW/year were documented; however, it was noted that the overall trend is a falling O&M expense over time. These amounts also include a factor for capital reserves to account for future equipment failures that may be experienced in some components of the systems.

Finally, the % change in NOI was calculated (equation 7):

$$NOI\ \%\ Change = \Delta NOI\ /\ Base\ NOI \times 100 \qquad (7)$$

Property Value Increase

Another primary consideration for investment property owners is the overall value of their investment property and the appreciation of that value over time. Using the results of the NOI % change of the properties in the different cities, the impact of the additional PV system income on the overall investment property asset value was determined and compared against the investment amount required for the system installation at each property.

A real estate cash flow valuation analysis was performed using the outcome of the ΔNOI analysis to determine the property value increase (PVI) resulting from the addition of the PVS system to each property location. This calculation was performed by dividing the ΔNOI from the PVS system installation in each city by the corresponding value for the RECR for the project (equation 8):

$$PVI = \Delta NOI \ / RECR \qquad (8)$$

Benefit-Cost Analysis

Many capital improvements to real property are performed with debt financing. To understand the impact that the PV solar systems have on the project economics under these scenarios, a benefit-cost analysis (BCA) was employed to account for the system financing cost (SFC) and all annual income and expenses expected from operating the systems. The benefit-cost ratios in each city location may yield more actionable information for the overall economic impact and may help inform property owner decisions as it closely simulates a real-world investment analysis for many investors. It may also indicate the relative value improvement when considering the addition of PV solar systems among the cities when investors are choosing where to best invest in PVS systems.

The BC ratio was determined by dividing the sum of all annual benefits by the sum of all of the annual costs of the system (equation 9):

$$BC\ ratio\ =\ \Sigma\ Annual\ Benefits\ /\ \Sigma\ Annual\ Costs \qquad (9)$$

For the study, the annual benefits equal the gross income, AGI, from all 50 apartments in the model MDU in each city location. The annual costs equal the sum of the SFC and O&M costs required in each location. To calculate the SFC it was assumed that the entire system cost calculated in (3) would be financed at the prevailing market interest rate and amortized over the 20-year project life of the system. An interest rate of 5.5% was taken as a finance rate for all locations in the study. This rate was used to determine the fully amortized system financing cost for a model system in each city location (Solar Reviews, 2023). The Excel payment function was used to calculate the annual SFC with the inputs of period nper = 20 years for the term, rate = 5.5% for the interest rate, and the principal value, pv = system cost, from (3), above, for each city. The calculated SFC was used with the previously calculated AGI and above-stated O&M value to calculate the BC ratio (equation 10):

$$BC\ ratio\ =\ AGI\ /\ (SFC\ +\ O\&M) \qquad (10)$$

The values of the BC ratios of all of the cities were considered in year one and no inflation factor was applied to the AGI, SFC, or O&M values. This is considered to be a conservative approach as it is likely that the annual income, AGI, in the numerator, will increase significantly over the life of the project due to annual escalating electricity costs, recently escalations have exceeded 14% annually and historically they have increased at approximately 7% annually (Brown & O'Sullivan, 2020; Singer, 2023). In the denominator, the SFC is a fixed value based upon a fixed interest rate while the O&M costs have been trending downward which results in a diminishing divisor (Origis, 2023). Although these factors all indicate that the BC ratios may increase over time, it is expected that all city locations will benefit from these effects so the relative ranking of the cities in the study is expected to hold as all cities will experience similar increasing BC ratio outcomes. The results of the BCA were organized in a table and ranked from the lowest value to the highest output for the BC ratio and were plotted in order of increasing value for all cities.

Statistical Analysis of Results

The statistical characteristics including the mean, standard deviation (SD), median, minimum, and maximum values for the % increase in the NOI, property value increase/PV system cost, and the BC ratio in each city were calculated.

Excel was used to plot the BC ratio vs. PVPF and to plot the BC ratio vs. the AUR for all cities in the study. To determine the statistical significance of the BC ratio on each of the variables, PVPF and AUR, linear regression of the BC ratio was also performed against both using the linear regression function in Excel so the P-value of each could be determined.

To determine the comparative influence of the variables, PVPF and AUR, on the BC ratio, a multiple regression analysis was also performed in Excel. The P-values of each variable were used to determine the statistical significance of each, and the variable coefficients were compared to understand their relative importance. The multiple regression equation for the dependent variable was constructed from the independent variables, PVPF and AUR, using the intercept and variable coefficients provided by the Excel regression analysis, and the summary results including the P-value for the F-significance were determined so that the null hypothesis could be tested.

The results of the multiple regression analysis were used to perform the Boersch-Pagan test to determine if the data was heteroscedastic which would indicate that BC ratio did not have a constant variance over the range of independent values for PVPF and AUR. Excel was used to perform this analysis.

Environmental Impacts

A fundamental environmental benefit of a renewable energy system in the built environment is the ability for it to decarbonization real property. To quantify the decarbonization impact of the PV solar system on multifamily properties, the model MDU configuration in each city was used to determine first the project level emissions avoided, and then the statewide CO_2e reduction potential for each state included in the study.

Annual emissions avoided. To determine the annually avoided emissions from the addition of the PVS on each property, the calculated system size in each city and the corresponding PVPF were used to determine the annual grid-tied electricity displaced in all locations (equation 11):

$$Electricity\ Avoided = System\ Size\ \times\ PVO\ \times \#Units \quad (11)$$

Regardless if the power is consumed on-site by the tenants as off-takers or not, all annual on-site generated power will offset an equal amount of grid-tied centrally generated electricity as the utility will be the off-taker of last resort. This results in a reduction in the overall demand of the electricity grid equal in amount to the on-site electricity generation.

The project level GHG emissions reductions were calculated using the EPA's eGRID database which provides CO_2e emissions factors for all U.S. regions and states (US EPA, 2022). Equation (12) was used to calculate the emissions avoided by each MDU project:

$$Project\ Emissions\ Avoided\ (PEA) = Electricity\ Avoided\ \times\ eGRID \quad (12)$$

The eGRID emissions factors for all cities are given in lbs/MWh. These values were converted to metric tons by applying the appropriate conversion factor when calculating the emissions avoided for each project.

To determine the potential statewide emission avoided by the introduction of the PVS systems, the Project Emissions Avoided (PEA) were extrapolated across the total MDUs in each state studied at an assumed PVS adoption rate of 25% (equation 13):

$$Statewide\ Emissions\ Avoided = PEA\ \times MFU\ \times ASA \quad (13)$$

PEA is the project emissions avoided, and MFU is the total statewide multifamily units in each state, and ASA is the assumed solar adoption rate.

Plots of both the PEA and the potential statewide emissions avoided were created. The project level plot was presented in order of increasing avoided emissions by each city. The same city order was then used for the statewide emissions reduction so the impact of the number of MDUs in each state could be easily seen in the statewide emissions reduction results.

Economic value of emissions. Because removing carbon from the built environment can itself have an economic value, it may be useful to consider the cost associated with the decarbonization that the PV solar systems can produce. This amount was based on the total annual costs which include the financing expense for the systems plus the operations and maintenance expenses, divided by the annual emissions eliminated by the substitution of clean renewable energy for the incumbent energy from the fossil fuel-based electrical grid. The calculation to determine the cost to remove one metric ton of CO_2e is seen in equation 14:

$$Emissions\ Reduction\ Costs = (AFC + O\&M)/\ PEA \qquad (14)$$

The results for all cities were plotted on a column chart in order of increasing cost per metric ton of CO_2e and the average cost for all cities was included as a reference.

Economic and environmental nexus. The combination of the economic and environmental impacts was examined by creating a scatter plot with the results of the BCA on the y-axis and the emissions avoided on the x-axis for each city in the study. They were presented in a four-quadrant format that ranged from low-low to high-high to provide a graphical display for a comparison of the cities based upon their relative rankings in both categories.

Energy Burden Analysis

An energy burden analysis was performed using the DOE Low-Income Energy Affordability Data (LEAD) tool (US DOE, 2023). First, the baseline energy burden value for the general population was collected and organized in a list for each city, and then the energy burden values for two additional populations were gathered for the same cities.

The first population was designed to be equivalent to the model MDU property type in this study. It was defined as renters, residing in MDUs with 5 or more units, built before the year 2000, and in the very-low and low-income ranges, defined as 0-30% and 30%-60%, respectively. The second population contained the same qualifiers as the first but with the extra constraint of restricting the data set by ethnicity to include only African Americans and White Hispanics and Latinos.

The energy burdens for these three populations were all collected and were placed with their respective cities in Table 19 in Appendix 9. Two separate column charts of the energy burden data were constructed to illustrate where the incorporation of PVS systems on MDUs may have the greatest opportunity to address energy justice inequalities. The first chart plotted the baseline energy burden for all cities along with the energy burden experienced by the renter population described above. The second plot included these two populations described above and added the energy burden for the same population restricted by ethnicity.

PV Solar Multifamily Index

To gain a perspective of how the three different categorical criteria—economic, environmental, and energy burden—interact and operate in each city studied, two scoring models were developed. One model is a two-dimensional economic and environmental index, and the second model is a three-dimensional economic, environmental, and energy justice index.

Two-dimensional index. The first scoring model was developed to reflect the combined effect of the two categories that are most typically quantified and associated with fiscal impacts, the economic and environmental categories. The two-dimensional scoring index was created by collecting and organizing the range of values for both the BC ratios and the avoided emissions totals for all cities. The individual values for each category were each normalized (equation 15):

$$Component = [Value - Range(\mathrm{min.})] / [\mathrm{Range(max.)} - \mathrm{Range(min.)}] \qquad (15)$$

The two components were then added to create the overall two-dimensional score for each city. The overall scores were then normalized and scaled to create a range of values from 1 to 100 (equation 16):

$$Score = \{[Value - Range(\mathrm{min.})] / [\mathrm{Range(max.)} - \mathrm{Range(min.)}]\} \times 99 + 1 \quad (16)$$

The score results were plotted on a stacked column chart that displayed the two constituent values that comprised the overall city scores in ascending order.

Three-dimensional index. The second scoring model was built using the data and methodology of the two-dimensional model and adding a third dimension of energy burden. To construct the energy burden score, the data for low-income renters was used without constraining the data by ethnicity so that the results would be more generally applicable to MDUs in the widest variety of locations. Equation 15 was applied to the energy burden data to create its component value. The three components were then summed to create a cumulative total for each city and equation 16 was then applied to the cumulative values to create the overall three-dimension score.

Sensitivity Analyses

To understand the primary factors affecting the viability boundaries of a PV solar system under the modeled systems, sensitivity analyses were performed on the primary factors affecting the economics of the systems: electricity cost, PV solar output, and installation cost. In the preceding analysis, the installation cost was held constant across all locations, as other location-dependent factors lead to a wide variation of values. However, as it is a primary factor that affects a project's financial feasibility, a sensitivity analysis considering installation cost was performed to understand its impact on the overall project economics. Because the environmental impacts and energy burden results were determined by each project's location and electricity consumption, relatively invariable conditions, they were not included in the sensitivity analyses.

To perform the first sensitivity analysis the Excel two-dimensional What-if function was used to study the effect of varying both the installation cost and the electricity cost on the project economics in the form of the BC ratio outcome. To span the entire range of outcomes, the lowest and highest-performing cities were chosen so the results for all other cities would fall between these two extremes. For this analysis, two What-if matrices were created, one for each city. A BC ratio for any combination of installation cost and electricity cost for the city can be read at the intersecting cell on the matrix. A large range of electricity costs that cover the entire range encountered in the cities in the study were included and installation costs as low as \$0.75/watt and as high as \$3.50/watt were included. All BC ratios that are below the 1.00 threshold are marked with red-shaded cells.

A second two-dimensional What-if analysis was performed on the effect of varying PV solar output and electricity costs on the BC ratio. For the BC ratio outcome, this analysis was city-independent and labeled as Anytown, USA. This ability arises because any solar output can be chosen along the horizontal axis to match any location's solar resource and can be matched with the operational electricity cost for that locality. The resulting cell intersection of the two choices yields the BC ratio for those selected conditions.

Chapter III

Results

The significant findings of the economic, environmental, and energy justice analysis of incorporating renewable energy systems on MDUs are presented in this chapter. The complete list of the 70 U.S. cities selected for the study is included in Table 11 in Appendix 1. Table 11 shows each city organized with its corresponding data used for the economic, environmental, and energy burden analyses and includes the values for the location-dependent operational variables, GHG emissions rates, solar resource, electricity cost, annual electricity consumption, rental values, real estate capitalization rates, and the total number of multifamily units located in each state.

Economic Impact and Analysis

To create a valid comparison of the economic impact of incorporating PV solar in MDUs in the selected cities, a model MDU was selected to be a 2-story apartment complex comprised of 50 units with 800 square feet in each unit and a traditional walk-up garden-style architecture that would be expected of properties that were built between 1960 to 2000. The analysis for all cities in the study was based on this model property and these basic assumptions. To ensure that a valid comparison was created across selected cities, an analysis of roof space available for the proposed solar array installations was performed among the cities to ensure that sufficient roof area would be available with this selected building morphology in all locations.

Roof Coverage Analysis

Table 1 displays the results of the roof coverage analysis for the three separate cities; Albuquerque, NM, St. Louis, MO, and Charleston, WV. These cities represent the smallest, average, and largest system size requirements from the overall selection of cities listed in Table 11. The size of the required solar system for each apartment varied significantly based on the solar resource of each city and the average regional apartment electricity consumption, with Albuquerque requiring a system capacity per unit of 2.63 kW, and St. Louis and Charleston requiring 4.16 kW and 7.09 kW, respectively.

Table 1. Roof coverage analysis.

	System Size/Apt (kW)	Usable Roof Factor	PVS Roof Area Occupied/Apt. (SF)	Usable Roof Area Available/Apt (SF)	Usable Roof Space Occupied
Albuquerque, NM	2.63				
One-Story		80%	141	640	22%
Two-Story		80%	141	320	44%
St. Louis, MO	4.16				
One-Story		80%	224	640	35%
Two-Story		80%	224	320	70%
Charleston WV	7.09				
One-Story		80%	381	640	60%
Two-Story		80%	381	320	119%

Roof space occupied by PV solar systems for each apartment unit in one- and two-story building morphologies in U.S. cities with the lowest, average, and highest PV system size requirements.

The roof space requirement in all locations for a one-story configuration was less than 100%, indicating that the full size of the PV solar system would be accommodated by one-story properties. Two-story multifamily configurations in Albuquerque and St. Louis had roof coverages of 44% and 77%, respectively, so no system size constraints existed in these locations. Only Charleston, as seen in Table 1, would be constrained in the two-story configuration as the roof size requirement exceeds the available roof by 19%. Besides Charleston, an additional dozen cities from the data set would experience lesser amounts of roof constraints that would vary from 1% to 10%, however, considering that the most conservative assumptions were applied to the available roof area calculations, it appears that in most jurisdictions studied, a two-story complex would have sufficient roof space to accommodate the PV solar system necessary to supply the annual electrical consumption of the occupants. Figure 4 displays the roof space occupied

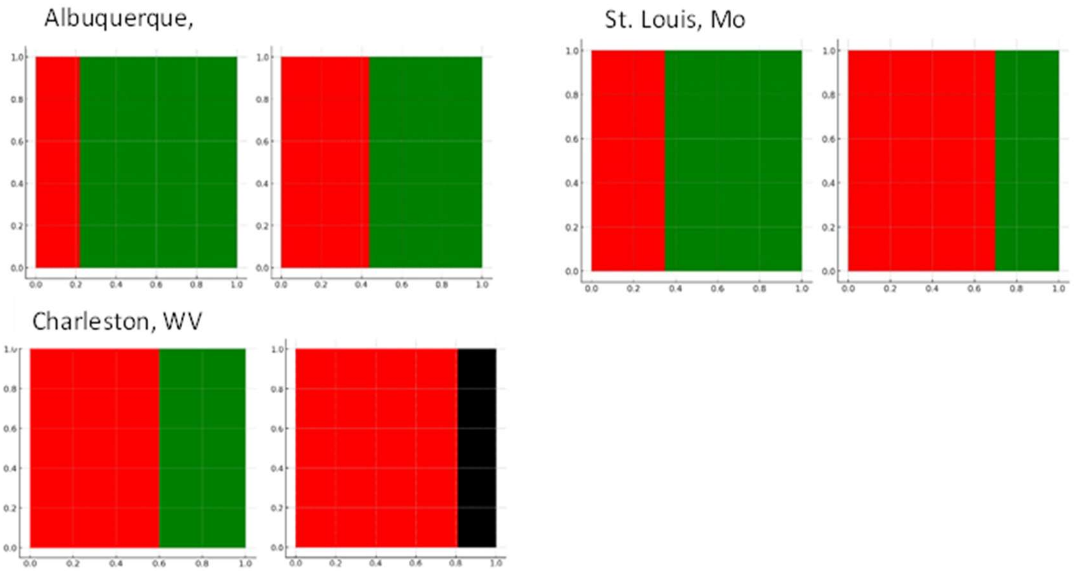


Figure 4. Roof coverage of PV solar systems in representative cities.
*Areas in **red** represent PVS system roof coverage, **green** represents free roof space remaining, and **black** represents the roof space deficit required for complete PVS system installation*

by the PV solar systems in each of the three cities from Table 1. The red represents the solar system area required and the green represents the free roof space remaining beyond the solar system area for each location. For the case of Charleston, the black area represents the deficit area that would be required to fully provide for the required system.

Net Operating Income

The percentage increase in NOI in all city locations is displayed from the lowest to highest value in Figure 5. The black dashed line represents the average investment capitalization rate for all of the cities studied.

The percentage change in NOI from the addition of the PV solar systems on MDUs ranged from a low of 2.83%, in Seattle, WA, to the highest value of 21.41% in Lubbock, TX (Figure 5). The percentage increase in NOI for all cities in the study is included in Table 12 in Appendix 2.

Table 2 shows the sample size, N, mean, standard deviation, median, minimum (Min), and maximum (Max) of the NOI % increase for the entire city data set. The average percentage increase was 9.56% and the SD was 4.17%.

Table 2. Statistical characteristics of NOI % increase across selected cities.

	N	Mean	SD	Median	Min	Max
NOI % Increase	70	9.56%	4.17%	8.97%	2.83%	21.41%

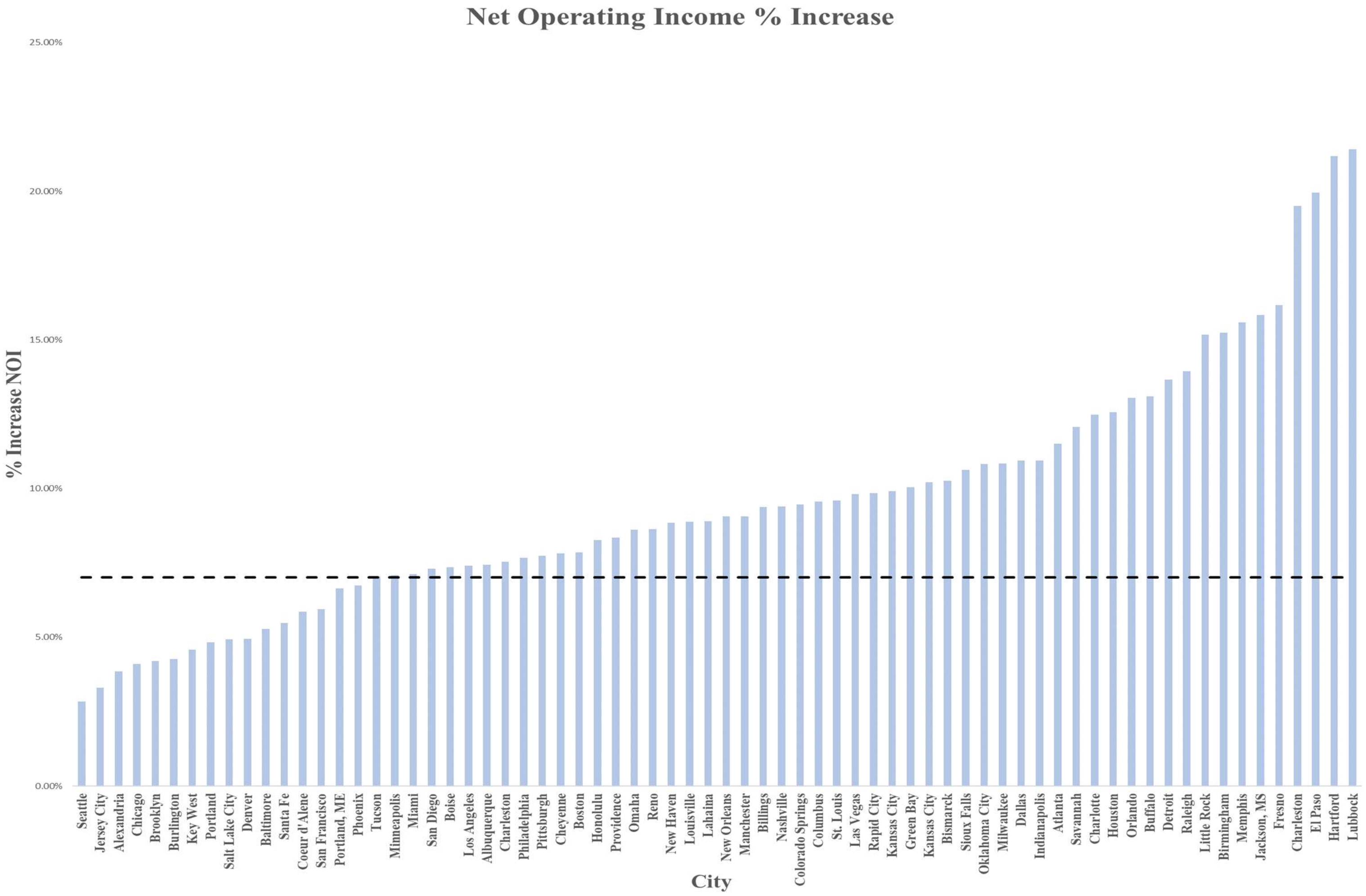


Figure 5. Net operating income % increase by city

Effect of addition of PV solar system on NOI of an MDU. The Black dashed line represents the average real estate capitalization rate across all cities.

Property Value Increase vs. PV System Cost

The calculated property value increase and the respective PV system installation cost for each city are displayed in Table 13, Appendix 3. Table 13 also contains the ratio of the property value increase divided by the PV system cost with the results presented in Figure 6. The red dashed line indicates a 1:1 ratio between property value increases for every dollar of investment in the PVS system.

Of all selected cities, Baltimore, MD has the lowest value increase at $0.93 for every dollar of system cost and Lahaina, HI has the highest value at a property value increase of 8.55 times each dollar of system cost.

Table 3 shows the statistical characteristics of the data of all 70 cities studied. Across the cities, the average increase in property value for each dollar of PV system investment was $2.08 with a SD of 1.48. Of all the sample cities, 68 of the 70 cities experienced property value increases greater than a 1:1 ratio relative to the investment cost. This observation can be seen by the dashed red horizontal line placed at the threshold of the 1:1 value in Figure 6. The distribution of the Property Value Increase/PV system cost is not a normal distribution and has a strong positive skew.

Table 3. Statistical characteristics of property value increase / PV system cost.

	N	Mean	SD	Median	Min	Max
Property Value Increase / PV System Cost	70.00	2.08	1.48	1.58	0.93	8.55

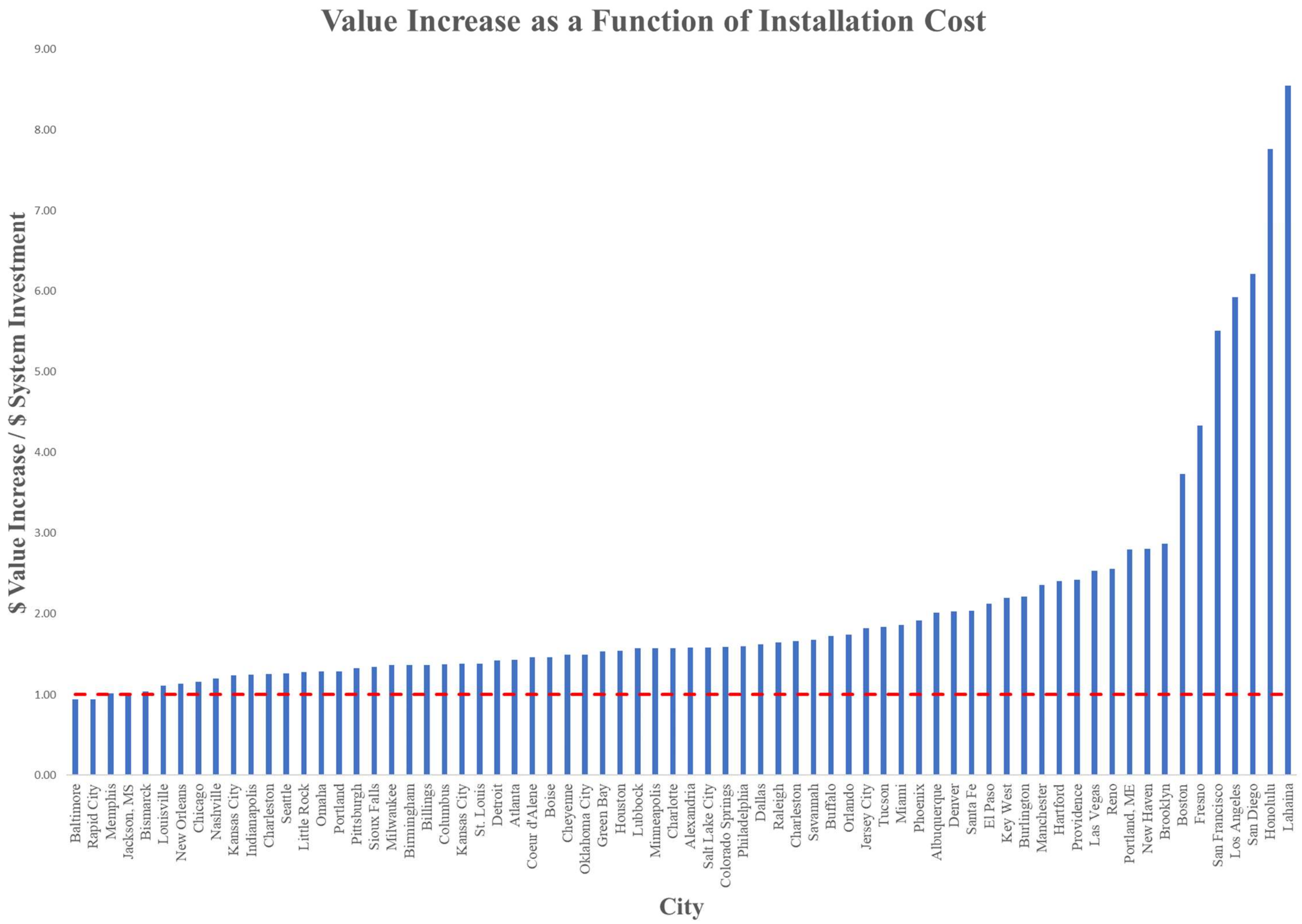


Figure 6. Property value increases as a function of PV solar installation cost.

*The **Red** dashed line displays the 1:1 threshold between asset value increase vs. PV solar system installation cost*

Benefit-Cost Ratio

Table 14 in Appendix 4 shows the complete list of cities organized with their BC ratio and includes the gross income, AGI, annual financing, SFC, and operations and maintenance, O&M, costs used to calculate the BC ratio for each city. The BC ratio was plotted for each city in order of ascension in Figure 7. The red dashed line represents a 1:1 threshold where all of the annual economic benefits of a PV solar system equal the required costs to service the system financing plus the ongoing operations and maintenance expenses. The black dashed line indicates the average BC ratio among all of the cities studied.

Table 4 shows the statistical characteristics of the results of the benefit-cost ratio analysis of all 70 cities studied.

Table 4. Statistical characteristics of benefit-cost ratio.

	N	Mean	SD	Median	Min	Max
Benefit Cost Ratio	70	1.55	0.68	1.29	0.81	4.17

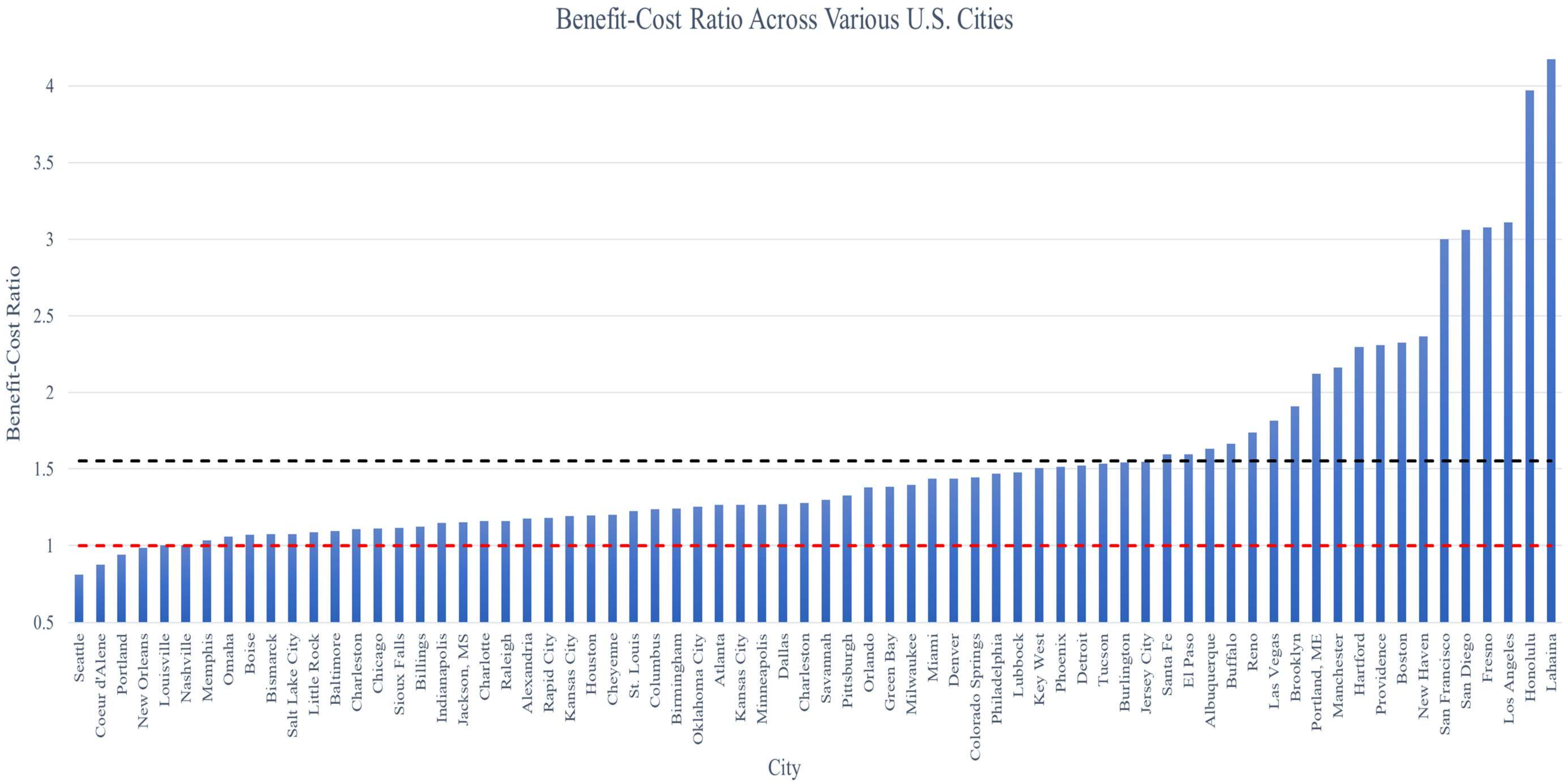


Figure 7. Benefit-cost ratio by city.

The ***Red*** *dashed line represents a 1:1 ratio of all annual benefits to all annual costs. The* ***Black*** *dashed line represents the average benefit-cost ratio of all cities.*

Benefit-cost ratio vs. solar resource. The BC ratio was also plotted as a function of the PV output for each city and the results are displayed in Figure 8. A representative number of cities were represented by the data callouts in the figure and all city data points from Table 14 were included, but not necessarily labeled.

A linear regression was performed for the entire set of data in Figure 7 and the results are included in Table 5. The regression analysis shows the BC Ratio had a P-value of .00038, indicating a high level of statistical significance of the BC Ratio on the PVPF.

Table 5. Regression coefficients of benefit-cost ratio on PV solar output.

	Coefficients	Standard Error	t Stat	P-value
Intercept	1381.419763	49.45116961	27.9350271	5.43462E-39
Benefit-Cost Ratio	109.0681146	29.21840424	3.73285665	0.00038898

Benefit-Cost ratio vs. electricity cost. The benefit-cost ratio was also plotted as a function of the electricity rate in each city. Figure 8 displays the relationship of the BC ratio on the AUR across the entire city data set with a select number of cities labeled with data call outs. Most of the same city callouts were included in both Figure 7 and Figure 8.

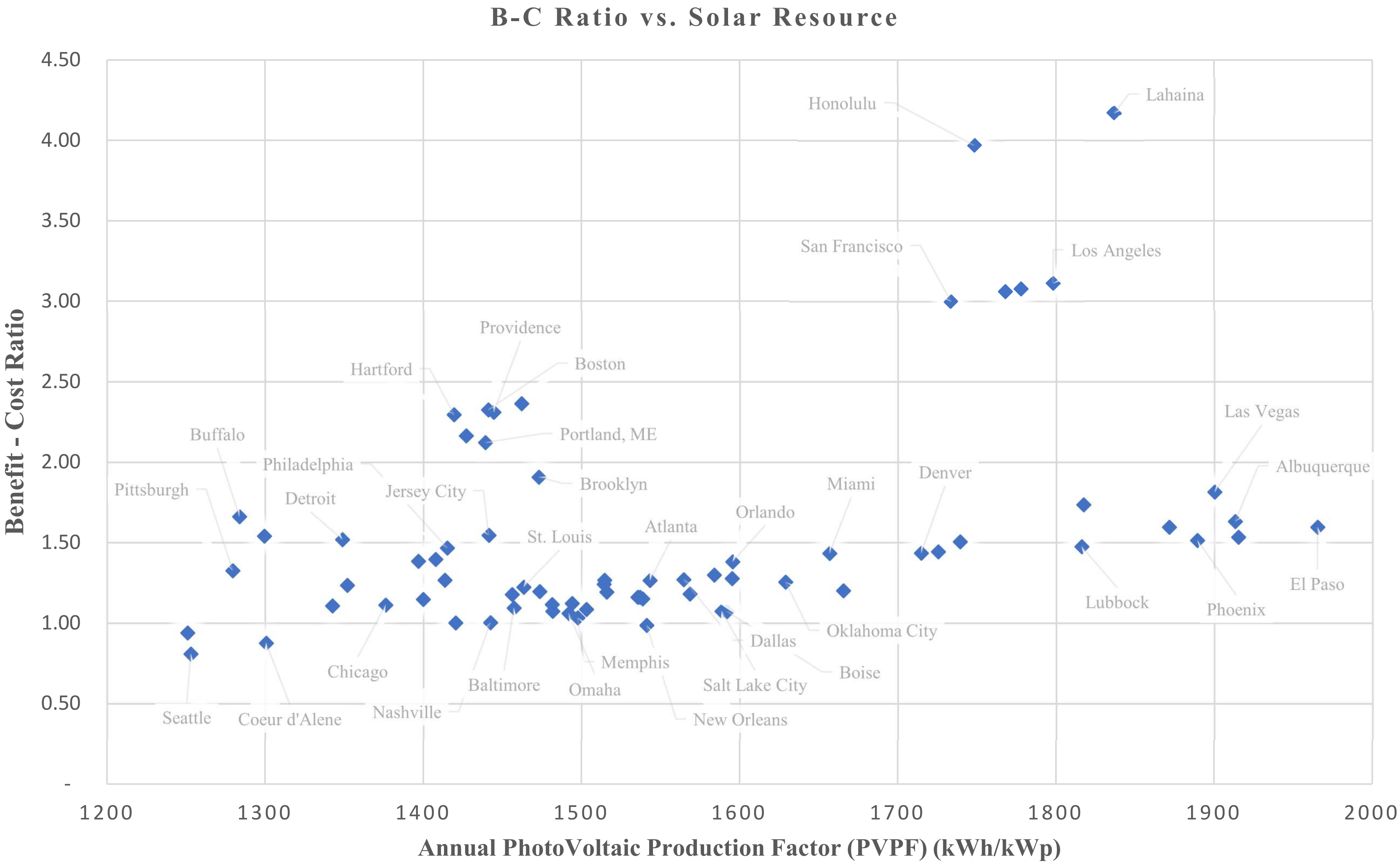


Figure 8. Benefit-cost ratio vs. solar resource.
All cities plotted, illustrated with selected cities call outs

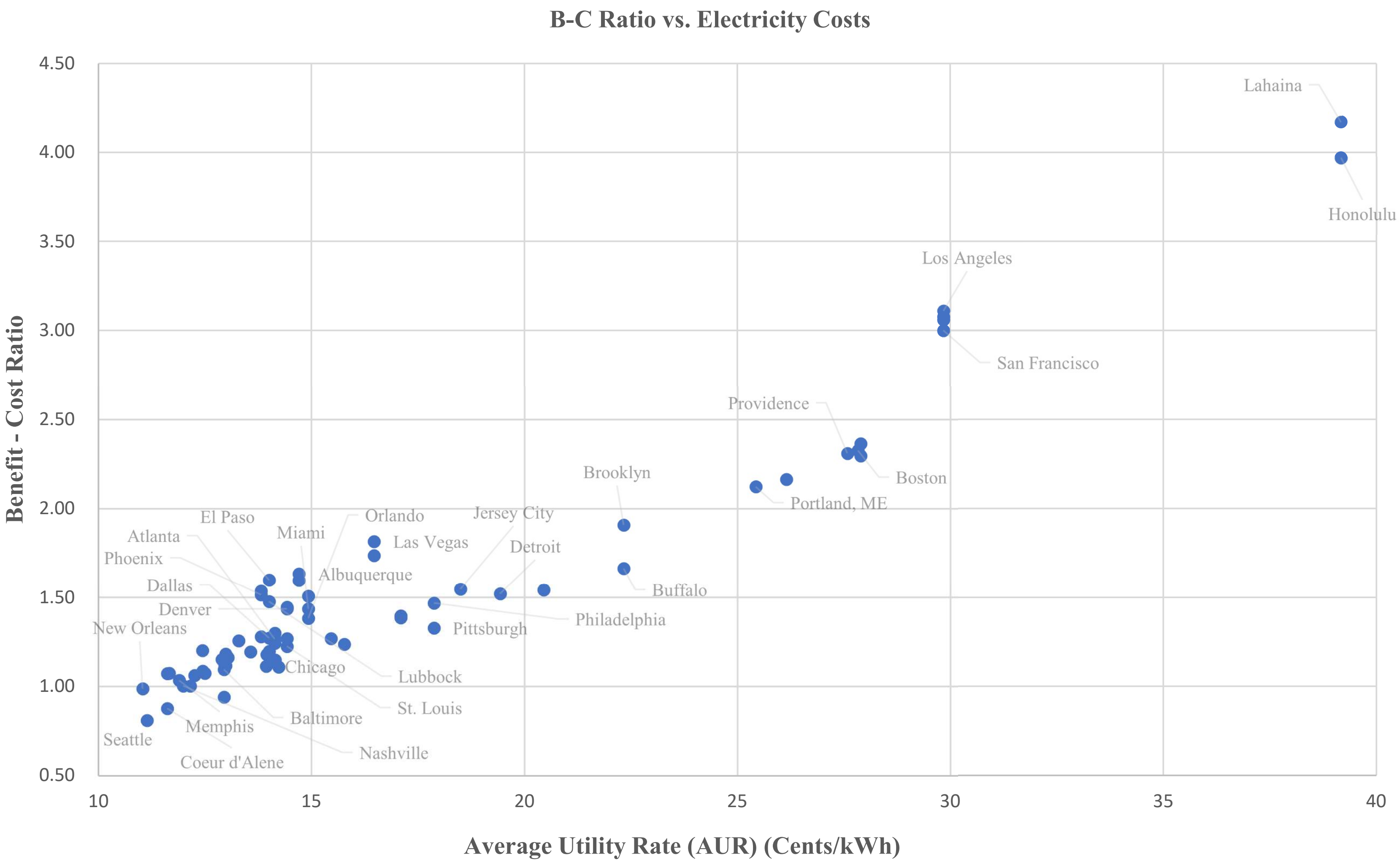


Figure 9. Benefit-cost ratio plotted vs. electricity cost.
All cities plotted, illustrated with selected city call outs

A linear regression of the entire set of data from Figure 9 yielded a BC ratio P-value of 4.50 E-39, indicating a very high statistical significance of the relationship of the BC ratio to the electricity cost for each city (Table 6).

Table 6. Regression coefficient of benefit-cost ratio on electricity cost.

	Coefficients	Standard Error	t Stat	P-value
Intercept	2.794282876	0.558482889	5.00334555	4.21907E-06
Benefit-Cost Ratio	9.245950651	0.329981655	28.0195899	4.49718E-39

Multiple regression analysis of BC ratio. A multiple regression analysis was performed to analyze the relative importance of the independent variables, PV production factor, and electricity cost for each city on the dependent variable, BC ratio. The results of the multiple regression analysis indicated a statistically significant relationship for both the PVPF and the electricity cost for the city data set with values of 6.49 E-33 and 5.02 E-67, respectively (Table 7). The coefficients of the PVPF and the electricity cost from Table 7 7 were 0.0010 and 0.095, respectively.

Table 7. Multiple regression BC ratio vs. PVPF and electricity cost.

	Coefficients	Standard Error	t Stat	P-value
Intercept	-1.654409512	0.070414898	-23.495163	4.59973E-34
PV Production Factor	0.001015597	4.51894E-05	22.4742204	6.48536E-33
Electricity Cost	0.09516551	0.001240043	76.7437001	5.02038E-67

The multiple regression equation for the independent and dependent variables was then constructed (equation 17):

$$BC = -1.65 + .0010(PVPF) + .095\,(AUR) \qquad (17)$$

The independent variable coefficients of the equation reveal that the local electricity cost has an impact on the BC ratio result almost two orders of magnitude greater than the PV production factor.

Heteroscedasticity of the benefit-cost ratio. The divergent appearance of the scatter plot in Figure 8 indicated that the relationship between the BC ratio and the PV production factor may be heteroskedastic, or non-constant over a range of values. Therefore, the Boersch-Pagan heteroscedasticity test was performed on the multiple regression model using the residuals output and the summary results of that analysis are included in Table 8. The full data including the residuals output, the predicted Y, and the residuals squared of the multiple regression model used in the Boersch-Pagan test are included in Table 15, Appendix 5.

Table 8. BC ratio Boersch-Pagan test for significance.

ANOVA	df	SS	MS	F	Significance F
Regression	2	0.00219553	0.001097763	32.7758121	1.1847E-10
Residual	67	0.00224404	3.34931E-05		
Total	69	0.00443956			

The P-value for the ANOVA was significant at <.0001 (Table 8). The null hypothesis that the data were homoscedastic was rejected and the alternative hypothesis that the error terms are heteroscedastic was accepted. The heteroscedasticity was an indication that the standard deviations of the dependent variable do not remain constant over the range of values of the independent variables; therefore, caution should be exercised when applying a linear regression model to these two independent variables.

Environmental Impact and Analysis

The environmental impacts were determined by calculating the project level impacts and then extrapolating these results to statewide values based on the prevalence of MDUs in a given state and an assumed PVS adoption rate in multifamily properties.

Annual Emissions Avoided

The data in Table 16, in Appendix 6, displays the selected cities organized with the calculated amount of avoided grid-tied electricity usage and CO_2e emissions reductions resulting from the addition of the PV solar systems to the 50-unit model project.

Annual project level emissions avoided. These data were used to generate Figure 10 which displays the annual metric tons of CO_2e avoided in each city location. Only one city per state from Table 16 was included in Figure 10 because the eGRID emissions for most states remain constant across the cities, in their respective states. In the instances where two of the selected cities in a single state were included in different eGRID regions, which resulted in different avoided emissions profiles, then both city results were included in the figure.

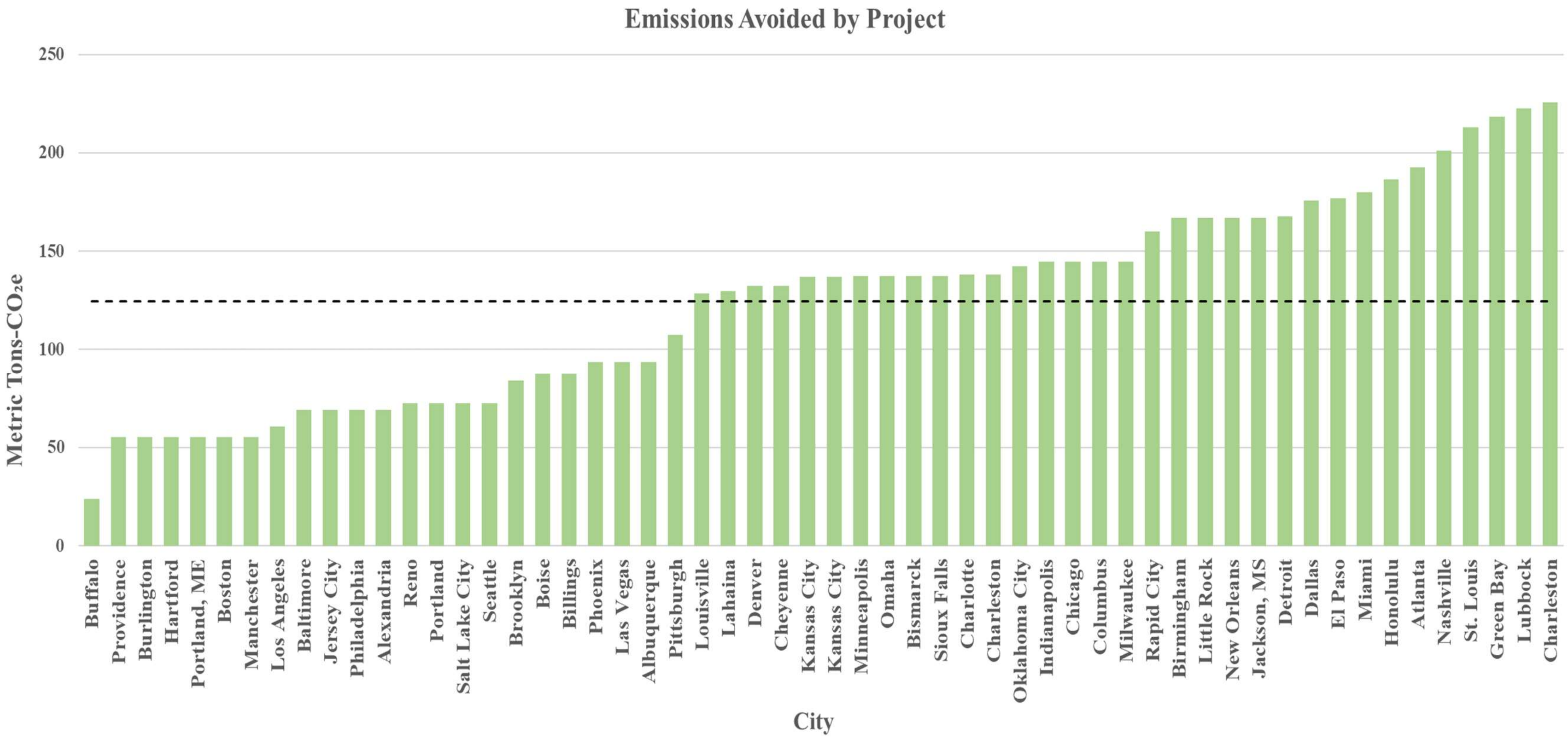


Figure 10. Avoided project CO_2e emissions by city.
*The **Black** dashed line represents the average project-level emissions avoided at 124.4 metric tons-CO_2e*

Statewide emissions avoided. The potential statewide emissions reductions were calculated by extrapolating the avoided emissions of the standard 50-unit MDU project across the total number of multifamily units in each state at a 25% adoption rate of PV solar. Both the project-avoided emissions and the statewide emissions were plotted in Figure 11. The cities are presented in the same ascending order based on project emissions as in Figure 10, which are shown in the same light green color, while the extrapolated statewide results are shown in dark green. The large disparities in the results between the project and statewide emissions avoidance arise as a factor of the number of MDUs present in a given state. Therefore, the largest statewide impacts were seen in states with the largest populations and number of MDUs such as Texas, California, Florida, and New York. It is also important to note that the project emissions are reported in metric tons, on the left axis, and the statewide emissions are reported in kilotonnes, on the right axis. The additional difference of 1000X should be noted in the visual representation (Figure 11).

Economic value of emissions. The calculated cost to remove a metric ton of carbon by the introduction of the PVS systems is paired with its city location in Table 17 in Appendix 7. This information is presented in graphic form in Figure 12 and was ordered by increasing the cost of CO_2e emission removal by city location. The average cost to remove one metric ton of CO_2e emissions in Table 17 is \$330 and is represented by the dashed black horizontal line in Figure 12.

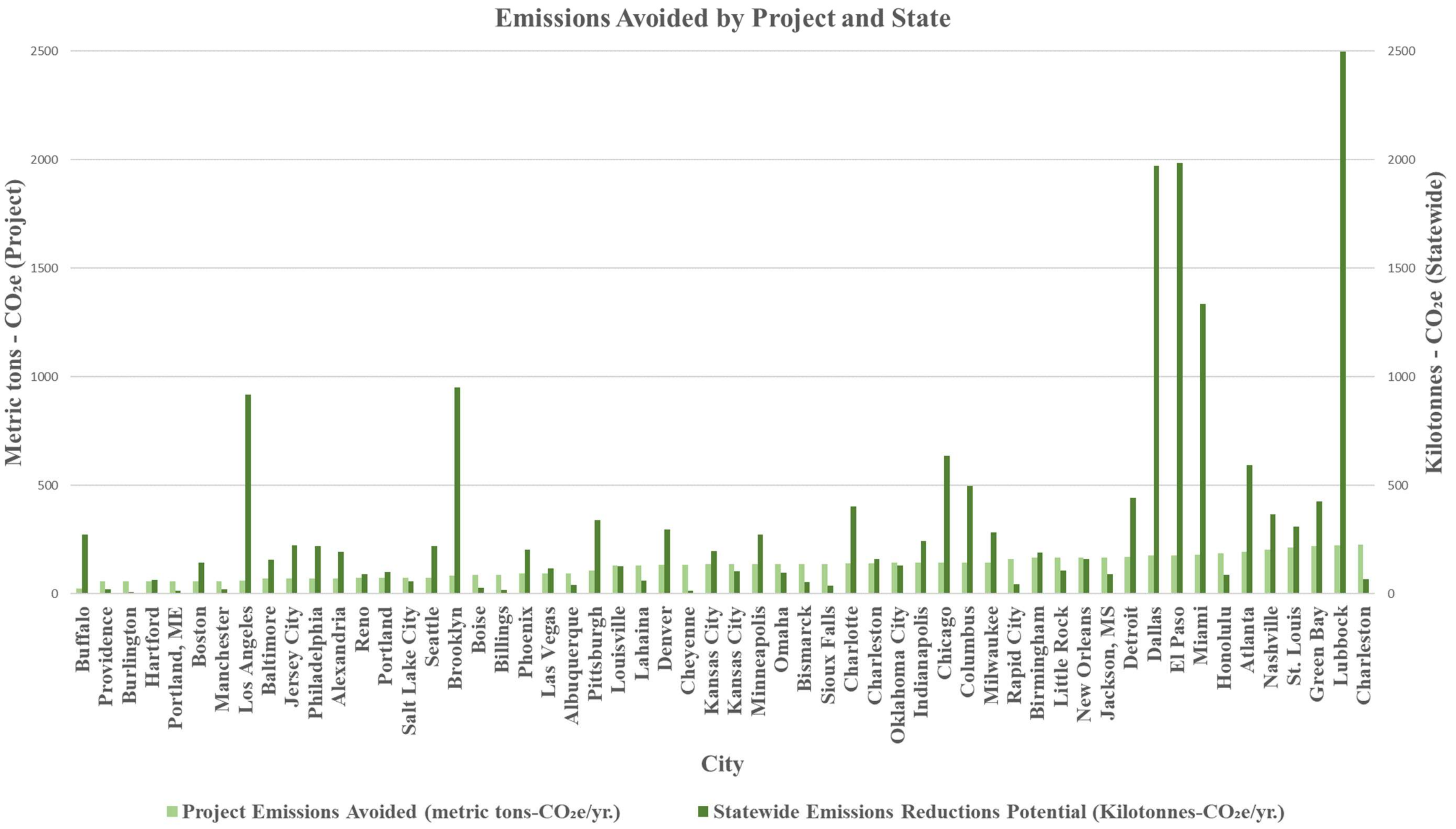


Figure 11. Annual avoided project and statewide CO_2e emissions by city.
The Light green represents project-level emissions avoided (metric tons – CO_2e) and the dark green represents statewide emissions avoided (kilotonnes – CO_2e) at a 25% PVS adoption rate

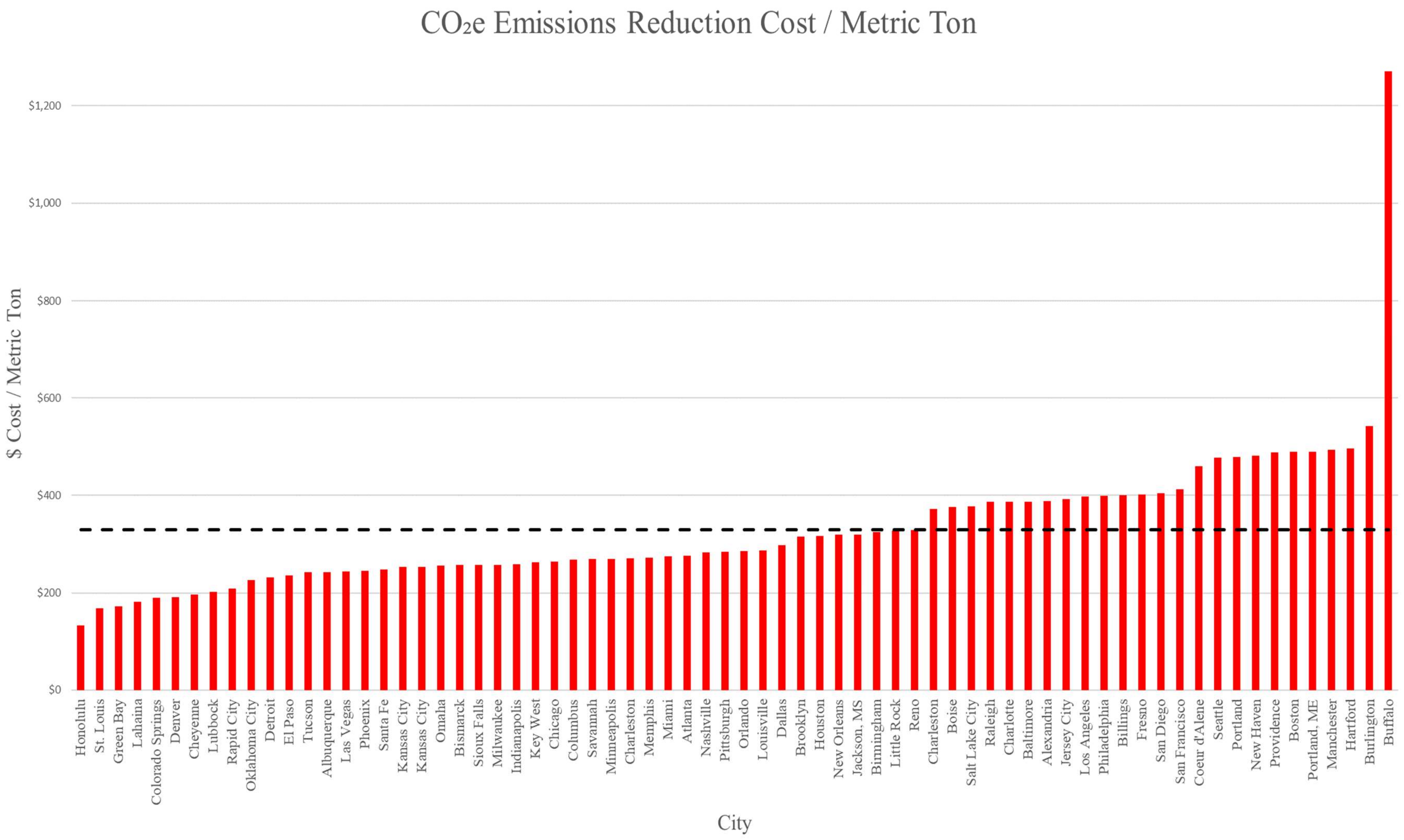


Figure 12. Cost per metric ton for CO₂e emissions reduction by city.
The Black dashed line represents the average cost per metric ton across all cities of $330

Economic and Environmental Nexus

To develop the implications of the interaction between the economic and environmental effects of PV systems on MDUs, the results of the separate foregoing analyses were incorporated into a combined chart created from the data in Table 18 in Appendix 8. Each city location was plotted in Figure 13 according to the amount of the project emissions avoided (x-axis) and the BC ratio (y-axis). Further, the same information was plotted in Figure 14, but for the sake of clarity, the two states that have significantly larger BC ratios, California and Hawaii, were omitted so the distribution of the cities in the remaining states is more evenly spread along the y-axis. The remaining analysis of this section proceeds with the understanding that the cities in California and Hawaii have meaningfully higher BC ratios as compared with the data for the remaining cities.

The emissions results of the cities varied by over an order of magnitude along the y-axis from a low of approximately 20, to a high value of over 220 metric tons-CO_2e/yr (Figure 13) primarily driven by the emissions profiles and factors of the fossil fuel-based electrical grids of the cities. In Figure 13, a dashed red line is included at the 1:1 threshold for the BC ratio. All cities lying above this threshold experience a greater than 1:1 B-C ratio benefit from the addition of a PV solar system on the model MDU. It is seen that only a handful of cities are at or below the 1:1 limit of the BC ratio while most cities have BC ratios above the 1:1 economic breakeven point. The cities in California and Hawaii possess significantly higher BC ratios ranging from 3:1 to over 4:1. These economic differences were based on the variables that influence the economic factors including the electricity rate, solar resource, and consumption of each city.

Figure 14, which plots the same data as Figure 13 without the economic outlying cities located in Hawaii and California, was segmented into four quadrants by the intersecting black lines crossing in the middle of the chart. The cities residing in the lower left quadrant represent the low BC ratio and low emissions-avoided conditions, and the cities in the upper right represent the high BC ratio and high emissions-avoided conditions. While these quadrants do not have an objective standard, they help organize the cities into high and low economic and environmental performers. As seen in Figure 13, almost all cities exceed the 1:1 BC economic threshold; however, only a minority of cities lay claim to being economic standouts lying above the 1.6:1 BC ratio line, which would also include the cities in California and Hawaii, omitted here. The environmental results show that a majority of the cities have avoided emissions rates greater than 125 metric tons-CO_2e/yr. This threshold also exceeded the average annual emissions avoided among all cities of 124.4 metric tons-CO2e/yr as noted in Figure 10. As only El Paso and the cities in Hawaii, omitted here, reside in the high-high quadrant, Figure 14 indicates that achieving superior economic and environmental results simultaneously is elusive.

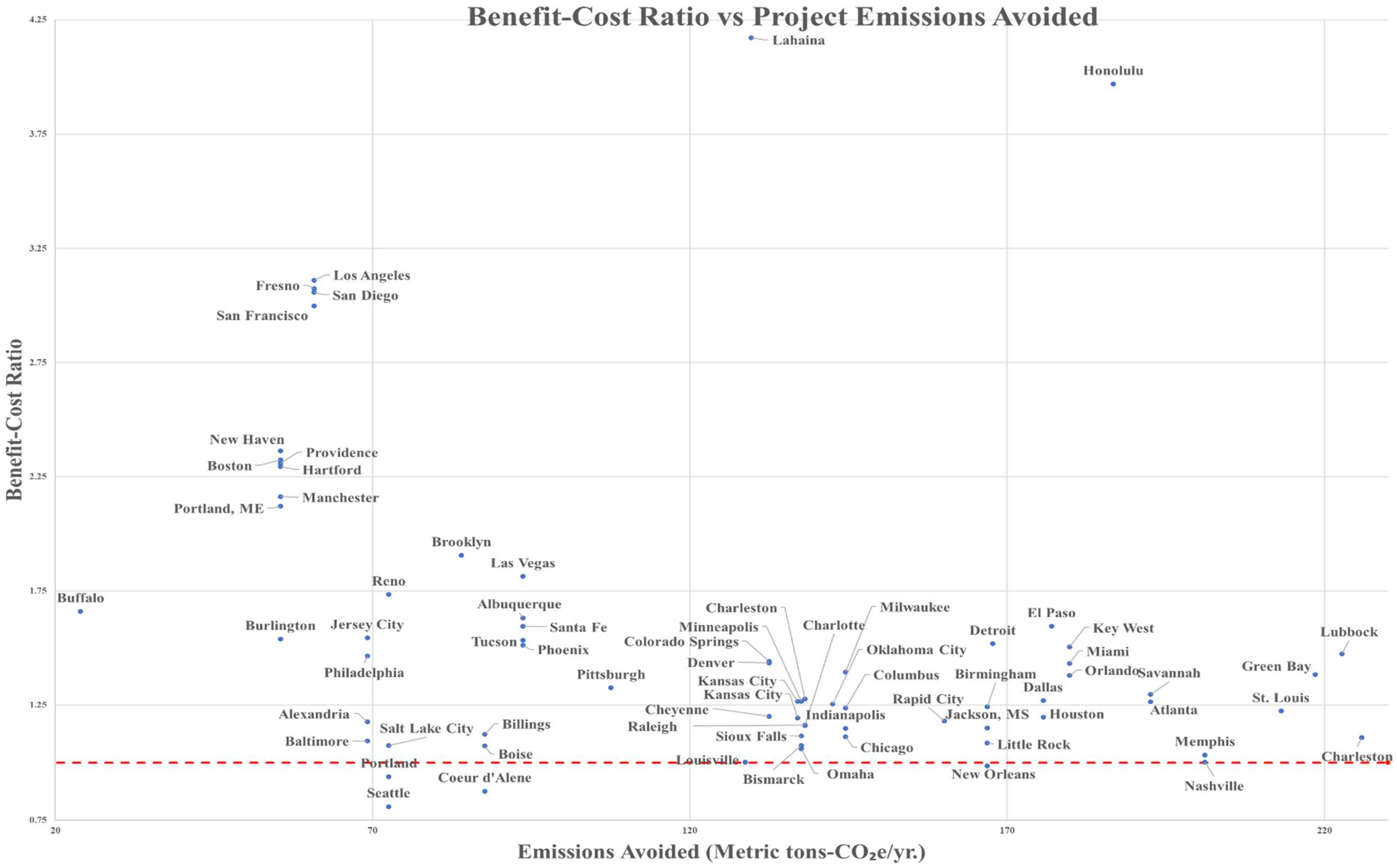


Figure 13. Benefit-cost ratio vs. project emissions avoided in all cities.
Complete city data set with all call outs for all cities

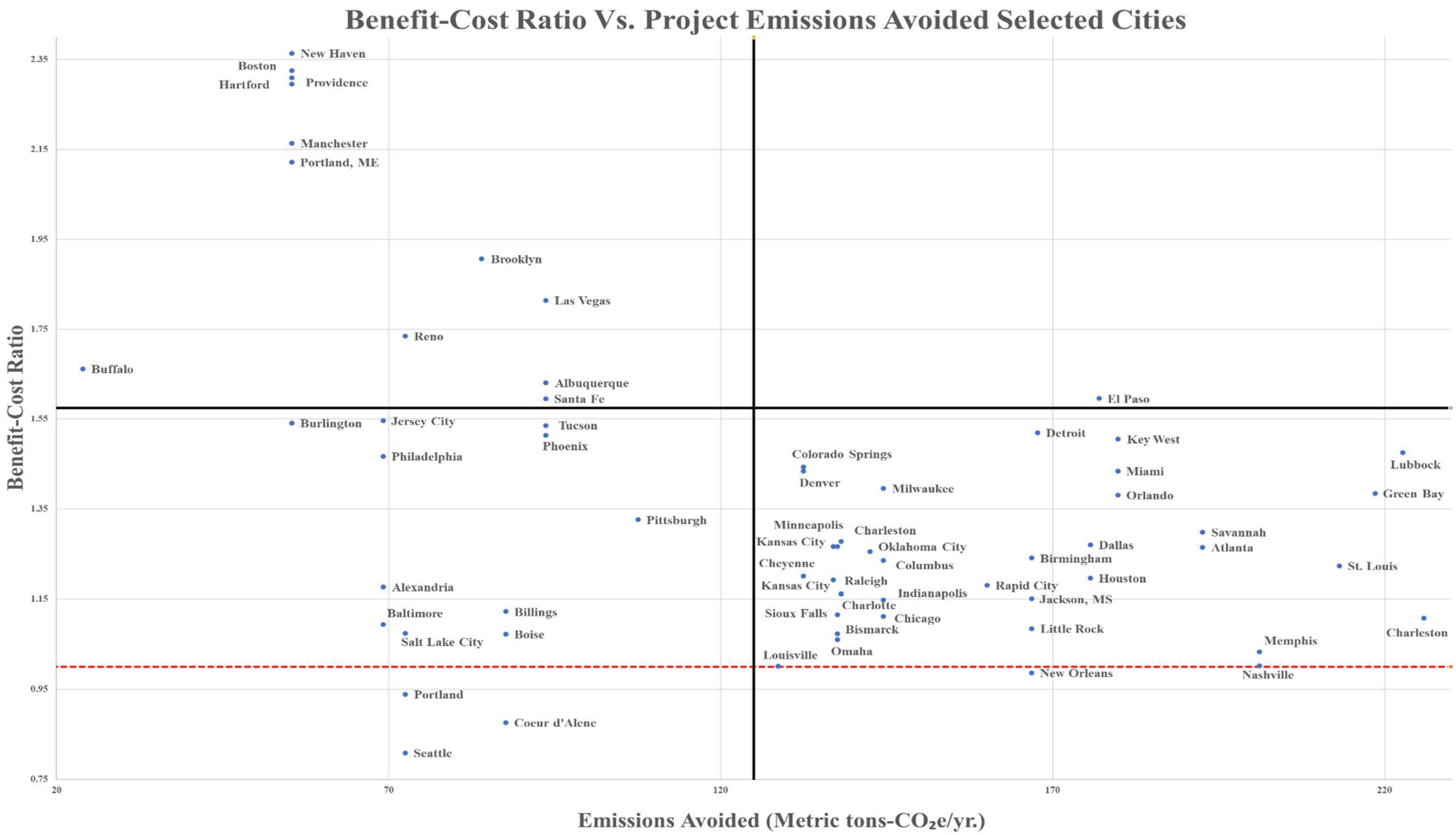


Figure 14. Benefit-cost ratio vs. emissions avoided selected cities.

The same data as Figure 13 is divided into four quadrants with outliers of Hawaii and California cities removed for greater clarity. The lower left quadrant is low-low condition and the upper right quadrant is high-high condition. The Red dashed line represents a 1:1 BC ratio

Energy Burden Analysis

The energy burden data gathered from the DOE LEAD tool for each city is presented in Appendix 9, Table 19. The averages of the three categories studied—city baseline, low-income renter, and low-income renter with ethnic constraints—are included at the bottom of each column in Table 19. These averages change significantly among the different populations as they range from 2.2% for the city baseline population, 4.9% for the renter population in the same cities, and finally to 41.9% for the renter population constrained by the African American and White Hispanic and Latino ethnic groups in the same cities (Table 19, Appendix 9).

For clarity, due to the large difference in scale in some of the values, these data are presented in two charts. The first representation in Figure 15 combines the baseline city EB data with the EB data for a general renter with the above-defined criteria. The horizontal blue and peach lines represent the averages of the energy burdens for the city baseline and low-income renter groups, respectively. The second chart, Figure 16, includes the same data as in Figure 15, however, it also includes the EB data when restricting the same renter criteria to only include the African American and White Hispanics and Latino population. A significant contrast between the EB experienced by each category can be clearly seen when examining the two figures. However, when the additional constraint of restricting data by ethnicity, as seen in the dark green columns in Figure 16, it significantly overshadows the EB impact of the other categories, blue and orange columns. The average energy burden for this population is represented by the horizontal dark green line in the figure. No data could be found for the cities of Lahaina and Honolulu that include the additional ethnic constraints for Figure 16.

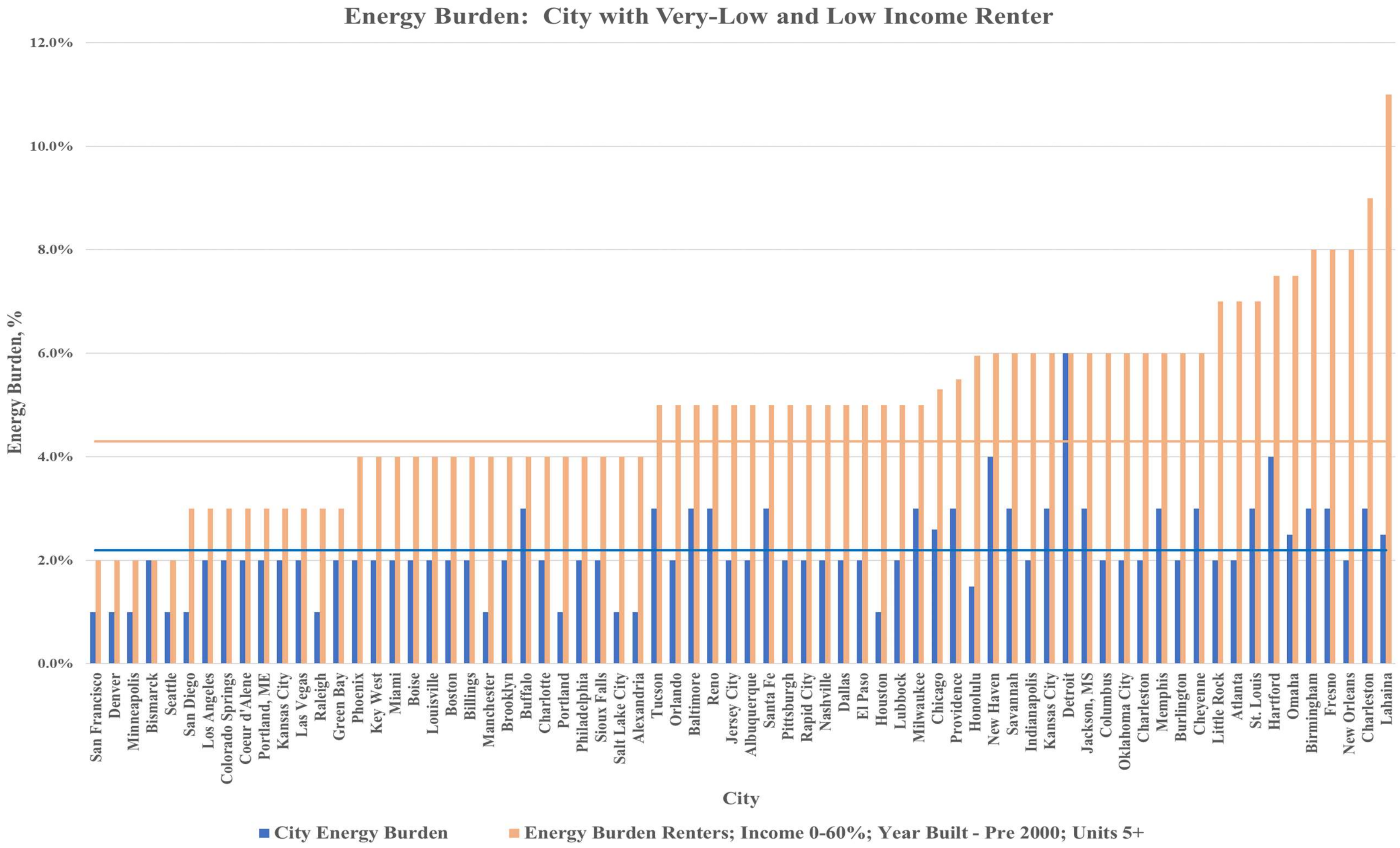


Figure 15. Energy burden for city and low-income renter.
The ***Blue*** *columns represent the city baseline energy burden and the orange represents the renter population energy burden in the same cities*

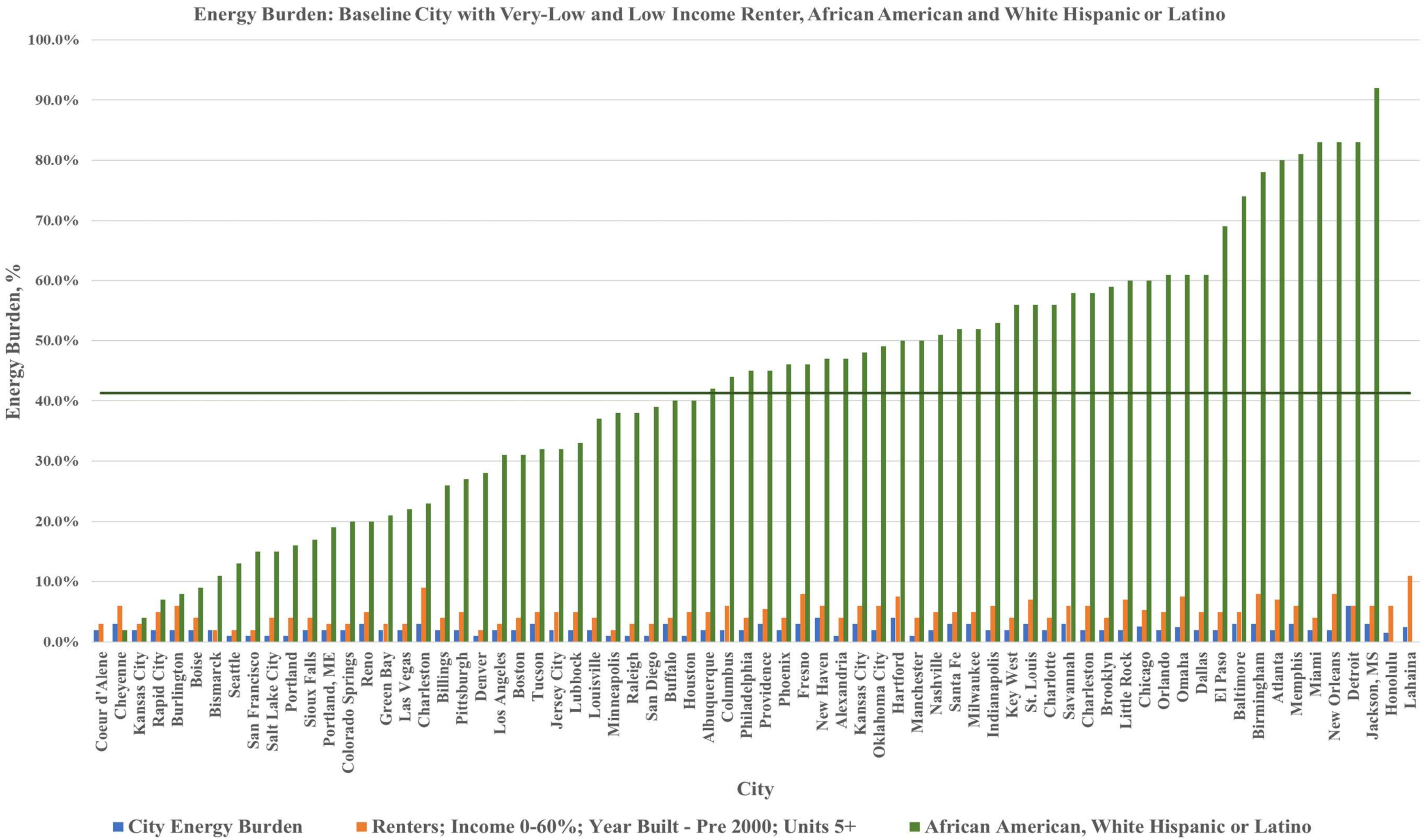


Figure 16. Energy burden of city and low-income renter with ethnicity.
*The **Blue** columns represent the city baseline energy burden, the orange represents the renter population energy burden, and the **green** represents the renter population constrained by ethnicity energy burden in the same cities*

PV Solar Multifamily Index

The results of each scoring model are presented here. The two-dimensional index considers the economic and environmental impact of the PVS systems and the three-dimensional index includes the economic, environmental, and energy justice implications.

Two-Dimensional Index

The results of the two-dimensional scoring index are included in Figure 17 and Table 9 below. The complete data set for the figure, including the constituent values that comprise the composite score, is included in Appendix 10, Table 20. The stacked column chart in Figure 17 shows the overall two-dimensional score as the combination of the BC ratio, shown in blue, combined with the emissions avoided component, shown in green. The cities have been arranged in ascending order according to the overall index score for the two components as listed in Table 9.

Except for the cities at both the lowest and highest extremes in Figure 17, the relative rankings for the substantial majority of the cities on the two-dimensional index required a balance of economic and environmental benefits. However, as the BC ratios of the cities were in a tighter range of values than the avoided emissions, the environmental components appear to have a greater influence on the overall two-dimensional rankings.

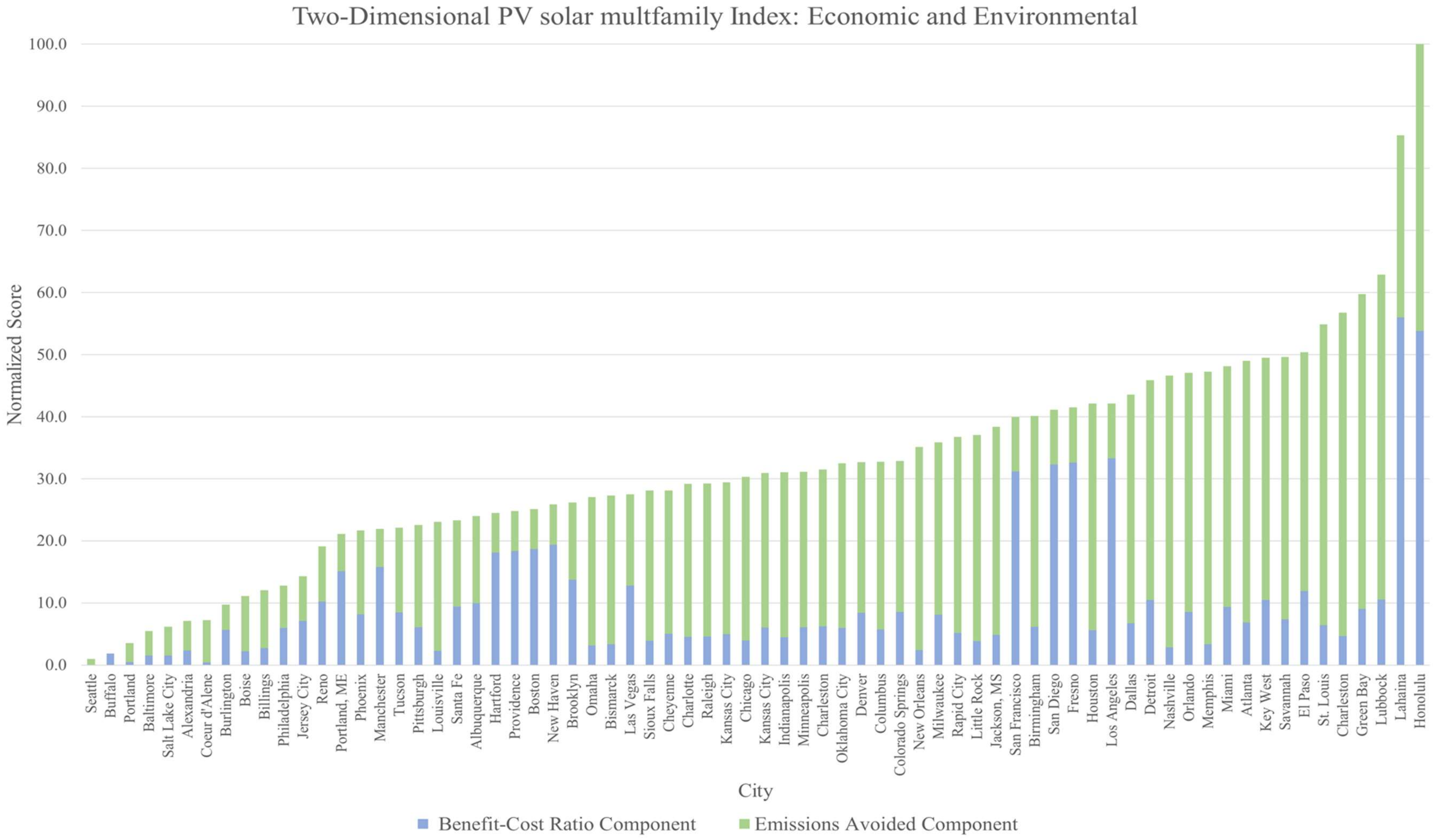


Figure 17. PV solar multifamily index with two dimensions.
*The **blue** column represents the financial BC component of the index and the green represents the environmental emissions component. The total stacked column represents the overall two-dimensional index score for each city*

Table 9. Two-dimensional PV solar index results by city.

City	Normalized Score	City	Normalized Score
Honolulu	100	Chicago	30
Lahaina	85	Kansas City	29
Lubbock	63	Raleigh	29
Green Bay	60	Charlotte	29
Charleston	57	Cheyenne	28
St. Louis	55	Sioux Falls	28
El Paso	50	Las Vegas	28
Savannah	50	Bismarck	27
Key West	50	Omaha	27
Atlanta	49	Brooklyn	26
Miami	48	New Haven	26
Memphis	47	Boston	25
Orlando	47	Providence	25
Nashville	47	Hartford	24
Detroit	46	Albuquerque	24
Dallas	44	Santa Fe	23
Los Angeles	42	Louisville	23
Houston	42	Pittsburgh	23
Fresno	42	Tucson	22
San Diego	41	Manchester	22
Birmingham	40	Phoenix	22
San Francisco	40	Portland, ME	21
Jackson, MS	38	Reno	19
Little Rock	37	Jersey City	14
Rapid City	37	Philadelphia	13
Milwaukee	36	Billings	12
New Orleans	35	Boise	11
Colorado Springs	33	Burlington	10
Columbus	33	Coeur d'Alene	7
Denver	33	Alexandria	7
Oklahoma City	33	Salt Lake City	6
Charleston	32	Baltimore	5
Minneapolis	31	Portland	4
Indianapolis	31	Buffalo	2
Kansas City	31	Seattle	1

Three-dimensional Index

The second index developed to determine the cumulative effect of the three combined categories, economic, environmental, and energy burden is presented in Figure 18 and Table 10. The combination of the three criteria in the scoring model; economic, environmental, and energy burden are seen in the three different colors comprising the stacked column chart in the figure. In a similar fashion as Figure 17, the BC ratio is displayed in blue and the emissions avoided are shown in green. The newly added energy burden component is represented in the stacked columns by the gray bars and the cities have been ordered according to their overall three-dimensional score from Table 10. The complete data set for Figure 18, including the three constituent values that comprise the composite score, is included in Table 21 in Appendix 11. The inclusion of the third energy burden component caused a modest reordering of the cities as seen when comparing the results in Table 9 with Table 10.

The ranking of the cities in Figure 18 illustrates that a balance of strong performance among at least two components was a requirement for placement in the top tier of the rankings. The two highest-ranked cities, Lahaina and Honolulu, possessed among the highest values in each of the three individual components.

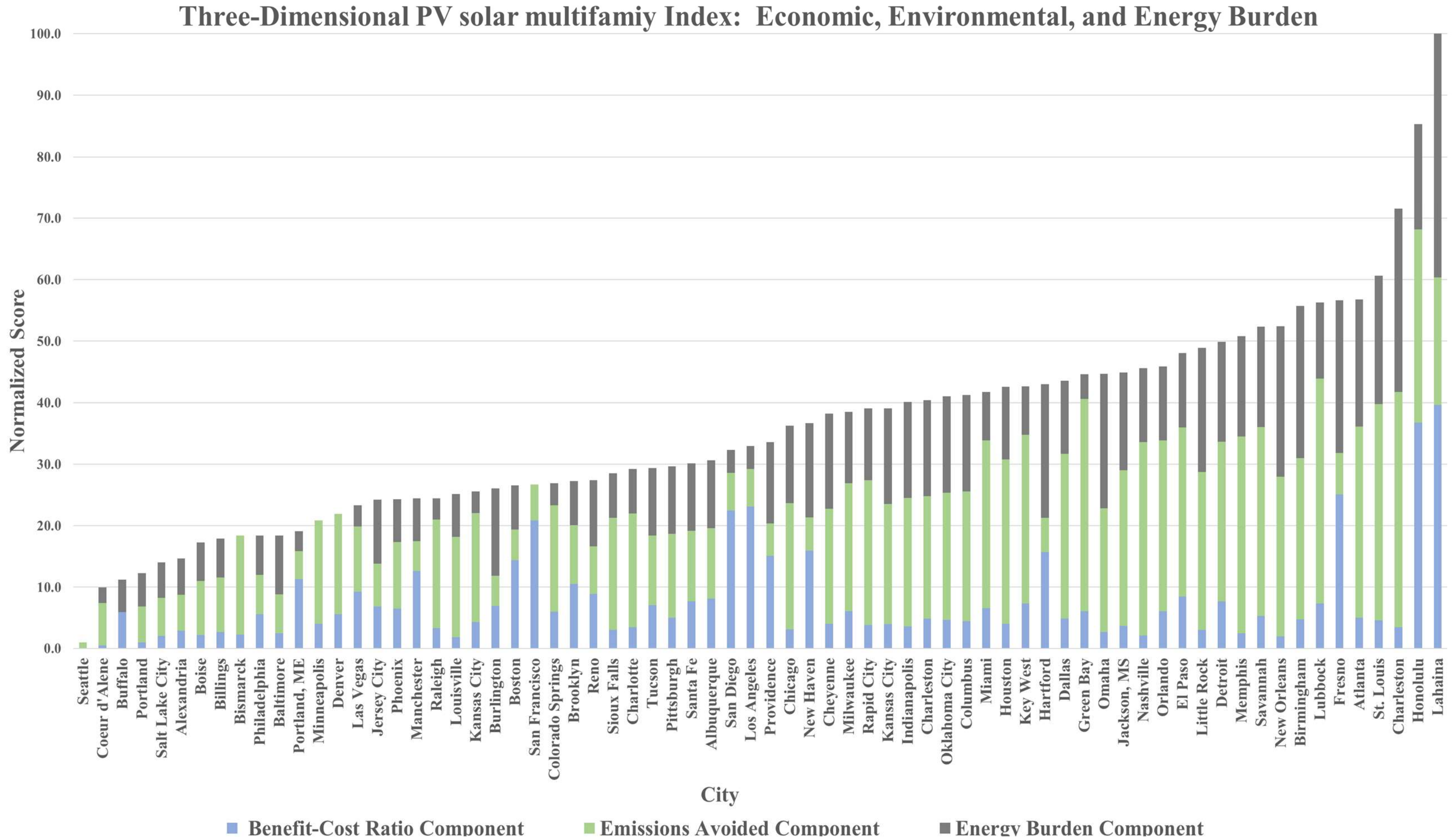


Figure 18. PV solar multifamily index with three dimensions.

The ***blue*** *column represents the financial BC component of the index, the* ***green*** *represents the environmental emissions component, and the* ***grey*** *indicates the energy burden component. The total stacked column represents the overall three-dimensional index score for each city*

Table 10. Three-dimensional PV solar index by city.

City	Normalized Score
Lahaina	100
Honolulu	85
Charleston	72
St. Louis	61
Atlanta	57
Fresno	57
Lubbock	56
Birmingham	56
New Orleans	52
Savannah	52
Memphis	51
Detroit	50
Little Rock	49
El Paso	48
Orlando	46
Nashville	46
Jackson, MS	45
Omaha	45
Green Bay	45
Dallas	44
Hartford	43
Key West	43
Houston	43
Miami	42
Columbus	41
Oklahoma City	41
Charleston	40
Indianapolis	40
Kansas City	39
Rapid City	39
Milwaukee	38
Cheyenne	38
New Haven	37
Chicago	36
Providence	34
Los Angeles	33
San Diego	32
Albuquerque	31
Santa Fe	30
Pittsburgh	30
Tucson	29
Charlotte	29
Sioux Falls	29
Reno	27
Brooklyn	27
Colorado Springs	27
San Francisco	27
Boston	27
Burlington	26
Kansas City	26
Louisville	25
Raleigh	24
Manchester	24
Phoenix	24
Jersey City	24
Las Vegas	23
Denver	22
Minneapolis	21
Portland, ME	19
Baltimore	18
Philadelphia	18
Bismarck	18
Billings	18
Boise	17
Alexandria	15
Salt Lake City	14
Portland	12
Buffalo	11
Coeur d'Alene	10
Seattle	1

Sensitivity Analyses

Two different types of sensitivity analyses were performed using the Excel What-if analysis tool. The first analysis explored the effect of changing the installation cost and electricity cost on the BC ratio results for both the lowest-performing BC ratio city, Seattle, and the highest-performing city, Lahaina. By using these two extremes, the BC ratio outcomes from adjusting these costs for the range of all cities in the study can be understood. The results for Seattle are shown in Figure 19, and Lahaina in Figure 20. The PV system installation cost varies across the rows and the electricity cost varies down the columns.

Each cell in the tables represents the resulting BC ratio at the intersection of a single installation cost value and electricity cost value. The baseline BC ratio with the original parameters of the study is included in the upper left-hand corner of each chart for the corresponding city, 0.81 for Seattle and 4.17 for Lahaina. The cells highlighted in red represent the intersection of the two variables that resulted in a BC ratio of less than one.

The analysis of the two city locations reveals the large impact of the PV system's upfront installation cost on the overall lifetime economic performance of the BC ratio. Figure 19 shows that the worst performing city, Seattle, at installation costs of $1.25/watt or less had BC ratios that all exceed the 1:1 threshold across the full range of electricity costs, $0.11 to $$0.39, while in Figure 20, Lahaina can achieve this performance at installation costs up to $2.00/watt. It is also seen in Figure 19 that at an installation cost of $0.75/watt, and an electricity cost of $0.28/kWh, the resulting BC ratio in Seattle, 4.21, would outperform the BC ratio found in the study for Lahaina, 4.17, which has a current electricity cost far higher at $0.39/kWh. Therefore, the installation cost alone can have the effect of making the economic return of the lowest-performing city exceed the economic return of the highest-performing city.

The importance of the amount of the solar resource available in a given location can also be inferred from a comparison of the number of cells that underperform the 1:1 BC ratio threshold, as represented by the amount of red-shaded areas in the charts for each of the two cities. In the Lahaina chart, only 4.48% of the cells have BC ratios less than 1:1 for all combinations of electricity rate and installation costs. While in Seattle, the underperforming red-shaded area is over three times greater and represents 14.7% of the total possible combinations.

Benefit-Cost Ratio

Seattle, WA

Installation Cost ($)

Electricity Cost (cents)

0.81	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**	**3.25**	**3.50**
11	1.65	1.33	1.11	0.95	0.83	0.74	0.67	0.61	0.55	0.51	0.48	0.44
12	1.80	1.45	1.21	1.04	0.91	0.81	0.73	0.66	0.61	0.56	0.52	0.48
13	1.95	1.57	1.31	1.12	0.98	0.87	0.79	0.72	0.66	0.61	0.56	0.52
14	2.10	1.69	1.41	1.21	1.06	0.94	0.85	0.77	0.71	0.65	0.61	0.57
15	2.26	1.81	1.51	1.29	1.13	1.01	0.91	0.83	0.76	0.70	0.65	0.61
16	2.41	1.93	1.61	1.38	1.21	1.07	0.97	0.88	0.81	0.75	0.69	0.65
17	2.56	2.05	1.71	1.47	1.28	1.14	1.03	0.94	0.86	0.79	0.74	0.69
18	2.71	2.17	1.81	1.55	1.36	1.21	1.09	0.99	0.91	0.84	0.78	0.73
19	2.86	2.29	1.91	1.64	1.44	1.28	1.15	1.05	0.96	0.88	0.82	0.77
20	3.01	2.41	2.01	1.73	1.51	1.34	1.21	1.10	1.01	0.93	0.87	0.81
21	3.16	2.53	2.11	1.81	1.59	1.41	1.27	1.16	1.06	0.98	0.91	0.85
22	3.31	2.65	2.21	1.90	1.66	1.48	1.33	1.21	1.11	1.02	0.95	0.89
23	3.46	2.77	2.31	1.98	1.74	1.55	1.39	1.27	1.16	1.07	0.99	0.93
24	3.61	2.89	2.41	2.07	1.81	1.61	1.45	1.32	1.21	1.12	1.04	0.97
25	3.76	3.01	2.51	2.16	1.89	1.68	1.51	1.38	1.26	1.16	1.08	1.01
26	3.91	3.13	2.61	2.24	1.96	1.75	1.57	1.43	1.31	1.21	1.12	1.05
27	4.06	3.25	2.71	2.33	2.04	1.81	1.63	1.49	1.36	1.26	1.17	1.09
28	4.21	3.37	2.82	2.42	2.11	1.88	1.69	1.54	1.41	1.30	1.21	1.13
29	4.36	3.49	2.92	2.50	2.19	1.95	1.75	1.60	1.46	1.35	1.25	1.17
30	4.51	3.62	3.02	2.59	2.27	2.02	1.81	1.65	1.51	1.40	1.30	1.21
31	4.66	3.74	3.12	2.67	2.34	2.08	1.88	1.71	1.56	1.44	1.34	1.25
32	4.81	3.86	3.22	2.76	2.42	2.15	1.94	1.76	1.61	1.49	1.38	1.29
33	4.96	3.98	3.32	2.85	2.49	2.22	2.00	1.82	1.66	1.54	1.43	1.33
34	5.11	4.10	3.42	2.93	2.57	2.28	2.06	1.87	1.71	1.58	1.47	1.37
35	5.26	4.22	3.52	3.02	2.64	2.35	2.12	1.93	1.77	1.63	1.51	1.41
36	5.41	4.34	3.62	3.11	2.72	2.42	2.18	1.98	1.82	1.68	1.56	1.45
37	5.56	4.46	3.72	3.19	2.79	2.49	2.24	2.04	1.87	1.72	1.60	1.49
38	5.71	4.58	3.82	3.28	2.87	2.55	2.30	2.09	1.92	1.77	1.64	1.53
39	5.86	4.70	3.92	3.36	2.95	2.62	2.36	2.15	1.97	1.82	1.69	1.57

Figure 19. Sensitivity analysis BC ratio for lowest index score city, Seattle, WA.
BC ratio results of a range of values for electricity costs and installation costs. ***Red*** *cells indicate electricity cost and installation cost conditions resulting in BC ratios < 1:1*

Lahaina, HI

		Installation Cost ($)										
	4.17	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**	**3.25**	**3.50**
Electricity Cost (cents)	**11**	2.42	1.94	1.62	1.39	1.22	1.08	0.98	0.89	0.81	0.75	0.70	0.65
	12	2.64	2.12	1.77	1.52	1.33	1.18	1.06	0.97	0.89	0.82	0.76	0.71
	13	2.87	2.30	1.92	1.64	1.44	1.28	1.15	1.05	0.96	0.89	0.82	0.77
	14	3.09	2.47	2.06	1.77	1.55	1.38	1.24	1.13	1.04	0.96	0.89	0.83
	15	3.31	2.65	2.21	1.90	1.66	1.48	1.33	1.21	1.11	1.02	0.95	0.89
	16	3.53	2.83	2.36	2.02	1.77	1.58	1.42	1.29	1.18	1.09	1.01	0.95
	17	3.75	3.00	2.51	2.15	1.88	1.67	1.51	1.37	1.26	1.16	1.08	1.01
	18	3.97	3.18	2.65	2.28	1.99	1.77	1.60	1.45	1.33	1.23	1.14	1.07
	19	4.19	3.36	2.80	2.40	2.10	1.87	1.68	1.53	1.40	1.30	1.20	1.12
	20	4.41	3.53	2.95	2.53	2.21	1.97	1.77	1.61	1.48	1.37	1.27	1.18
	21	4.63	3.71	3.10	2.66	2.33	2.07	1.86	1.69	1.55	1.43	1.33	1.24
	22	4.85	3.89	3.24	2.78	2.44	2.17	1.95	1.77	1.63	1.50	1.39	1.30
	23	5.07	4.06	3.39	2.91	2.55	2.26	2.04	1.85	1.70	1.57	1.46	1.36
	24	5.29	4.24	3.54	3.04	2.66	2.36	2.13	1.94	1.77	1.64	1.52	1.42
	25	5.51	4.42	3.69	3.16	2.77	2.46	2.22	2.02	1.85	1.71	1.59	1.48
	26	5.73	4.59	3.83	3.29	2.88	2.56	2.31	2.10	1.92	1.77	1.65	1.54
	27	5.95	4.77	3.98	3.41	2.99	2.66	2.39	2.18	2.00	1.84	1.71	1.60
	28	6.17	4.95	4.13	3.54	3.10	2.76	2.48	2.26	2.07	1.91	1.78	1.66
	29	6.39	5.12	4.27	3.67	3.21	2.86	2.57	2.34	2.14	1.98	1.84	1.72
	30	6.61	5.30	4.42	3.79	3.32	2.95	2.66	2.42	2.22	2.05	1.90	1.78
	31	6.83	5.48	4.57	3.92	3.43	3.05	2.75	2.50	2.29	2.12	1.97	1.83
	32	7.05	5.65	4.72	4.05	3.54	3.15	2.84	2.58	2.37	2.18	2.03	1.89
	33	7.27	5.83	4.86	4.17	3.65	3.25	2.93	2.66	2.44	2.25	2.09	1.95
	34	7.49	6.01	5.01	4.30	3.76	3.35	3.01	2.74	2.51	2.32	2.16	2.01
	35	7.71	6.18	5.16	4.43	3.88	3.45	3.10	2.82	2.59	2.39	2.22	2.07
	36	7.93	6.36	5.31	4.55	3.99	3.55	3.19	2.90	2.66	2.46	2.28	2.13
	37	8.15	6.54	5.45	4.68	4.10	3.64	3.28	2.98	2.74	2.53	2.35	2.19
	38	8.38	6.71	5.60	4.81	4.21	3.74	3.37	3.06	2.81	2.59	2.41	2.25
	39	8.60	6.89	5.75	4.93	4.32	3.84	3.46	3.14	2.88	2.66	2.47	2.31

Figure 20. Sensitivity analysis BC ratio for highest index score, Lahaina., HI
BC ratio results of a range of values for electricity costs and installation costs. ***Red*** *cells indicate electricity cost and installation cost conditions resulting in BC ratios < 1:1*

A second two-dimensional city-independent What-if analysis was performed on the effect of varying PV production factor and electricity costs on the BC ratio and the results are shown in Figure 21. Solar production varies along the rows and electricity costs down the columns. The same cell color formatting that was used in both Figure 19 and Figure 20, is used in Figure 21. This analysis applies to the model multifamily configuration of the study in all city locations across the nation as the different solar resources available and electricity costs in different jurisdictions are accounted for by the variation along the two axes. This chart uses the installation cost chosen in the study of $1.75/watt for all locations. Should this amount decrease, as some forecast will continue to happen in the future, all BC results in each cell would increase as seen in the results in Figure 19 and Figure 20.

The values for each axis cover the full range of electricity costs and solar outputs encountered for all cities in the studies. Therefore, the value of cells at each intersection possibility in Figure 21 represents the complete set of possibilities throughout the 70 cities in the study and more generally characterizes all outcomes that could be expected throughout the United States. To determine a BC ratio output in a given location, the appropriate electricity cost and PV production factor can be chosen from the axes and the intersection point on the table would determine the resulting BC ratio.

The Anytown, USA chart in Figure 21 contains 663 distinct combinations of electricity costs and solar outputs of which only 2.5% underperform the BC ratio threshold of 1:1, as represented by the red shaded area. The overall message of these three charts in the sensitivity analyses, Figure 19 through Figure 21, indicates that there are no locations that are inherently undesirable for PVS system economic performance;

however, certain locations that are imbued with more positive local PV variables will readily produce positive economic results, while in challenging locations, much attention needs to be paid to the all of the factors that will result in a positive economic outcome.

Benefit-Cost Ratio

Anytown, USA

Solar Output (kWh/kWp)

Electricity Cost (cents)	**1200**	**1250**	**1300**	**1350**	**1400**	**1450**	**1500**	**1550**	**1600**	**1650**	**1700**	**1750**	**1800**	**1850**	**1900**	**1950**	**2000**
11	0.77	0.80	0.83	0.86	0.89	0.92	0.96	0.99	1.02	1.05	1.08	1.12	1.15	1.18	1.21	1.24	1.28
12	0.83	0.87	0.90	0.94	0.97	1.01	1.04	1.08	1.11	1.15	1.18	1.22	1.25	1.29	1.32	1.36	1.39
13	0.90	0.94	0.98	1.02	1.06	1.09	1.13	1.17	1.21	1.24	1.28	1.32	1.36	1.39	1.43	1.47	1.51
14	0.97	1.01	1.06	1.10	1.14	1.18	1.22	1.26	1.30	1.34	1.38	1.42	1.46	1.50	1.54	1.58	1.62
15	1.04	1.09	1.13	1.17	1.22	1.26	1.30	1.35	1.39	1.43	1.48	1.52	1.57	1.61	1.65	1.70	1.74
16	1.11	1.16	1.21	1.25	1.30	1.35	1.39	1.44	1.48	1.53	1.58	1.62	1.67	1.72	1.76	1.81	1.86
17	1.18	1.23	1.28	1.33	1.38	1.43	1.48	1.53	1.58	1.63	1.68	1.72	1.77	1.82	1.87	1.92	1.97
18	1.25	1.30	1.36	1.41	1.46	1.51	1.57	1.62	1.67	1.72	1.77	1.83	1.88	1.93	1.98	2.03	2.09
19	1.32	1.38	1.43	1.49	1.54	1.60	1.65	1.71	1.76	1.82	1.87	1.93	1.98	2.04	2.09	2.15	2.20
20	1.39	1.45	1.51	1.57	1.62	1.68	1.74	1.80	1.86	1.91	1.97	2.03	2.09	2.15	2.20	2.26	2.32
21	1.46	1.52	1.58	1.64	1.70	1.77	1.83	1.89	1.95	2.01	2.07	2.13	2.19	2.25	2.31	2.37	2.43
22	1.53	1.59	1.66	1.72	1.79	1.85	1.91	1.98	2.04	2.10	2.17	2.23	2.30	2.36	2.42	2.49	2.55
23	1.60	1.67	1.73	1.80	1.87	1.93	2.00	2.07	2.13	2.20	2.27	2.33	2.40	2.47	2.53	2.60	2.67
24	1.67	1.74	1.81	1.88	1.95	2.02	2.09	2.16	2.23	2.30	2.37	2.43	2.50	2.57	2.64	2.71	2.78
25	1.74	1.81	1.88	1.96	2.03	2.10	2.17	2.25	2.32	2.39	2.46	2.54	2.61	2.68	2.75	2.83	2.90
26	1.81	1.88	1.96	2.03	2.11	2.19	2.26	2.34	2.41	2.49	2.56	2.64	2.71	2.79	2.86	2.94	3.01
27	1.88	1.96	2.03	2.11	2.19	2.27	2.35	2.43	2.50	2.58	2.66	2.74	2.82	2.90	2.97	3.05	3.13
28	1.95	2.03	2.11	2.19	2.27	2.35	2.43	2.52	2.60	2.68	2.76	2.84	2.92	3.00	3.08	3.17	3.25
29	2.02	2.10	2.19	2.27	2.35	2.44	2.52	2.61	2.69	2.77	2.86	2.94	3.03	3.11	3.19	3.28	3.36
30	2.09	2.17	2.26	2.35	2.43	2.52	2.61	2.70	2.78	2.87	2.96	3.04	3.13	3.22	3.30	3.39	3.48
31	2.16	2.25	2.34	2.43	2.52	2.61	2.70	2.79	2.88	2.97	3.06	3.15	3.23	3.32	3.41	3.50	3.59
32	2.23	2.32	2.41	2.50	2.60	2.69	2.78	2.88	2.97	3.06	3.15	3.25	3.34	3.43	3.52	3.62	3.71
33	2.30	2.39	2.49	2.58	2.68	2.77	2.87	2.97	3.06	3.16	3.25	3.35	3.44	3.54	3.64	3.73	3.83
34	2.37	2.46	2.56	2.66	2.76	2.86	2.96	3.06	3.15	3.25	3.35	3.45	3.55	3.65	3.75	3.84	3.94
35	2.43	2.54	2.64	2.74	2.84	2.94	3.04	3.15	3.25	3.35	3.45	3.55	3.65	3.75	3.86	3.96	4.06
36	2.50	2.61	2.71	2.82	2.92	3.03	3.13	3.23	3.34	3.44	3.55	3.65	3.76	3.86	3.97	4.07	4.17
37	2.57	2.68	2.79	2.90	3.00	3.11	3.22	3.32	3.43	3.54	3.65	3.75	3.86	3.97	4.08	4.18	4.29
38	2.64	2.75	2.86	2.97	3.08	3.19	3.30	3.41	3.52	3.64	3.75	3.86	3.97	4.08	4.19	4.30	4.41
39	2.71	2.83	2.94	3.05	3.17	3.28	3.39	3.50	3.62	3.73	3.84	3.96	4.07	4.18	4.30	4.41	4.52

Figure 21. What-if analysis of BC vs. solar output and electricity cost.
City independent BC ratio results of a range of values for electricity costs and Solar Output. ***Red*** *cells indicate electricity cost and solar output conditions resulting in BC ratios < 1:1*

Chapter IV

Discussion

The results of the analyses of PV solar systems on multifamily properties across the economic, environmental, and energy burden dimensions demonstrated that meaningful impacts could be realized by their widespread introduction in many cities, and in almost all regions of the United States. However, the benefits are not distributed equally in all cities, and the elements comprising the overall positive impact change amongst the different locations. Accordingly, attention must be given to the primary drivers of the economic, environmental, and energy burden outcomes that are dependent upon each city's profile, including the local solar resource available, prevailing electrical cost, electrical grid GHG emissions, and energy burden characteristics of the population. Also, the decision-makers and stakeholders need to define which dimension of benefits they value when considering a PV solar system installation.

Because most MDUs are controlled by private investors, financial considerations of the model are assumed to be the primary criteria for the basis of PV solar decisions. The two strictly financial impacts that the study addressed included the property income stream growth, NOI, and the resulting property value increase. The impact on the NOI of each property was of chief importance. Over 77% of the cities in Table 12 demonstrated an increase in the NOI greater than 7.01%, the average real estate capitalization rate of the entire city data set. The prevailing RECR figure could be considered a return threshold demanded by the investment community because it represents an amount that could be gained by simply investing in alternative real estate opportunities. Additionally, 35.7% of the cities had increases greater than 10.0%, a significant return value by almost any measure, and the top four cities had returns at, or just above, 20% in NOI.

A few unexpected outcomes of the city rankings based on the NOI results occurred. Hartford, CT secured the second highest NOI increase position with a 21.2% increase, without the benefit of a high solar resource as its PV solar output is below the average of all of the cities, 1550.5 kWh/kWp. Lubbock, TX was ranked first, despite having an electricity rate of 14.0 cents/kWh which is meaningfully below the national average of 17.1 cents/kWh for the cities studied. Finally, Charleston, WV ranked fourth highest while having both a below-average solar resource and electricity cost, 1342.5 kWh/kWp and 14.2 cents/kWh, respectively. The city with the worst NOI performance was Seattle, WA at 2.83%. As may be expected, it had both a solar resource and electricity cost at the bottom end of the range of cities.

Concerning property value increases driven by the increases in net income, 97% of the properties in Table 13 experienced a value increase greater than a 1:1 ratio relative to the installation cost of the system. In only two cities did the addition of the systems fail to increase the value of the property at an amount equal to or greater than the system cost, Baltimore, MD, and Rapid City, SD.

The top-performing group of cities that received the greatest value increase included seven that were more than one standard deviation, 1.48, above the average increase of 2.08 times the value of the system. Their multiples ranged from 3.74 to 8.55 and Lahaina, HI held the top position. The top six cities were occupied by locations in Hawaii and California. These locations benefit from high electrical rates, high solar resources, and low real estate capitalization rates that operate to magnify the effects of the PV solar system revenue streams when they are translated into property value. The final city in the top performers was Boston, MA which has a below-average solar resource, 1441.0 kWh/kWp. However, Boston had an electricity rate far above the average of the cities at 27.8 cents/kWh and a low capitalization rate of 5.55%. Similar dynamics to Boston were demonstrated in the cities just below Boston, in Brooklyn, NY, New Haven, CT, and Portland, ME, which experienced value multiples of 2.9, 2.8, and 2.8, respectively.

Because most investment property improvements are financed, the treatment of the system performance in the BC analysis, which includes servicing the system debt and O&M costs, may be more relevant to actual use cases for renewable energy upgrades to multifamily units. The ordering of the cities in the benefit-cost ranking in Table 14 generally followed the ordering of the cities in the property value increase analysis, although there is a fair amount of movement among the cities in relation to each other; however, they seem to stay within similar tiers in the rankings results of both analyses. Similar to the property value increase, when financing is factored in, 96% of the cities returned a BC ratio result equal to or greater than 1:1 when considering all of the benefits and costs of the systems. The inclusion of PV system debt service did mute the return as the top performing city, Lahaina, returned a 4.17 BC ratio result, as opposed to the 8.55 that Lahaina experienced in the property value analysis. However, ten cities exceeded one standard deviation, .68, above the BC average of 1.55, which is three more than overcame this threshold in the property value analysis. The ultimate result of the BC analysis indicates that property owners in a preponderance of the cities could achieve positive financial returns without requiring additional investment if financing was available at rates considered in the study and with the presence of supportive net metering tariff structures.

The BC ratio results displayed in Figure 8 and Figure 9 show a dependence on both the locality solar resource and the electricity cost. However, the heteroscedastic nature of the data may have introduced variation in some of the combinations of the variables studied. The multiple regression analysis indicated that the electricity rate had a greater influence on the BC outcome than the solar resource.

The potential project emissions avoidance was seen to scale closely with the EPA eGRID emissions factors and the average amount of electricity consumed by multifamily residents in a given region. These factors combined resulted in Charleston, WV, Lubbock, TX, Green Bay, WI, and St. Louis, MO holding the top positions for largest potential emissions reductions at the project scale. All of these cities have a combination of high eGRID emissions factors and electricity consumption rates at the upper end of the range.

The cost of decarbonization for the cities was noted to have an inverse relationship with the emissions factors and electricity consumption, with few significant exceptions. Therefore, the cities with the highest emissions factors and large electricity consumption tended to have lower carbon removal costs per ton. Conversely, Buffalo, NY was an outlier with a cost of $1,270 for each metric-ton of CO_2e avoided due to its extremely low eGRID factor of 233.1 lbs-CO_2e/MWh.

The average cost of carbon removal by the PV solar systems within the city data set was $330 / metric-ton CO_2e; a figure that appears to be significantly higher than recent voluntary carbon market prices. Carbon credit pricing is subject to market forces and has been seen to vary dramatically, this aspect of the model illustrates the opportunity to derive value for owners as the PVS systems are designed to have serviceable lives of twenty or more years and could create a recurring annual benefit based on the state of the carbon offset markets. Based on the range of values of emissions avoided and the current range of values available for carbon credits in the market, it appears that the economic value of decarbonization is currently marginal relative to the value of the energy created by the PVS systems.

The potential to have a larger statewide emissions impact was demonstrably seen to be driven by the number of multifamily units in any given state, in conjunction with the project-level emissions avoidance values. In this analysis, the top four states accounted for 40% of the collective statewide emissions avoidance potential; Texas, Florida, New York, and California, in descending order.

Examining the energy burden among the selected cities revealed that low-income renters of pre-2000 multifamily dwellings with five or more units spent more than two times their gross income on their energy costs than did the general city population, 4.9% vs. 2.2%, respectively. Additionally in the same cities when this same population group is restricted to ethnicities including only African American and White Hispanic or Latino, this amount jumps to 41.9% of the gross income.

The two-dimensional scoring index results showed agreement with the benefit-cost ratio ordering at the low and high ends of the city rankings, with Seattle at the lowest, and Honolulu and Lahaina at the highest; however, many of the cities in between were significantly reordered by the blending of the economic and environmental impacts by the nature of the scoring model. For example, the economic factors were the dominant influence for the top two cities, but the environmental component was the main driver for 35 of the next 40 cities.

The expansion of the scoring index to three dimensions to include the energy burden consideration for low-income renters did not result in a wholesale reordering of the cities, but it did have a meaningful impact on the position of cities that either included large EB components or had little, if any, EB component. As an example, Fresno, CA held the 19th position, just three positions higher than San Francisco, on the two-dimensional economic and environmental index. On the three-dimensional index, Fresno, with a sizeable EB influence, moved to the sixth highest overall ranking when taking energy burden into account, while San Francisco, with no EB component, fell to the 47th position. Similar, although less severe, reductions in rankings were experienced by cities such as Denver, Minneapolis, and Las Vegas, while large EB components operated to make marked advances in cities such as Omaha, New Orleans, and Birmingham. It can be seen that many of the cities that have a large EB influence also have large environmental components and in all but a handful of cities, these combine to swamp out the economic factor.

The sensitivity analysis compared the cities that consistently ranked among the highest and lowest performers of the cities on the economic metrics, Lahaina and Seattle, respectively. Even in the most challenging conditions at the low end of the range, when the total installation costs of the systems fall below $1.50/watt, the systems provide a greater than 1:1 BC ratio at all electricity costs considered (11 cents/kWh – 30 cents/kWh). Similarly, at all installation costs, even in the worst performance conditions such as Seattle, all BC ratios exceed 1:1 at electricity costs above 24 cents/kWh.

When the most favorable city, Lahaina, is considered, all installation costs below $2.25/watt resulted in BC ratios greater than 1:1 at any electricity rate studied. Also, at electricity costs above 16 cents/kWh, all BC ratios exceeded 1:1 even when considering installation costs as high as $3.50/watt. If PV solar installation costs continue to fall, it can have a dramatic effect on the overall project economics. As an extreme example, in Lahaina, if installation costs fall to $1.00/watt, at the current electricity rate of 39.2 cents/kWh, the sensitivity analysis shows that the BC ratio will rise to 6.89.

For the final sensitivity analysis that was location independent and considered solar output and electricity cost, it was seen that at solar resource levels of 1550kWh/kWp and above, all BC ratios would exceed 1:1. Also, within the range of solar resources examined, 1200-2000 kWh/kWp, at electricity rates above 14 cents/kWh the BC ratios all exceeded 1:1.

The foregoing discussion indicates that the addition of PV solar systems on multifamily properties can serve the purposes of contributing positively to both environmental progress and energy justice while providing a private financial mechanism to entice the property owners to invest their time and resources into the projects. However, these positive outcomes can only be achieved with the right combination of policy, regulation, and property and market conditions. Fortunately, it seems that there are many opportunities in most parts of the United States for the stakeholders to harmonize their efforts to create a positive outcome for all parties.

Conclusions

The study investigated the economic and environmental impact of the deployment of PVS systems on MDUs across a range of U.S. cities. The cities were chosen to represent the wide variety of location-dependent variables that affect PVS performance that exists throughout the country. I employed a model system and a set of consistent test conditions across the city data set to determine the project-level financial results and built environment decarbonization impacts that the systems can produce. The environmental impacts were then extrapolated to quantify the statewide emissions reductions that could be achieved with a representative rate of adoption.

The primary intent of the study was to provide a framework to investors with properties in a wide array of jurisdictions. The study allowed comparisons to be made to the local conditions that affect the PVS outcomes at investors' projects to help form the basis of a rational investment decision. The results showed that in the vast majority of cities examined, under the study conditions, a positive financial return would be generated by the introduction of PVS systems on multifamily apartments. The overall investment results may encourage property owners to invest in these systems for the benefit of their financial return, while also reaping the concomitant environmental and occupant well-being benefits. These outcomes could empower property owners to overcome the split-incentive deterrent that is often cited as a reason for the intractably low rates of renewable energy and energy efficiency measures in for-rent properties.

A second intent of the study was to correlate the economic and environmental results of PVS system installation on MDUs with the energy burden rates of the tenants across all of the cities in the study. This facet of the study was designed to illustrate the energy justice issues currently present in the older vintage workforce rental property sector that could be serviced and enhanced by the PVS systems. A three-dimensional index that incorporates the energy burden metrics with the financial and environmental results was developed to permit property owners and regulators to understand locales where policy could be effective in promoting private investment in renewable energy systems, thereby creating benefits that accrue to investors, occupants, and the surrounding communities.

A final outcome of the study was more nuanced but could be a subject for further work. Because the study established the positive financial returns available in a wide variety of conditions across the country, mass private deployment of PVS systems on MDUs could be economically feasible. However, the current regulatory and policy environment in many jurisdictions currently constrains or prevents private investors from fully benefitting from the financial benefits of PVS systems on their properties. These conditions potentially raise the question if a reexamination of the current prevailing pricing model that exists in the multifamily apartment market is warranted. Currently, tenants primarily carry the economic obligation of the apartment energy consumption. An alternative model whereby landlords retained the obligation for the apartment unit energy consumption, and in return created a subscription-based flat-fee energy structure for their tenants, could democratize clean energy availability and tenant energy abundance that eviscerates energy injustice and the split-incentive problem. This model could incentivize landlords to fully optimize their properties with the most energy-efficient and cost-effective PVS systems available to be able to deliver affordable and plentiful renewable energy to their tenants. Because of the financial benefits available to all stakeholders, this paradigm could further incentivize landlords to eagerly participate in the electrification transition currently being promoted by policymakers across the country.

Appendix 1

U.S. Cities and Corresponding Data and Operational Variables

Table 11. List of selected cities and primary data.

State	City	EPA eGRID subregion	CO2e Emissions (lbs./MWh)	Global Solar Atlas (kWh/kWp)	Electricity Cost (cents/kWh)	Annual Electricity Consumption (kWh/Apartment)	Rent ($/Square Foot)	Real Estate Capitalization Rates	Total Statewide Multifamily Units (1000s)
Alabama	Birmingham	SRMV	772.7	1514.2	14.14	8652	1.38	7.69	225
Arizona	Phoenix	AZNM	819.7	1889.3	13.82	4581	1.65	6.81	435
Arizona	Tucson	AZNM	819.7	1915.2	13.82	4581	1.58	7.24	435
Arkansas	Little Rock	SRMV	772.7	1503	12.45	8652	1.2	7.08	129
California	Fresno	CAMX	531.7	1778.1	29.84	4581	1.55	6.42	3023
California	San Francisco	CAMX	531.7	1733.5	29.84	4581	4.22	4.92	3023
California	San Diego	CAMX	531.7	1768.1	29.84	4581	3.43	4.45	3023
California	Los Angeles	CAMX	531.7	1798.3	29.84	4581	3.39	4.75	3023
Colorado	Denver	RMPA	1158.9	1714.7	14.43	4581	2.33	6.07	448
Colorado	Colorado Springs	RMPA	1158.9	1725.4	14.43	4581	1.22	7.81	448
Connecticut	Hartford	NEWE	539.4	1419.4	27.89	4120	0.98	8.5	229
Connecticut	New Haven	NEWE	539.4	1462	27.89	4120	2.35	7.51	229
Florida	Key West	FRCC	832.9	1739.3	14.93	8652	4.95	5.91	1485
Florida	Miami	FRCC	832.9	1656.8	14.93	8652	3.17	6.62	1485
Florida	Orlando	FRCC	832.9	1595.4	14.93	8652	1.72	6.79	1485
Georgia	Atlanta	SRSO	891.9	1543.2	14.14	8652	1.83	7.49	615
Georgia	Savannah	SRSO	891.9	1583.9	14.14	8652	1.75	6.58	615
Hawaii	Honolulu	HIOA	1633.1	1748.4	39.17	4581	4.02	4.67	94
Hawaii	Lahaina	HIMS	1134.4	1836.8	39.17	4581	3.74	4.46	94

State	City	EPA eGRID subregion	CO2e Emissions (lbs./MWh)	Global Solar Atlas (kWh/kWp)	Electricity Cost (cents/kWh)	Annual Electricity Consumption (kWh/Apartment)	Rent ($/Square Foot)	Real Estate Capitalization Rates	Total Statewide Multifamily Units (1000s)
Idaho	Boise	NWPP	634.6	1591.9	11.62	5536	1.48	6.09	59
Idaho	Coeur d'Alene	NWPP	634.6	1300.6	11.62	5536	1.8	4.85	59
Illinois	Chicago	RFCW	1046.1	1376.1	13.94	5536	3.19	8.01	879
Indiana	Indianapolis	RFCW	1046.1	1399.9	14.15	5536	1.22	7.72	333
Kansas	Kansas City	SPNO	991.7	1515.9	13.57	5536	1.26	7.29	149
Kentucky	Louisville	SRTV	931.6	1420.3	12.16	5536	1.27	7.41	198
Louisiana	New Orleans	SRMV	772.7	1541.1	11.04	8652	1.76	7.13	192
Maine	Portland, ME	NEWE	539.4	1439.1	25.43	4120	2.84	6.72	52
Maryland	Baltimore	RFCW	672.8	1457.2	12.95	4120	1.71	9.8	452
Massachusetts	Boston	NEWE	539.4	1441	27.83	4120	2.64	5.55	512
Michigan	Detroit	RFMC	1214.1	1348.8	19.43	5536	1.38	9.23	524
Minnesota	Minneapolis	MROE	995.8	1413.6	15.46	5536	2.08	6.85	397
Mississippi	Jackson, MS	SRMV	772.7	1538.5	12.9	8652	1.2	9.49	107
Missouri	St. Louis	SRMW	1543	1463.4	14.43	5536	1.43	7.5	288
Missouri	Kansas City	SPNO	991.7	1514.4	14.43	5536	1.39	8.7	288
Montana	Billings	NWPP	634.6	1493.9	12.96	5536	1.3	6.86	41
Nebraska	Omaha	MROW	995.8	1491.9	12.26	5536	1.33	6.84	138
Nevada	Las Vegas	AZNM	819.7	1900.2	16.47	4581	1.37	6.28	246
Nevada	Reno	NWPP	634.6	1817.4	16.47	4581	1.55	5.94	246
New Hampshire	Manchester	NEWE	539.4	1427.1	26.15	4120	2.14	8.15	79
New Jersey	Jersey City	RFCE	672.8	1441.3	18.5	4120	4.06	7.36	645
New Mexico	Albuquerque	AZNM	819.7	1913.2	14.71	4581	1.6	7.06	86
New Mexico	Santa Fe	AZNM	819.7	1871.5	14.71	4581	2.17	6.79	86
New York	Brooklyn	NYCW	816.8	1473	22.33	4120	3.92	5.85	2268
New York	Buffalo	NYUP	233.1	1283.7	22.33	4120	1.24	8.39	2268
North Carolina	Charlotte	SRVC	639.7	1535.5	13.04	8652	1.54	6.21	580
North Carolina	Raleigh	SRVC	639.7	1536.9	13.04	8652	1.38	5.95	580

State	City	EPA eGRID subregion	CO2e Emissions (lbs./MWh)	Global Solar Atlas (kWh/kWp)	Electricity Cost (cents/kWh)	Annual Electricity Consumption (kWh/Apartment)	Rent ($/Square Foot)	Real Estate Capitalization Rates	Total Statewide Multifamily Units (1000s)
North Dakota	Bismarck	MROW	995.8	1481.6	12.5	5536	1.14	8.63	80
Ohio	Columbus	RFCW	1046.1	1351.9	15.77	5536	1.57	7.61	690
Oklahoma	Oklahoma City	SPSO	1031.6	1629	13.29	5536	1.17	7.12	180
Oregon	Portland	NWPP	634.6	1250.9	12.95	4581	2.04	5.95	278
Pennsylvania	Philadelphia	RFCE	672.8	1415.1	17.88	4120	1.68	7.9	630
Pennsylvania	Pittsburgh	RCFW	1046.1	1279.5	17.88	4120	1.65	8.54	630
Rhode Island	Providence	NEWE	539.4	1444.5	27.58	4120	2.46	8.5	70
South Carolina	Charleston	SRVC	639.7	1595.1	13.82	8652	2.74	6.53	232
South Dakota	Sioux Falls	MROW	995.8	1481.3	12.99	5536	1.15	6.94	55
South Dakota	Rapid City	RMPA	1158.9	1568.4	12.99	5536	1.25	10.65	55
Tennessee	Nashville	SRTV	931.6	1442.4	11.99	8652	1.85	6.88	362
Tennessee	Memphis	SRTV	931.6	1497.5	11.9	8652	1.11	8.42	362
Texas	Dallas	ERCT	813.6	1564.5	14.01	8652	1.91	6.66	2244
Texas	El Paso	AZNM	819.7	1965.3	14.01	8652	1.07	6.51	2244
Texas	Houston	ERCT	813.6	1473.4	14.01	8652	1.65	6.56	2244
Texas	Lubbock	SPSO	1031.6	1816.1	14.01	8652	0.99	8.1	2244
Utah	Salt Lake City	NWPP	634.6	1588.6	11.66	4581	1.83	5.65	158
Vermont	Burlington	NEWE	539.4	1299.4	20.45	4120	3.47	6.03	30
Virginia	Alexandria	RFCE	672.8	1456	13.95	4120	2.55	6.28	560
Washington	Seattle	NWPP	634.6	1253	11.14	4581	2.91	5.1	606
West Virginia	Charleston	RFCW	1046.1	1342.5	14.23	8652	1.07	7.39	60
Wisconsin	Green Bay	MORE	1582.1	1396.8	17.1	5536	1.64	7.73	388
Wisconsin	Milwaukee	RFCW	1046.1	1407.8	17.1	5536	1.52	8.77	388
Wyoming	Cheyenne	RMPA	1158.9	1665.4	12.44	4581	1.25	6.79	20
AVERAGE			839.5	1550.5	17.13	5853	1.98	7.01	673

Appendix 2

Net Operating Income Percentage Change by City

Table 12. Net operating income percentage increase by city.

State	City	Rent Per Square Foot	Real Estate Capitalization Rates	Modeled Original NOI	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Projected PV System NOI	% Increase in NOI
Alabama	Birmingham	1.38	7.69	$397,440	$67,287	$6,734	$60,552	15.24%
Arizona	Phoenix	1.65	6.81	$475,200	$34,820	$2,858	$31,962	6.73%
Arizona	Tucson	1.58	7.24	$455,040	$34,820	$2,819	$32,001	7.03%
Arkansas	Little Rock	1.2	7.08	$345,600	$59,245	$6,784	$52,460	15.18%
California	Fresno	1.55	6.42	$446,400	$75,183	$3,036	$72,147	16.16%
California	San Francisco	4.22	4.92	$1,215,360	$75,183	$3,115	$72,069	5.93%
California	San Diego	3.43	4.45	$987,840	$75,183	$3,054	$72,130	7.30%
California	Los Angeles	3.39	4.75	$976,320	$75,183	$3,002	$72,181	7.39%
Colorado	Denver	2.33	6.07	$671,040	$36,357	$3,149	$33,208	4.95%
Colorado	Colorado Springs	1.22	7.81	$351,360	$36,357	$3,129	$33,228	9.46%
Connecticut	Hartford	0.98	8.5	$282,240	$63,199	$3,421	$59,778	21.18%
Connecticut	New Haven	2.35	7.51	$676,800	$63,199	$3,321	$59,877	8.85%
Florida	Key West	4.95	5.91	$1,425,600	$71,046	$5,863	$65,183	4.57%
Florida	Miami	3.17	6.62	$912,960	$71,046	$6,155	$64,891	7.11%
Florida	Orlando	1.72	6.79	$495,360	$71,046	$6,392	$64,654	13.05%
Georgia	Atlanta	1.83	7.49	$527,040	$67,287	$6,608	$60,679	11.51%
Georgia	Savannah	1.75	6.58	$504,000	$67,287	$6,438	$60,849	12.07%

State	City	Rent Per Square Foot	Real Estate Capitalization Rates	Modeled Original NOI	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Projected PV System NOI	% Increase in NOI
Hawaii	Honolulu	4.02	4.67	$1,157,760	$98,691	$3,088	$95,603	8.26%
Hawaii	Lahaina	3.74	4.46	$1,077,120	$98,691	$2,939	$95,751	8.89%
Idaho	Boise	1.48	6.09	$426,240	$35,381	$4,099	$31,282	7.34%
Idaho	Coeur d'Alene	1.8	4.85	$518,400	$35,381	$5,017	$30,364	5.86%
Illinois	Chicago	3.19	8.01	$918,720	$42,445	$4,741	$37,703	4.10%
Indiana	Indianapolis	1.22	7.72	$351,360	$43,084	$4,661	$38,423	10.94%
Kansas	Kansas City	1.26	7.29	$362,880	$41,318	$4,304	$37,014	10.20%
Kentucky	Louisville	1.27	7.41	$365,760	$37,025	$4,594	$32,431	8.87%
Louisiana	New Orleans	1.76	7.13	$506,880	$52,535	$6,617	$45,918	9.06%
Maine	Portland, ME	2.84	6.72	$817,920	$57,624	$3,374	$54,250	6.63%
Maryland	Baltimore	1.71	9.8	$492,480	$29,345	$3,332	$26,012	5.28%
Massachusetts	Boston	2.64	5.55	$760,320	$63,063	$3,370	$59,693	7.85%
Michigan	Detroit	1.38	9.23	$397,440	$59,160	$4,837	$54,323	13.67%
Minnesota	Minneapolis	2.08	6.85	$599,040	$47,073	$4,616	$42,457	7.09%
Mississippi	Jackson, MS	1.2	9.49	$345,600	$61,386	$6,628	$54,758	15.84%
Missouri	St. Louis	1.43	7.5	$411,840	$43,936	$4,459	$39,478	9.59%
Missouri	Kansas City	1.39	8.7	$400,320	$43,936	$4,308	$39,628	9.90%
Montana	Billings	1.3	6.86	$374,400	$39,461	$4,367	$35,093	9.37%
Nebraska	Omaha	1.33	6.84	$383,040	$37,329	$4,373	$32,956	8.60%
Nevada	Las Vegas	1.37	6.28	$394,560	$41,497	$2,841	$38,656	9.80%
Nevada	Reno	1.55	5.94	$446,400	$41,497	$2,971	$38,526	8.63%
New Hampshire	Manchester	2.14	8.15	$616,320	$59,256	$3,403	$55,853	9.06%
New Jersey	Jersey City	4.06	7.36	$1,169,280	$41,921	$3,369	$38,552	3.30%
New Mexico	Albuquerque	1.6	7.06	$460,800	$37,063	$2,822	$34,241	7.43%

State	City	Rent Per Square Foot	Real Estate Capitalization Rates	Modeled Original NOI	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Projected PV System NOI	% Increase in NOI
New Mexico	Santa Fe	2.17	6.79	$624,960	$37,063	$2,885	$34,178	5.47%
New York	Brooklyn	3.92	5.85	$1,128,960	$50,600	$3,296	$47,303	4.19%
New York	Buffalo	1.24	8.39	$357,120	$50,600	$3,783	$46,817	13.11%
North Carolina	Charlotte	1.54	6.21	$443,520	$62,052	$6,641	$55,411	12.49%
North Carolina	Raleigh	1.38	5.95	$397,440	$62,052	$6,635	$55,417	13.94%
North Dakota	Bismarck	1.14	8.63	$328,320	$38,060	$4,404	$33,656	10.25%
Ohio	Columbus	1.57	7.61	$452,160	$48,016	$4,826	$43,190	9.55%
Oklahoma	Oklahoma City	1.17	7.12	$336,960	$40,465	$4,005	$36,460	10.82%
Oregon	Portland	2.04	5.95	$587,520	$32,628	$4,316	$28,312	4.82%
Pennsylvania	Philadelphia	1.68	7.9	$483,840	$40,516	$3,431	$37,085	7.66%
Pennsylvania	Pittsburgh	1.65	8.54	$475,200	$40,516	$3,795	$36,721	7.73%
Rhode Island	Providence	2.46	8.5	$708,480	$62,496	$3,362	$59,135	8.35%
South Carolina	Charleston	2.74	6.53	$789,120	$65,764	$6,393	$59,371	7.52%
South Dakota	Sioux Falls	1.15	6.94	$331,200	$39,552	$4,405	$35,147	10.61%
South Dakota	Rapid City	1.25	10.65	$360,000	$39,552	$4,160	$35,392	9.83%
Tennessee	Nashville	1.85	6.88	$532,800	$57,056	$7,069	$49,986	9.38%
Tennessee	Memphis	1.11	8.42	$319,680	$56,627	$6,809	$49,818	15.58%
Texas	Dallas	1.91	6.66	$550,080	$66,668	$6,518	$60,150	10.93%
Texas	El Paso	1.07	6.51	$308,160	$66,668	$5,189	$61,479	19.95%
Texas	Houston	1.65	6.56	$475,200	$66,668	$6,921	$59,747	12.57%
Texas	Lubbock	0.99	8.1	$285,120	$66,668	$5,615	$61,053	21.41%
Utah	Salt Lake City	1.83	5.65	$527,040	$29,378	$3,399	$25,979	4.93%
Vermont	Burlington	3.47	6.03	$999,360	$46,340	$3,737	$42,603	4.26%
Virginia	Alexandria	2.55	6.28	$734,400	$31,611	$3,335	$28,276	3.85%

State	City	Rent Per Square Foot	Real Estate Capitalization Rates	Modeled Original NOI	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Projected PV System NOI	% Increase in NOI
Washington	Seattle	2.91	5.1	$838,080	$28,068	$4,309	$23,759	2.83%
West Virginia	Charleston	1.07	7.39	$308,160	$67,715	$7,596	$60,119	19.51%
Wisconsin	Green Bay	1.64	7.73	$472,320	$52,066	$4,671	$47,395	10.03%
Wisconsin	Milwaukee	1.52	8.77	$437,760	$52,066	$4,635	$47,431	10.84%
Wyoming	Cheyenne	1.25	6.79	$360,000	$31,343	$3,242	$28,101	7.81%
AVERAGE				$569,335	$52,296	$4,491	$47,804	9.56%

Appendix 3

Property Value Increase as a Function of System Cost by City

Table 13. Property value increase vs. PV solar system installation cost.

State	City	Real Estate Capitalization Rates	Modeled Original Property Value	System Size (kW/Unit)	Total System Installation Cost ($/watt)	System Cost (50-Units)	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Property Value Increase	Value Increase/ System Cost
Alabama	Birmingham	7.69	$5,168,270	6.29	1.83	$575,105	$67,287	$6,734	$787,417	1.37
Arizona	Phoenix	6.81	$6,977,974	2.67	1.83	$244,047	$34,820	$2,858	$469,346	1.92
Arizona	Tucson	7.24	$6,285,083	2.63	1.83	$240,746	$34,820	$2,819	$442,005	1.84
Arkansas	Little Rock	7.08	$4,881,356	6.33	1.83	$579,390	$59,245	$6,784	$740,962	1.28
California	Fresno	6.42	$6,953,271	2.83	1.83	$259,309	$75,183	$3,036	$1,123,784	4.33
California	San Francisco	4.92	$24,702,439	2.91	1.83	$265,981	$75,183	$3,115	$1,464,814	5.51
California	San Diego	4.45	$22,198,652	2.85	1.83	$260,776	$75,183	$3,054	$1,620,894	6.22
California	Los Angeles	4.75	$20,554,105	2.80	1.83	$256,396	$75,183	$3,002	$1,519,602	5.93
Colorado	Denver	6.07	$11,055,025	2.94	1.83	$268,897	$36,357	$3,149	$547,091	2.03
Colorado	Colorado Springs	7.81	$4,498,848	2.92	1.83	$267,229	$36,357	$3,129	$425,454	1.59
Connecticut	Hartford	8.5	$3,320,471	3.19	1.83	$292,150	$63,199	$3,421	$703,268	2.41
Connecticut	New Haven	7.51	$9,011,984	3.10	1.83	$283,637	$63,199	$3,321	$797,303	2.81
Florida	Key West	5.91	$24,121,827	5.47	1.83	$500,675	$71,046	$5,863	$1,102,931	2.20
Florida	Miami	6.62	$13,790,937	5.74	1.83	$525,606	$71,046	$6,155	$980,231	1.86
Florida	Orlando	6.79	$7,295,434	5.97	1.83	$545,834	$71,046	$6,392	$952,200	1.74
Georgia	Atlanta	7.49	$7,036,582	6.17	1.83	$564,297	$67,287	$6,608	$810,132	1.44

State	City	Real Estate Capitalization Rates	Modeled Original Property Value	System Size (kW/Unit)	Total System Installation Cost ($/watt)	System Cost (50-Units)	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Property Value Increase	Value Increase/ System Cost
Georgia	Savannah	6.58	$7,659,574	6.01	1.83	$549,797	$67,287	$6,438	$924,752	1.68
Hawaii	Honolulu	4.67	$24,791,435	2.88	1.83	$263,714	$98,691	$3,088	$2,047,169	7.76
Hawaii	Lahaina	4.46	$24,150,673	2.74	1.83	$251,022	$98,691	$2,939	$2,146,892	8.55
Idaho	Boise	6.09	$6,999,015	3.83	1.83	$350,021	$35,381	$4,099	$513,661	1.47
Idaho	Coeur d'Alene	4.85	$10,688,660	4.68	1.83	$428,416	$35,381	$5,017	$626,062	1.46
Illinois	Chicago	8.01	$11,469,663	4.43	1.83	$404,911	$42,445	$4,741	$470,701	1.16
Indiana	Indianapolis	7.72	$4,551,295	4.35	1.83	$398,027	$43,084	$4,661	$497,710	1.25
Kansas	Kansas City	7.29	$4,977,778	4.02	1.83	$367,569	$41,318	$4,304	$507,735	1.38
Kentucky	Louisville	7.41	$4,936,032	4.29	1.83	$392,310	$37,025	$4,594	$437,665	1.12
Louisiana	New Orleans	7.13	$7,109,116	6.18	1.83	$565,066	$52,535	$6,617	$644,015	1.14
Maine	Portland, ME	6.72	$12,171,429	3.15	1.83	$288,151	$57,624	$3,374	$807,295	2.80
Maryland	Baltimore	9.8	$5,025,306	3.11	1.83	$284,572	$29,345	$3,332	$265,433	0.93
Massachusetts	Boston	5.55	$13,699,459	3.15	1.83	$287,771	$63,063	$3,370	$1,075,551	3.74
Michigan	Detroit	9.23	$4,305,959	4.51	1.83	$413,107	$59,160	$4,837	$588,550	1.42
Minnesota	Minneapolis	6.85	$8,745,109	4.31	1.83	$394,170	$47,073	$4,616	$619,811	1.57
Mississippi	Jackson, MS	9.49	$3,641,728	6.19	1.83	$566,021	$61,386	$6,628	$577,008	1.02
Missouri	St. Louis	7.5	$5,491,200	4.16	1.83	$380,756	$43,936	$4,459	$526,373	1.38
Missouri	Kansas City	8.7	$4,601,379	4.02	1.83	$367,933	$43,936	$4,308	$455,496	1.24
Montana	Billings	6.86	$5,457,726	4.08	1.83	$372,982	$39,461	$4,367	$511,562	1.37
Nebraska	Omaha	6.84	$5,600,000	4.08	1.83	$373,482	$37,329	$4,373	$481,812	1.29
Nevada	Las Vegas	6.28	$6,282,803	2.65	1.83	$242,647	$41,497	$2,841	$615,536	2.54
Nevada	Reno	5.94	$7,515,152	2.77	1.83	$253,702	$41,497	$2,971	$648,590	2.56
New Hampshire	Manchester	8.15	$7,562,209	3.18	1.83	$290,574	$59,256	$3,403	$685,318	2.36

State	City	Real Estate Capitalization Rates	Modeled Original Property Value	System Size (kW/Unit)	Total System Installation Cost ($/watt)	System Cost (50-Units)	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Property Value Increase	Value Increase/ System Cost
New Jersey	Jersey City	7.36	$15,886,957	3.14	1.83	$287,711	$41,921	$3,369	$523,805	1.82
New Mexico	Albuquerque	7.06	$6,526,912	2.63	1.83	$240,998	$37,063	$2,822	$484,994	2.01
New Mexico	Santa Fe	6.79	$9,204,124	2.69	1.83	$246,368	$37,063	$2,885	$503,354	2.04
New York	Brooklyn	5.85	$19,298,462	3.08	1.83	$281,519	$50,600	$3,296	$808,603	2.87
New York	Buffalo	8.39	$4,256,496	3.53	1.83	$323,033	$50,600	$3,783	$558,012	1.73
North Carolina	Charlotte	6.21	$7,142,029	6.20	1.83	$567,127	$62,052	$6,641	$892,292	1.57
North Carolina	Raleigh	5.95	$6,679,664	6.19	1.83	$566,611	$62,052	$6,635	$931,384	1.64
North Dakota	Bismarck	8.63	$3,804,403	4.11	1.83	$376,079	$38,060	$4,404	$389,992	1.04
Ohio	Columbus	7.61	$5,941,656	4.50	1.83	$412,159	$48,016	$4,826	$567,546	1.38
Oklahoma	Oklahoma City	7.12	$4,732,584	3.74	1.83	$342,049	$40,465	$4,005	$512,080	1.50
Oregon	Portland	5.95	$9,874,286	4.03	1.83	$368,597	$32,628	$4,316	$475,833	1.29
Pennsylvania	Philadelphia	7.9	$6,124,557	3.20	1.83	$293,038	$40,516	$3,431	$469,427	1.60
Pennsylvania	Pittsburgh	8.54	$5,564,403	3.54	1.83	$324,094	$40,516	$3,795	$429,989	1.33
Rhode Island	Providence	8.5	$8,335,059	3.14	1.83	$287,074	$62,496	$3,362	$695,703	2.42
South Carolina	Charleston	6.53	$12,084,533	5.97	1.83	$545,937	$65,764	$6,393	$909,206	1.67
South Dakota	Sioux Falls	6.94	$4,772,334	4.11	1.83	$376,155	$39,552	$4,405	$506,446	1.35
South Dakota	Rapid City	10.65	$3,380,282	3.88	1.83	$355,265	$39,552	$4,160	$332,319	0.94
Tennessee	Nashville	6.88	$7,744,186	6.60	1.83	$603,733	$57,056	$7,069	$726,543	1.20
Tennessee	Memphis	8.42	$3,796,675	6.36	1.83	$581,518	$56,627	$6,809	$591,663	1.02
Texas	Dallas	6.66	$8,259,459	6.08	1.83	$556,615	$66,668	$6,518	$903,157	1.62
Texas	El Paso	6.51	$4,733,641	4.84	1.83	$443,100	$66,668	$5,189	$944,385	2.13
Texas	Houston	6.56	$7,243,902	6.46	1.83	$591,030	$66,668	$6,921	$910,781	1.54
Texas	Lubbock	8.1	$3,520,000	5.24	1.83	$479,502	$66,668	$5,615	$753,743	1.57

State	City	Real Estate Capitalization Rates	Modeled Original Property Value	System Size (kW/Unit)	Total System Installation Cost ($/watt)	System Cost (50-Units)	Annual Gross Income (Net Metered)	Annual Operations and Maintenance Costs	Property Value Increase	Value Increase/ System Cost
Utah	Salt Lake City	5.65	$9,328,142	3.17	1.83	$290,242	$29,378	$3,399	$459,811	1.58
Vermont	Burlington	6.03	$16,573,134	3.49	1.83	$319,130	$46,340	$3,737	$706,514	2.21
Virginia	Alexandria	6.28	$11,694,268	3.11	1.83	$284,806	$31,611	$3,335	$450,250	1.58
Washington	Seattle	5.1	$16,432,941	4.02	1.83	$367,979	$28,068	$4,309	$465,861	1.27
West Virginia	Charleston	7.39	$4,169,959	7.09	1.83	$648,658	$67,715	$7,596	$813,523	1.25
Wisconsin	Green Bay	7.73	$6,110,220	4.36	1.83	$398,911	$52,066	$4,671	$613,131	1.54
Wisconsin	Milwaukee	8.77	$4,991,562	4.33	1.83	$395,794	$52,066	$4,635	$540,838	1.37
Wyoming	Cheyenne	6.79	$5,301,915	3.03	1.83	$276,857	$31,343	$3,242	$413,863	1.49
Average		7.01	$8,839,910	4.19	1.83	$383,550	$52,296	$4,491	$720,674	2.08

Appendix 4

Benefit-Cost Ratio by City Location

Table 14. Benefit-Cost ratio at each city location.

State	City	Annual Gross Income (Net Metered)	Annual System Financing Cost	Annual Operations and Maintenance Costs	Benefit-Cost Ratio
Alabama	Birmingham	$67,287	$47,473	$6,734	1.24
Arizona	Phoenix	$34,820	$20,145	$2,858	1.51
Arizona	Tucson	$34,820	$19,873	$2,819	1.53
Arkansas	Little Rock	$59,245	$47,827	$6,784	1.08
California	Fresno	$75,183	$21,405	$3,036	3.08
California	San Francisco	$75,183	$21,956	$3,115	3.00
California	San Diego	$75,183	$21,526	$3,054	3.06
California	Los Angeles	$75,183	$21,165	$3,002	3.11
Colorado	Denver	$36,357	$22,196	$3,149	1.43
Colorado	Colorado Springs	$36,357	$22,059	$3,129	1.44
Connecticut	Hartford	$63,199	$24,116	$3,421	2.30
Connecticut	New Haven	$63,199	$23,413	$3,321	2.36
Florida	Key West	$71,046	$41,329	$5,863	1.51
Florida	Miami	$71,046	$43,387	$6,155	1.43
Florida	Orlando	$71,046	$45,057	$6,392	1.38
Georgia	Atlanta	$67,287	$46,581	$6,608	1.27
Georgia	Savannah	$67,287	$45,384	$6,438	1.30
Hawaii	Honolulu	$98,691	$21,769	$3,088	3.97
Hawaii	Lahaina	$98,691	$20,721	$2,939	4.17
Idaho	Boise	$35,381	$28,893	$4,099	1.07
Idaho	Coeur d'Alene	$35,381	$35,364	$5,017	0.88
Illinois	Chicago	$42,445	$33,424	$4,741	1.11
Indiana	Indianapolis	$43,084	$32,856	$4,661	1.15
Kansas	Kansas City	$41,318	$30,342	$4,304	1.19
Kentucky	Louisville	$37,025	$32,384	$4,594	1.00
Louisiana	New Orleans	$52,535	$46,644	$6,617	0.99
Maine	Portland, ME	$57,624	$23,786	$3,374	2.12
Maryland	Baltimore	$29,345	$23,490	$3,332	1.09
Massachusetts	Boston	$63,063	$23,754	$3,370	2.32
Michigan	Detroit	$59,160	$34,101	$4,837	1.52
Minnesota	Minneapolis	$47,073	$32,537	$4,616	1.27
Mississippi	Jackson, MS	$61,386	$46,723	$6,628	1.15

State	City	Annual Gross Income (Net Metered)	Annual System Financing Cost	Annual Operations and Maintenance Costs	Benefit-Cost Ratio
Missouri	St. Louis	$43,936	$31,430	$4,459	1.22
Missouri	Kansas City	$43,936	$30,372	$4,308	1.27
Montana	Billings	$39,461	$30,788	$4,367	1.12
Nebraska	Omaha	$37,329	$30,830	$4,373	1.06
Nevada	Las Vegas	$41,497	$20,030	$2,841	1.81
Nevada	Reno	$41,497	$20,942	$2,971	1.74
New Hampshire	Manchester	$59,256	$23,986	$3,403	2.16
New Jersey	Jersey City	$41,921	$23,750	$3,369	1.55
New Mexico	Albuquerque	$37,063	$19,894	$2,822	1.63
New Mexico	Santa Fe	$37,063	$20,337	$2,885	1.60
New York	Brooklyn	$50,600	$23,238	$3,296	1.91
New York	Buffalo	$50,600	$26,665	$3,783	1.66
North Carolina	Charlotte	$62,052	$46,814	$6,641	1.16
North Carolina	Raleigh	$62,052	$46,772	$6,635	1.16
North Dakota	Bismarck	$38,060	$31,044	$4,404	1.07
Ohio	Columbus	$48,016	$34,022	$4,826	1.24
Oklahoma	Oklahoma City	$40,465	$28,235	$4,005	1.26
Oregon	Portland	$32,628	$30,426	$4,316	0.94
Pennsylvania	Philadelphia	$40,516	$24,189	$3,431	1.47
Pennsylvania	Pittsburgh	$40,516	$26,753	$3,795	1.33
Rhode Island	Providence	$62,496	$23,697	$3,362	2.31
South Carolina	Charleston	$65,764	$45,065	$6,393	1.28
South Dakota	Sioux Falls	$39,552	$31,050	$4,405	1.12
South Dakota	Rapid City	$39,552	$29,326	$4,160	1.18
Tennessee	Nashville	$57,056	$49,836	$7,069	1.00
Tennessee	Memphis	$56,627	$48,002	$6,809	1.03
Texas	Dallas	$66,668	$45,947	$6,518	1.27
Texas	El Paso	$66,668	$36,576	$5,189	1.60
Texas	Houston	$66,668	$48,787	$6,921	1.20
Texas	Lubbock	$66,668	$39,581	$5,615	1.48
Utah	Salt Lake City	$29,378	$23,958	$3,399	1.07
Vermont	Burlington	$46,340	$26,343	$3,737	1.54
Virginia	Alexandria	$31,611	$23,510	$3,335	1.18
Washington	Seattle	$28,068	$30,375	$4,309	0.81
West Virginia	Charleston	$67,715	$53,544	$7,596	1.11
Wisconsin	Green Bay	$52,066	$32,929	$4,671	1.38
Wisconsin	Milwaukee	$52,066	$32,671	$4,635	1.40
Wyoming	Cheyenne	$31,343	$22,854	$3,242	1.20
AVERAGE		$52,296	$31,661	$4,491	1.55

Appendix 5

Boersch-Pagan Test Data, Predicted Y and Residuals Squared

Table 15. Boersch-Pagan test data.

Observation	Predicted Y	Residuals	Residuals Squared
1	1.229047898	0.012239062	0.000149795
2	1.579545398	-0.06581508	0.004331625
3	1.605849362	-0.071367647	0.005093341
4	1.056843498	0.028001956	0.00078411
5	2.991162481	0.084895679	0.007207276
6	2.945866851	0.053034684	0.002812678
7	2.98100651	0.077751958	0.006045367
8	3.011677542	0.099325995	0.009865653
9	1.46027311	-0.025794685	0.000665366
10	1.471139999	-0.027710201	0.000767855
11	2.441295064	-0.146241337	0.021386529
12	2.4845595	-0.120625056	0.014550404
13	1.532839553	-0.027363519	0.000748762
14	1.449052794	-0.014985817	0.000224575
15	1.386695134	-0.005773806	3.33368E-05
16	1.258500213	0.006559908	4.30324E-05
17	1.299835014	-0.001410489	1.98948E-06
18	3.84889346	0.12150333	0.014763059
19	3.938672242	0.232469845	0.054042229
20	1.068142705	0.004268771	1.82224E-05
21	0.772299277	0.103872823	0.010789563
22	1.06976084	0.042360848	0.001794441
23	1.113916808	0.034482693	0.001189056
24	1.176530072	0.016056575	0.000257814
25	0.945255622	0.056018988	0.003138127
26	0.961354377	0.02501467	0.000625734
27	2.227195171	-0.105529863	0.011136552
28	1.057911907	0.036116182	0.001304379
29	2.457522031	-0.132555374	0.017570927
30	1.564493692	-0.045136453	0.002037299
31	1.252497306	0.014499639	0.00021024
32	1.135721674	0.014884639	0.000221552

Observation	Predicted Y	Residuals	Residuals Squared
33	1.205053565	0.019193083	0.000368374
34	1.256849016	0.010063054	0.000101265
35	1.096135975	0.026311611	0.000692301
36	1.027488924	0.032911093	0.00108314
37	1.842804009	-0.028406443	0.000806926
38	1.758712571	-0.023376219	0.000546448
39	2.283527174	-0.119983626	0.014396071
40	1.569932497	-0.024088525	0.000580257
41	1.688515472	-0.056919642	0.003239846
42	1.646165074	-0.050131416	0.002513159
43	1.966610829	-0.059697249	0.003563762
44	1.774358303	-0.112508362	0.012658132
45	1.145998054	0.014827483	0.000219854
46	1.14741989	0.014464036	0.000209208
47	1.039867996	0.033825998	0.001144198
48	1.219336275	0.016656133	0.000277427
49	1.264747759	-0.009626727	9.26739E-05
50	0.848394231	0.090749152	0.008235409
51	1.484321237	-0.017442589	0.000304244
52	1.346606274	-0.020289243	0.000411653
53	2.437285243	-0.12760771	0.016283728
54	1.280756738	-0.002743066	7.52441E-06
55	1.086194417	0.029362454	0.000862154
56	1.174652923	0.006498361	4.22287E-05
57	0.951522181	0.051116462	0.002612893
58	0.998916684	0.034209418	0.001170284
59	1.267760915	0.002968972	8.8148E-06
60	1.674812223	-0.078541563	0.006168777
61	1.175240021	0.021495943	0.000462076
62	1.523285139	-0.048198819	0.002323126
63	1.068597855	0.005274471	2.782E-05
64	1.611392017	-0.070842308	0.005018633
65	1.151858701	0.025679823	0.000659453
66	0.678277411	0.130959724	0.017150449
67	1.063234776	0.044303479	0.001962798
68	1.391506713	-0.00676148	4.57176E-05
69	1.40267828	-0.007027981	4.93925E-05
70	1.220824808	-0.019726701	0.000389143

Appendix 6

Avoided Grid Tied Electricity and CO$_2$e Emissions

Table 16. Emissions avoided by project and state.

State	City	EPA eGRID CO2e Emissions Factor (lbs./MWh)	Global Solar Atlas (kWh/kWp)	System Size (kW/Unit)	Grid Tied Electricity Avoided (MWh)	Emissions Avoided (metric tons-CO$_2$e/yr.)	Total Statewide Multifamily Units (1000s)	Potential Statewide Emissions Reductions (Kilotonnes-CO$_2$e/yr.)
Alabama	Birmingham	772.7	1514.2	6.29	476	167	225	188
Arizona	Phoenix	819.7	1889.3	2.67	252	94	435	204
Arizona	Tucson	819.7	1915.2	2.63	252	94	435	204
Arkansas	Little Rock	772.7	1503	6.33	476	167	129	108
California	Fresno	531.7	1778.1	2.83	252	61	3,023	919
California	San Francisco	531.7	1733.5	2.91	252	61	3,023	919
California	San Diego	531.7	1768.1	2.85	252	61	3,023	919
California	Los Angeles	531.7	1798.3	2.80	252	61	3,023	919
Colorado	Denver	1158.9	1714.7	2.94	252	132	448	297
Colorado	Colorado Springs	1158.9	1725.4	2.92	252	132	448	297
Connecticut	Hartford	539.4	1419.4	3.19	227	55	229	63
Connecticut	New Haven	539.4	1462	3.10	227	55	229	63
Florida	Key West	832.9	1739.3	5.47	476	180	1,485	1,335
Florida	Miami	832.9	1656.8	5.74	476	180	1,485	1,335
Florida	Orlando	832.9	1595.4	5.97	476	180	1,485	1,335
Georgia	Atlanta	891.9	1543.2	6.17	476	193	615	592
Georgia	Savannah	891.9	1583.9	6.01	476	193	615	592

State	City	EPA eGRID CO2e Emissions Factor (lbs./MWh)	Global Solar Atlas (kWh/kWp)	System Size (kW/Unit)	Grid Tied Electricity Avoided (MWh)	Emissions Avoided (metric tons-CO_2e/yr.)	Total Statewide Multifamily Units (1000s)	Potential Statewide Emissions Reductions (Kilotonnes-CO_2e/yr.)
Hawaii	Honolulu	1633.1	1748.4	2.88	252	187	94	88
Hawaii	Lahaina	1134.4	1836.8	2.74	252	130	94	61
Idaho	Boise	634.6	1591.9	3.83	304	88	59	26
Idaho	Coeur d'Alene	634.6	1300.6	4.68	304	88	59	26
Illinois	Chicago	1046.1	1376.1	4.43	304	145	879	635
Indiana	Indianapolis	1046.1	1399.9	4.35	304	145	333	241
Kansas	Kansas City	991.7	1515.9	4.02	304	137	149	102
Kentucky	Louisville	931.6	1420.3	4.29	304	129	198	127
Louisiana	New Orleans	772.7	1541.1	6.18	476	167	192	160
Maine	Portland, ME	539.4	1439.1	3.15	227	55	52	14
Maryland	Baltimore	672.8	1457.2	3.11	227	69	452	156
Massachusetts	Boston	539.4	1441	3.15	227	55	512	142
Michigan	Detroit	1214.1	1348.8	4.51	304	168	524	439
Minnesota	Minneapolis	995.8	1413.6	4.31	304	138	397	273
Mississippi	Jackson, MS	772.7	1538.5	6.19	476	167	107	89
Missouri	St. Louis	1543	1463.4	4.16	304	213	288	307
Missouri	Kansas City	991.7	1514.4	4.02	304	137	288	197
Montana	Billings	634.6	1493.9	4.08	304	88	41	18
Nebraska	Omaha	995.8	1491.9	4.08	304	138	138	95
Nevada	Las Vegas	819.7	1900.2	2.65	252	94	246	115
Nevada	Reno	634.6	1817.4	2.77	252	73	246	89
New Hampshire	Manchester	539.4	1427.1	3.18	227	55	79	22
New Jersey	Jersey City	672.8	1441.3	3.14	227	69	645	223
New Mexico	Albuquerque	819.7	1913.2	2.63	252	94	86	40

State	City	EPA eGRID CO2e Emissions Factor (lbs./MWh)	Global Solar Atlas (kWh/kWp)	System Size (kW/Unit)	Grid Tied Electricity Avoided (MWh)	Emissions Avoided (metric tons-CO_2e/yr.)	Total Statewide Multifamily Units (1000s)	Potential Statewide Emissions Reductions (Kilotonnes-CO_2e/yr.)
New Mexico	Santa Fe	819.7	1871.5	2.69	252	94	86	40
New York	Brooklyn	816.8	1473	3.08	227	84	2,268	952
New York	Buffalo	233.1	1283.7	3.53	227	24	2,268	272
North Carolina	Charlotte	639.7	1535.5	6.20	476	138	580	401
North Carolina	Raleigh	639.7	1536.9	6.19	476	138	580	401
North Dakota	Bismarck	995.8	1481.6	4.11	304	138	80	55
Ohio	Columbus	1046.1	1351.9	4.50	304	145	690	499
Oklahoma	Oklahoma City	1031.6	1629	3.74	304	143	180	128
Oregon	Portland	634.6	1250.9	4.03	252	73	278	101
Pennsylvania	Philadelphia	672.8	1415.1	3.20	227	69	630	218
Pennsylvania	Pittsburgh	1046.1	1279.5	3.54	227	108	630	339
Rhode Island	Providence	539.4	1444.5	3.14	227	55	70	19
South Carolina	Charleston	639.7	1595.1	5.97	476	138	232	160
South Dakota	Sioux Falls	995.8	1481.3	4.11	304	138	55	38
South Dakota	Rapid City	1158.9	1568.4	3.88	304	160	55	44
Tennessee	Nashville	931.6	1442.4	6.60	476	201	362	364
Tennessee	Memphis	931.6	1497.5	6.36	476	201	362	364
Texas	Dallas	813.6	1564.5	6.08	476	176	2,244	1,971
Texas	El Paso	819.7	1965.3	4.84	476	177	2,244	1,986
Texas	Houston	813.6	1473.4	6.46	476	176	2,244	1,971
Texas	Lubbock	1031.6	1816.1	5.24	476	223	2,244	2,499
Utah	Salt Lake City	634.6	1588.6	3.17	252	73	158	57
Vermont	Burlington	539.4	1299.4	3.49	227	55	30	8
Virginia	Alexandria	672.8	1456	3.11	227	69	560	194

State	City	EPA eGRID CO2e Emissions Factor (lbs./MWh)	Global Solar Atlas (kWh/kWp)	System Size (kW/Unit)	Grid Tied Electricity Avoided (MWh)	Emissions Avoided (metric tons-CO_2e/yr.)	Total Statewide Multifamily Units (1000s)	Potential Statewide Emissions Reductions (Kilotonnes-CO_2e/yr.)
Washington	Seattle	634.6	1253	4.02	252	73	606	220
West Virginia	Charleston	1046.1	1342.5	7.09	476	226	60	68
Wisconsin	Green Bay	1582.1	1396.8	4.36	304	219	388	424
Wisconsin	Milwaukee	1046.1	1407.8	4.33	304	145	388	280
Wyoming	Cheyenne	1158.9	1665.4	3.03	252	132	20	13
Average						124		

Appendix 7

CO_2e Emissions Reduction Cost Per Metric Ton

Table 17. CO_2e emissions reduction cost per metric ton by city.

State	City	Annual System Financing Cost	Annual Operations and Maintenance Costs	Emissions Avoided (metric tons-CO_2e/yr.)	Cost / Metric ton
Hawaii	Honolulu	$21,769	$3,088	187	$133
Missouri	St. Louis	$31,430	$4,459	213	$168
Wisconsin	Green Bay	$32,929	$4,671	219	$172
Hawaii	Lahaina	$20,721	$2,939	130	$182
Colorado	Colorado Springs	$22,059	$3,129	132	$190
Colorado	Denver	$22,196	$3,149	132	$191
Wyoming	Cheyenne	$22,854	$3,242	132	$197
Texas	Lubbock	$39,581	$5,615	223	$203
South Dakota	Rapid City	$29,326	$4,160	160	$209
Oklahoma	Oklahoma City	$28,235	$4,005	143	$226
Michigan	Detroit	$34,101	$4,837	168	$232
Texas	El Paso	$36,576	$5,189	177	$236
Arizona	Tucson	$19,873	$2,819	94	$242
New Mexico	Albuquerque	$19,894	$2,822	94	$242
Nevada	Las Vegas	$20,030	$2,841	94	$244
Arizona	Phoenix	$20,145	$2,858	94	$245
New Mexico	Santa Fe	$20,337	$2,885	94	$248
Kansas	Kansas City	$30,342	$4,304	137	$253
Missouri	Kansas City	$30,372	$4,308	137	$253
Nebraska	Omaha	$30,830	$4,373	138	$256
North Dakota	Bismarck	$31,044	$4,404	138	$258
South Dakota	Sioux Falls	$31,050	$4,405	138	$258
Wisconsin	Milwaukee	$32,671	$4,635	145	$258
Indiana	Indianapolis	$32,856	$4,661	145	$260
Florida	Key West	$41,329	$5,863	180	$262
Illinois	Chicago	$33,424	$4,741	145	$264
Ohio	Columbus	$34,022	$4,826	145	$269
Georgia	Savannah	$45,384	$6,438	193	$269
Minnesota	Minneapolis	$32,537	$4,616	138	$270
West Virginia	Charleston	$53,544	$7,596	226	$271
Tennessee	Memphis	$48,002	$6,809	201	$273

State	City	Annual System Financing Cost	Annual Operations and Maintenance Costs	Emissions Avoided (metric tons-CO_2e/yr.)	Cost / Metric ton
Florida	Miami	$43,387	$6,155	180	$275
Georgia	Atlanta	$46,581	$6,608	193	$276
Tennessee	Nashville	$49,836	$7,069	201	$283
Pennsylvania	Pittsburgh	$26,753	$3,795	108	$284
Florida	Orlando	$45,057	$6,392	180	$286
Kentucky	Louisville	$32,384	$4,594	129	$287
Texas	Dallas	$45,947	$6,518	176	$299
New York	Brooklyn	$23,238	$3,296	84	$316
Texas	Houston	$48,787	$6,921	176	$317
Louisiana	New Orleans	$46,644	$6,617	167	$319
Mississippi	Jackson, MS	$46,723	$6,628	167	$320
Alabama	Birmingham	$47,473	$6,734	167	$325
Arkansas	Little Rock	$47,827	$6,784	167	$327
Nevada	Reno	$20,942	$2,971	73	$330
South Carolina	Charleston	$45,065	$6,393	138	$373
Idaho	Boise	$28,893	$4,099	88	$376
Utah	Salt Lake City	$23,958	$3,399	73	$377
North Carolina	Raleigh	$46,772	$6,635	138	$387
North Carolina	Charlotte	$46,814	$6,641	138	$387
Maryland	Baltimore	$23,490	$3,332	69	$388
Virginia	Alexandria	$23,510	$3,335	69	$388
New Jersey	Jersey City	$23,750	$3,369	69	$392
California	Los Angeles	$21,165	$3,002	61	$398
Pennsylvania	Philadelphia	$24,189	$3,431	69	$399
Montana	Billings	$30,788	$4,367	88	$401
California	Fresno	$21,405	$3,036	61	$402
California	San Diego	$21,526	$3,054	61	$404
California	San Francisco	$21,956	$3,115	61	$412
Idaho	Coeur d'Alene	$35,364	$5,017	88	$461
Washington	Seattle	$30,375	$4,309	73	$478
Oregon	Portland	$30,426	$4,316	73	$479
Connecticut	New Haven	$23,413	$3,321	55	$482
Rhode Island	Providence	$23,697	$3,362	55	$488
Massachusetts	Boston	$23,754	$3,370	55	$489
Maine	Portland, ME	$23,786	$3,374	55	$490
New Hampshire	Manchester	$23,986	$3,403	55	$494
Connecticut	Hartford	$24,116	$3,421	55	$497
Vermont	Burlington	$26,343	$3,737	55	$542
New York	Buffalo	$26,665	$3,783	24	$1,270
AVERAGE					330

Appendix 8

Benefit-Cost Ratio and Emissions Reductions

Table 18. Benefit-cost ratio and project emissions avoided for all cities.

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)
Alabama	Birmingham	1.24	167
Arizona	Phoenix	1.51	94
Arizona	Tucson	1.53	94
Arkansas	Little Rock	1.08	167
California	Fresno	3.08	61
California	San Francisco	3.00	61
California	San Diego	3.06	61
California	Los Angeles	3.11	61
Colorado	Denver	1.43	132
Colorado	Colorado Springs	1.44	132
Connecticut	Hartford	2.30	55
Connecticut	New Haven	2.36	55
Florida	Key West	1.51	180
Florida	Miami	1.43	180
Florida	Orlando	1.38	180
Georgia	Atlanta	1.27	193
Georgia	Savannah	1.30	193
Hawaii	Honolulu	3.97	187
Hawaii	Lahaina	4.17	130
Idaho	Boise	1.07	88
Idaho	Coeur d'Alene	0.88	88
Illinois	Chicago	1.11	145
Indiana	Indianapolis	1.15	145
Kansas	Kansas City	1.19	137
Kentucky	Louisville	1.00	129
Louisiana	New Orleans	0.99	167
Maine	Portland, ME	2.12	55
Maryland	Baltimore	1.09	69
Massachusetts	Boston	2.32	55
Michigan	Detroit	1.52	168
Minnesota	Minneapolis	1.27	138
Mississippi	Jackson, MS	1.15	167

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)
Missouri	St. Louis	1.22	213
Missouri	Kansas City	1.27	137
Montana	Billings	1.12	88
Nebraska	Omaha	1.06	138
Nevada	Las Vegas	1.81	94
Nevada	Reno	1.74	73
New Hampshire	Manchester	2.16	55
New Jersey	Jersey City	1.55	69
New Mexico	Albuquerque	1.63	94
New Mexico	Santa Fe	1.60	94
New York	Brooklyn	1.91	84
New York	Buffalo	1.66	24
North Carolina	Charlotte	1.16	138
North Carolina	Raleigh	1.16	138
North Dakota	Bismarck	1.07	138
Ohio	Columbus	1.24	145
Oklahoma	Oklahoma City	1.26	143
Oregon	Portland	0.94	73
Pennsylvania	Philadelphia	1.47	69
Pennsylvania	Pittsburgh	1.33	108
Rhode Island	Providence	2.31	55
South Carolina	Charleston	1.28	138
South Dakota	Sioux Falls	1.12	138
South Dakota	Rapid City	1.18	160
Tennessee	Nashville	1.00	201
Tennessee	Memphis	1.03	201
Texas	Dallas	1.27	176
Texas	El Paso	1.60	177
Texas	Houston	1.20	176
Texas	Lubbock	1.48	223
Utah	Salt Lake City	1.07	73
Vermont	Burlington	1.54	55
Virginia	Alexandria	1.18	69
Washington	Seattle	0.81	73
West Virginia	Charleston	1.11	226
Wisconsin	Green Bay	1.38	219
Wisconsin	Milwaukee	1.40	145
Wyoming	Cheyenne	1.20	132
Average		1.55	124

Appendix 9

Energy Burden Data from DOE LEAD Tool

Table 19. DOE LEAD tool energy burden data.

State	City	Baseline City Energy Burden	Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	African American, White Hispanic or Latino
Alabama	Birmingham	3.0%	8.0%	78.0%
Arizona	Phoenix	2.0%	4.0%	46.0%
Arizona	Tucson	3.0%	5.0%	32.0%
Arkansas	Little Rock	2.0%	7.0%	60.0%
California	Fresno	3.0%	8.0%	46.0%
California	San Francisco	1.0%	2.0%	15.0%
California	San Diego	1.0%	3.0%	39.0%
California	Los Angeles	2.0%	3.0%	31.0%
Colorado	Denver	1.0%	2.0%	28.0%
Colorado	Colorado Springs	2.0%	3.0%	20.0%
Connecticut	Hartford	4.0%	7.5%	50.0%
Connecticut	New Haven	4.0%	6.0%	47.0%
Florida	Key West	2.0%	4.0%	56.0%
Florida	Miami	2.0%	4.0%	83.0%
Florida	Orlando	2.0%	5.0%	61.0%
Georgia	Atlanta	2.0%	7.0%	80.0%
Georgia	Savannah	3.0%	6.0%	58.0%
Hawaii	Honolulu	1.5%	6.0%	No Data
Hawaii	Lahaina	2.5%	11.0%	No Data
Idaho	Boise	2.0%	4.0%	9.0%
Idaho	Coeur d'Alene	2.0%	3.0%	0.0%
Illinois	Chicago	2.6%	5.3%	60.0%
Indiana	Indianapolis	2.0%	6.0%	53.0%
Kansas	Kansas City	3.0%	6.0%	48.0%
Kentucky	Louisville	2.0%	4.0%	37.0%
Louisiana	New Orleans	2.0%	8.0%	83.0%

State	City	Baseline City Energy Burden	Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	African American, White Hispanic or Latino
Maine	Portland, ME	2.0%	3.0%	19.0%
Maryland	Baltimore	3.0%	5.0%	74.0%
Massachusetts	Boston	2.0%	4.0%	31.0%
Michigan	Detroit	6.0%	6.0%	83.0%
Minnesota	Minneapolis	1.0%	2.0%	38.0%
Mississippi	Jackson, MS	3.0%	6.0%	92.0%
Missouri	St. Louis	3.0%	7.0%	56.0%
Missouri	Kansas City	2.0%	3.0%	4.0%
Montana	Billings	2.0%	4.0%	26.0%
Nebraska	Omaha	2.5%	7.5%	61.0%
Nevada	Las Vegas	2.0%	3.0%	22.0%
Nevada	Reno	3.0%	5.0%	20.0%
New Hampshire	Manchester	1.0%	4.0%	50.0%
New Jersey	Jersey City	2.0%	5.0%	32.0%
New Mexico	Albuquerque	2.0%	5.0%	42.0%
New Mexico	Santa Fe	3.0%	5.0%	52.0%
New York	Brooklyn	2.0%	4.0%	59.0%
New York	Buffalo	3.0%	4.0%	40.0%
North Carolina	Charlotte	2.0%	4.0%	56.0%
North Carolina	Raleigh	1.0%	3.0%	38.0%
North Dakota	Bismarck	2.0%	2.0%	11.0%
Ohio	Columbus	2.0%	6.0%	44.0%
Oklahoma	Oklahoma City	2.0%	6.0%	49.0%
Oregon	Portland	1.0%	4.0%	16.0%
Pennsylvania	Philadelphia	2.0%	4.0%	45.0%
Pennsylvania	Pittsburgh	2.0%	5.0%	27.0%
Rhode Island	Providence	3.0%	5.5%	45.0%
South Carolina	Charleston	2.0%	6.0%	58.0%
South Dakota	Sioux Falls	2.0%	4.0%	17.0%
South Dakota	Rapid City	2.0%	5.0%	7.0%
Tennessee	Nashville	2.0%	5.0%	51.0%
Tennessee	Memphis	3.0%	6.0%	81.0%
Texas	Dallas	2.0%	5.0%	61.0%
Texas	El Paso	2.0%	5.0%	69.0%
Texas	Houston	1.0%	5.0%	40.0%

State	City	Baseline City Energy Burden	Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	African American, White Hispanic or Latino
Texas	Lubbock	2.0%	5.0%	33.0%
Utah	Salt Lake City	1.0%	4.0%	15.0%
Vermont	Burlington	2.0%	6.0%	8.0%
Virginia	Alexandria	1.0%	4.0%	47.0%
Washington	Seattle	1.0%	2.0%	13.0%
West Virginia	Charleston	3.0%	9.0%	23.0%
Wisconsin	Green Bay	2.0%	3.0%	21.0%
Wisconsin	Milwaukee	3.0%	5.0%	52.0%
Wyoming	Cheyenne	3.0%	6.0%	2.0%
Average		2.2%	4.9%	41.9%

Appendix 10

Two-Dimensional City Scoring Model Components and Total

Table 20. Two-dimensional PV solar multifamily index results.

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)	Benefit-Cost Ratio Component	Emissions Avoided Component	Total
Alabama	Birmingham	1.24	167	6.2	34.0	40
Arizona	Phoenix	1.51	94	8.2	13.5	22
Arizona	Tucson	1.53	94	8.5	13.6	22
Arkansas	Little Rock	1.08	167	3.9	33.2	37
California	Fresno	3.08	61	32.7	8.8	42
California	San Francisco	3.00	61	31.2	8.7	40
California	San Diego	3.06	61	32.3	8.8	41
California	Los Angeles	3.11	61	33.3	8.9	42
Colorado	Denver	1.43	132	8.4	24.3	33
Colorado	Colorado Springs	1.44	132	8.6	24.4	33
Connecticut	Hartford	2.30	55	18.1	6.4	24
Connecticut	New Haven	2.36	55	19.3	6.5	26
Florida	Key West	1.51	180	10.5	39.1	50
Florida	Miami	1.43	180	9.3	38.8	48
Florida	Orlando	1.38	180	8.5	38.6	47
Georgia	Atlanta	1.27	193	6.8	42.2	49
Georgia	Savannah	1.30	193	7.4	42.3	50
Hawaii	Honolulu	3.97	187	53.8	46.2	100
Hawaii	Lahaina	4.17	130	56.0	29.3	85
Idaho	Boise	1.07	88	2.2	8.9	11
Idaho	Coeur d'Alene	0.88	88	0.4	6.8	7
Illinois	Chicago	1.11	145	4.0	26.4	30
Indiana	Indianapolis	1.15	145	4.5	26.6	31
Kansas	Kansas City	1.19	137	5.0	24.5	29
Kentucky	Louisville	1.00	129	2.3	20.8	23
Louisiana	New Orleans	0.99	167	2.4	32.7	35
Maine	Portland, ME	2.12	55	15.1	6.0	21
Maryland	Baltimore	1.09	69	1.5	4.0	5

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)	Benefit-Cost Ratio Component	Emissions Avoided Component	Total
Massachusetts	Boston	2.32	55	18.6	6.4	25
Michigan	Detroit	1.52	168	10.5	35.4	46
Minnesota	Minneapolis	1.27	138	6.1	25.1	31
Mississippi	Jackson, MS	1.15	167	4.8	33.6	38
Missouri	St. Louis	1.22	213	6.4	48.5	55
Missouri	Kansas City	1.27	137	6.1	24.9	31
Montana	Billings	1.12	88	2.7	9.3	12
Nebraska	Omaha	1.06	138	3.2	23.9	27
Nevada	Las Vegas	1.81	94	12.8	14.8	28
Nevada	Reno	1.74	73	10.2	8.9	19
New Hampshire	Manchester	2.16	55	15.8	6.1	22
New Jersey	Jersey City	1.55	69	7.1	7.2	14
New Mexico	Albuquerque	1.63	94	9.9	14.0	24
New Mexico	Santa Fe	1.60	94	9.4	13.9	23
New York	Brooklyn	1.91	84	13.7	12.5	26
New York	Buffalo	1.66	24	1.9	0.0	2
North Carolina	Charlotte	1.16	138	4.6	24.7	29
North Carolina	Raleigh	1.16	138	4.6	24.7	29
North Dakota	Bismarck	1.07	138	3.4	24.0	27
Ohio	Columbus	1.24	145	5.7	27.0	33
Oklahoma	Oklahoma City	1.26	143	6.0	26.5	33
Oregon	Portland	0.94	73	0.5	3.1	4
Pennsylvania	Philadelphia	1.47	69	6.0	6.8	13
Pennsylvania	Pittsburgh	1.33	108	6.1	16.4	23
Rhode Island	Providence	2.31	55	18.4	6.4	25
South Carolina	Charleston	1.28	138	6.2	25.3	32
South Dakota	Sioux Falls	1.12	138	3.9	24.2	28
South Dakota	Rapid City	1.18	160	5.2	31.6	37
Tennessee	Nashville	1.00	201	2.9	43.8	47
Tennessee	Memphis	1.03	201	3.3	43.9	47
Texas	Dallas	1.27	176	6.7	36.9	44
Texas	El Paso	1.60	177	11.9	38.5	50
Texas	Houston	1.20	176	5.6	36.6	42
Texas	Lubbock	1.48	223	10.5	52.4	63
Utah	Salt Lake City	1.07	73	1.5	4.7	6
Vermont	Burlington	1.54	55	5.7	4.1	10
Virginia	Alexandria	1.18	69	2.3	4.8	7

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)	Benefit-Cost Ratio Component	Emissions Avoided Component	Total
Washington	Seattle	0.81	73	0.0	1.0	1
West Virginia	Charleston	1.11	226	4.6	52.1	57
Wisconsin	Green Bay	1.38	219	9.0	50.8	60
Wisconsin	Milwaukee	1.40	145	8.1	27.8	36
Wyoming	Cheyenne	1.20	132	5.0	23.2	28
Average		1.55	124	9.8	22.4	32

Appendix 11

Three-Dimensional City Scoring Model Components and Total

Table 21. Three-dimensional PV solar multifamily index results.

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)	Energy Burden Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	Benefit-Cost Ratio Component	Emissions Avoided Component	Energy Burden Component	Normalized Score
Alabama	Birmingham	1.24	167	8.0%	4.8	26.2	24.7	56
Arizona	Phoenix	1.51	94	4.0%	6.5	10.8	6.9	24
Arizona	Tucson	1.53	94	5.0%	7.1	11.3	10.9	29
Arkansas	Little Rock	1.08	167	7.0%	3.0	25.7	20.2	49
California	Fresno	3.08	61	8.0%	25.1	6.8	24.8	57
California	San Francisco	3.00	61	2.0%	20.9	5.8	0.0	27
California	San Diego	3.06	61	3.0%	22.5	6.1	3.7	32
California	Los Angeles	3.11	61	3.0%	23.1	6.1	3.7	33
Colorado	Denver	1.43	132	2.0%	5.6	16.3	0.0	22
Colorado	Colorado Springs	1.44	132	3.0%	6.1	17.3	3.6	27
Connecticut	Hartford	2.30	55	7.5%	15.7	5.5	21.7	43
Connecticut	New Haven	2.36	55	6.0%	15.9	5.4	15.3	37
Florida	Key West	1.51	180	4.0%	7.4	27.4	7.9	43
Florida	Miami	1.43	180	4.0%	6.6	27.3	7.9	42
Florida	Orlando	1.38	180	5.0%	6.1	27.8	12.0	46
Georgia	Atlanta	1.27	193	7.0%	5.0	31.1	20.7	57
Georgia	Savannah	1.30	193	6.0%	5.3	30.7	16.3	52

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)	Energy Burden Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	Benefit-Cost Ratio Component	Emissions Avoided Component	Energy Burden Component	Normalized Score
Hawaii	Honolulu	3.97	187	6.0%	36.7	31.5	17.1	85
Hawaii	Lahaina	4.17	130	11.0%	39.6	20.7	39.6	100
Idaho	Boise	1.07	88	4.0%	2.2	8.9	6.2	17
Idaho	Coeur d'Alene	0.88	88	3.0%	0.4	7.0	2.5	10
Illinois	Chicago	1.11	145	5.3%	3.1	20.5	12.6	36
Indiana	Indianapolis	1.15	145	6.0%	3.5	21.0	15.6	40
Kansas	Kansas City	1.19	137	6.0%	4.0	19.6	15.5	39
Kentucky	Louisville	1.00	129	4.0%	1.8	16.4	7.0	25
Louisiana	New Orleans	0.99	167	8.0%	1.9	26.0	24.5	52
Maine	Portland, ME	2.12	55	3.0%	11.3	4.5	3.2	19
Maryland	Baltimore	1.09	69	5.0%	2.4	6.4	9.6	18
Massachusetts	Boston	2.32	55	4.0%	14.4	5.0	7.1	27
Michigan	Detroit	1.52	168	6.0%	7.7	26.0	16.2	50
Minnesota	Minneapolis	1.27	138	2.0%	4.1	16.8	0.0	21
Mississippi	Jackson, MS	1.15	167	6.0%	3.6	25.4	15.9	45
Missouri	St. Louis	1.22	213	7.0%	4.6	35.2	20.8	61
Missouri	Kansas City	1.27	137	3.0%	4.3	17.7	3.5	26
Montana	Billings	1.12	88	4.0%	2.6	9.0	6.3	18
Nebraska	Omaha	1.06	138	7.5%	2.7	20.1	21.9	45
Nevada	Las Vegas	1.81	94	3.0%	9.2	10.7	3.4	23
Nevada	Reno	1.74	73	5.0%	8.9	7.8	10.8	27
New Hampshire	Manchester	2.16	55	4.0%	12.6	4.9	7.0	24
New Jersey	Jersey City	1.55	69	5.0%	6.8	7.0	10.4	24

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO₂e/yr.)	Energy Burden Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	Benefit-Cost Ratio Component	Emissions Avoided Component	Energy Burden Component	Normalized Score
New Mexico	Albuquerque	1.63	94	5.0%	8.1	11.4	11.0	31
New Mexico	Santa Fe	1.60	94	5.0%	7.7	11.4	11.0	30
New York	Brooklyn	1.91	84	4.0%	10.5	9.6	7.2	27
New York	Buffalo	1.66	24	4.0%	6.0	0.0	5.2	11
North Carolina	Charlotte	1.16	138	4.0%	3.4	18.5	7.3	29
North Carolina	Raleigh	1.16	138	3.0%	3.3	17.7	3.5	24
North Dakota	Bismarck	1.07	138	2.0%	2.3	16.1	0.0	18
Ohio	Columbus	1.24	145	6.0%	4.5	21.1	15.7	41
Oklahoma	Oklahoma City	1.26	143	6.0%	4.7	20.7	15.7	41
Oregon	Portland	0.94	73	4.0%	0.9	5.9	5.5	12
Pennsylvania	Philadelphia	1.47	69	4.0%	5.6	6.4	6.4	18
Pennsylvania	Pittsburgh	1.33	108	5.0%	5.1	13.6	11.0	30
Rhode Island	Providence	2.31	55	5.5%	15.1	5.3	13.2	34
South Carolina	Charleston	1.28	138	6.0%	4.9	19.9	15.6	40
South Dakota	Sioux Falls	1.12	138	4.0%	3.0	18.3	7.2	29
South Dakota	Rapid City	1.18	160	5.0%	3.9	23.6	11.6	39
Tennessee	Nashville	1.00	201	5.0%	2.1	31.5	12.0	46
Tennessee	Memphis	1.03	201	6.0%	2.4	32.1	16.3	51
Texas	Dallas	1.27	176	5.0%	4.9	26.8	11.9	44
Texas	El Paso	1.60	177	5.0%	8.5	27.5	12.1	48
Texas	Houston	1.20	176	5.0%	4.1	26.7	11.8	43
Texas	Lubbock	1.48	223	5.0%	7.4	36.6	12.4	56
Utah	Salt Lake City	1.07	73	4.0%	2.0	6.2	5.8	14

State	City	Benefit-Cost Ratio	Emissions Avoided (metric tons-CO_2e/yr.)	Energy Burden Renters; Income 0-60%; Year Built - Pre 2000; Units 5+	Benefit-Cost Ratio Component	Emissions Avoided Component	Energy Burden Component	Normalized Score
Vermont	Burlington	1.54	55	6.0%	6.9	5.0	14.1	26
Virginia	Alexandria	1.18	69	4.0%	2.9	5.9	5.9	15
Washington	Seattle	0.81	73	2.0%	0.0	1.0	0.0	1
West Virginia	Charleston	1.11	226	9.0%	3.4	38.3	29.8	72
Wisconsin	Green Bay	1.38	219	3.0%	6.1	34.5	4.0	45
Wisconsin	Milwaukee	1.40	145	5.0%	6.1	20.8	11.6	38
Wyoming	Cheyenne	1.20	132	6.0%	4.1	18.7	15.5	38
Average		2	124	4.9%	7.5	17.0	11.2	36

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