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Constructing a Model to Identify Markets for Rooftop Solar on Multifamily Housing

A Group Project submitted in partial satisfaction of the requirements for the degree of

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Eric Masanet

Date

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Glossary of Terms

CBSA: unique six digit code known as core based statistical area used to identify Metropolitan Statistical Areas

Criteria: seven criteria categories were made which together comprise the investment favorability score– real estate, solar IRR, landlord policies, climate risk avoidance, CO_2 emissions, health impacts, and renewable electricity production

Equity-centric: a model scenario adjusting the seven criteria weights, giving higher weighting to health impacts and CO_2 emissions avoided

ESG: Environmental Social Governance

FEMA: Federal Emergency Management Agency

FIPS: Federal Information Processing Standards

GIS: Geographical information systems

Investment favorability score: the combination of all seven criteria scores ranging from 0 - 1; comparative indicator for which Metropolitan Statistical Areas are most favorable for solar photovoltaic installation

IRR: Internal rate of return

LCC: the present value of lifecycle costs associated with a proposed project

MESM: Master of Environmental Science and Management

Metric: data category that contributes to one of the model's seven criteria. Ex: population growth is a metric that contributes to the real estate criterion

Model: the framework comprising several criteria which generates an investment favorability score

MSA: Metropolitan statistical area

NEM: Net Energy Metering

NPV: Net Present Value

NREL: National Renewable Energy Laboratory

NRI: National Risk Index developed by the Federal Emergency Management Agency (FEMA) to visualize the risk of climate disasters in the United States at the county and census tract scales

Normalization: standard equation applied (see Appendix B) so that data points lie between 0 and 1

REopt: web-based model used to simulate the financial performance of installing solar photovoltaics on an apartment building. Contributes to the electricity, solar internal rate of return, CO_2 abatement potential, and health impact criteria

Solar PV: Solar photovoltaic systems

UCSB: University of California, Santa Barbara

ZNE: Zero Net Energy Capital (Client)

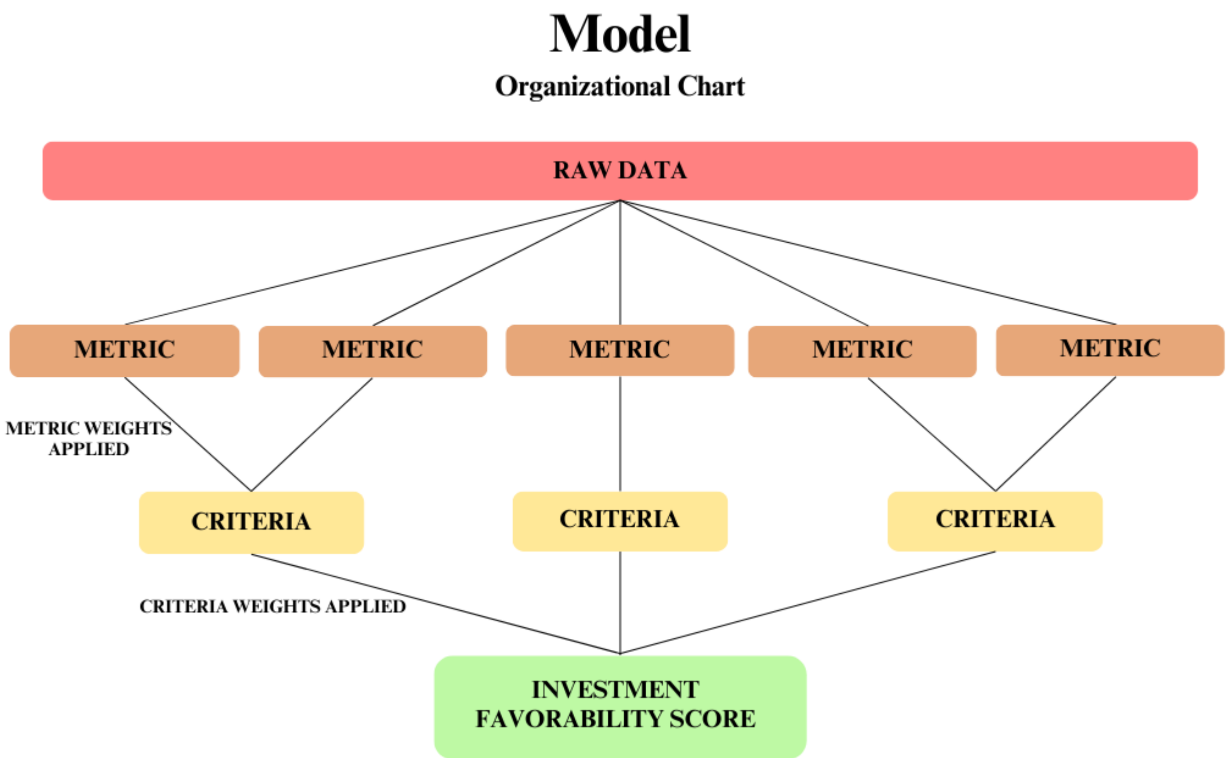

Figure 1. Organizational chart of model to clarify terminology used in methods

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Abstract

As the renewable energy transition accelerates, housing, due to its high energy demand, can play a critical role in the clean energy shift. Specifically, multifamily housing provides a unique opportunity for solar photovoltaic (PV) system adoption, given the existing competing interests between landlords and tenants which has historically slowed this transition. Landlords are less incentivized to install solar due to upfront costs, but ultimately tenants receive the benefits from solar installations in the form of reduced electricity bills. To address this transition gap, this project identified and ranked Metropolitan Statistical Areas (MSAs)[1] in the United States for ZNE Capital (the client) to acquire multifamily housing to install solar PV systems. Working with the client, the group identified seven criteria to determine favorable markets for rooftop solar PV on multifamily housing: landlord policy favorability, real estate market potential, CO_2 abatement potential, electricity generation potential, solar installation internal rate of return, climate risk avoidance, and health costs associated with primary air pollutants. A total investment favorability score is calculated based on criteria importance assigned by the user. Investment favorability scores were investigated for different preferences to demonstrate the robustness and generalizability of the framework. The data analysis and criteria calculations were conducted using RStudio, ultimately to provide reproducible code to be used for future projects. The results are presented in a ranked list and GIS map of MSAs based on the overall favorability score. In addition, GIS maps of each criterion are included with the relative scores of each MSA to shed light on geographic trends. Future studies can utilize the reproducible code to inform decisions on where to invest in solar PV on multifamily housing anywhere in the United States by changing weights within the model depending on preferences.

[1] Metropolitan statistical areas (MSAs) are defined by the U.S. Census Bureau as "one or more counties that contain a city of 50,000 or more inhabitants, or contain a Census Bureau-defined urbanized area (UA) and have a total population of at least 100,000".

Project Objectives

The main objective of this project was to develop a model that includes seven criteria to identify U.S. MSAs ideal for installing rooftop solar PV systems on multifamily housing complexes. This model was designed to be flexible enough to capture the perspectives and desires of the various stakeholders for such investments, including real estate companies interested in solar PV, solar installation nonprofits, and state governments, which can express their priorities through weights assigned for each of the seven criteria. Each criterion consists of indicator metrics calculated from data. Each criterion is multiplied by its respective user-assigned weight to determine the investment favorability score. Once created, the model was employed to identify MSAs in the United States where the acquisition of multifamily housing complexes and installation of rooftop solar PV was most favorable for the client, Zero Net Energy (ZNE) Capital. In addition to the client scenario, an example equity-centered scenario was calculated using this model by adjusting the seven criteria weights, giving higher weighting to health impacts and CO_2 emissions avoided. These weights can be adjusted based on the priorities of the model user.

The final deliverables of this project include: a data-driven and reproducible model for prioritizing rooftop solar PV systems on multifamily housing complexes, ranked lists of MSAs recommended for multifamily housing rooftop solar PV investments based on client preferences and equity-centric preferences, data visualizations (GIS maps) with layers corresponding to the investment favorability score and each of the seven criteria scores, a written report, an oral presentation, and a spreadsheet containing final results including data and all data sources.

Background and Significance

A. Significance

Transitioning from fossil fuels to renewable energy is critical for mitigating climate change, and solar energy has a significant role to play. In 2021, the residential sector accounted for 21% of the total U.S. energy consumption, and a significant portion of this energy consumption, 43%, came from electricity, as reported by the U.S. Energy Information Administration (2022). Despite solar PV adoption within the residential sector, they are mostly limited to single family homes due to split tenant and landlord incentives (St. John, 2022). Landlords stand to gain few benefits from rooftop solar PV other than reduced electricity demand in common areas, while tenants receive reduced electricity bills. This creates a gap in solar PV adoption as 30.9% of U.S. households live in rental housing (U.S. Census Bureau, 2023). Therefore, ZNE Capital targets a subset of the residential sector that is often ignored in the clean energy transition. This allows low-income households and renters to be included in the transition to onsite renewable energy. This group project not only equipped the client with a model to identify locations ideal for solar energy investments on its rental properties, but also created a resource that other investors and stakeholders can use to do the same for themselves, providing insights that can further accelerate the multifamily housing clean energy transition.

B. ZNE Capital

ZNE Capital is a real estate company that "enhances the traditional, multifamily, value-add model by adding onsite renewable electricity to disrupt an industry with enormous potential for environmental and social impact" (ZNE Capital, 2022). The company was founded in 2018 by Owen Barrett, a Bren School MESM alumnus from the class of 2012. The company's business model involves acquiring existing multifamily housing complexes, installing solar PV systems, and decreasing utility costs to increase their net operating income while renting units at affordable rates. This strategy provides environmental and social value, while delivering competitive returns to investors. Historically, ZNE Capital has conducted business with more traditional multifamily housing real estate investors who often do not prioritize environmental factors; however, they are now pivoting to target a more Environmental Social Governance (ESG) oriented impact investor. ZNE Capital sets out specific criteria for their properties, including areas with favorable net metering policies, landlord-friendly policies, historically high electricity consumption, and high grid electricity costs to result in the most profitable returns from their solar PV investments. At the time of this group project, the company was looking to expand its operations into new regions across the U.S., prioritizing garden style (two to three story) apartment complexes. To this end, a key goal of this group project was to focus on identifying and ranking ideal MSAs for ZNE to acquire properties.

C. Demographic and Real Estate trends

Regions where multifamily housing will be in the highest demand were classified as most favorable based on their expected economic and demographic growth. Multifamily housing complexes with at least 100 units were a top priority for ZNE Capital real estate investments. ZNE Capital was looking to own Class A, B, and C properties with garden-style apartments. Class A, B, and C designations are common terms in the commercial real estate industry and somewhat subjective classifications. Class A properties tend to be newer and more expensive due to more amenities and better locations, thus presenting a lower investment risk. Class C properties tend to be older, have fewer amenities, less ideal locations, and likely require renovation, presenting higher investment risk. Class B properties lie between Class A and Class C (Gower Crowd, n.d.). Initially, ZNE Capital targeted only Class B and C properties because doing so enabled them to lease apartments at affordable rates. However, the rise in interest rates has caused the company to target Class A properties to reduce renovation costs and achieve better loan rates.

D. Landlord Policies

Landlord policies were a factor in determining if the client should invest in a property. The specific landlord policies, or tenant protection laws, contributing to this criteria were whether or not rent control policies were present, the number of days required for an eviction notice, and the minimum security deposit amount (Law Depot, 2023). Tenant protection laws vary by state. For the client scenario, states with landlord-friendly policies received higher landlord criterion scores when calculating each MSA's investment scores.

E. Electricity Generation from Renewables

Transitioning to onsite renewable energy generation, such as rooftop solar, is a tangible and direct way to reduce greenhouse gas emissions associated with residential electricity use. In 2020, 2.7% of single-family homes used electricity generated from small-scale solar systems (Hronis et al., 2022). A significant incentive for small-scale renewable energy generation is the existence and terms of local net energy metering (NEM) policies. NEM policies dictate the metering and billing arrangement to compensate distributed energy generators for the energy they export onto the grid (National Renewable Energy Laboratory, n.d.). According to the National Renewable Energy Laboratory, 41 states offer NEM, but ultimately the utilities control NEM program availability and rates (National Renewable Energy Laboratory, n.d.). Favorable NEM policies allow home solar generators to be compensated near generation rates for the excess electricity they provide to the electricity grid.

In addition, the utilities' residential time-of-use rate is an essential factor in determining the economic feasibility of rooftop solar. The residential time-of-use rate enables utilities to charge less for electricity when demand is low and energy generation is high. Onsite solar installation, without batteries for energy storage, allows users to cover their daytime energy consumption, then export excess energy generated under local NEM policy. In the evening and on cloudy days, users are required to purchase electricity from the grid. The goal of ZNE Capital is to operate net zero energy properties on a per annual basis. This means that the total electricity produced by their rooftop solar system (kWh) matches their apartment buildings' total annual electricity consumption (kWh).

F. Financing the Transition to Renewable Energy

Installing solar PV is profitable long-term due to electricity cost savings, net metering, government incentives, increasing energy prices, and increased property values resulting from solar PV. Properties start generating electricity from solar (free of charge) once the solar PV system is installed, meaning landlords and businesses can reduce their reliance on the grid and save money on electricity bills. NEM allows landlords with solar PV systems to sell excess electricity to the grid, earn credits on their electricity bills, and receive payments from the utility company for their electricity generation. Additionally, many governments offer financial incentives for installing solar PV, such as tax credits or rebates, which can significantly reduce the upfront installation cost. Over the long-term, electricity prices are expected to increase due to inflation and increased demand for electricity (U.S. Energy Information Administration, 2011, 93). By installing a solar PV system, landlords can insulate themselves from these price increases and save more money on electricity bills in the future. Lastly, properties with solar PV systems have increased property values, so the property owner can generate income if they decide to sell their property (Vernay, 2020). From a tenant perspective, the climate benefits of renewable energy increase the appeal of the property to rent, particularly the climate-concerned tenants.

G. Decreasing CO_2 Emissions

Residential energy use accounts for around 20% of greenhouse gas emissions in the United States; thus, it must be decarbonized as soon as possible to prevent irreversible environmental damage (Goldstein, 2020). The most recent report from the Intergovernmental Panel on Climate Change (IPCC) supports the necessity of a rapid transition away from fossil fuels (IPCC, 2023). ZNE Capital's business model prioritizes a short time frame in decarbonizing the built environment by acquiring existing buildings. This project assists ZNE Capital in accelerating their work to decarbonize the residential sector, while providing an investment model for other businesses to implement similar decarbonization strategies.

H. Mitigating Health Impacts of Fossil Fuels

Burning fossil fuels (such as coal, oil, or natural gas) releases pollutants into the air that cause respiratory disorders, asthma, heart attacks, and premature deaths. (Center for Climate, Health, and the Global Environment, n.d.). Three of the most harmful pollutants emitted by fossil fuel combustion are sulfur dioxide (SO_2), nitrous oxides (NO_x), and PM2.5 (a general category of pollutant that consists of fine particulates that are 2.5 microns or less in diameter) (Anderson et al., 2021). Electricity generation from renewable resources, such as solar PV, does not release these pollutants. Decreasing electricity generated from fossil fuels and increasing renewable resources in the grid reduces the amount of these dangerous pollutants released into the atmosphere and the health impacts associated.

I. Climate Risk Avoidance

From the perspective of the client, MSAs with a high risk of climate disasters would be poor long-term investment options. Climate disasters cause costly property damage and reduce the area's appeal for prospective tenants. The Federal Emergency Management Agency (FEMA) created the National Risk Index (NRI) using historic and predictive climate disaster data from federal and state sources (see Appendix G) and socioeconomic indicators of community resilience and social vulnerability (FEMA, 2021). The NRI includes predictions of risk to communities from 18 different climate hazards: avalanche, coastal flooding, cold wave, drought, earthquake, hail, heat wave, hurricane, ice storm, landslide, lightning, riverine flooding, strong wind, tornado, tsunami, volcanic activity, wildfire, and winter weather. County-level data was used in this analysis as it most closely corresponds to MSAs.

Methods

1. Region/Scale Selection

The MSA spatial scale was selected based on data availability and time constraints. A Metropolitan Statistical Area (MSA) "consists of one or more counties with at least one urbanized area with a population greater than 50,000 inhabitants, with a high degree of economic and social integration with adjacent communities" (U.S. Census Bureau, 2021). MSAs are identified by a unique six-digit code known as core-based statistical area (CBSA) Federal Information Processing Standards (FIPS), which can be used for geospatial analysis.

All MSAs within the contiguous United States were considered with the exception of California due to its prohibitively high real estate costs. The list of MSAs was narrowed down to include areas with populations greater than 500,000 due to the client's involvement with traditional real estate investors who prefer investing in larger markets. In addition, the client requested the removal of 27 MSAs to avoid hyper-competitive real estate markets such as Tucson, Tallahassee, Salt Lake City, Dallas, etc. (full list in Appendix A). However, the model and framework developed in this project can be applied to any MSA in the future, not just those selected by ZNE Capital. All of the data for this project was collected for the most recent and complete year, 2021.

2. Real Estate

The metrics included in this criteria were population growth, employment growth, average annual occupancy, annual rent change, the ratios of median annual rent to median income, and median income to median home price. The data for each metric was gathered and normalized individually before being weighted and used to calculate the Real Estate score (see *section 2.7, Data Normalization and Weights*).

2.1 Population Growth

Population growth in a MSA is a commonly used real estate metric to gauge the demand for housing. The National Association of Realtors (NAR) identifies population growth as a key factor in determining a region's real estate market potential and a strong indicator of future demand for housing (Tracey, 2022).

The U.S. Census Bureau provides accurate demographic data at the MSA level, making it a reliable source for population estimates. To quantify the change in MSA populations, the group utilized the annual population estimates provided by the U.S. Census Bureau between April 1, 2020, and July 1, 2021. Additionally, the group excluded MSAs with a population growth rate below 0.5% to streamline the analysis. Population change was calculated using the following equation:

$$Population\ change\ = \frac{2021\ population\ estimate - 2020\ population\ estimate}{2020\ population\ estimate} \times 100$$

2.2 Employment Growth

This metric was included to ensure potential areas had prosperous economies as employment growth improves individuals ability to pay rent. Monthly unemployment rates were collected from the civil labor force data provided by the Bureau of Labor Statistics (BLS), an independent federal statistical agency that collects and analyzes data on labor market activity, including employment and unemployment rates. The BLS uses a sample survey methodology to collect data from households and businesses across the country, ensuring that its data is representative of the entire population. In the survey methodology, the civilian labor force includes those "who worked during reference week as paid employees, worked in their own business or profession, worked on their own farm, or worked 15 hours or more as unpaid workers on a family farm or in a family business; or those who did not work during the reference week but had jobs or businesses from which they were temporarily absent due to illness, bad weather, industrial dispute, vacation, or other personal reasons. This data excludes individuals working around the house or unpaid volunteer work for religious, charitable, and similar organizations; also excluded are all institutionalized people and people on active duty in the United States Armed Forces" (U.S. Bureau of Labor Statistics, 2022).

Monthly employment rates were calculated by dividing the employment count by the civilian labor force, and then the monthly rates were averaged to annual employment rates. The change in employment growth was calculated using the following equation:

$$change\ in\ employment\ rate\ = \frac{2021\ average\ employment\ rate - 2020\ average\ employment\ rate}{2020\ average\ employment\ rate} \times 100$$

2.3 Average Annual Occupancy Rates

Occupancy rate is the ratio of rented units to the total available units for rent in an MSA. Yardi Matrix is a robust research platform that gives users access to property-level information, including occupancy rates, for multifamily properties in the United States (Yardi Systems, n.d.).

Students used Yardi Matrix to collect average occupancy rates at the city level, identifying an anchor city based on the largest population size for MSAs comprising more than one city. For this metric, lower occupancy rates in an MSA signify lower demand for rental units.

2.4 Change in Median Rent

Median rent rates for fiscal year 2021 and 2022 were gathered for each MSA from the U.S. Department of Housing and Urban Development (HUD) and represent rates for one bedroom apartments (Office of Policy Development and Research, 2021). HUD is a government agency that collects and maintains vast amounts of data related to housing, community development, and urban affairs, which is rigorously reviewed, analyzed, and made available to the public. The agency is widely regarded as a reliable source for its' standardized methodologies for data collection.

It's worth noting that ZNE Capital offers apartments of various sizes, ranging from studios (~400 ft^2) to three-bedroom units(~1,150 ft^2), with the most common unit size being a 2 bedroom 1 bath apartment (~900 ft^2). Although the collected rental rates don't accurately represent the majority of ZNE Capital's units, assuming a one-bedroom apartment rental rate allows for a valid comparison between MSAs, as apartments across MSAs are uniform in size.

$$change\ in\ median\ rent\ = \frac{2022\ median\ rent - 2021\ median\ rent}{2021\ median\ rent} \times 100$$

2.5 Median Rent to Median Income

The U.S. Census Bureau provided data on the household median income for 2021 at the MSA level, using a standardized distribution in increments of $2,500 (U.S. Census Bureau, 2020, 89). To avoid a positive skew caused by high-income outliers, the median income was chosen over the mean income as a population indicator.

To assess apartment affordability, the 2021 annual median rent was divided by the median income, resulting in a rent-to-income ratio. Lower values indicate better affordability, which is favorable for ZNE Capital, as they seek tenants who are not rent-burdened. The rent-to-income ratio was then subtracted from 1 to generate an additive real estate score, with higher values indicating greater affordability and a better ability for renters to pay. This indicator directly captures renters' ability to pay, making it a useful tool for investment decision-making. Equations for calculations are seen below:

$$Rent\ to\ Income\ Ratio\ = \frac{2021\ median\ rent*12}{2021\ \ median\ household\ income}$$

$$Renter's\ Ability\ to\ Pay\ = 1 - \frac{2021\ annual\ median\ rent}{2021\ median\ household\ income}$$

2.6 Median Income to Median House Price

Median house prices were sourced from the National Association of REALTORS®, a prominent real estate platform for realtors. To determine the level of housing affordability, the 2021 median income was divided by the 2021 median house price, producing a metric that reflects the affordability of houses given income. Lower values indicate less affordability, which may lead individuals to rent. Therefore, the ratio was subtracted from 1 with higher values representing less affordable houses, meaning there individuals are more likely to rent than buy a house. Equations are below:

$$Income\ to\ Home\ Price\ Ratio = \frac{2021\ annual\ median\ household\ income}{2021\ median\ house\ price}$$

$$Renter's\ Inability\ to\ Buy\ a\ House = 1 - \frac{2021\ annual\ median\ household\ income}{2021\ median\ house\ price}$$

2.7 Data Normalization and Weights

Once the metrics were calculated, each was normalized for comparison across MSAs. Normalizing sets all metric values between 0 (indicating the worst investment area for a given metric) and 1 (best investment area for a given metric). This creates values in which metric scores are relative to each other. Normalization was performed using the following equation, where *x* refers to the metric that one wants to normalize:

$$x_{normalized} = \frac{x - x_{min}}{x_{max} - x_{min}}$$

The weights for the real estate criteria were provided by the client and are seen in Table 1. Higher weights represent the greater importance of the metric in calculating the real estate score. Each metric was multiplied by its corresponding weight, resulting in weighted metrics that summed to a real estate score for each MSA. The real estate criteria score was calculated using the following equation:

$$Score = \sum(weight * metric)$$

More specifically, the full equation is:

Real Estate Score = (0.35*Population Growth)+
(0.20*Employment Growth) +
(0.15*Average Occupancy Rate) +
(0.10* Rent Change) +
(0.10*Renter's Ability to Pay)+
(0.10*Renter's Inability to Buy a House)

The metrics for the real estate score are summarized below with the relative meaning. The weights below are associated with the client scenario, but can be adjusted by any stakeholder.

Table 1. Real Estate metrics with weights provided by the client.

Metric	Weight	Normalized Score Meaning
Population Growth (%)	0.35	Higher value = more favorable
Employment Growth (%)	0.20	Higher value = more favorable
Average Annual Occupancy (%)	0.15	Higher value =more favorable
Annual Rent Change (%)	0.10	Higher value = more favorable
Renter's Ability to Pay	0.10	Score was subtracted from 1, so higher value = more favorable
Renter's Inability to Buy a House	0.10	Score was subtracted from 1, so higher values = more favorable

3. Landlord Policies

3.1 Rent Control

The National Multifamily Housing Council (NMHC) collected publicly available data for each state's rent control policy and compiled it into a report (National Multifamily Housing Council, 2022). Rent control laws limit rental rates and prohibit landlords from raising rents, which can be seen as disadvantageous to rental property investors. This report offers a comprehensive summary of rent control laws across states, with the state laws linked in their document for ease of reference. This source was selected for its ability to consolidate all state laws in one place, with convenient links to the actual laws for further reading.

3.2 Eviction Notice

State eviction laws, including requirements for eviction notices, were collected from the The Policy Surveillance Program, housed at the Temple University Beasley School of Law (updated through January 1, 2021). This program collaborated with The Legal Services Corporation, an independent nonprofit created by Congress to fund civil legal aid for low-income people in America. The Policy Surveillance Program's data on eviction laws was chosen as it is comprehensive and legitimate, and produced in collaboration with a credible and established nonprofit organization. Landlords favor shorter required eviction notices as they can quickly replace non-paying tenants with paying ones.

Shorter eviction notice values allows landlords to carry out evictions promptly. The eviction notice (in days) for each state was normalized then subtracted from 1. This resulted in higher landlord policy scores for shorter eviction notices, which are more favorable for landlords, and subsequently, additive to the landlord policies score.

$$Eviction\ timeliness\ =\ 1 - normalized\ eviction\ notice$$

3.3 Security Deposit Limit

Security deposits are paid by renters upfront before moving in, and it serves as a financial safety net in case the tenant causes damage or loss during the lease period. State laws set a limit on the maximum security deposit limits that a landlord can charge. State security deposit limit data was collected from NOLO Law for All, a publisher that produces do-it-yourself legal books and software. NOLO Law for All is an accessible, informative source that provided the project with the information needed. The security deposit limit data was mapped onto a three-tiered score from 0 to 1 as seen in Table 2. “No limit” was determined to be most favorable and was therefore mapped to a value of “1”.

Table 2. State Security Deposit Limit Scoring System with 1 being most favorable

State Security Deposit Limit Policy	**Normalized score [0, 1]**
No limit	1.0
2 months of rent	0.5
1 month of rent	0.0

3.4 Landlord Policy Metric Weights

The client provided weights for each metric (Table 3), in which higher weights represent the greater importance of the metric in calculating the landlord policies score. Each metric was multiplied by its corresponding weight, resulting in weighted metrics that summed to the landlord score for each state. The landlord score was calculated using the same weight sum method as the real estate score. The complete equation including weights is:

Landlord Policies Score = $(0.80\ *\ Eviction\ Notice)\ +(0.20\ *\ Security\ Deposit\ Limit)$

Table 3. Landlord policies metrics with weights provided by the client.

Metric	Weight	Notes
Rent Control (Y/N)	Y = disqualify	Immediately disqualify location if there is rent control. This policy may be disregarded for model users who prefer to invest in rent control-affected states.[2]
Eviction Notice (days)	0.80	Fewer number of days is more favorable
Security Deposit Limit (# months of rent)	0.20	Larger security deposit limit is more favorable

4. REopt Model Overview

The REopt model is a publicly available, open-source web tool created by the National Renewable Energy Laboratory (NREL) that was used in this project to analyze the solar electricity generation, internal rate of return (IRR), CO_2 abatement potential, and human health impacts of installing rooftop solar on a standard apartment building (4 floors, 33,740 square feet). REopt was chosen for this analysis because by modeling rooftop solar energy generation and demand for an apartment building, it was able to model cohesive metrics across economic, environmental, and social criteria. Furthermore, REopt drew from other reliable national databases, including PVWatts, EPA AVERT, and OpenEI. All input values except location, electricity rate, and net metering system capacity were held constant in order to compare MSAs accurately. For MSAs that contained multiple cities, an "anchor city" was selected based on population size; a list of anchor cities can be found in the appendix. The REopt model calculated all metrics using both the optimal recommended solar installation and a business-as-usual (no solar) scenario to provide a baseline for comparison.

5. Electricity Generation from Solar

The electricity criterion contained one metric, the percentage of total annual energy consumption generated by solar, which was calculated by simulating an apartment building in a given area. Energy production data is provided by NREL's PVWatts Calculator, which analyzes the performance of potential PV installations. The energy production is calculated using a scenario that optimizes solar financials. The REopt tool recommends a solar PV system size for the building in a given area based on local residential utility rates. If an area receives 100% of total annual energy consumption from solar, it achieves net zero energy.

[2] Although rent control policy did not show up in the equation for landlord policies score, it was included as a metric in the landlord policies criteria and not as a generalized screening criteria because if users do not weight landlord criteria as important, rent controlled locations will not be disqualified.

6. Solar Internal Rate of Return

Solar internal rate of return (IRR) is the annual rate of return expected for installing the financially optimally sized rooftop solar project for an apartment at the simulated location. IRR is used to measure the profitability of investing in solar panels. In the REopt model, the IRR is calculated from the maximized net present value (NPV). The NPV of the alternative, investing in rooftop solar, is the present value of the savings (or costs if negative) from doing the project and determined using the equation:

$$NPV\ of\ alternative = (LCC\ of\ BAU) - (LCC\ of\ Investment\ Scenario)$$

In this equation, LCC is the total life-cycle costs after taxes and incentives for each project option. The total life cycle cost of energy in the business-as-usual (BAU) scenario represents the total cost of energy over the time period of analysis, without installing additional on-site solar.

7. CO_2 Abatement Potential

CO_2 abatement potential is an estimate of tons of carbon dioxide not emitted as a direct result of solar installation. This was calculated by approximating the electricity use of one standardized apartment building based on the generated load profile (see Appendix F), and the marginal emissions of the EPA AVERT[3] regional electric grid over a 25 year period. Marginal emissions factors were used to quantify the increase in grid emissions of CO_2 that result from a marginal change in electricity purchased from the grid. The CO_2 abatement potential of solar installation was calculated using the following equation:

$$CO2\ Abatement\ Potential = (BAU\ Lifecycle\ CO2\ Emissions) - (Investment\ Scenario\ Lifecycle\ CO2\ Emissions)$$

The metric was then normalized using the equation in Appendix B and subtracted from 1 to give greater CO_2 abatement a higher score:

$$CO2\ Abatement\ Potential\ Score = 1 - (Normalized\ \ CO2\ Abatement\ Potential)$$

8. Health Impact Mitigation

Health impacts are quantified using the social cost of carbon to represent the cost of premature mortality due to pollution from residential electricity generation. The social cost of carbon is a monetary estimate of the damages that would result from emitting one additional ton of carbon dioxide; it is commonly used in cost-benefit analyses of implementing environmental policies

[3] EPA AVERT (Avoided Emissions Generation Tool) "estimates emissions reductions based on regional conditions and data" (U.S. Environmental Protection Agency, 2023).

and investment decisions (Rennert et al., 2022). The social cost of carbon is determined based on multiple economic, climate, and demographic factors as well as a discount rate which heavily influences the final calculation. The social cost of carbon used in this model was \$185/ton CO_2, the most accurate value at the time of publication (Rennert et al., 2022). The health impacts metric was calculated by the REopt model as the combined costs of marginal emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx) and PM 2.5 over a 25 year period (Anderson et al., 2023 p. 45) using the following equation:

$$Lifecycle\ costs\ of\ health\ emissions\ (\$)\ =\ \$185/ton\ *\ [(\ tons\ SO2)\ +\ (tons\ NOx)\ +\ (tons\ PM2.5)]$$

For the purposes of this analysis, the difference between the business as usual (BAU) scenario and the investment scenario was used to represent the potential impacts on human health that could be mitigated by installing rooftop solar on multifamily housing in each MSA. The raw health impact mitigation score was calculated using the following equation:

$$Health\ Impact\ Mitigation\ (\$)\ =\ (BAU\ lifecycle\ costs\ of\ health\ emissions)\ -\ (Investment\ scenario\ lifecycle\ costs\ of\ health\ emissions)$$

The health impact mitigation score was then normalized using the equation in Appendix B and subtracted from 1 to give greater mitigation a higher score:

$$Health\ Impact\ Mitigation\ Score\ =\ 1\ -\ (Normalized\ \ Health\ Impact\ Mitigation\ Score)$$

9. Climate Risk Avoidance

9.1 Climate Risk Avoidance Overview

Climate risk avoidance was incorporated into the model using the overall risk score from the National Risk Index (NRI) created by the Federal Emergency Management Agency (FEMA). The overall risk score is a representation of risk relative to the expected annual loss, social vulnerability, and community resilience of all other counties (see section 5.2). Areas with a high climate risk score according to the NRI were ranked lower in the investment favorability score.

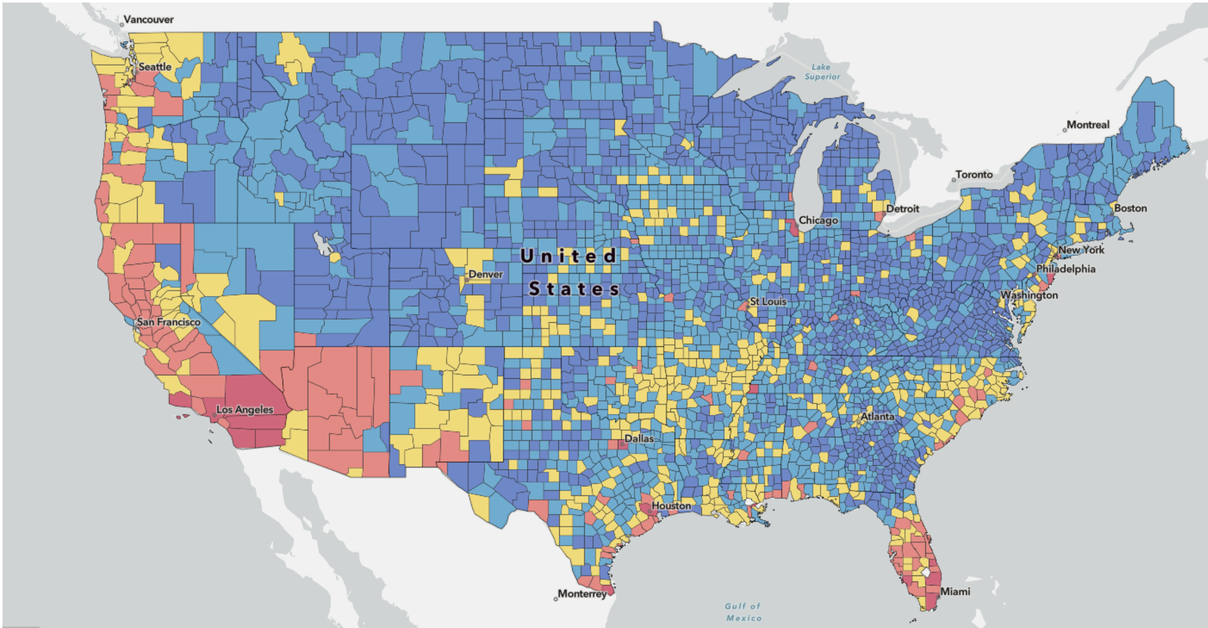

Figure 2. Map visualization of relative overall climate risk scores by county. *Source: Federal Emergency Management Agency, 2021*

9.2 National Risk Index Terms and Definitions

- Community resilience: FEMA draws this from the National Institute of Standards and Technology which defines community resilience as "the ability of a community to prepare for anticipated natural hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions."

- Expected annual loss: This is the average economic loss from natural hazards per year. Expected annual loss is computed for the different hazard types since some hazards impact buildings, some impact agriculture, etc. The expected annual loss for drought exclusively quantifies harm to agriculture.

- Social vulnerability: This metric is calculated using 29 different socioeconomic variables, including median gross rent for renter-occupied housing units, per capita income, percentage of population over 25 with <12 years of education, percentage of population speaking English as second language (with limited English proficiency), and data on racial demographics.

9.3 FEMA Risk Index Calculation

FEMA's overall risk score was calculated using the "Generalized National Risk Index Risk Equation" (FEMA, 2021, pg. 35), which multiplies the expected annual loss by social vulnerability (a risk-compounding factor) and inverse community resilience (a risk-reducing factor). These calculations were done on both county and census tract levels; county-level data was used in this study because it was closer in scale to the MSAs used for other model criteria. Each component of the risk score was calculated relative to other counties (Federal Emergency Management Agency, 2021). For detailed information on FEMA's source data, see Appendix G. A low overall risk score is more favorable since it indicates a low threat of damage from natural disasters and a high ability of a community to recover if a natural disaster occurs. The overall risk score was subtracted from 1 to compute the climate risk avoidance score. Higher climate risk avoidance scores represent lower climate risk and are preferred to add to the investment favorability score.

$$Overall\ risk\ score\ =\ expected\ annual\ loss\ x\ social\ vulnerability\ x\ (1/community\ resilience)$$

$$Climate\ Risk\ Avoidance\ =\ 1-Overall\ Risk\ Score$$

9.4 Notes on Reproducibility of the Climate Risk Avoidance Criterion

When replicating this methodology to locate areas for investment in multifamily housing, it is necessary to consider that the hazards FEMA prioritizes might differ from what investors prioritize. For example, real estate investors might be more concerned with potential property damage from coastal flooding but not concerned with the impact of drought on agriculture. Fortunately, FEMA's map and raw data allow users to analyze risk scores for each climate hazard individually. Therefore, parties interested in reproducing this methodology using the open source code can incorporate into the model specific climate risks in addition to or instead of overall risk.

10. Investment Favorability Score

The investment favorability score of rooftop solar on apartment buildings was calculated as a weighted additive total of the seven criteria scores.

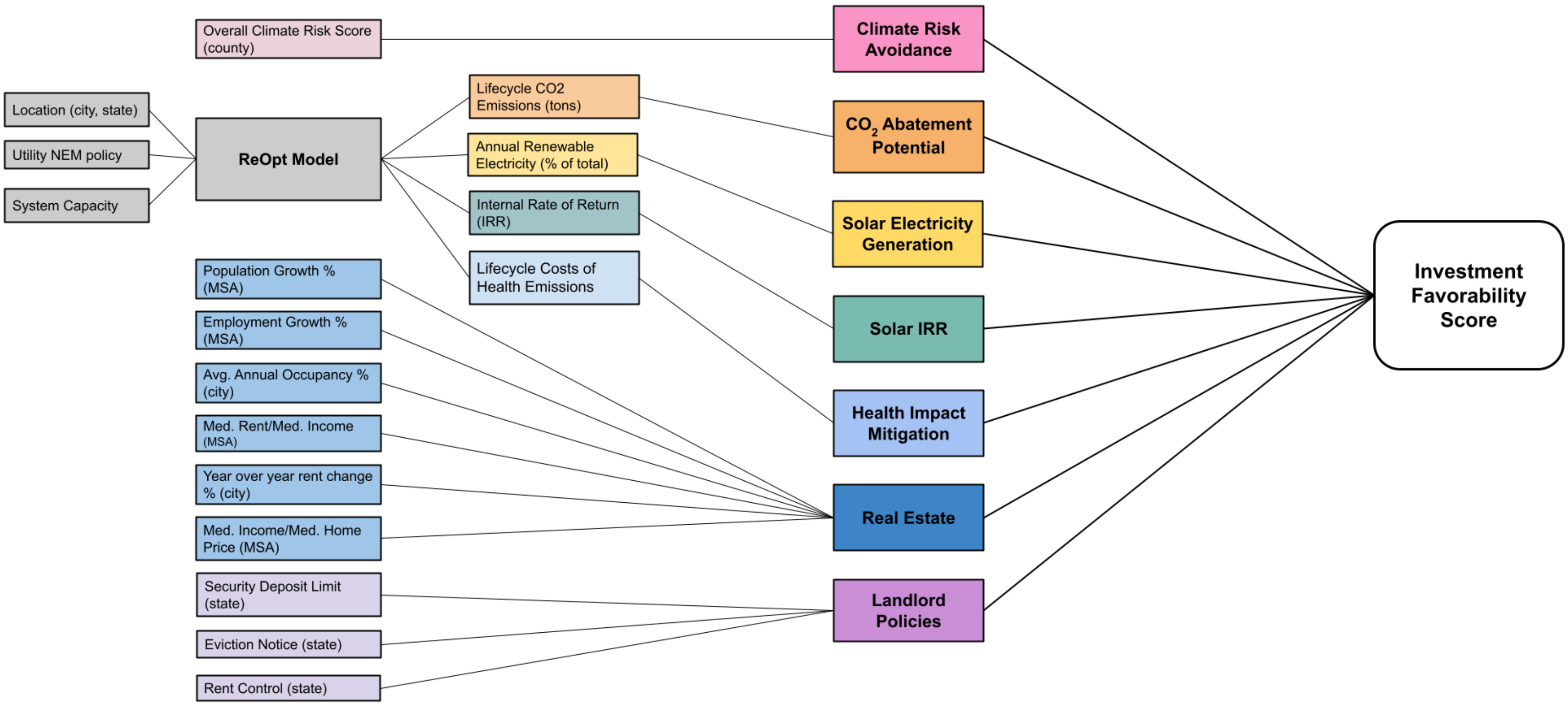

Figure 3. Full model schematic showing the indicator metrics (left) for each of the seven model criteria (right): climate risk avoidance (pink), CO_2 Abatement Potential (orange), Electricity (yellow), Solar IRR (green), Health Impacts (light blue), Real Estate (dark blue), and Landlord Policies (purple).

Weights for each criterion can be adjusted in the model based on user priorities. The client's weights reflect relative importance in ZNE Capital's decision making for their business model. An example equity-centric scenario was included to represent non-profit or government stakeholders that maximize positive social and environmental impact by prioritizing CO_2 abatement potential and health impacts. See Table 4 for client and equity-centric weights for each criterion.

Table 4. Client and equity-centric weights for each model criteria.

Criteria	Client Weights	Equity-Centric Weights
Real Estate	0.18	0.18
Landlord Policies	0.07	0.00
Solar IRR	0.11	0.10
CO_2 Abatement Potential	0.07	0.19
Health Impacts	0.00	0.17
Climate Risk Avoidance	0.50	0.22
Electricity Production	0.07	0.14

Results

The seven criteria scores were calculated for each of the 29 MSAs included in the analysis using the client weights (Table 4), and the results of the scores can be seen in the following GIS maps.

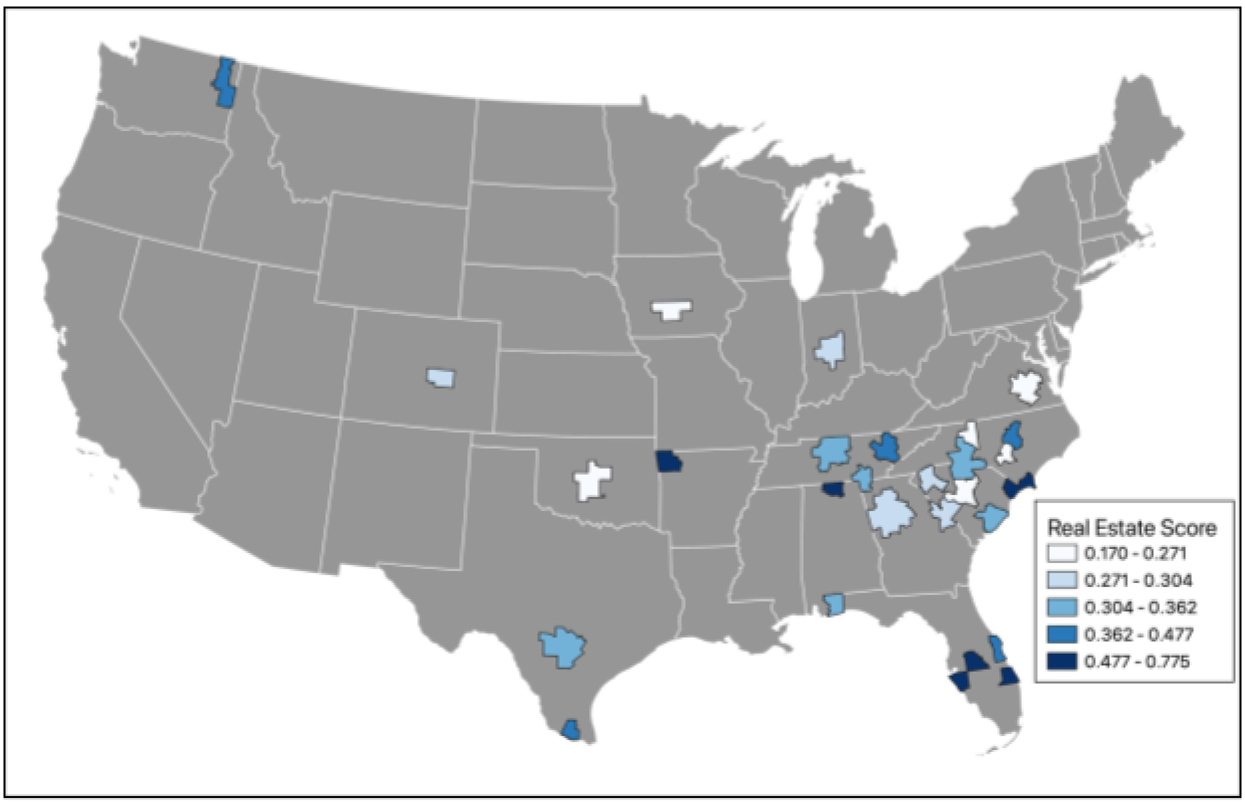

Figure 4. Real Estate Score Map. Relative real estate scores for MSAs (n = 29), calculated from normalized and weighted metrics. The top performing MSAs in the real estate criteria were Myrtle Beach, SC (0.78), followed by Lakeland, FL (0.73) and Sarasota, FL (0.62). These locations were driven to the top by their high population growth and employment growth.

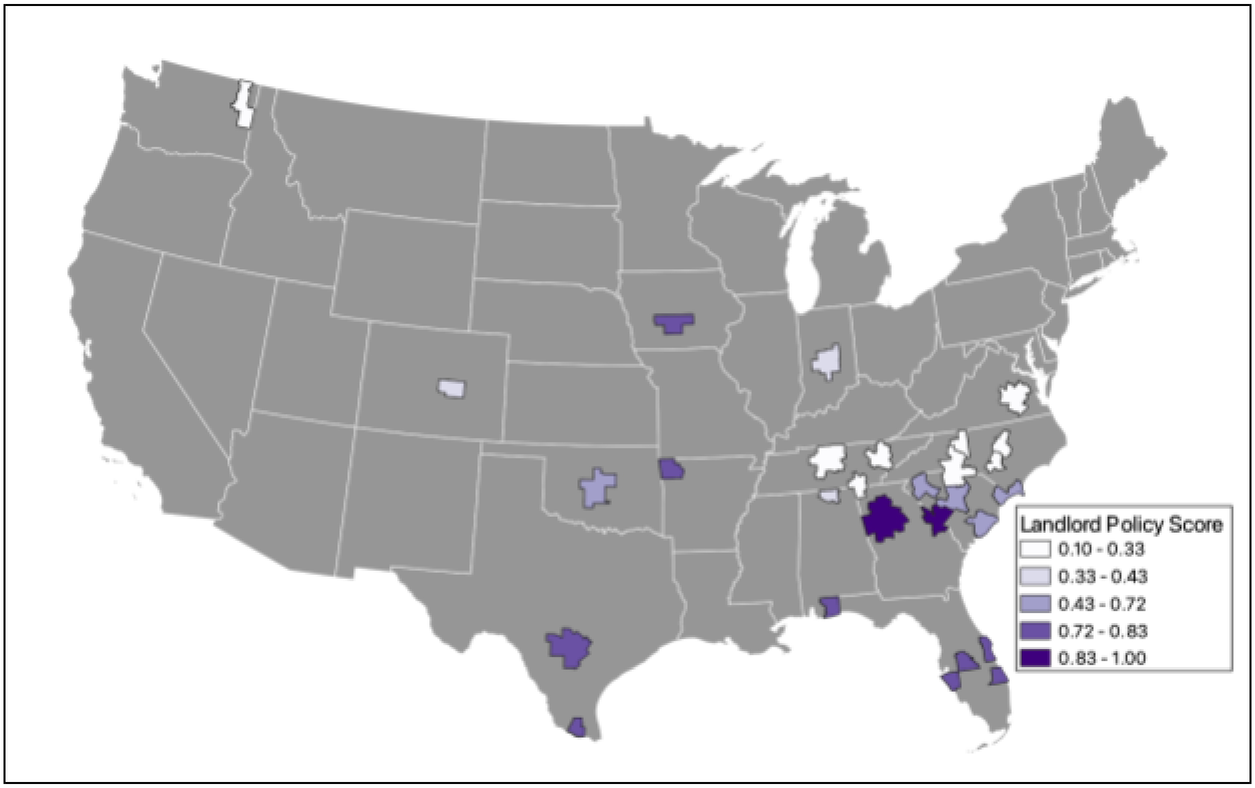

Figure 5. Landlord Policies Score Map. Relative landlord policies scores, in which MSAs (n=28) within the same states had consistent scores. Since the landlord policies data was consistent throughout each state, MSAs within each state had the same score for the landlord criteria. Georgia had a perfect score (1.0), followed by a tie between Florida and Texas (0.829). One MSA in Maine did not receive a score for this criteria due to state rent control policies.

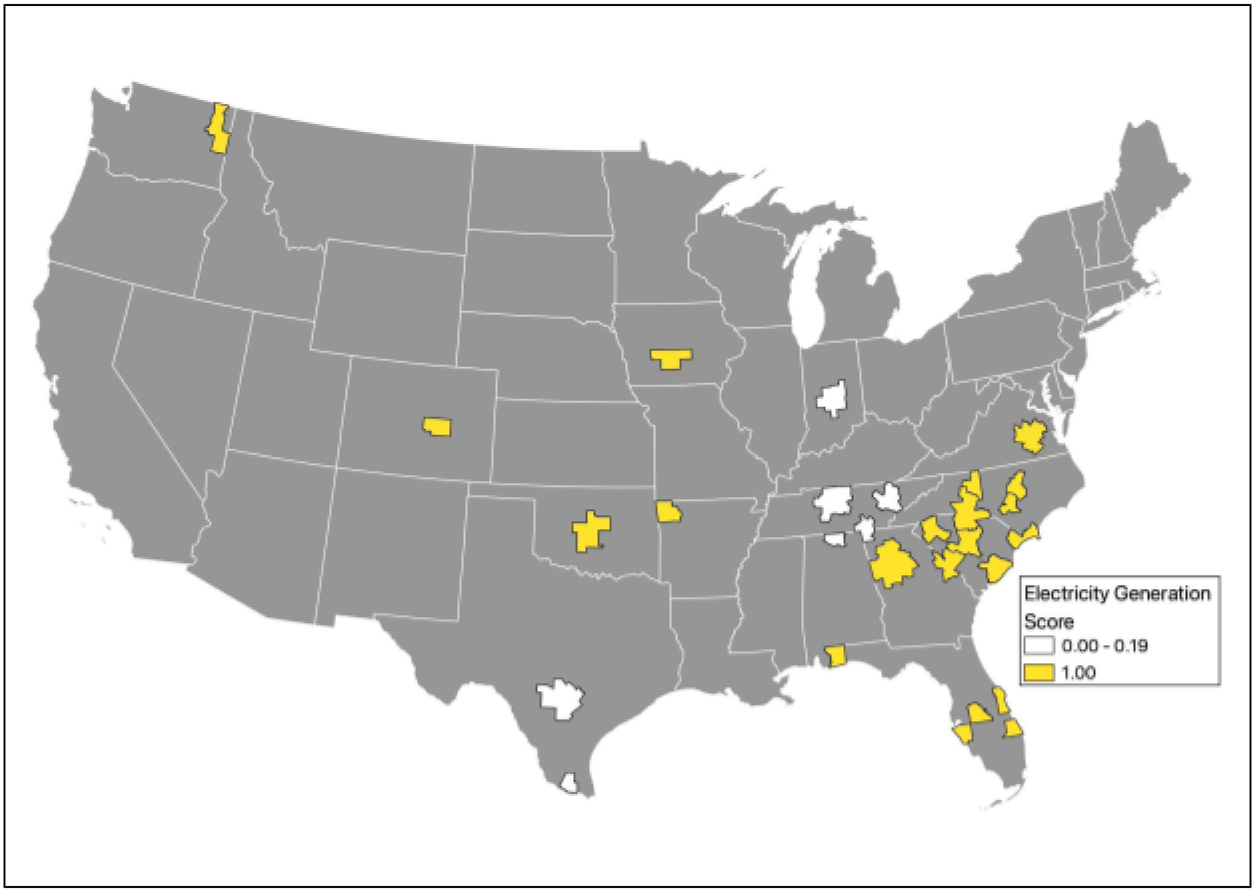

Figure 6. Solar Electricity Score Map. Relative electricity score using percent annual renewable energy production. For 22 of the 29 MSAs analyzed, recommended solar PV installation size was sufficient to make the apartment complexes net zero energy, meaning the total amount of energy generated by rooftop solar is equal or greater than the apartment energy consumption on an annual basis according to the REopt model. This means that the financially optimal recommended rooftop solar installation size was sufficient to cover the apartment building's electricity use. These net zero locations are depicted in yellow on the above map.

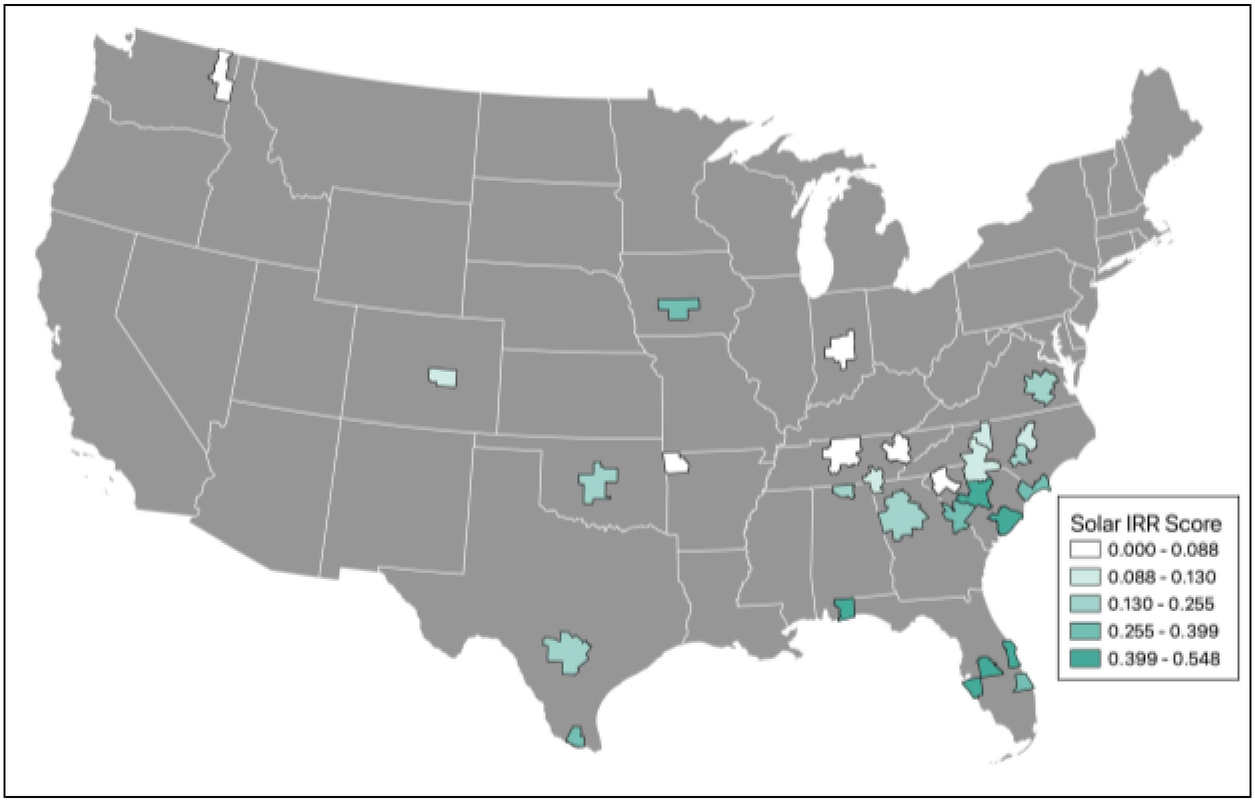

Figure 7. Solar IRR Score Map. Relative internal rate of return (IRR) of a rooftop solar project on an apartment building in the given MSA based on REopt model calculations. The IRR is the annual rate of return expected for installing the financially optimally sized rooftop solar project for an apartment at the simulated location. Portland, ME ranked the best with an IRR of 25.40% followed by Charleston, SC (IRR 17.66%) and Columbia, SC (IRR 17.30%). The location's NEM policy and residential time of use rates were primary drivers of IRR.

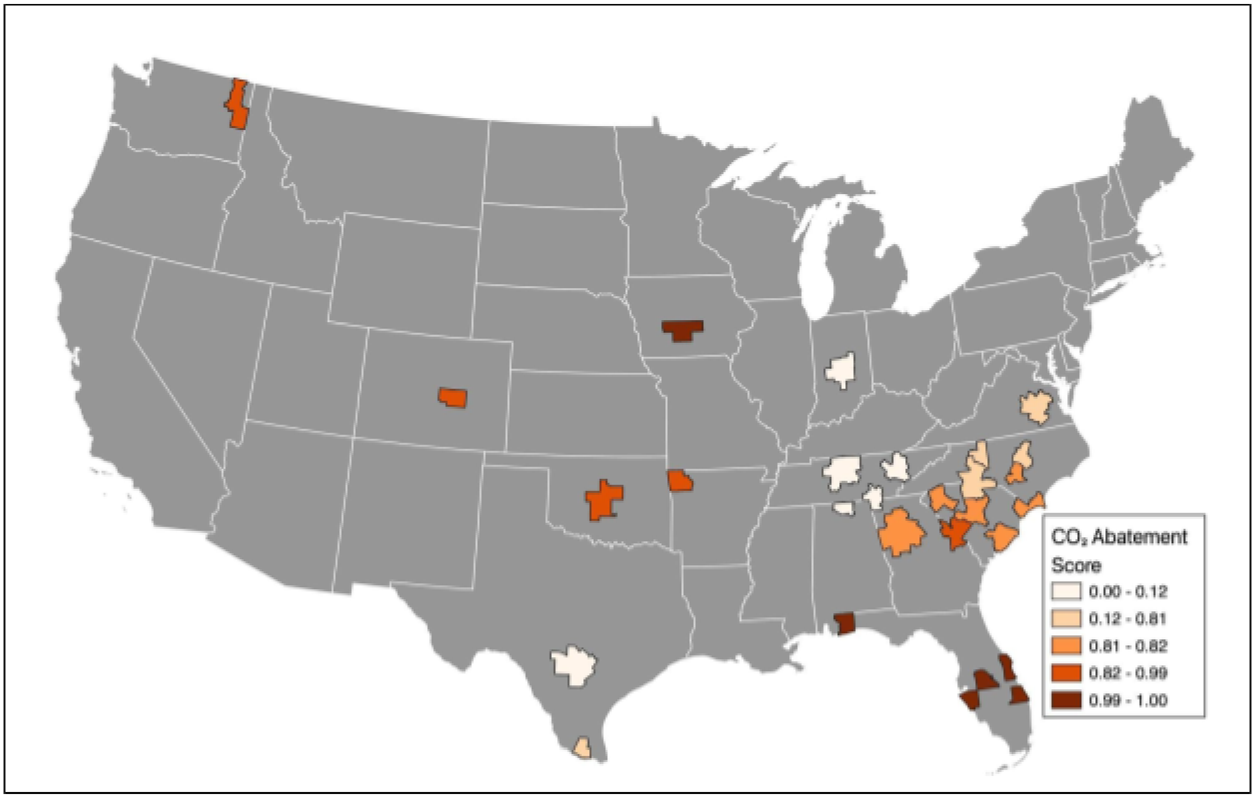

Figure 8. CO_2 Abatement Potential Score Map. Relative abatement of CO_2 emissions compared to BAU scenario without solar installation in a given MSA. The REopt model calculated the reduction in CO_2 emissions due to installing the recommended rooftop solar project, as compared to business as usual where no solar is installed. The top locations for abatement in CO_2 emissions were Port St. Lucie, FL (4,848 tons CO_2), Lakeland, FL (4,835 tons CO_2) and Pensacola, FL (4,834 tons CO_2). This is largely driven by high recommended solar installation sizes, high average annual solar energy production, and large mitigated total utility electricity costs in these locations.

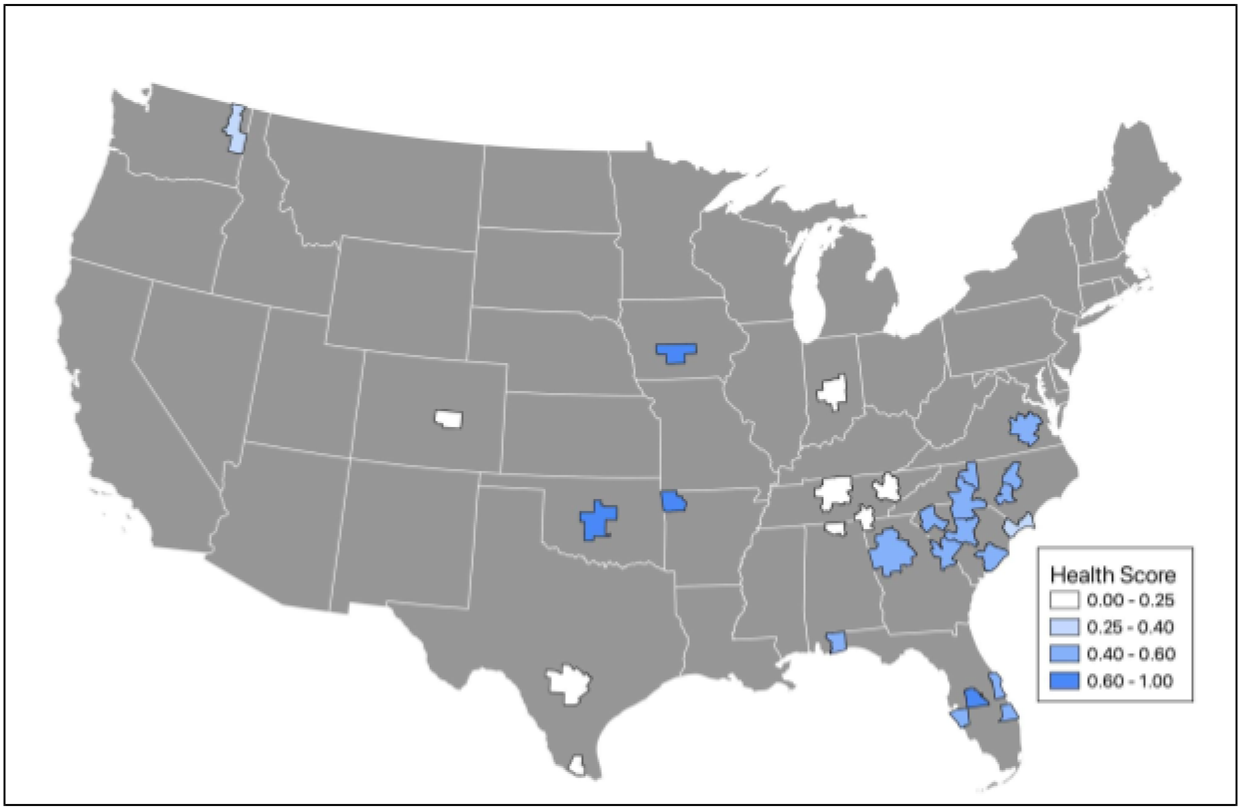

Figure 9. Health Impacts Mitigation Score Map. Relative health score for given MSA using reduction in health costs from BAU. The REopt model calculated the reduction in lifecycle costs of health emissions from business as usual (no solar installation) due to mitigated NOx, SO_2, and PM2.5 pollutants. The top MSAs for mitigated heath costs were Des Moines, IA ($189,373), Oklahoma City, OK ($127,479), and Fayetteville, AR ($125,724). These locations ranked highest due to relatively dirty grid mixes and high grid emissions factors for the midwest and central U.S.

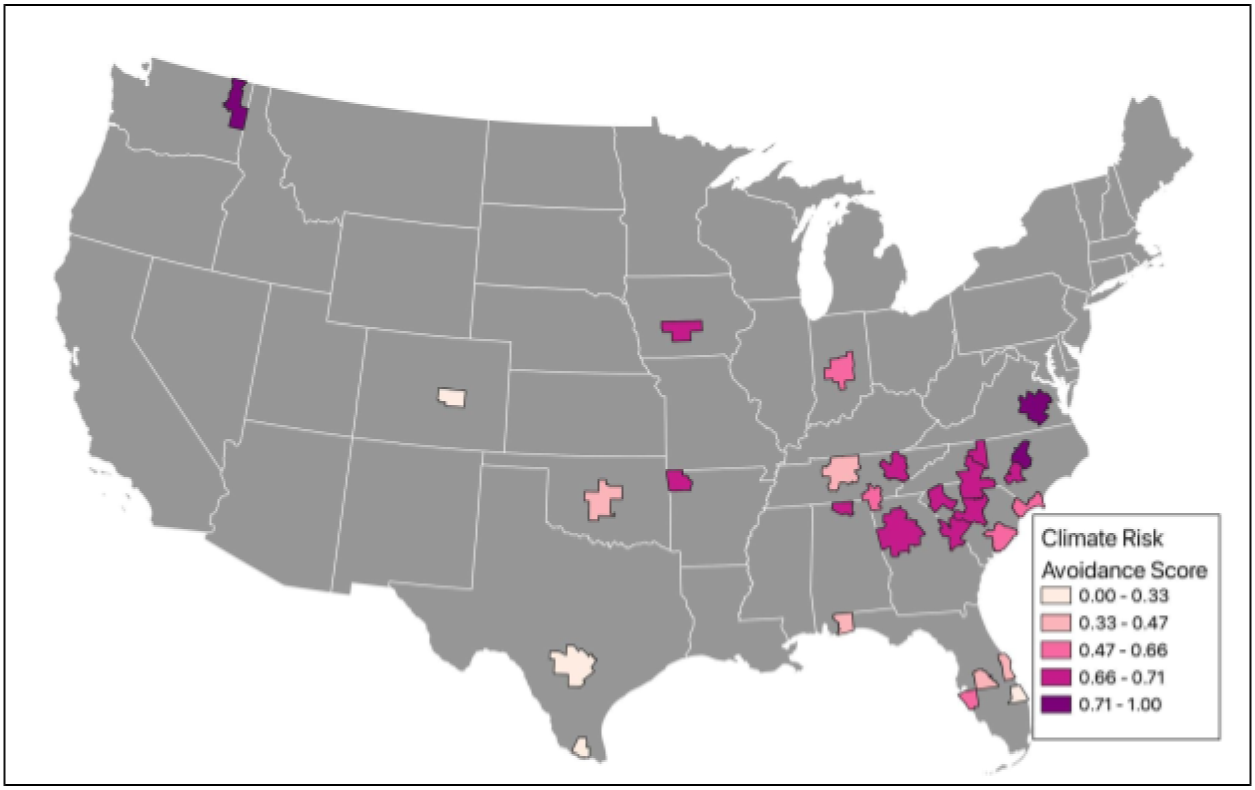

Figure 10. Climate Risk Avoidance Score Map. Relative climate risk avoidance avoidance for MSAs. MSAs with high climate risk avoidance are subject to lower damages from natural disasters and have the ability to recover from natural disasters that occur. The relative climate risk avoidance was lowest for Richmond, VA (1.0), Portland, ME (0.86), Raleigh, NC (0.81) and Spokane, WA (0.76). These locations have low overall climate risk avoidance scores, which can be driven by a combination of relatively low expected annual loss from natural hazards, low social vulnerability, and high community resilience.

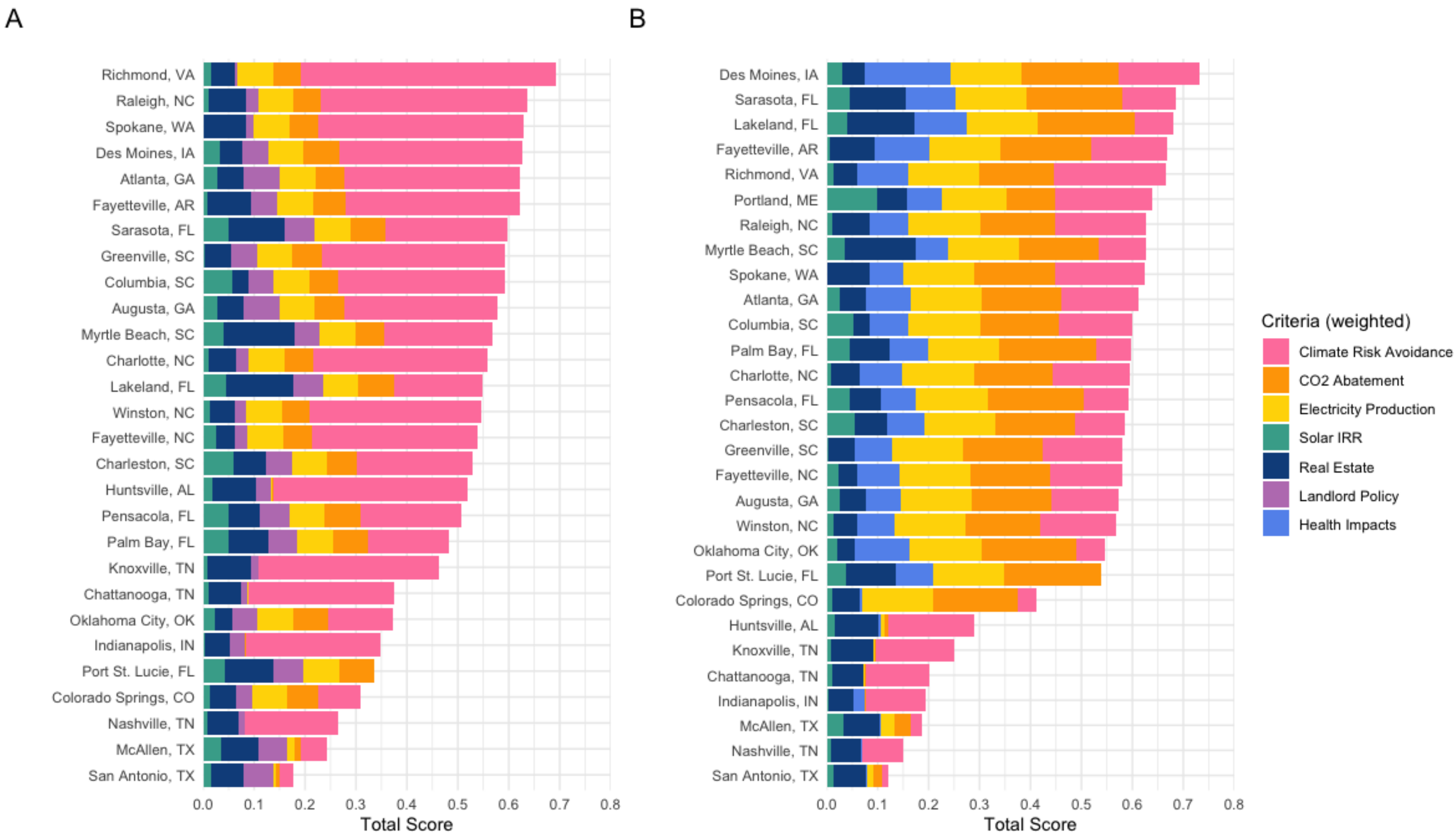

Figure 11. Investment Favorability Score Bar Charts **A)** Bar chart of overall investment favorability score factoring in all seven criteria based on client weights with MSAs listed from best to worst. Since the client weighted climate risk avoidance so highly (50%), overall suitability scores were dominated by the climate risk avoidance criteria for the top-performing MSAs. The top three performing MSAs were Richmond, VA (0.692), Raleigh, NC (0.637), and Spokane, WA (0.630). These top-performing MSAs also had strong contributions from the abatement of CO_2 emissions, percentage of electricity generated by solar, and real estate criteria. These MSAs performed relatively poorly in the solar IRR and landlord criteria. **B)** Bar chart of investment favorability score based on equity-centric weights with MSAs listed from best to worst. The equity-centric weights aim to find a socially and environmentally optimal ranking, and thus provide more equal weightings to climate risk avoidance, abatement of CO_2 emissions, percentage renewable electricity, and real estate criteria. As such, the investment favorability scores have more even contributions from each criteria. The top three performing MSAs were Des Moines, IA (0.731), Sarasota, FL (0.685), and Lakeland, FL (0.681).

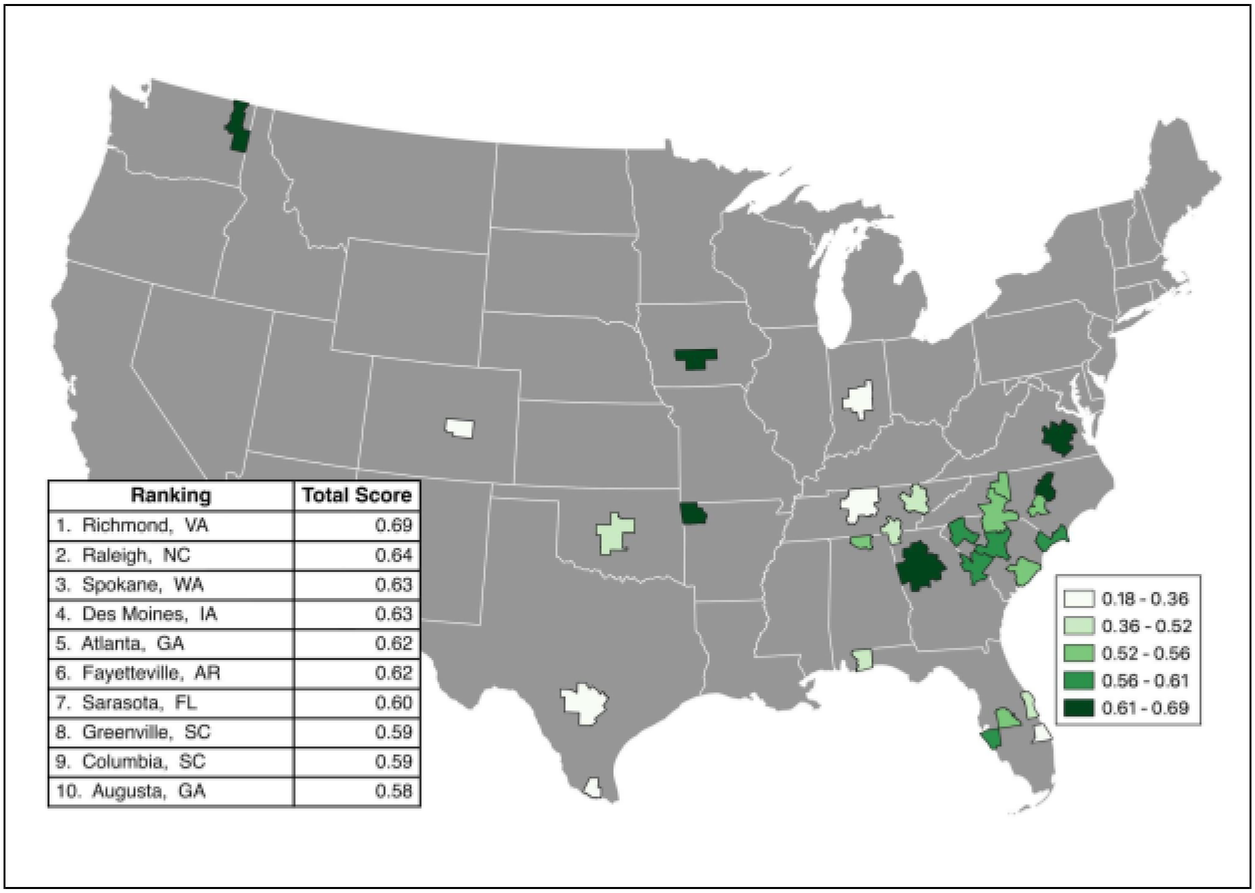

Figure 12. Client Investment Favorability Score Map. Spatial representation of investment favorability scores based on client weights. This map shows the investment favorability score of MSAs based on the client's weights. The top 10 performing MSAs and their scores are displayed to the left. Darker green MSAs had higher investment favorability scores. This spatial representation of the same data from the bar chart in Figure 11 A allows for geographic trends to be more easily identified. For example, it can be seen that MSAs in the southeast states of Georgia, South Carolina, North Carolina, and Virginia are all relatively favorable for investments. Meanwhile, states without net energy metering policies (Texas, Tennessee, Indana) score unfavorably.

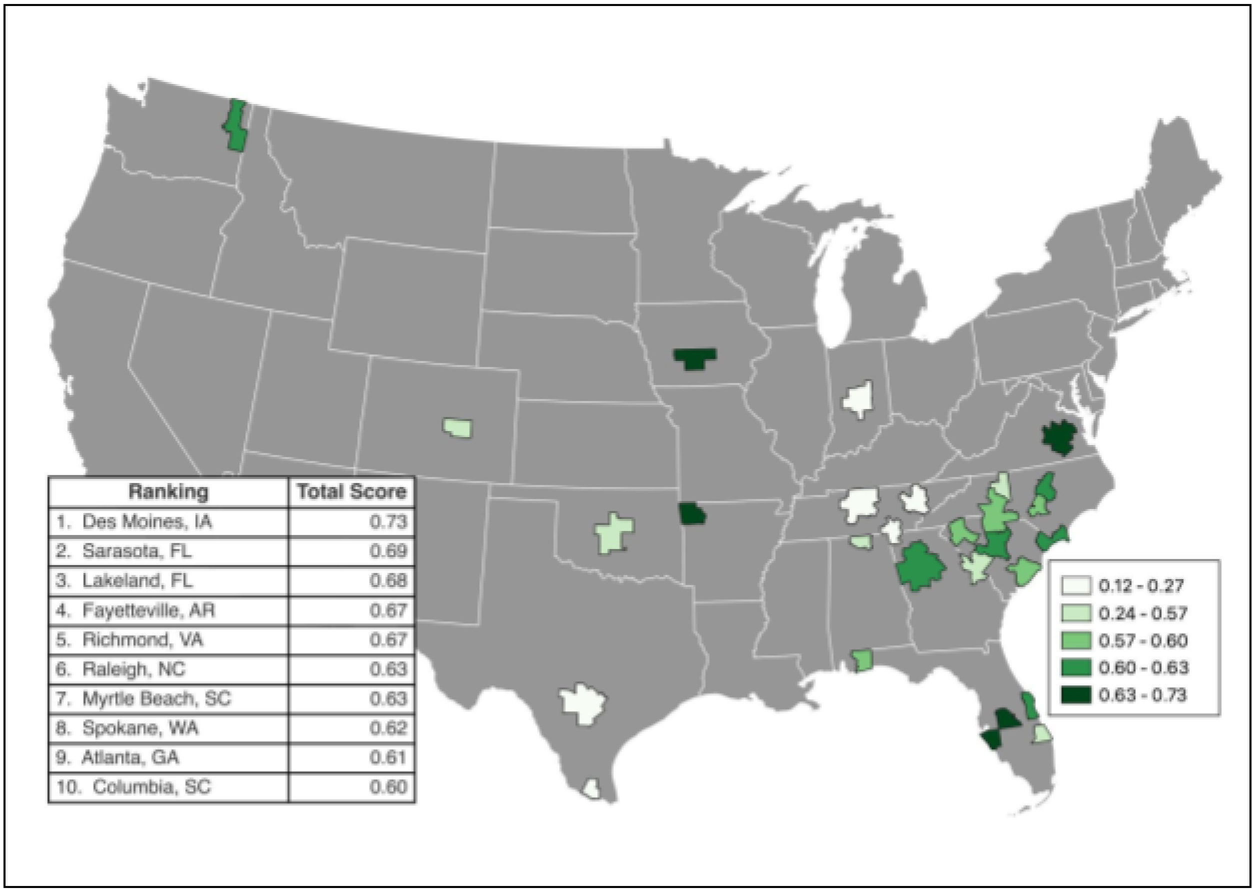

Figure 13. Equity-Centric Investment Favorability Score Map. Spatial representation of investment favorability scores based on equity-centered weights This map shows the investment favorability score of MSAs based on the equity-centric weights. The top 10 performing MSAs and their scores are displayed to the left. Darker green MSAs had higher investment favorability scores. This spatial representation of the same data from the bar chart in Figure 11 B allows for geographic trends to be more easily identified.

Discussion

Rationale for Client Weights

The client chose weights based on what was necessary to prioritize in order to attract investors to ZNE Capital. This is why landlord policies were an important criteria for ZNE Capital but not for an equity-centric approach. Landlord friendly policies (such as the absence of rent control) can make multifamily real estate seem like a "safer" option for investors. In addition to landlord policies, the biggest difference between client and equity-centric weights was the climate risk avoidance category. ZNE Capital gave this a weight of 0.50 while the equity-centric approach gave it a weight of 0.22. ZNE Capital wanted to weigh climate risk avoidance heavily because they are looking at long term investment potential and want their properties to be low long term risk for investors. Since collecting capital from investors is necessary for ZNE Capital's mission of decarbonizing multifamily housing, their weights tend to reflect the priorities of investors.

Rationale for Equity Weights

An example of equity-centric weighting was determined by the student team. The students voted anonymously on how they would weight the criteria from the perspective of prioritizing general societal and environmental welfare. Each criteria's weight was chosen based on how important each student felt it was to the mission of equitably decarbonizing the built environment. Anonymous student weights for each criteria were averaged and rounded to sum to 1 (see Table 4 for all weights). This resulted in the equity-centric weight of 0.17 for health impacts, which measures where solar installation would have the greatest positive impact on human physical well being, and 0.19 for CO_2 abatement potential, which measures the contribution of solar installation in a given location to reducing greenhouse gas emissions. The equity-centric approach also weighed climate risk avoidance notably lower than the client (0.22 and 0.5, respectively) because students agreed that even communities with higher relative climate risk would greatly benefit from solar installation in the near term.

Impact of Criteria Weights on Investment Favorability Score

As shown in Figures 11, 12 and 13, weighting criteria differently results in different investment favorability high-scoring MSAs. The model is structured in such a way that users can weight criteria according to their priorities, both within criteria and for the investment favorability score. For example, the client prioritized the long-term climate risk avoidance and real estate criteria, which resulted in higher scores for MSAs that had the lowest overall climate risk and most favorable real estate metrics (primarily high population growth and employment rate). In contrast, the equity-centric model prioritized climate and health impacts of solar installation.

Model Uses

By altering the seven criteria weights, this model can capture the preferences of a wide range of stakeholder priorities. For example, a state government interested in funding rooftop solar on multi-family housing may assign higher weights to CO_2 abatement, climate risk avoidance, and solar IRR, while criteria such as renewable electricity production, health impacts, and real estate may receive lower weights. As another example, a philanthropic green investor may prioritize social equity benefits by assigning higher criteria weights to health impacts, CO_2 emissions abatement, and real estate. In conclusion, this study analyzed 29 MSAs using seven criteria categories to rank each for investment favorability. Two scenarios, client and equity-centric, were compared to understand the impacts of the criteria weights. While the order of the areas varied between scenarios, 7 MSAs were included in both scenarios' top ten list. This indicates the model is highly robust to score areas based on investment favorability.

Future Work

The model in this project is flexible, but it currently excludes some potentially profitable smaller markets due to a population size requirement. Removing this requirement would increase the number of analyzed MSAs and allow for investment in overlooked markets. California, Alaska, and Hawaii were excluded due to high real estate costs and logistical constraints, but including them would enable a more complete analysis of solar potential in multifamily housing across the US. In addition, this analysis was conducted using 2021 data, the most recent complete year of data available. It was important to capture post-COVID pandemic demographic trends and real estate demand. The model can be updated using more recent data, allowing real estate investors to quickly respond to market trends.

This model may also be applied to other types of commercial properties by running the REopt model to simulate the financial feasibility of solar PV on these building types. Other building types offered by REopt include: hospitals and health care centers, hotels, schools, office buildings, retail stores, supermarkets, and warehouses. Each of these building types have specific customer needs that may find value in rooftop solar. For example, keeping electricity during a power outage event is critical to refrigeration of medicines and providing lifesaving health services at hospitals and health centers. The adaptability of the model allows it to be applied to other applications that aim to decarbonize the pre-existing build environment.

For the climate risk category, the National Risk Index scores used for each MSA include data about the community's resources available to respond to climate change-induced natural disasters. To ensure that potentially disadvantaged communities are not ranked lower due to their lower resource availability, future iterations of the model may draw upon only total damages from natural disasters, rather than community resilience to balance out equity concerns.

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Appendix

A. MSAs Removed by the Client due to Hyper-competitive Real Estate Market

1. Albany-Schenectady-Troy, NY
2. Allentown-Bethlehem-Easton, PA-NJ
3. Austin-Round Rock-Georgetown, TX
4. Baton Rouge, LA
5. Boise City, ID
6. Cape Coral-Fort Myers, FL
7. Corpus Christi, TX
8. Dallas-Fort Worth-Arlington, TX
9. Deltona-Daytona Beach-Ormond Beach, FL
10. Denver-Aurora-Lakewood, CO
11. Gainesville, FL
12. Harrisburg-Carlisle, PA
13. Houston-The Woodlands-Sugar Land, TX
14. Jacksonville, FL
15. Las Vegas-Henderson-Paradise, NV
16. Naples-Marco Island, FL
17. Ogden-Clearfield, UT
18. Orlando-Kissimmee-Sanford, FL
19. Phoenix-Mesa-Chandler,AZ
20. Poughkeepsie-Newburgh-Middletown, NY
21. Provo-Orem, UT
22. Reno, NV
23. Salt Lake City, UT
24. Tallahassee, FL
25. Tampa-St. Petersburg-Clearwater, FL
26. Tucson, AZ
27. Tulsa, OK

B. Normalization Equation

$$x_{normalized} = \frac{x - x_{min}}{x_{max} - x_{min}}$$

C. Anchor Cities

For MSAs with multiple cities, the city with the largest population was chosen as a representative anchor city to run the REopt model, which operates on a city level.

Table 5. Anchor cities

MSA	Anchor City	State
Atlanta-Sandy Springs-Alpharetta	Atlanta	GA
Augusta-Richmond County	Augusta	GA
Charleston-North Charleston	Charleston	SC
Charlotte-Concord-Gastonia	Charlotte	NC
Chattanooga	Chattanooga	TN
Colorado Springs	Colorado Springs	CO
Columbia	Columbia	SC
Des Moines-West Des Moines	Des Moines	IA
Fayetteville	Fayetteville	NC
Fayetteville-Springdale-Rogers	Fayetteville	AR
Greenville-Anderson	Greenville	SC
Huntsville	Huntsville	AL
Indianapolis-Carmel-Anderson	Indianapolis	IN
Knoxville	Knoxville	TN
Lakeland-Winter Haven	Lakeland	FL
McAllen-Edinburg-Mission	McAllen	TX
Myrtle Beach-Conway-North Myrtle Beach	Myrtle Beach	SC
Nashville-Davidson--Murfreesboro--Franklin	Nashville	TN
North Port-Sarasota-Bradenton	Sarasota	FL
Oklahoma City	Oklahoma City	OK
Palm Bay-Melbourne-Titusville	Palm Bay	FL
Pensacola-Ferry Pass-Brent	Pensacola	FL
Port St. Lucie	Portland	ME
Portland-South Portland	Port St. Lucie	FL
Raleigh-Cary	Raleigh	NC
Richmond	Richmond	VA
San Antonio-New Braunfels	San Antonio	TX
Spokane-Spokane Valley	Spokane	WA
Winston-Salem	Winston	NC

D. REopt model inputs

Table 6. REopt model inputs. *Source: National Renewable Energy Laboratory*

ReOPT Parameter	**Value**	**Notes**
Electricity Goals	Cost savings, clean electricity	Omitting resilience, as Client is not interested in battery storage due to costs
Technologies	PV, Grid	PV = photovoltaic (solar)
Site Location	**City, State**	MSAs contain one or more cities; for MSAs with multiple cities, the city with the highest population will be used to represent the MSA
Electricity Rate	**Utility: Residential Rate Time of Use (if available)**	Utilities provided by REopt with electricity rates from OpenEI: International Utility Rate Database
PV Space Available	**Roofspace only**	Client will be installing solar on rooftops only
Net Metering System Size Limit (kW)	**State net metering limit *100**	Assuming 100 units per apartment, one meter per apartment (submetered); value of 0 indicates no NEM policy
Typical Electrical Load: Type of Building	**Mid-rise Apartment**	33,740 ft^2, 4 floors (standardized building size across all MSAs)
Analysis Period (years)	25	REopt, SAM, ASTM International use 25 years, range from 10 to 40 years.
Host Discount Rate (%)	5.64%	Default value, accepted by client; the rate at which the future value of all future costs and savings is discounted
Electricity cost escalation rate (1.9%)	1.9%	Average value from U.S. Energy Information Administration's (EIA) Annual Energy Outlook, calculated from expected inflation rate; range from 1.5% to 2.4%
Host effective tax rate (%)	**0%**[4]	The percent of income that goes to tax.

[4] The client's effective tax rate is zero because the IRS allows real estate investors to depreciate the value of their property over 27.5 years, or do a cost segregation study, so that the calculated depreciation is greater than their revenue from the property.

		The tax value default is currently 26%—the sum of a 21% federal rate plus a 5% average state rate
O&M Cost Escalation Rate (%)	2.5%	Assumed to escalate at inflation rate
Projected annual percent decrease in grid emission factors (%/year)	1.174%	National average, likely varies by state/region
Include climate and health costs in the objective?	No, just report costs	CO_2 and health emissions do not influence recommended solar installation
CO_2 Cost (\$/ton CO_2)	**$185**	Based on a 2% discount rate (Rennert et. al 2022)
System Capital Cost ($/kW-DC)	$1,592	Based on numerous recent NREL studies
O&M Cost ($/kW/year)	$17	Based on 2021 Annual Technology Baseline and Standard Scenarios (NREL), assumed fixed cost
Array Type	**Premium, Rooftop fixed**	
Array Azimuth (degrees)	180	Assumes the array is in the northern hemisphere and is facing due south, which yields the greatest electricity production
Array Tilt (degrees)	**10**	Default value; angle from horizontal of solar panels in the rooftop array
DC to AC Size Ratio	**1.35**	Advised by client
System Losses (%)	**5**	Advised by client
Federal Incentive based on percentage of cost (%)	**30%**	Based on Inflation Reduction Act solar tax rebate going in effect January 1, 2023

E. Technical Documentation of REopt

I. REopt model assumptions (from the REopt User Manual):

Economic output assumptions:

- CAPEX/capital costs are considered overnight costs (i.e., all projects are completed at the end of year zero and produce electricity starting in year one) and assumed to be the same in both ownership models (see Section 4.2). Construction periods and construction loans are not modeled.
- A site's annual electric and thermal load demand profiles remain constant from year to year for the duration of the analysis period (25 years)
- One-year discounting periods are used (i.e., no mid-year discounting subperiods).
- All cash flows occur at end of year.
- When tax benefits are considered, the system buyer has sufficient tax appetite to capture all available tax incentives in their entirety.
- O&M costs escalate at the O&M cost escalation rate (2.5%)
- Sales tax, insurance costs, and property taxes are not considered.
- Debt service coverage and reserve requirements are not considered.
- Net present value (NPV) or net savings of financial case (solar installation) = lifecycle cost (LCC) of business as usual case - LCC of investment case

II. REopt Data Sources

Default inputs in the REopt model were determined by an extensive list of sources. See Section 20, Table 28 in the REopt user manual for detailed information.

F. Load Curves

These load curves were obtained by running the REopt model for three different MSAs in varying regions. Each load profile exhibits varying peak months depending on regional demand. Charleston appears to have the highest and broadest maximum load during the summer months, while Spokane appears to have lower load and a narrower peak. This is due to a multitude of factors; a significant one of which is likely energy demand from HVAC systems.

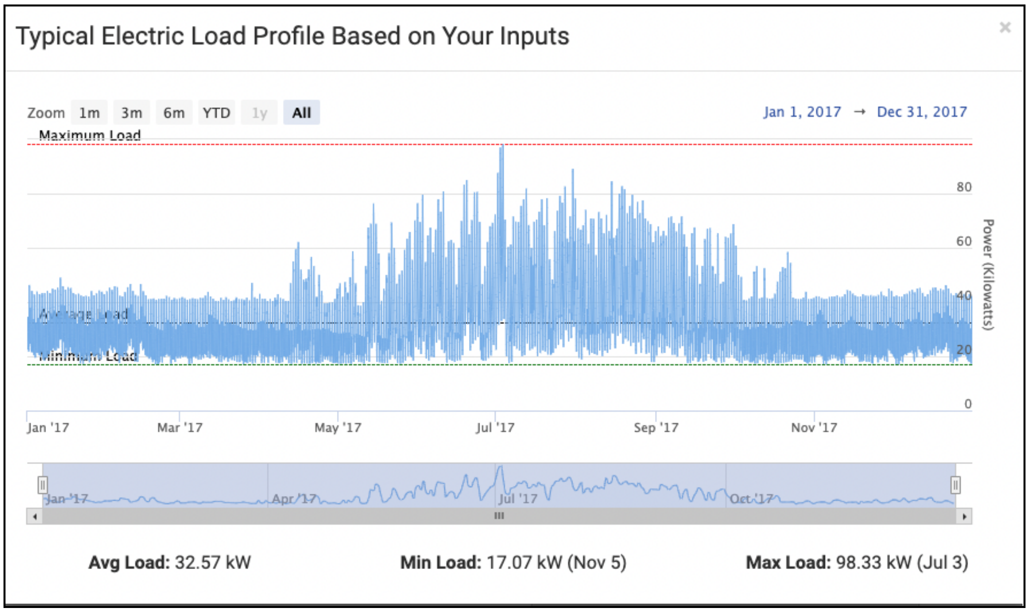

Figure 14. Load profile of Charleston, South Carolina. *Source: NREL*

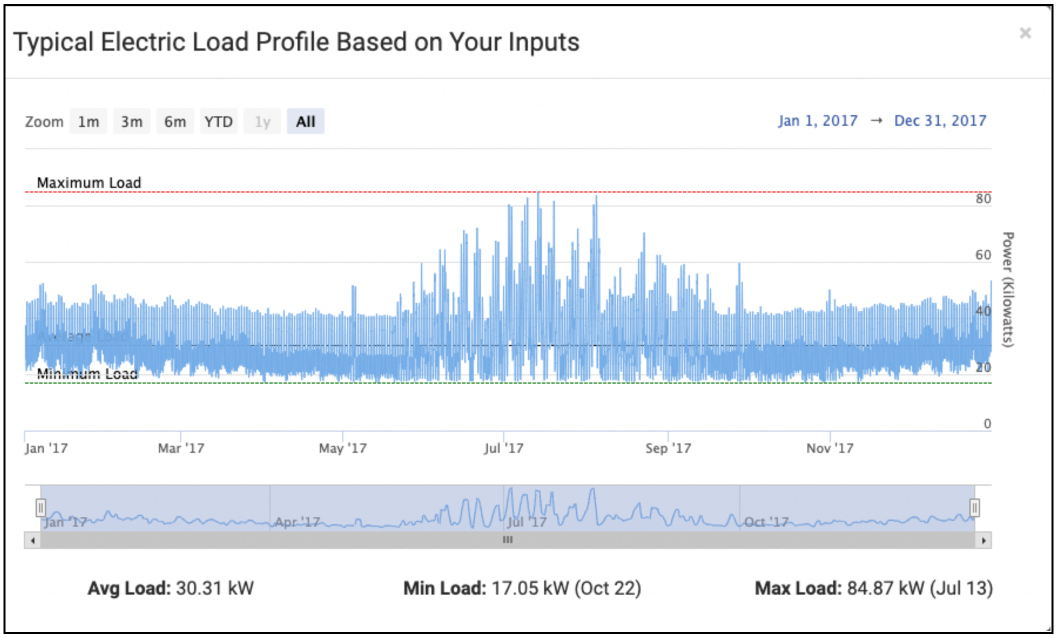

Figure 15. Load profile of Des Moines, Iowa. *Source: NREL*

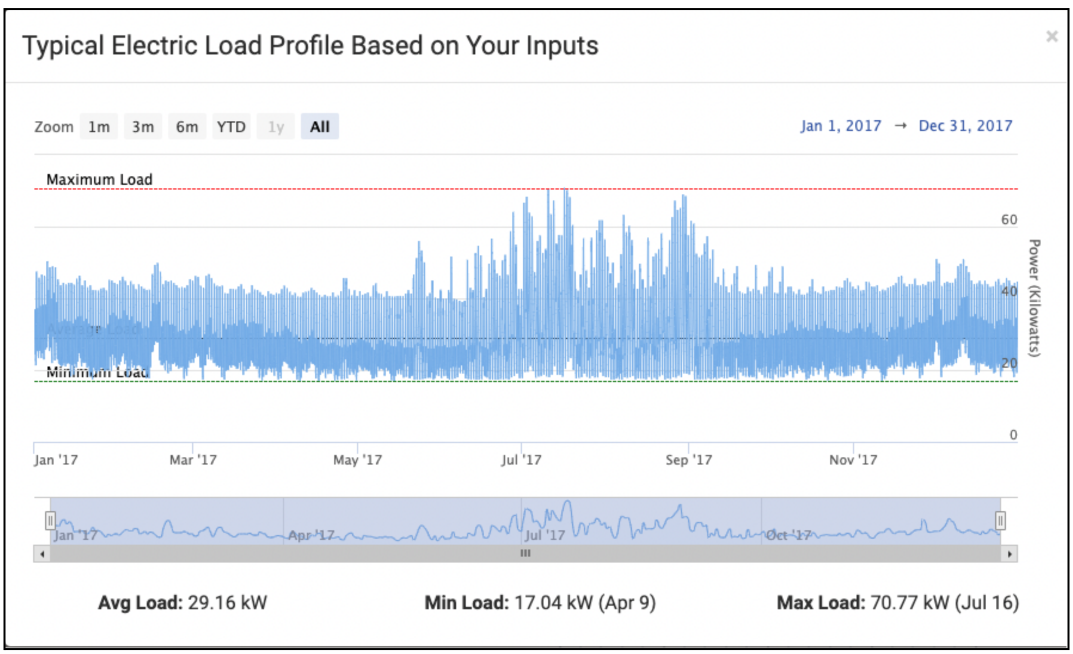

Figure 16. Load profile of Spokane, Washington. *Source: NREL*

G. National Risk Index Source Data

Table 7. National Risk Index Source Data. *Source: FEMA 2021*

Category/Metric	Source Data	Notes
Social Vulnerability	University of South Carolina's Hazards and Vulnerability Research Institute (HVRI) Social Vulnerability Index (SoVI)	29 socioeconomic variables "deemed to contribute to a community's reduced ability to prepare for, respond to, and recover from hazards"
Community Resilience	University of South Carolina's Hazards and Vulnerability Research Institute (HVRI) Baseline Resilience Indicators for Communities (BRIC)	"49 indicators that represent six types of resilience: social, economic, community capital, institutional capacity, housing/infrastructure, and environmental"
Avalanche	Susceptible Area Source: National Avalanche Center Historical Occurrence Source: Arizona State University, Spatial Hazard Events and Losses Database of the United States	60 year period (1960 - 2019)
Coastal Flooding	Susceptible Area Sources: 1. National Flood Insurance Program, National Flood Hazard Layer 2. NOAA Office for Coastal Management, Flood Frequency and Sea Level Rise 3. NOAA National Hurricane Center, Sea, Lake, and Overland Surges from Hurricane 4. NOAA National Hurricane Center, HURDAT2 Best Track Data Archive	
Cold Wave	Historical Occurrence Generating Source: National Weather Service, Weather Alerts Historical Occurrence Compiling	12.14 year period (2005 - 2017)

	Source: Iowa State University, Iowa Environmental Mesonet	
Drought	University of Nebraska-Lincoln National Drought Mitigation Center (NDMC), U.S. Drought Monitor	5-Level Scale: "Abnormally Dry" to "Extreme Drought"; 18 year period (2000 - 2017)
Earthquake	Susceptible Area Source: USGS Loss Quantification Source: Federal Emergency Management Agency, Hazus P-366 Study	
Hail	National Weather Service, Storm Prediction Center, Severe Weather Database Files	32 year period (1986 - 2017)
Heat Wave	Historical Occurrence Generating Source: National Weather Service, Weather Alerts Historical Occurrence Compiling Source: Iowa State University, Iowa Environmental Mesonet	12.14 year period (2005 - 2017)
Hurricane	NOAA, National Hurricane Center, HURDAT2 Best Track Data	167 year period in the Atlantic Ocean (1851 - 2017), 69 year period in the Pacific Ocean (1949 - 2017)
Ice Storm	U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL), Damaging Ice Storm GIS	67 year period (1946 - 2014)
Landslide	Susceptible Area Source: Dr. Jonathan Godt, Landslide Hazards Program Coordinator, USGS, Landslide Hazard Map Historical Occurrence Source: National Aeronautics and Space Administration (NASA), Cooperative Open Online Landslide Repository (COOLR)	10 year period (2010 - 2019)
Lightning	NOAA, National Centers for Environmental Information (NCEI),	22 year period (1991 - 2012)

	Cloud- to-Ground Lightning Strikes	
Riverine Flooding	Susceptible Area Source: Federal Emergency Management Agency, National Flood Insurance Program, National Flood Hazard Layer Historical Event Source: National Centers for Environmental Information, Storm Events Database	24 year period (1996 - 2019)
Strong Wind	National Weather Service, Storm Prediction Center, Severe Weather Database Files	32 year period (1986 - 2017)
Tornado	National Weather Service, Storm Prediction Center, Severe Weather Database Files	34 year period (1986 - 2019)
Tsunami	Susceptible Area Sources: 1. State of California, Department of Conservation, California Official Tsunami Inundation Maps 2. Hawaii Statewide GIS Program, Tsunami Evacuation Zones 3. Hawaii Statewide GIS Program, Extreme Evacuation Zones 4. Oregon Department of Geology and Mineral Industries, Tsunami Inundation Zones 5. Washington State Department of Natural Resources, Tsunami Inundation Data 6. Alaska Department of Natural Resources, Tsunami Inundation Maps Historical Occurrence Source: NOAA, National Centers for Environmental Information (formerly NGDC), Global Historical Tsunami Runup Data	219 year period (1800 - 2018)

Volcanic Activity	Susceptible Area Source: United Nations Office for Disaster Risk Reduction, Volcano-Population Exposure Index Historical Occurrence Source: Smithsonian Institution, Volcanoes of the World	
Wildfire	U.S. Department of Agriculture, Forest Service, FSim Burn Probability and Fire Intensity Level Data	
Winter Weather	Historical Occurrence Generating Source: National Weather Service, Winter Weather Alerts Historical Occurrence Compiling Source: Iowa State University, Iowa Environmental Mesonet	"winter storm events in which the main types of precipitation are snow, sleet, or freezing rain"; 12.14 year period (2005 - 2017)