Investigating the Feasibility of Replacing Conventional Energy Sources in New York City

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Abstract

The purpose of this study is to examine the feasibility of replacing conventional energy sources in New York City using solar powered products for residential homes. Mainly in this study we are concerned on quantifying the annual electricity and water heating consumption at a city scale. A Single Building Energy Model (SBEM) for residential homes is used to estimate the cities energy consumption using a bottom-up approach with detailed spatial distribution of the residential area available for solar products installation. The results showed that with solar power products up to 92% and 74% of the water heating and electricity use can be met, respectively. By replacing the energy consumed with solar panels and collectors, we estimated the Green House Gas (GHG) emissions can be reduced by approximately 94 percent on an annual basis.

1. Introduction

With the growing population and increasing energy demand, developed areas can be highly impacted by the changing climate. Today dense urban environments are home to more than half of the people in this world and account for more than 70 percent of Green House Gas (GHG) emissions [1,2]. The emissions due to these stationary sources can have unfavorable effects by increasing the local air temperature and contributing an increase in the frequency of heat wave events [2,3]. Mitigating the environmental consequences emerging from high energy consumption in cities is essential to preserve public health. One solution to reduce the local impact of energy use is to power most of our cities with energy generated from renewable sources. According to the National Renewable Energy Laboratory (NREL) study in 2012, renewable energy can decrease the emissions due to electricity consumption nearly 81 percent [4].

For this study we are interested in the spatial distribution of residential building energy use in New York City (NYC) to identify areas where solar powered renewable energies can potentially replace conventional energy sources. NYC is the most densely populated city in the United States [5]. The city accounts for approximately one-third of the total energy consumed in New York State (NYS) and only occupies 0.6 percent of total area in the state [6]. NYC building energy use accounts more than two-thirds of total energy consumption and GHG Emissions [3,7]. Jacobson et al. (2013) considered the possibility of replacing NYC's current energy infrastructure with wind, water, and solar energy sources. The study showed that all energy in NYS can be generated from renewable sources. The proposed infrastructure can reduce end power energy demand by 37 percent, aid economic growth, and decrease air pollution [8]. Although the study proposed an all

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roof-top Photovoltaic system in NYC, the study does not show the feasibility of implementing this strategy throughout the different areas in the city. In this study we use a detailed building dataset for the city of New York along with a buildings energy simulation software and a renewable energy and financial model to study the possibility of replacing current energy sources with solar powered ones.

3. Methodology

In the following section we provide a detailed explanation of the different methods and tools used for the analysis. The study consisted of the use of a high-resolution building data base for the urban setting distribution of residential area. Along with the building dataset we used a Single Building Energy Model (SBEM) and a renewable energy simulation software to estimate the percentage of building for which solar energy sources would be able to meet the annual energy demand for electricity and water heating specifically.

3.1. Data Collection and Analysis

The building data used for this is from the New York City Department of Planning Public Land Use and Tax Lot (PLUTO) database [9]. The PLUTO database has detailed information on the buildings in NYC including the use of the building as well as its area and other characteristics. Using the building classification from PLUTO, we found a total of 759,095 buildings in the city are used as a residence. Fig. 1a shows the spatial distribution of residential area in NYC Manhattan and certain part of Queens and Brooklyn have the most building area. However, for this study we area interested only in the available roof area for all this residences for the installation of solar panels and collectors. Fig. 1b illustrates the available surface area for residential buildings in the

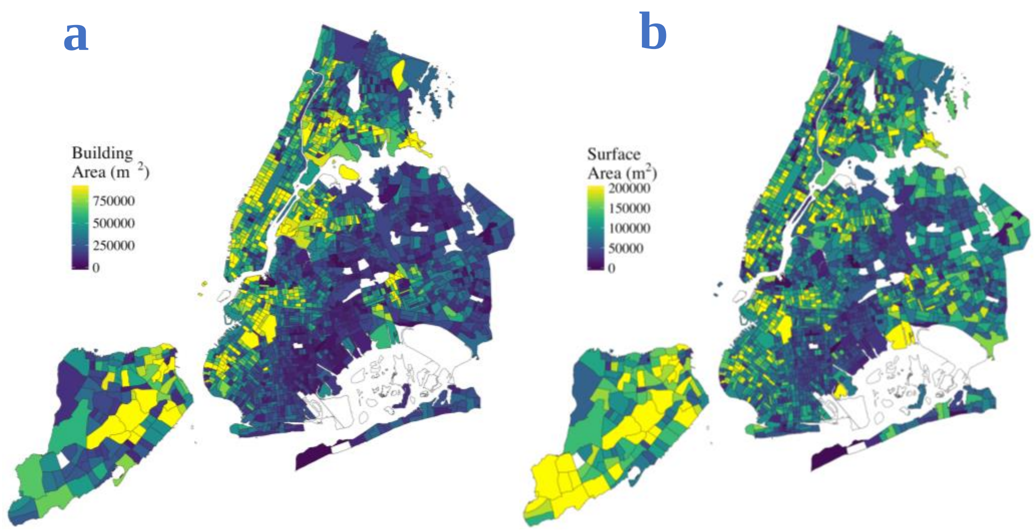

Fig. 1. Spatial distribution of (a) total residential area (b) available surface area

city for approximately 95 percent can be used for the installation of solar products. Since spacing is needed between solar panels, collectors, and additional system components as well as for mobility, we only used 75 percent of the available area for this study.

3.2. Single Building Energy Model Validation and Estimation

The energy simulation tool used for the SBEM is a Department of Energy software known as eQuest [10]. The software has been validated in a variety of different locations and environments. Olivo et al. (2017) showed that a SBEM can be upscaled using a bottom up approach to estimate the energy consumption patterns with the PLUTO database and a detailed building classification scheme [3]. As a base model, we used a low-rise multifamily building model to simulate the energy use of an average residential home in NYC. Based on the consumption per unit area from the SBEM, 80 percent of the energy was used for electricity and 20 percent for water heating. Using the eQuest along with the detailed building database for residential buildings we estimated the spatial distribution of annual electricity and water consumption for NYC in kilowatt hours. Fig. 2a and Fig. 2b illustrate the electricity consumption and water heating use respectively. The figure shows that the areas in the city that consume the most energy are lower Manhattan, Williamsburg in Brooklyn and Astoria in Queens. It is important to observe in Fig. 1 that these areas have high building are but low surface area available compared to the rest of the city. The reason why is because these areas have tall buildings with a high total area. If you only consider the roof area of these buildings, then on average there is less area available for installation of solar powered products. The values obtained from this model are used as a benchmark to determine if the renewable energy production is enough to meet the annual energy demand for the residential building in the city.

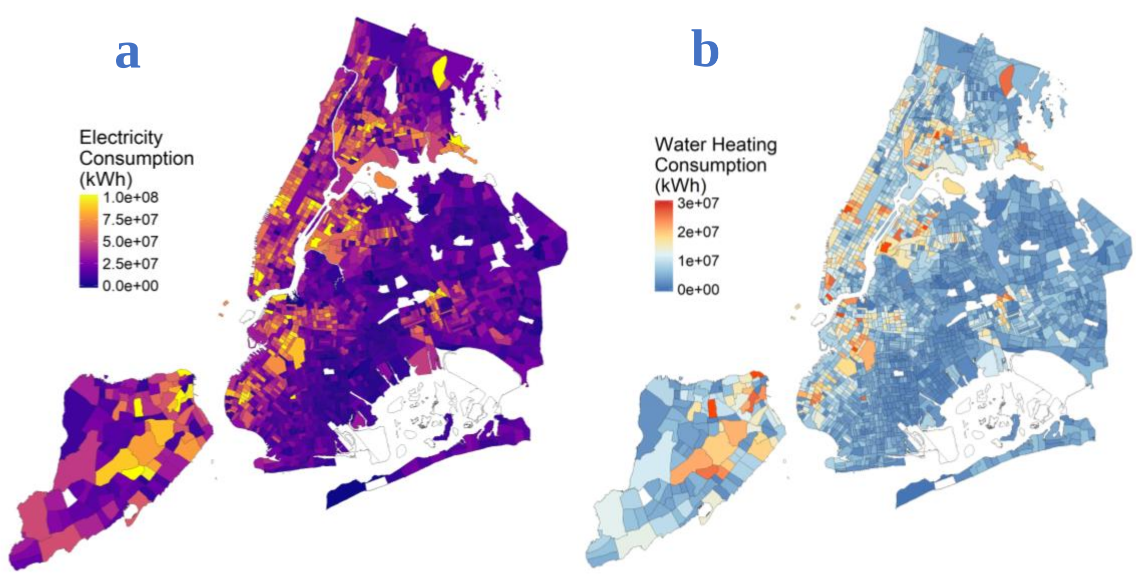

Fig. 2. Spatial distribution of (a) electricity consumption (b) water heating consumption

3.3. Solar Simulation Software

For the renewable energy simulation, we used the NREL System Advisory Model (SAM) performance and financial modeling tool [11]. In this section ran different design iterations for a solar panel and solar collector systems to determine which system design can be more adequate for implementation in the city. We conducted the solar collector simulation for different iterations where we varied design parameters. The first simulation was for a flat plate solar collector for which we tested water and glycol as working fluids. The second simulation was for an evacuated tubes solar collector. For the solar panel we used two different system designs: a regular PV system and a PV system with a 1-axis tracking system that would change angles up to 50 degrees for optimum performance throughout the year.

4. Results and Analysis

4.1. Solar Products Energy Generated

The water heating energy generated from solar collectors was estimated by upscaling the energy per unit area from the SAM simulation using the PLUTO residential surface area for the buildings in the city. The water energy produced for the flat solar collector using water as the working fluid is 367 $\mathrm{kWh/m^2}$. Fig. 3a illustrates the spatial distribution of the energy generated by for each census track after linearly scaling the consumption for each residential building area in the city. Fig. 3b shows the spatial distribution of the difference between the energy consumed by water heating and the estimate of energy generated from the solar collector. When comparing map in Fig. 3a to the one in Fig. 2b we can observe that the areas with the highest energy consumption are the location with a deficit in the amount of energy generated. These areas densely populated and do not have enough surface area to meet the energy demand at this location. Outside of these

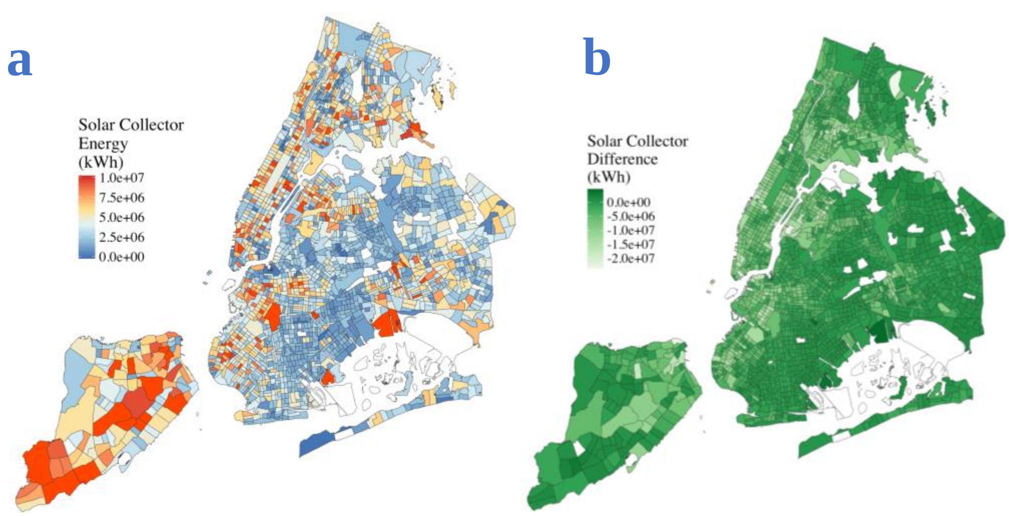

Fig. 3. Spatial distribution of (a) solar collector energy produced (b) water heating consumption and generated energy estimate difference

high density areas most of the energy demand for water heating can be supplied by using solar collectors. From the results 77 percent of building have enough surface area to replace their water heaters with solar collectors. In Fig. 4a we can observe can observe a similar result as the one from water heating and solar collector but for energy consumption and solar panels. The electricity produced from the solar panel system with no tracking is 276 kWh/m^2. From the results 64 percent of NYC's building electricity demand by using solar panels. The number of building for which electricity consumption is met is relatively lower than that of water heaters. This is expected since water collectors are more efficient at converting the useful energy from the sun.

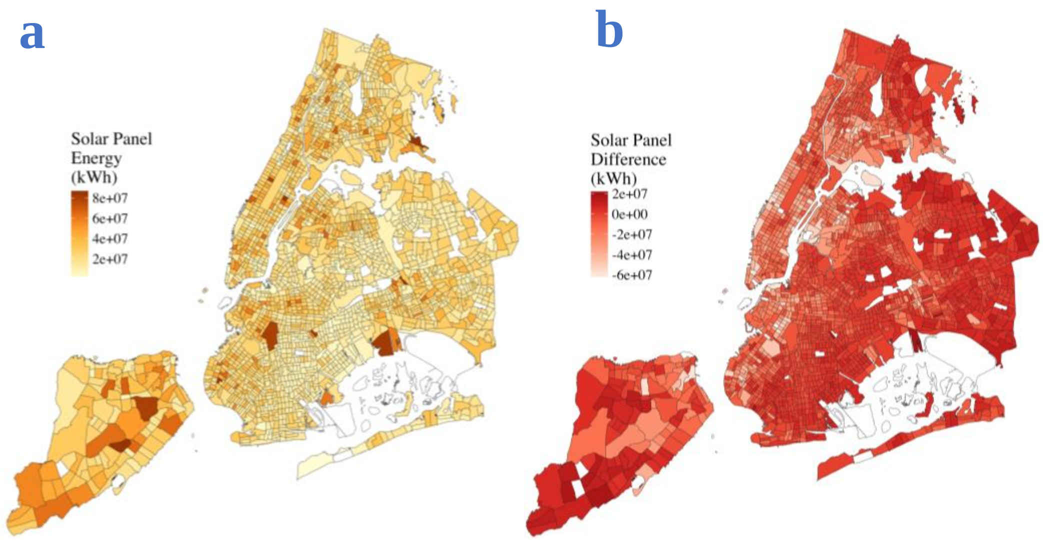

Fig. 4. Spatial distribution of (a) solar panel energy produced (b) electricity consumed and generated energy estimate difference

4.2. Solar System Efficiency

Overall in NYC the average daily solar irradiation available in 4.72 kWh/m^2. The solar collector system used has a heat exchanger efficiency of 75 percent and converts 21 percent of the available energy to usable energy. The water heating system with evacuated tubes is more efficient than the flat collector producing 463 kWh/m^2 and converting 27 percent of the available energy. With an evacuated tubes system, the number of buildings for which water heating energy demand is met increases to 92 percent. Similarly, for the solar panel infrastructure with an in inverter with 96 percent efficiency and the same daily available energy, the system converted only 15 percent of the available energy. The solar system with tracking is slight more efficient at 21 percent and producing 344 kWh/m^2. The system with tracking increases the amount of buildings for which electricity demand is met by 10 percent, satisfying 74 percent of the overall energy demand from all buildings in the city.

4.3. Cost and Environmental Assessment

In this section we discuss the cost of the different systems and also take into consideration what would be the environmental benefits of switching to conventional energy sources. In **Table 1** we can observe the cost of the two different solar panel systems. Design 1 shows the cost of the solar panel system without tracking while Design 2 shows the cost of the solar panel with tracking. The system with tracking is relatively more expensive to install but over its lifetime it is a better investment because the energy production is greater. Over its lifetime the Levelized Cost of Electricity (LCOE) for Design 2 to is 10 percent lower than Design 1. In **Table 2** we can observe the cost of the two different solar collector systems. Design 1 shows the cost of the flat collector system while Design 2 shows the cost of the solar collector system with evacuated tubes. The cost to install both system design is nearly identical but over its lifetime the second design is a better investment because the energy production is greater. Over its lifetime the Levelized Cost of Electricity (LCOE) for Design 2 to is 26 percent lower than Design 1.

Table 1
Cost estimate of the solar panel system implementation for the entire city.

Cost	Design 1 – No Tracking	Design 2 - Tracking
Before Incentives ($\$/m^2$)	823	973
After Incentives ($\$/m^2$)	372	438
LCOE (¢/kWh)	12.58	12.04
Citywide ($ in billions)	21	25

Table 2
Cost estimate of the solar collector system implementation for the entire city.

Cost	Design 1 – Flat	Design 2 – Evacuated Tubes
Before Incentives ($\$/m^2$)	1343	1339
After Incentives ($\$/m^2$)	940	936
LCOE (¢/kWh)	25.13	18.52
Citywide ($ in billions)	13	13

It can be observed that the overall cost for the system is considerably large. The citywide solar infrastructure would cost approximately 1.2 billion dollars per year for a 30-year lifetime of the system. The cost includes installation, maintenance, and degradation of the system. Although the cost for changing the cities energy infrastructure to a solar powered one is high, the environmental benefits over the system lifetime can greatly improve the health and comfortability of its habitants. Wild-Scholten et al. (2013) study showed the long-term benefits of solar system by comparing them to the equivalent GHG released by conventional sources. According to the study GHG emission from electricity consumption and natural gas are 0.00055925 and 0.000642 metric tons of CO2 per kWh. In comparison the GHG released on average for a 30-year lifetime of a solar system the yearly emission is just 0.000038 metric tons of CO2 per kWh. As such, changing our current energy infrastructure to a solar system can reduce the GHG emissions by 93.8 percent over 30 years.

5. Conclusion

The world's population will keep growing, cities will become denser, and as such the energy use will increases exponentially along with GHG emissions. Using available surface area in the most city in the United States we replace the energy consumption from the conventional sources for at least 74 percent of the residences in NYC. Some of the homes even have an excess amount of energy produce which can be used as an additional sources of power for the 26 percent of homes left with a deficit. From the current study using 80 percent of the available roof for a solar panel system with tracking and 20 percent for an evacuated solar collector for water heating system most of the building energy consumption can be satisfied. The cost of the system pays of financially and environmentally by reducing the GHG emissions by 94 percent which can greatly reduce the climate change catastrophes and health issues due to global warming and pollution.

6. References

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