ScienceDirect

Solar Energy
Volume 230, December 2021, Pages 635-644

The potential for community solar in Connecticut: A geospatial analysis of solar canopy siting on parking lots

Kieren Rudge [1]

Yale School of the Environment, United States
People's Action for Clean Energy, United States

Received 9 July 2021, Revised 31 August 2021, Accepted 11 October 2021, Available online 28 October 2021, Version of Record 28 October 2021.

What do these dates mean?

Check for updates

Show less

Share Cite

https://doi.org/10.1016/j.solener.2021.10.038
Get rights and content

Highlights

- Geospatial analysis was used to analyze solar canopy siting in Connecticut.
- Solar canopies can produce 37% of current electricity demand in Connecticut.
- Solar canopies can be beneficial for achieving energy justice in Connecticut.

- A methodology has been developed to model the solar canopy potential of a region.
- State energy policy can address barriers to adoption of solar canopies.

Abstract

Local, state, and national governments across the world have set goals of transitioning their energy generation to 100% renewable sources. Connecticut is one example of a sub-national state that has set a target for a zero-carbon electric sector by 2040. Government reports released on how this statewide renewable energy transition will occur pay significant attention to utility-scale solar and rooftop solar, but do not mention solar canopies as a priority. Yet, solar canopies provide a promising approach to fostering decentralized community solar. This study develops a novel methodology for assessing the potential for solar canopies on a regional scale. The study uses geospatial approaches to assess all large parking lots in the state for the viability of solar canopies. By applying this methodology to the research setting of Connecticut, the study produces the first estimates of the potential electrical generation from solar canopies in any region and analyzes how solar canopies can contribute to energy justice. The analysis revealed that there are 8,416 sites across the state, capable of producing a total of 9,042 GWh of electricity, which is equivalent to 37.0% of current electricity use in Connecticut. The analysis compared findings to census tract-level demographic data across the state and investigated two case study cities to understand energy justice considerations related to solar canopy siting. This study demonstrates that solar canopies have significant potential as a component of Connecticut's energy portfolio and discusses policies that could foster their adoption. Finally, the study lays a foundation for future research on solar canopy potential by providing a methodology that is replicable across various geographical scales.

Introduction

In recognition of the dire consequences of climate change and the need to mitigate carbon emissions, governments of varying scales across the world have created plans to transition towards renewable sources in the coming decades (Bassett and Shandas, 2010). However, a transition from fossil fuels to renewables alone does not address all the problems of present-day energy systems. A particularly important challenge is assessing whether existing modes of centralized electricity generation or less common decentralized energy systems should be prioritized.

Centralized systems support long-distance transmission where a large power plant can be located far from the many end-users it serves. The prevalence of centralized energy systems is due to multiple factors, such as the ease of regional coordination, strong reliability during times of peak loads, and economic efficiency due to scale. Additionally, centralized systems can support communities in areas where a specific energy resource may not be available (U.S. EPA, 2021). This can be accomplished by connecting locations demanding electricity to distant power plants that are sited in optimal places for a particular form of energy production. For example, large-scale solar arrays may be sited in a desert that provides excellent conditions for solar power generation, and then transmitted to an area with heavy cloud coverage that would not support much solar.

While centralized energy systems are the most commonly used systems across the world there are multiple drawbacks. Factors that are inherent to centralized systems such as the loss of energy over long transmission distances, low resilience to severe storms, and environmental degradation due to infrastructure construction demonstrate significant problems that need to be addressed (Jufri et al., 2019, Mccoy et al., 2020). While transitioning towards a 100% renewable energy electric sector is of the utmost importance, decision-makers must also consider that systems reliant only on utility-scale generation sources, such as large solar or wind farms, are subject to the same issues as those found in current centralized systems. Therefore, in addition to transitioning to renewables, it is necessary to consider alternatives to centralized energy production as it presently exists.

In contrast to the negative impacts of centralized systems, decentralized energy systems provide multiple advantages. Decentralized systems can be beneficial by helping to prevent grid failures, which are becoming more prevalent with aging infrastructure and increasingly extreme weather events due to climate change. Additionally, by relying on multiple local sources, a decentralized system reduces energy losses via long transmission lines thereby decreasing the total amount of electricity needed to support an area (Danish et al., 2019, Mccoy et al., 2020). Enabling residents to use energy that is locally produced can also help to ameliorate multiple equity concerns related to climate change. However, it is important to note that decentralized energy systems lack some of the previously discussed advantages of centralized systems, such as the distribution of energy from an area that has optimal production conditions to one that has poor conditions and requires external support.

While both centralized and decentralized renewable energy systems have merit, this study focuses on one type of decentralized energy that has multiple benefits: community solar (and more specifically solar canopies). Developing an understanding of how different forms of community solar can be sited is important to assessing a potential transition towards a more resilient, decentralized grid. This study aims to evaluate the potential for solar canopies, which is a form of community solar when sited in a distributed manner, in Connecticut. To achieve this, a novel methodology has been developed to assess the potential for solar canopies on a regional scale. By applying this methodology to the research setting of Connecticut, the study produces the first estimates of the electrical generation from solar canopies in any region and analyzes how solar canopies can contribute to energy justice. Notably, this research aims to analyze an energy source that is currently a low priority in Connecticut and is understudied by renewable energy researchers more broadly.

In 2019 Connecticut Governor Ned Lamont issued Executive Order No. 3 (E.O. 3) establishing the goal of a 100% zero-carbon electric sector by 2040 (CT E.O. 3, 2019). The order states that the *Integrated*

Resources Plan (IRP), which is produced every two years, shall analyze pathways and recommend strategies to decarbonize the electric sector (CT E.O. 3, 2019). The Draft 2020 IRP is the first version of this plan released following E.O. 3, and the transition strategies being developed in it are informed by a 2018 report produced by the Governor's Council on Climate Change (GC3) entitled *Building a Low Carbon Future for Connecticut* (CT E.O. 3, 2019, GC3, 2018). Examining these two documents can provide insight into the areas of the electric sector transition that are being prioritized and those that are not receiving attention from the state. The reports address concerns such as the development of solar and wind power, electrification of buildings, and adoption of clean transportation infrastructure (DEEP, 2020, GC3, 2018).

While the multitude of issues addressed in each report is important, this study is interested in examining decentralized, community solar in Connecticut. The IRP and GC3 reports both demonstrate an interest in supporting decentralized solar in addition to large-scale arrays (DEEP, 2020, GC3, 2018). However, the only small-scale arrays the reports discuss are rooftop solar projects (DEEP, 2020, GC3, 2018). Neither document explicitly references solar canopies as a form of community solar, or as a potential component of the future energy portfolio (DEEP, 2020, GC3, 2018). This is an important oversight as solar canopies have multiple unique advantages and can support an energy transition that centers environmental justice (Neumann et al., 2011, Pantić et al., 2020). To address the omission of solar canopies from energy transition planning in Connecticut, this study aims to demonstrate the statewide potential of solar canopies and the associated energy justice implications of this form of energy.
Community solar systems come in multiple forms with different technical, social, and economic models. These systems are defined by the U.S. Department of Energy (U.S. DOE) as solar-electric systems that provide power and/or financial benefits to multiple community members (U.S. DOE, 2012). Community solar systems are generally one component of an energy portfolio and can be integrated with a variety of other sources. These systems can be beneficial to residents who want to be involved in renewable energy production, but may not have the means or physical requirements for rooftop solar on their homes. Due to a variety of ownership models and technical factors, community solar can support energy justice by attracting marginalized groups such as low-income residents who cannot afford to invest in solar individually, or renters who cannot install solar because they do not own property (Luke and Heynen, 2020, A Guide to Community Shared Solar: Utility, 2012). It is important to note that the various models provide a diverse array of financing pathways that can make cost-saving solar power more accessible. Additionally, federal, state, and municipal policies that provide funding or other implementation tools can make community solar more feasible and equitable (U.S. DOE, 2012). Community solar is becoming more favorable for potential participants due to increased efficiency of panels, decreased prices due to economies of scale, and collective action that enables access to unique funding sources, lower investment costs, and flexibility in ownership (Luke and Heynen, 2020, Mccoy et al., 2020).

An additional environmental benefit of community solar is that it does not require large amounts of space to be cleared, which would be necessary for utility-scale solar. This avoids competition between

solar power and natural resources or agricultural land that could be infringed upon (DEEP, 2020; Mccoy et al., 2020, Schunder et al., 2020). Importantly, reducing the amount of open space dedicated to solar would allow for better coalition-building between diverse groups of people, such as rural and urban dwellers with different social and economic interests.
While community solar can be implemented through a variety of array types, solar canopies have unique benefits over other technologies like rooftop or ground-mounted solar. For example, ground-mounted solar limits an entire area to solely support energy production while solar canopies have a raised structure that leaves room beneath them for other land uses. Canopy arrays are commonly sited on parking lots where energy can be produced without sacrificing the current operations. Allowing for multiple uses improves the favorability of this form of solar for small business owners, local governments, or others who want the benefits of solar energy, without dedicating space solely for one use. Solar canopies have additional co-benefits, such as the possibility to pair with electric vehicles by supporting charging stations and providing protection from weather for existing vehicles (Neumann et al., 2011, Pantić et al., 2020).

Another advantage of solar canopies is their impact in reducing the urban heat island (UHI) effect, especially when sited on asphalt parking lots (Bretz et al., 1998, Pantić et al., 2020, Sanchez and Reames, 2019). This is possible because solar canopy arrays serve as highly reflective surfaces, which decrease absorption of heat from the sun (Bretz et al., 1998, Sanchez and Reames, 2019). This mitigation of heat islands can lead to improved air quality, as extreme heat can worsen environmental hazards from pollution (Bretz et al., 1998). The UHI effect is not just harmful, but it is inequitable as it often impacts low-income communities and communities of color at a higher rate (Bretz et al., 1998, Chapman et al., 2017, Pantić et al., 2020, Sanchez and Reames, 2019). A decreased magnitude of UHI can also reduce the amount of air conditioning use in the summer due to reduced ambient temperature, leading to lower energy consumption (Bretz et al., 1998). The combined effects of indirectly lowering energy consumption, reducing dangerous heat, and increasing renewable energy production make solar canopies an excellent potential energy source that acts as a form of both climate change mitigation and adaptation.

While previous research has discussed the benefits of solar canopies, no studies have modeled solar canopy potential on a municipal or regional scale. However, rooftop solar and utility-scale solar potential have been modeled in cases of varying large-scale scopes. In a review of multiple solar potential models, Freitas et al. showed that GIS-based analyses have only focused on rooftop or utility-scale projects (Freitas et al., 2015). Models in those studies and others have excluded the potential of solar canopies when examining other forms of solar power on neighborhood-scale, city-scale, and regional-scale cases (Chow et al., 2014; Singh and Banerjee, 2015; Sun et al., 2013). While an assessment of rooftop solar and utility-scale solar is incredibly valuable for understanding renewable energy potential, the inclusion of solar canopies in analyses would expand the scope of any estimates that are made. Importantly, a more thorough analysis of energy potential would better inform key decision-makers who guide energy planning.

The methodology developed in this study seeks to apply components of previous research to analyze solar canopy potential on a regional scale. This study draws on a hierarchical methodology developed by Izquierdo et. al that uses three classifications of solar analysis: physical, geographical, and technical (Izquierdo et al., 2018). Developing a novel methodology guided by these categories is necessary to understand the level of detail that can be found by any resulting analyses. The first component of the hierarchy is physical potential. This refers to the maximum energy production that is possible in an area when considering climatic conditions, such as average temperatures, and cloud cover. Second, geographical potential considers what type of land use zones are within the analysis, such as parking lots, rooftops, and roads. Lastly, the technical potential considers factors pertaining to the practical installation of solar panels, including the degree of tilt of panels, spacing needed between modules, efficiency over time, and geotechnical issues with building infrastructure. This hierarchical structure has previously been applied using remote sensing and GIS techniques to evaluate solar on national and sub-national levels, with most studies focusing on large-scale arrays or rooftop solar, and excluding solar canopies (Freitas et al., 2015, Izquierdo et al., 2008). Building off previous research, this study will aim to develop a methodology that utilizes core components of the hierarchy model and apply them to an analysis of solar canopies on a larger scale than has been previously done.

While large-scale solar potential studies have utilized GIS methods and a hierarchical analysis model without the inclusion of solar canopies, some smaller-scale studies have focused on solar canopies. Two relevant studies used aerial images in combination with geospatial datasets containing site characteristics to evaluate solar canopy potential in parking lots (Izquierdo et al., 2008, Pantić et al., 2020). One such study investigated Walmart Supercenter parking lots using previously reported data on parking lots in addition to local climatic information and economic considerations to evaluate solar canopy potential (Krishnan et al., 2017). While this research produced results that demonstrated the potential of solar canopies in the chosen sites, it was limited only to parking lots of uniform size on properties owned by one company (Krishnan et al., 2017). Another relevant study focused on a large parking lot in Serbia using a similar methodology to assess the potential for solar canopies (Pantić et al., 2020). In their study, Pantić et al. based the area of their solar canopy arrays on the number of parking spaces in a lot and were able to model factors such as array tilt, panel type, and climatic conditions (Pantić et al., 2020).

These previous studies demonstrate that a wide range of methods has been used to estimate and model different forms of solar generation across multiple spatial scales. The current study aims to bridge the different approaches found in small-scale parking lot analyses with those used in municipal and regional analyses of rooftop and utility-scale solar. The methodology developed in this study will allow the analysis to consider multiple physical, geographical, and technical concerns. This study is novel both in the size of its geographic scope and in the tangible results found in the research setting of Connecticut. This research will describe a methodological foundation for future studies on these issues and provide valuable analyses for clean energy planning in Connecticut.

Researching the total potential and geographic distribution of potential solar canopy sites in Connecticut will also allow this study to address important energy justice concerns. By using a GIS-based model that integrates consideration for demographics and the locations of marginalized communities in the state, this study will provide insight into distributive justice factors concerning the siting of solar canopies. The methodology developed in this study can also be used to analyze energy justice related to the spatial distribution of solar canopies in other case studies of varying scales.

Section snippets

Research questions

To understand the potential for solar canopies in Connecticut and develop broadly applicable results, this study will seek to answer the following two research questions:

(1) What is the total potential energy production from solar canopies in Connecticut? …

(2) How can solar canopies contribute to energy justice in Connecticut? …

…

Methods outline

To investigate the research questions at hand, this study followed seven methodological steps as outlined in Fig. 1. This methodology can be applied to understand solar canopy potential in future regional and municipal-scale cases. …

Initial database processing

The study began by adapting a previously created database of all impervious surfaces in Connecticut. This spatial database includes classifications for various types of surfaces and breaks up different areas into separate vector objects (UConn and CT DEEP, 2012). To …

Statewide findings

The statewide analysis covered all 169 towns in Connecticut. A total of 8,416 sites were identified in the state after filtering the dataset and excluding unwanted sites. The combined capacity of all sites was 7,021 MW. The total estimated annual production of the sites was 9,042 GWh, which is equal to 37.0% of the current annual electricity consumption of Connecticut.

This amount of production is equivalent to the energy use of about 870,000 homes (U.S. EIA, 2015). Additionally, when this data …

Implications of statewide potential

This study has demonstrated that solar canopies can be a significant component of Connecticut's energy portfolio, potentially producing more than one-third of current electricity consumption. Additionally, these results should be considered in the context of energy-saving measures that are becoming more prevalent through government policy and private development. These practices, such as weatherization, energy-efficient lighting, and other technical and social interventions can reduce …

Conclusion

This study examined the siting potential of solar canopies in Connecticut using a novel geospatial analysis methodology. This research was motivated by the need for local and regional climate mitigation action that can create more equitable and resilient energy systems. This study focused on solar canopies because this technology and other forms of community solar provide strong approaches to address the myriad of issues associated with greenhouse gas emissions and centralized energy production …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgments

This work was funded by People's Action for Clean Energy (PACE), Connecticut, USA. I would like to thank PACE President Mark Scully and PACE Vice President Bernie Pelletier for helping to guide this research. I would also like to thank Professor Ken Gillingham from the Yale School of the Environment for his assistance in revising this paper. …

References (43)

S. Bretz *et al.*

Practical issues for using solar-reflective materials to mitigate urban heat islands

Atmos. Environ. (1998)

Salvador Izquierdo *et al.*
A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations
Sol. Energy (2008)

Lino Sanchez *et al.*
Cooling Detroit: a socio-spatial analysis of equity in green roofs as an urban heat island mitigation strategy
Urban For. Urban Greening (2019)

Rhythm Singh *et al.*
Estimation of rooftop solar photovoltaic potential of a city
Sol. Energy (2015)

Yan-Wei Sun *et al.*
GIS-based approach for potential analysis of solar PV generation at the regional scale: a case study of Fujian province
Energy Policy (2013)

Bruce Tonn *et al.*
State-level benefits of energy efficiency
Energy Policy (2007)

A Guide to Community Shared Solar: Utility, Private, and Nonprofit Development. Report. SunShot Initiative, U.S....

An Act Concerning Connecticut's Energy Future, Public Act. No 18-50. State of Connecticut....

An Act Concerning Implementation of Connecticut's Comprehensive Energy Strategy And Various Revisions to the Energy...

An Act Relating to Public Utilities and Carriers – Renewable Energy Programs. H.B. 8354, State of Rhode Island....

Cited by (9)