Beyond Zero Net Energy?

Alternative Approaches to Enhance Consumer and Environmental Outcomes

PREPARED FOR

NRECA
America's Electric Cooperatives

NRDC
NATURAL RESOURCES DEFENSE COUNCIL

PREPARED BY

Ryan Hledik

Bruce Tsuchida

John Palfreyman

June 2018

THE Brattle GROUP

This report was prepared for the National Rural Electric Cooperative Association (NRECA) and the Natural Resources Defense Council (NRDC). All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group or its clients.

The authors would like to thank Keith Dennis of NRECA and Robin Roy and Dylan Sullivan of NRDC. Their insights, leadership, experience, and data were invaluable to this project. We are also grateful for solar project data provided by Great River Energy and Jackson EMC.

Please direct any questions or comments to Ryan Hledik: ryan.hledik@brattle.com.

About the Authors

Ryan Hledik is a Principal in The Brattle Group's New York office. He specializes in the economics of policies and technologies that are focused on the energy consumer. Hledik received his M.S. in Management Science and Engineering from Stanford University, with a concentration in Energy Economics and Policy. He received his B.S. in Applied Science from the University of Pennsylvania, with minors in Economics and Mathematics.

Bruce Tsuchida, a Principal in The Brattle Group's Boston office, has over twenty five years of experience in utility operations, power market analysis, and power generation development for both domestic and international markets. Mr. Tsuchida received his Masters of Science in Technology and Policy, and in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology, and Bachelors of Engineering in Mechanical Engineering from Waseda University (Tokyo, Japan).

John Palfreyman is a Research Analyst in The Brattle Group's Boston office. He works on a variety of financial issues in the energy sector, with experience in regulatory and project finance. He earned his B.S. in Chemical and Nuclear Engineering from the University of California, Berkeley.

Table of Contents

Executive Summary

Highlights

- Zero net energy (ZNE) initiatives focus narrowly on energy efficiency and clean energy generation at the individual building level, ignoring the advantages of a more inclusive approach.
- A broader, system-oriented approach to satisfying decarbonization objectives could improve upon the consumer and environmental outcomes that would otherwise be achieved through ZNE initiatives. The use of community solar to power a development of energy efficient homes is one example of such an alternative approach.
- Due to economies of scale and a higher capacity factor, the community solar-based approach could serve a development of 200 energy efficient homes with **total solar PV project cost savings of approximately 30 to 35 percent** relative to conventional ZNE configurations.

Introduction

A zero net energy (ZNE) home is designed to produce as much energy from clean on-site energy sources as it consumes each year.[1] Policymakers have become interested in ZNE building code initiatives as a way to achieve decarbonization goals. Recently, the California Energy Commission adopted an update to the state's building code, requiring that new homes offset their annual electricity consumption using solar power beginning in 2020 (though natural gas use does not have to be offset).[2]

However, the narrow focus of ZNE initiatives on energy reductions and on-site generation at the individual building level presents several often overlooked challenges. For instance:

- The potential economic advantages of grid-connected renewable generation are often discounted or ignored in ZNE initiatives.

---

1 While ZNE homes produce as much energy as they consume on a net annual basis, they still rely on the power grid (in the absence of on-site energy storage). When on-site generation is producing less than the home's consumption, the home must be powered by electricity from the grid. Similarly, when on-site generation produces more than is being consumed at the home, it is exported to the grid

2 Press Release from the California Energy Commission on May 9, 2018: http://www.energy.ca.gov/releases/2018_releases/2018-05-09_building_standards_adopted_nr.html.

- A focus on energy conservation overlooks the potential environmental benefits of "beneficial electrification," which could produce net environmental benefits even if the result does not minimize the home's total energy consumption.[3]
- Certain residential building types – including some that are environmentally advantageous, like high-rises – may have difficulty meeting ZNE standards because of site qualities, roof area, or size.
- While ZNE with rooftop solar PV implies energy independence, customers still must rely on the grid for electricity when the sun is not shining, and may export electricity to the grid when solar PV output exceeds the home's energy demand.

Given the above considerations, there may be attractive alternatives to ZNE initiatives with lower costs, expanded participant eligibility, and improved environmental benefits. Possibilities include expanding the ZNE "boundary" beyond that of the individual home, considering a broader range of zero-carbon generation resources, aligning generation with the timing of the home's consumption profile, and recognizing the system-wide benefits of new electric end-uses beyond a narrow focus on energy conservation (e.g., accounting for the grid resiliency benefits of appliances with flexible electricity demand).

In this report, we explore just one of many possible ways to improve upon the consumer and environmental outcomes that may otherwise be achieved through ZNE initiatives. Specifically, we analyze the possible impacts of powering a development of efficient homes using "community solar" rather than on-site generation.

The community solar concept allows individual households to purchase a share of the output of a larger solar PV project.[4] Community solar programs can be sited in advantageous locations of the distribution grid, benefit from economies of scale in construction, and are capable of greater total electricity production through advanced technical options that are prevalent in larger-scale PV installations, such as tracking or ideal orientation of the panels. Therefore, the inclusion of community solar is one way to ensure that future ZNE initiatives do not ignore opportunities for system-wide environmental and economic improvements.

The National Rural Electric Cooperative Association (NRECA) and the Natural Resources Defense Council (NRDC) commissioned The Brattle Group to quantify the potential economic and environmental advantages of strategies that are more inclusive than current ZNE initiatives.

---

[3] In addition to improving environmental outcomes, such an approach has the potential to reduce the average cost of energy production for the system.

[4] Community solar programs can be designed in a variety of ways. In this study, "community solar" refers to a roughly 500 kW to 1,000 kW solar project with output that is tied to the energy needs of a new housing development.

Rather than producing clean energy from individual rooftop solar installations, our study illustrates the benefits of powering energy efficient homes from a larger solar PV project that is shared by the community.[5]

Several aspects of the study scope should be noted. First, the study does not endorse or criticize the concept of ZNE buildings, but instead looks for opportunities to improve future policies with similar objectives where they are being pursued. Second, the study takes a system-level view of costs and benefits, rather than the perspective of individual stakeholders. Third, the study focuses on the *relative* costs and benefits between ZNE homes and other configurations (specifically energy efficient homes with community solar in this analysis), not the cost-effectiveness of standalone projects. Fourth, the study focuses specifically on new ZNE housing developments in non-urban locations. Lastly, but importantly, the study is based on a review of publicly available data and should be updated and expanded as additional data becomes available.

Methodology

This study relied on a multi-step framework for comparing costs and benefits between ZNE homes to an alternative configuration that relies on community solar.

First, the characteristics of the ZNE configuration and the alternative community solar-based configuration were defined. Then, project costs were established based on reviews of publicly available data.

Economic benefits included avoided marginal energy costs (including losses) and deferred generation capacity costs. We additionally quantified CO_2 emissions reductions, though this was not included as an economic benefit. To establish avoided energy costs, the hourly output of each solar project was simulated using NREL's System Advisor Model (SAM).

The costs and benefits for the ZNE homes were then compared to those of the alternative community solar-based configuration to identify relative differences. We specifically focused on the costs and benefits of 200 hypothetical homes in Minnesota and, separately in New Mexico. These markets were chosen because they present significant differences across key variables that drive the results, such as marginal energy costs, generation capacity needs, and solar radiation levels. Analysis of both markets was based on observed system conditions in 2016, which was assumed to represent an average year going forward.

---

5 We believe this is the first study to examine the economics of rooftop and community solar in the context of ZNE homes. Prior studies have examined the relative costs and benefits of rooftop solar and grid-scale solar more broadly. See, for instance, Bruce Tsuchida et al, "Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area," prepared by The Brattle Group for First Solar, July 2015.

Findings

Under the specific market characteristics considered in this study, the economies of scale and technological advantages of the homes configured with community solar provide roughly:

- 13% lower total solar PV project expenditures per watt than ZNE homes
- 25 to 30% greater annual energy output per watt than ZNE homes

As a result of these advantages, a community solar-based approach could serve a development of 200 homes with total solar PV project cost savings of approximately 30 to 35 percent relative to conventional ZNE configurations.

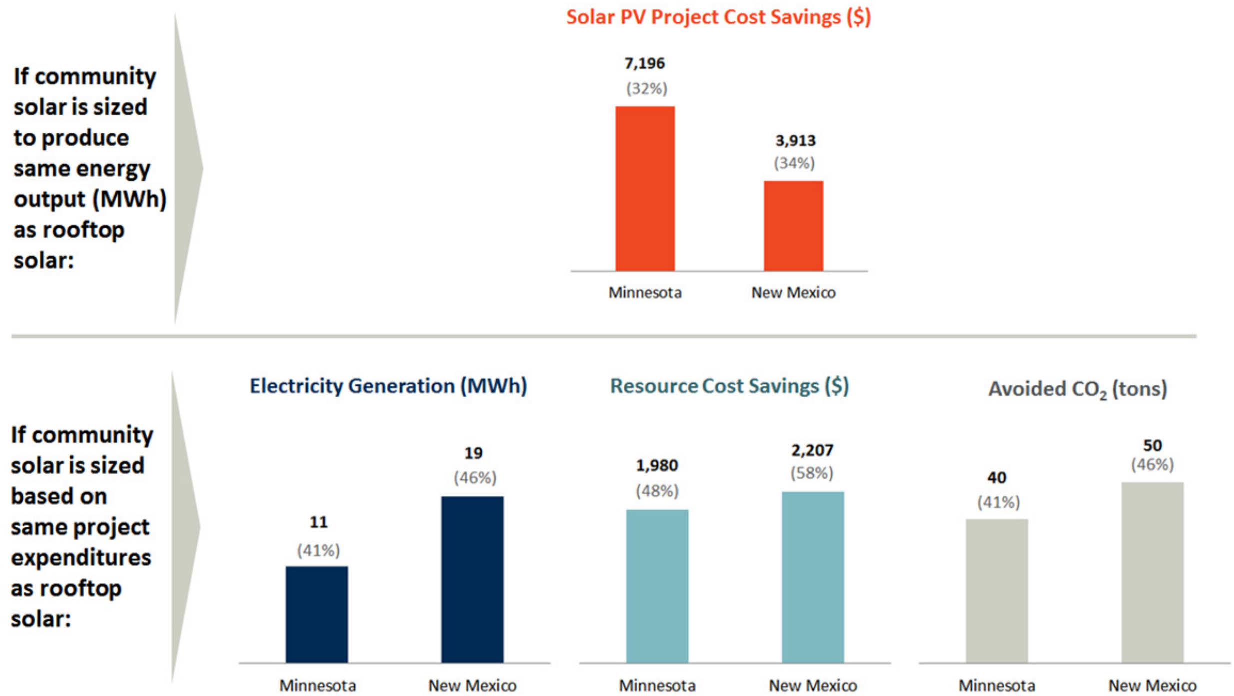
Viewed an alternative way, the same total expenditure on the community solar-based approach that would have been required in the conventional ZNE approach could produce:

- Enough additional electricity production to power another 80 to 90 efficient homes
- 50 to 60% resource cost savings (i.e., avoided generation from the power grid)
- 40 to 45% reduction in average CO_2 emissions (equivalent to 80 to 100 cars off the road, or roughly one car per two ZNE homes)

In addition to these economic and environmental benefits, the inclusion of community solar projects could expand the types of dwellings that may be considered ZNE (e.g., individual tenants of large apartment buildings). Figure ES-1 provides a summary of the 20-year cumulative benefits quantified in this study.[6]

[6] All costs are reported in 2017 dollars unless otherwise specified.

Figure ES-1: 20-year Incremental Benefits of Using Community Solar, per Home
(Percent savings relative to conventional ZNE configuration shown in parentheses)



Notes: Bottom panel reflects community solar project sized based on the same expenditures that would be required for 200 individual rooftop solar installations. 20-year savings represent undiscounted sum of annual values in 2017 dollars. Avoided system CO_2 emissions are based on average state emissions profiles for power generation.

The findings of this study suggest that community solar - and possibly other sources of clean energy - present an important opportunity for policy innovation. Where a decision has been made to implement initiatives for new home construction, community solar could be incorporated in a variety of forms. For instance, policymakers may wish to explore making the provision of financial support for the development of homes contingent on the economic evaluation of a broader range of renewable generation options. Policymakers may also wish to analyze and quantify the extent to which the deliberate inclusion of community solar in ZNE policies, or policies with similar objectives, will expand the potential market impacts of the policies.

For utilities and solar developers, partnering with housing developers may serve as a new business model for community solar projects. Doing so could reduce marketing and sales costs that would otherwise be associated with recruiting individual customers into the community solar program. Similarly, housing developers may wish to explore opportunities to incorporate community solar into new housing developments to capture development cost savings. Community solar used to meet a ZNE or similar building code or mandate would be an integral part of meeting the standard. Homeowners, builders, and code officials will need assurance of the community solar project's development, permanence, and long-term tie to the building.

From the homeowner's perspective, it would be useful to extend our analysis to consider a range of solar pricing models (e.g., rooftop, community-scale, and utility-scale). This study only accounted for system-level costs and benefits. Customer-oriented analysis would provide valuable insight regarding the effective design of ZNE and community solar programs, and the distributional effects of such initiatives.

The analysis presented in this study should be extended to multi-family dwellings and non-residential buildings, other geographic markets, and other configurations of renewable energy projects. The analysis could also be extended to include a detailed assessment of the impacts of these projects on distribution system costs. Such analysis would provide a broader sense of the robustness of the conclusions.

I. Introduction

OVERVIEW

A zero net energy (ZNE) home is designed to produce as much energy from clean on-site energy sources as it consumes each year. Recently, policymakers have become interested in ZNE home initiatives as a way to achieve decarbonization goals. Most notably, the California Energy Commission adopted an update to the state's Title 24 building code which requires new homes to offset their electricity use with onsite or offsite solar beginning in 2020 (though natural gas use does not have to be offset).[7] Elsewhere, cities like Austin, TX, Cambridge, MA, and Fort Collins, CO have created task forces and established goals to make new homes and downtown areas ZNE.

Currently, rooftop solar PV is the predominant source of on-site electricity generation for ZNE homes. Additionally, ZNE homes typically include advanced energy efficiency measures and may be 70 percent more efficient than the typical home. A community of 200 ZNE homes could plausibly account for more than 1 MW in collective installed rooftop PV capacity.

The concept of a ZNE home has gained traction in part due to its simplicity. The ZNE concept is easy to explain and, on the surface, it is intuitive. The concept is also likely to appeal to consumers who want to be seen as green and/or experience a perceived sense of "energy independence."

However, the orientation of ZNE initiatives toward maximizing energy reductions and on-site generation at the individual building level presents several often overlooked challenges. For instance:

- The potential advantages of larger-scale, grid-connected renewable generation are often discounted or ignored in ZNE initiatives. It is possible that these larger-scale resources could provide economic and environmental advantages relative to rooftop PV.

- As the power supply mix continues to decarbonize in many regions, initiatives to reduce the carbon footprint of homes should evolve accordingly. Rather than focusing narrowly on reducing total energy use, positive environmental outcomes may also be achieved by shifting consumption to the lowest-emitting energy sources. Such an approach – also known as "efficient electrification" or "beneficial electrification" - could produce net environmental benefits even if the result does not minimize the home's total energy consumption.[8]

---

7 Press Release from the California Energy Commission on May 9, 2018: http://www.energy.ca.gov/releases/2018_releases/2018-05-09_building_standards_adopted_nr.html.

8 When the lowest-emitting energy source also has lower marginal costs of energy than the alternative, this approach can also lower the average cost of power production.

- Some residential building types – including some that are environmentally-advantageous, like high-rises – may have difficulty meeting ZNE standards, because of their site, roof area, or size.

- On the surface, ZNE with rooftop solar PV suggests energy independence for the consumer. However, a ZNE home is still likely to rely on the power grid (in the absence of on-site energy storage). When on-site generation production is lower than the home's energy consumption (such as when sun is not shining, the home must be powered by electricity from the grid. Similarly, when the on-site generation produces more than is being consumed at the home, it is exported to the grid.

Given the above considerations, there may be alternatives to ZNE initiatives with lower costs, expanded participant eligibility, and improved environmental benefits. Possibilities include expanding the ZNE "boundary" beyond that of the individual home, considering a broader range of zero-carbon generation resources, aligning generation with the timing of the home's consumption profile, and recognizing the system-wide benefits of new electric end-uses beyond a narrow focus on energy conservation (e.g., accounting for the grid resiliency benefits of appliances with flexible electricity demand).

In this report, we explore just one of many possible ways to improve upon the consumer and environmental outcomes that may otherwise be achieved through ZNE initiatives. Specifically, we analyze the possible impacts of powering a development of efficient homes from "community solar" rather than on-site generation.

The community solar concept allows individual households to purchase a share of the output of a larger solar PV project.[9] There is currently more than 300 MW of community solar capacity across the U.S. The Rocky Mountain Institute has identified untapped U.S. community solar market potential of up to 30 GW by 2020.[10] According to GTM Research, community solar will drive 20 to 25% of annual non-residential solar PV growth over the next several years.[11]

Community solar programs can be sited in advantageous locations of the distribution grid, benefit from economies of scale in construction, and are capable of greater total electricity

---

9 Community solar programs can be designed in a variety of ways. In this study, "community solar" refers to a roughly 500 kW to 1,000 kW solar project with output that is tied to the energy needs of a new housing development.

10 The Rocky Mountain Institute, "Community-Scale Solar: Why Developers and Buyers Should Focus on this High Potential Market Segment," RMI Insight Brief, March 2016.

11 Cory Honeyman, MJ Shiao, and Sarah Krulewitz, "U.S. Community Solar Outlook 2017," GTM Research, February 2017.

production through advanced technical options that are prevalent in larger-scale PV installations, such as tracking or ideal orientation of the panels.[12] Therefore, the inclusion of community solar is one way to ensure that future ZNE initiatives do not ignore opportunities for system-wide environmental and economic improvements.

The National Rural Electric Cooperative Association (NRECA) and the Natural Resources Defense Council (NRDC) commissioned The Brattle Group to quantify the potential economic and environmental advantages of strategies that are more inclusive than current ZNE initiatives. Rather than producing clean energy from individual rooftop solar installations, our study illustrates the benefits of powering energy efficient homes from a single solar PV project that is shared by the community.[13]

STUDY SCOPE

Several aspects of the study scope should be noted. First, the study does not endorse or condemn the concept of ZNE buildings. Rather, the study is intended to provide analysis that is useful for forward-looking policy development.

Second, the study takes a system-level view of costs and benefits. This is akin to the total resource cost (TRC) test perspective that has been established for evaluating the benefits and cost of demand-side management programs. Economic benefits in the analysis are focused on avoided resource costs.[14] Quantified costs include equipment, installation, and supporting administrative costs. Thus, costs and benefits are evaluated for the system as a whole rather than for individual stakeholders such as the utility, the solar developer, or the customer. By definition, the analysis does not incorporate the effects of policies like net metering, rate design, tax incentives, or other financial support for solar development.

Third, the study analyzes the impacts on CO_2 emissions, but does not place a financial value on those for inclusion in the cost and benefit analysis.

---

12 There may be further benefits associated with the locational flexibility of larger-scale generation. For example, it may be possible to locate community solar in areas with less shading or interference, while individual home owners rarely have such an option.

13 We believe this is the first study to examine the economics of rooftop and community solar in the context of ZNE homes. Prior studies have examined the relative costs and benefits of rooftop solar and grid-scale solar more broadly. See, for instance, Bruce Tsuchida et al, "Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area," prepared by The Brattle Group for First Solar, July 2015.

14 We also analyze the impacts on CO_2 emissions, though that is not included as a financial benefit.

Fourth, the study focuses on the *relative* costs and benefits of typical rooftop and community solar installations. In focusing only on this relative difference of typical installations, the study does not present commentary on the overall cost-effectiveness of individual solar projects, which are necessarily project-specific.

Fifth, the study focuses specifically on the use of community solar to power a new energy efficient housing development in non-urban locations. Results could differ significantly if analyzing solar installations for an existing housing development, or for homes in a densely populated area (e.g., due to differences in typical siting constraints and land values).

Sixth, there are many different models for community solar projects. For the purposes of this study, we have defined community solar as a roughly 500 kW to 1,000 kW solar project with output that is tied to the energy needs of a new housing development. An alternative term for this type of project could be "building-tied community solar."

Lastly, but importantly, the study is based on review of publicly available data. We found that there is enough data available to establish meaningful conclusions about the potential benefits of using community solar projects to power ZNE homes. However, throughout this report we identify gaps where additional data would refine the conclusions. The conclusions can vary significantly depending on the characteristics of the individual projects and markets being considered. Further project-specific analysis is recommended.

Sidebar: Defining ZNE and Community Solar

Zero Net Energy

The term "zero net energy" is used throughout this report, though common alternative terms include "zero energy," "net zero energy." According to the U.S. Department of Energy's (DOE's) *A Common Definition for Zero Energy Buildings*, a ZNE building is "an efficient building where, on a source energy basis, actual annual delivered energy is less than or equal to the on-site renewable exported energy." DOE also developed the concept of a "zero energy community," which would allow a group of buildings to be supplied by renewable energy that is located within the "boundary" of the community.

The ZNE concept can be applied to homes or other buildings. According to the Net Zero Energy Coalition's *To Zero and Beyond: Zero Energy Residential Buildings Study* (2017), there were over 8,000 ZNE homes (including multi-dwelling units) and over 4,000 ZNE buildings in the U.S. and Canada at the end of 2016. The number of ZNE homes increased by 33 percent relative to 2015, whereas the number of ZNE buildings increased by over 80 percent. Roughly 40 percent of ZNE homes are single family homes; the other 60 percent are multi-family apartment units. California accounts for roughly 40 percent of all ZNE homes, though there are ZNE buildings in at least 31 states.

Community Solar

According to the National Renewable Energy Laboratory's (NREL's) *A Guide to Community Solar: Utility, Private, and Non-profit Project Development*, community solar is defined as "a solar-electric system that, through a voluntary program, provides power and/or financial benefit to, or is owned by, multiple community members."

Community solar projects can come in many sizes and configurations. Historically, individual projects have ranged in size from a few hundred kilowatts to several megawatts of capacity. Types of community solar projects range from rooftop PV installations on schools and commercial buildings to larger-scale, ground-mounted projects that could be connected at either the distribution or transmission level.

According to the Smart Electric Power Alliance (SEPA), there are over 700 MW of community solar capacity in the U.S., with an additional 300+ MW in the pipeline. GTM Research has identified nearly 3 GW of community solar projects that are in development across 29 states.

II. Methodology

Overview

This study relied on a multi-step framework for comparing the economics of ZNE homes to an alternative configuration that relies on community solar.

First, the characteristics of power generation for each of these two cases were defined. The conventional ZNE home relies on rooftop solar PV ("Rooftop Projects") whereas the alternative configuration relies on a community solar project ("Community Solar Project"). Rooftop Projects were assumed to be in the range of 5 kW to 10 kW of installed capacity. The orientation and angle of the panels was assumed to be fixed based on the orientation and angle of the roof. The Community Solar Project was assumed to be in the range of 500 kW to 1 MW. We assumed that the Community Solar Project was ground mounted, with single-axis tracking.[15]

Second, project costs were established based on a review of publicly available data. We relied on data developed by the National Renewable Energy Laboratory (NREL) for both project types, to ensure consistency in the cost comparisons. Basic cost categories include equipment, labor, permitting/inspection, and general overhead. As discussed in Section I of this report, the costs do not reflect any discounts associated with incentives such as tax credits or renewable energy certificates (RECs).

Economic benefits included avoided marginal energy costs (including losses) and deferred generation capacity costs. All data was based on observed 2016 system conditions. We additionally quantified CO_2 emissions reductions, though this was not included as a financial benefit. Transmission and distribution (T&D) cost impacts were not quantified in the analysis and are discussed qualitatively later in this section of the report.

To establish avoided costs, the output of each solar project was simulated using NREL's System Advisor Model (SAM).[16] The simulated hourly solar PV output was assumed to avoid the marginal energy cost in each associated hour. Avoided capacity costs were determined using

---

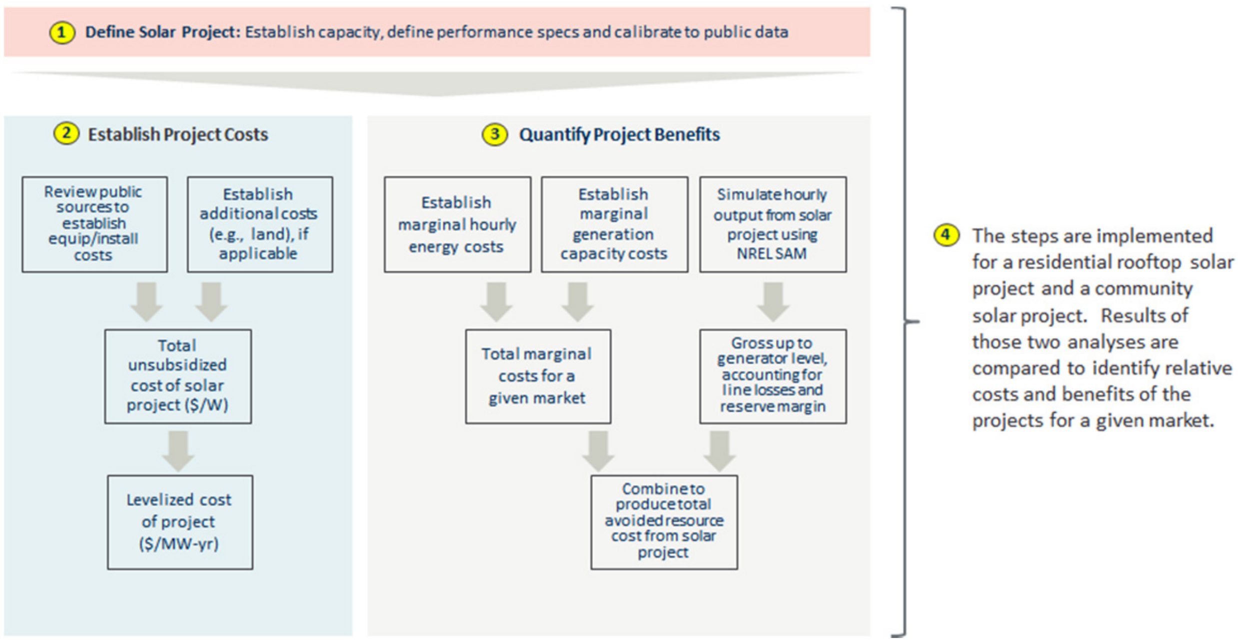
15 Single-axis tracking is a common feature of ground-mounted projects of this size. It allows the solar panels to track the sun along a single axis as it moves across the sky, thus increasing the total electricity production relative to fixed systems, particularly during non-peak hours.

16 System Advisor Model (SAM), National Renewable Energy Laboratory. https://sam.nrel.gov/.

established metrics for measuring the contribution of solar generation during system peak hours.[17]

The costs and benefits of Rooftop Projects were then compared to those of the Community Solar Project to identify relative differences between ZNE homes and the alternative community solar-based configuration. To facilitate this comparison, the costs and benefits of both project types were levelized in $/MW-year terms. An overview of this methodological approach is summarized in Figure 1.

Figure 1: Overview of Study Methodology



Methodology Details

The following is a summary of key methodological assumptions and data sources. Further detail on the study approach is provided in Appendix A. All costs are reported in 2017 dollars unless otherwise specified.

Solar PV Costs

We relied on NREL's *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017* as the starting point for the installed cost assumptions.[18] While there are a number of public data sources on

[17] This is referred to as the effective load carrying capability (ELCC) of solar PV. We relied on the Midcontinent Independent System Operator's (MISO's) method for calculating ELCC. Further detail is provided later in this report and in Appendix A.

installed solar PV costs, NREL's data was the most recent, aligned well with the size of projects considered in this study, and provided a useful degree of granularity on individual components of the total cost. We relied on NREL's "Residential" (3 to 10 kW) system for the Rooftop Project costs, and NREL's "Commercial" (10 kW to 2 MW) system for Community Solar Project costs.

Several adjustments were made to the NREL estimates to tailor them to the scope of this analysis:

- **Customer recruitment/marketing:** To the extent possible, customer recruitment and marketing costs have been excluded from the analysis for both project types. We would expect these costs to be lower for a new ZNE housing development than they are for standard rooftop or community solar projects, because marketing would be geared toward a small number of housing developers rather than toward individual consumers. We did not identify any data specifically on marketing costs for either solar project type in the context of ZNE homes. Since the focus of our study is on relative differences between the projects, and since we would expect these costs to be small and roughly similar between the two solar project types, they were excluded. The adjustment involved a reduction in NREL's rooftop solar cost data, which included significant sales and marketing costs for standard projects.

- **New construction efficiencies:** Our analysis is focused on new ZNE housing developments. As such, there would likely be efficiencies associated with installing rooftop solar at the time of home construction. We relied on NREL's *Cost-Reduction Roadmap for Residential Solar Photovoltaics, 2017-2030* to develop associated cost adjustments.[19] Based on that research, reductions were made to installation labor, permitting, inspection, and interconnection (PII) costs associated with rooftop solar.

- **Tracking technology:** We have assumed that the Community Solar Project will have single-axis tracking, which increases total output of the solar project by allowing the panels to follow the sun as it moves across the sky. Such technology is very common among ground-mounted projects of this size. Using relationships in the NREL data, the cost of the Community Solar Project was increased accordingly.

Continued from previous page

18 Ran Fu, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017," National Renewable Energy Laboratory, September 2017.

19 Kristen Ardani, Jeffrey J. Cook, Ran Fu, and Robert Margolis, "Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030." National Renewable Energy Laboratory, January 2018.

- **Land lease:** Ground-mounted community solar projects will include additional costs associated with the land on which they are located. Such costs were not included for the Commercial project in the NREL data. Land lease costs can vary dramatically depending on the location of the community solar project. Land for such projects is commonly very inexpensive in rural or less-densely populated areas, but would be significantly more expensive in urban areas. In cases where the community solar project is located on unutilized utility land, it could come at no cost. For this study, we have assumed that the Community Solar Project would be located in a less densely populated area with modest land lease costs. Careful consideration should be given to land cost when considering the economics of individual community solar projects.

Accounting for these adjustments, the costs of the Community Solar Project is roughly 15 percent lower than Rooftop Projects installed on individual homes, on a per-watt basis. A summary of the cost assumptions is provided in Table 1. Note that, throughout this report, costs are reported in 2017 dollars unless otherwise specified.

Table 1: Modeled Solar PV Costs

	Rooftop Solar ($/$W_{DC}$)	Community Solar ($/$W_{DC}$)
NREL installed cost	**2.80**	**1.85**
Adjustments		
Sales/marketing	-0.34	0.00
Installation labor	-0.09	0.00
PII	-0.06	0.00
Tracking technology	0.00	0.14
Land lease	0.00	0.01
Modeled installed cost	**2.31**	**2.00**

Notes: Modeled installed costs assume application to new ZNE housing development. Customer recruitment and marketing costs are excluded from the total. Costs shown do not reflect reductions due to tax incentives or other financial support.

Market Assumptions

The study models two different geographic markets in order to capture the significant variability in solar irradiation and energy costs across the U.S.[20] These two markets, Minnesota and New

[20] Solar PV costs were not assumed to vary across the two markets. While we would expect there to be some regional variation, particularly with respect to labor costs, reliable public data for estimating these differences was limited. Further, the magnitude of the relative difference in costs between

Continued on next page

Mexico, were selected because they present stark contrast across the key analytical variables of interest. Neither market is intended to be representative of the national landscape. Rather, the markets illustrate how different system conditions impact the findings of this study. Analysis in both markets is based on observed 2016 system conditions. The analytical approach used in this study could be repeated for any state or utility service territory of interest.

Key assumptions specific to each market include the following:

- **Marginal energy costs:** Minnesota is in the Midcontinent Independent System Operator (MISO) market, so hourly marginal energy costs were based on the energy component of MISO Minnesota Hub day-ahead locational marginal prices (LMPs). New Mexico is not part of an organized wholesale market. To approximate marginal energy costs, we relied on Public Service Company of New Mexico's (PNM's) hourly system lambdas.[21] We verified that system lambdas are a reasonable proxy for energy market prices.[22] Average marginal energy costs in both regions are similar – as they are across much of the U.S. due to low natural gas prices – though Minnesota's price shape demonstrates a more pronounced differential between peak and off-peak hours.

- **Marginal capacity costs:** Capacity prices in MISO have historically been very low. While the capacity needs of specific utilities in Minnesota vary, we relied on the MISO capacity market prices to represent a scenario where there is limited value in peak demand reductions. In New Mexico, we represented the marginal capacity cost as the levelized cost of a new peaking unit over 20 years, conforming to the approach discussed in PNM's latest Integrated Resource Planning (IRP) study. We assumed no avoided capacity benefit in the first seven years, because PNM in its IRP does not project a need for new capacity until 2023.

- **Average CO_2 emissions:** For both regions, we relied on U.S Energy Information Administration (EIA) data to establish the average annual emissions rate of the state's power generation mix.[23] New Mexico's supply is dominated by coal, leading to a higher

---

Continued from previous page

rooftop and community solar by region is likely to be modest compared to other important variables in this study.

21 The system lambda represents the dispatch cost of the utility's marginal generating unit. Hourly system lambdas are filed with the FERC through FERC Form 714.

22 See Appendix A for further detail.

23 Ideally, analysis of avoided emissions would consider the emissions rate of the displaced (marginal) unit in each hour, rather than the average rate of the generation fleet. As is discussed in Appendix A,

Continued on next page

average emissions rate than Minnesota, which includes considerably more natural gas and wind generation.

- **Solar radiation:** As discussed later in this section, solar radiation varies significantly across the two study markets. New Mexico has significantly higher solar PV potential than Minnesota.

Table 2 contrasts the market data for Minnesota and New Mexico.

Table 2: Summary of Study Market Characteristics

	Minnesota	New Mexico
Wholesale market structure	Deregulated (MISO)	Regulated
Marginal energy cost	Moderate ($26.61/MWh avg)	Moderate ($26.32/MWh avg)
Marginal capacity cost	Very low market prices ($7/kW-yr)	Capacity need in 2023 ($50/kW-yr)
Average CO_2 Emissions	Near U.S. average	8th-highest emitting state
Solar Radiation	Modest	High

T&D Costs

T&D costs will be impacted by the addition of both rooftop solar and community solar. Those impacts are not quantified in this study due to data limitations and the system- and location-specific nature of the calculations. Impacts on T&D costs could be addressed through additional engineering assessments.

A reduction in the system peak could reduce or defer the need for new peak-driven transmission capacity investments. In this study, the rooftop and community solar projects were both assumed to be located at the distribution level. As such, both would have the potential to defer long-term investments in transmission infrastructure. The effective load carrying capability

---

Continued from previous page

as bookends we considered cases where a natural gas combined-cycle unit or a coal unit are on the margin.

(ELCC) of the respective projects should determine the relative cost savings advantage that community solar has in this regard. Further discussion of ELCC is provided later in this report.

Both types of solar PV projects considered in this study have the potential to either decrease or increase distribution capacity investment needs. Distribution capacity needs may potentially be deferred if load is consistently reduced in constrained portions of the system during hours when the constraints would otherwise occur. Several studies have quantified this potential to reduce costs.[24] Alternatively, distribution costs may increase if exports from the PV systems to the grid lead to issues such as reverse power flow, voltage fluctuations, overloading of feeders, etc. Studies have also considered the possibility of increased distribution costs, specifically in the context of ZNE homes.[25]

Whether the distribution cost impact would favor rooftop or community solar is very dependent on system conditions. On one hand, under certain circumstances community solar projects have the flexibility to be located in beneficial locations on the distribution system. Whether this presents an economic advantage to community solar would depend on the utility's ability to identify these locations and align them with low-cost land leasing opportunities. On the other hand, rooftop solar can more feasibly be located nearer to load centers in more densely populated areas, which may help to address distribution system constraints in those areas.

T&D line losses are the one aspect of T&D costs that were quantitatively represented in our study. Both types of solar projects were assumed to avoid T&D losses. For distribution losses, we have assumed that Rooftop Projects avoid losses on the both primary and secondary feeders, while the Community Solar Project only avoids losses on primary feeders.[26] The result is a modest net financial advantage to the Rooftop Projects in this regard. In a future where rooftop PV "exports" power beyond its local area (e.g., to a neighboring distribution network), the exported power will suffer more from secondary feeder losses, thus reducing the slight economic advantage that Rooftop Projects have over the Community Solar Project.

Solar Project Performance

NREL's System Advisor Model (SAM) was used to simulate hourly output for both project types.[27] The simulations rely on 20-year historical insolation profiles for the two study markets.

---

[24] See, for instance, Rocky Mountain Institute, "A Review of Solar PV Benefit & Cost Studies," September 2013.

[25] DNV GL, "Customer Distributed Energy Resources Grid Integration Study," prepared for the California Public Utilities Commission, October 18, 2017.

[26] We are assuming the Community Solar Project is interconnected to the distribution network at the primary feeder level.

[27] System Advisor Model (SAM), National Renewable Energy Laboratory. https://sam.nrel.gov/.

Both systems were modeled with 1 MW_{AC} capacity using standard quality panels. Orientation and tilt assumptions were based on default SAM values and validated against historical observations. Rooftop Projects were assumed to have an orientation of 160 degrees, which is slightly off of due south to account for the fact that homes are not always situated to maximize solar PV output.[28] Consistent with NREL modeling assumptions, both projects were assumed to have an inverter loading ratio (ILR) of 1.15, meaning the capacity of the panels is 15% larger than that of the inverter. We also used NREL inverter efficiency modeling assumptions of 94 percent for rooftop solar and 96 percent for community solar. See Appendix A for further detail.

Based on these assumptions, the annual output of the Community Solar Project is roughly 30 percent higher than that of the Rooftop Projects.[29] The Community Solar Project also makes a greater contribution during system peak hours, as measured by the ELCC. A solar project's ELCC roughly represents its average availability during those peak hours, and determines the extent to which a resource can avoid the need for new peaking capacity in the region.[30] Across the geographic markets, higher solar radiation in New Mexico leads to output that is 50 to 60 percent higher than in Minnesota.[31]

Table 3 summarizes the relative performance of the solar PV projects across the two markets.

---

28 The impact of this assumption on the quantitative study results is inconsequential.

29 Community solar output is 27 percent higher in Minnesota and 31 percent higher in New Mexico.

30 There are many established ways to calculate ELCC, with no clear industry standard across utilities and market operators. The method is subject to the objectives and preferences of system planners. We have adopted the MISO ELCC calculation methodology for both markets in our analysis to allow for a consistent comparison of capacity value across the two markets. Alternative methodologies could lead to higher or lower capacity value estimates for both PV project types. See Appendix A for further discussion.

31 Community solar is 59 percent higher in New Mexico than in Minnesota, and rooftop solar is 54 percent higher in New Mexico than in Minnesota.

Table 3: Modeled Solar PV Performance

	Rooftop Solar	Community Solar
Capacity Factor (DC)		
Minnesota	12.4%	15.7%
New Mexico	19.0%	24.9%
Capacity Factor (AC)		
Minnesota	14.2%	18.0%
New Mexico	21.8%	28.6%
ELCC (AC)		
Minnesota	35.6%	50.1%
New Mexico	39.9%	60.4%

Notes: Modeled using NREL SAM. ELCC determined using MISO methodology.

ZNE Homes

To understand the incremental value of the community solar-based configuration relative to a conventional ZNE configuration, we simulated the energy needs of a development of 200 ZNE homes in each study market. In both cases, an average ZNE home was assumed to be 70 percent more energy efficient than the average home in that market. Additionally, differences in climate and solar radiation between New Mexico and Minnesota lead to a significantly different need for solar PV capacity between the two markets. Whereas the estimated size of a ZNE rooftop solar installation was 6.1 kW_{DC} in Minnesota, it was only 3.1 kW_{DC} in New Mexico. Across all 200 ZNE homes, this amounts to roughly 1,230 kW_{DC} of installed rooftop PV capacity in Minnesota and 620 kW_{DC} in New Mexico. Appendix A provides more detail behind these calculations.

III. Key Findings

ZNE Home Benefits

There are two ways to look at the benefits of the alternative community solar-based configuration. The first is to assume that the Community Solar Project is designed to produce the exact same **annual output** as the collection of 200 ZNE Rooftop Projects. Since community solar provides more output per unit of installed capacity, solar PV project cost savings are the metric of interest in this case. Assuming the Community Solar Project is sized to produce the same output as the Rooftop Projects, the total solar PV project costs of the ZNE homes would be reduced by more than 30 percent. Annual savings per home would equal $196 in New Mexico and $360 in Minnesota.[32] Table 4 summarizes these results.

Table 4: Solar PV Project Cost Savings of Community Solar-Based Configuration

	Minnesota	New Mexico
Savings per home per year	$360	$196
20-yr savings per home	$7,196	$3,913
20-yr savings for 200-home community	$1,440,000	$780,000
Savings relative to rooftop solar costs	32%	34%

Notes: Assumes community solar project is sized to produce the same annual output as would be required of 200 individual rooftop solar installations. 20-year savings represent undiscounted sum of annual values in 2017 dollars. Savings for 200-home community are rounded to nearest $10,000.

The other way to evaluate the relative benefits of the alternative community solar-based configuration is to assume that the size of the Community Solar Project is based on the exact same **project expenditures** as otherwise would have been collectively spent powering ZNE homes from individual Rooftop Projects. In this case, since costs are the same, the metrics of interest relate to the additional value that the Community Solar Project provides by virtue of its greater output. For the same budget, the Community Solar Project would provide incremental benefits in the form of additional avoided resource costs and reduced CO_2 emissions.

Relative to conventional ZNE homes, the community solar-based configuration produces resource cost savings that are roughly 50 to 60 percent higher. CO_2 emissions reductions are roughly 40 to 45 percent higher due to the use of community solar. For a community of 200

32 Aggregate savings are higher in Minnesota because more solar capacity is required to serve a Minnesota ZNE home's energy needs, and therefore greater total project expenditures are required. On a percentage basis, the financial savings of community solar are slightly higher in New Mexico.

highly efficient homes, these CO_2 savings would amount to nearly 8 million tons of CO_2 in Minnesota and nearly 10 million tons of CO_2 in New Mexico over 20 years. Those CO_2 savings are the equivalent of taking 80 cars off the road in Minnesota and 100 cars off the road in New Mexico.[33] Table 5 summarizes these findings.

Table 5: Incremental System Benefits of Community Solar-Based Configuration

	Minnesota			New Mexico		
	Annual	20-yr cumulative	Increase relative to conventional ZNE	Annual	20-yr cumulative	Increase relative to conventional ZNE
Per home						
Energy (kWh)	557	11,132	41%	957	19,144	46%
System resource cost savings ($)	$99	$1,980	48%	$110	$2,207	58%
Avoided system CO_2 emissions (tons)	2.0	40	41%	2.5	50	46%
200-home community						
Energy (kWh)	111,321	2,230,000	41%	191,438	3,830,000	46%
System resource cost savings ($)	$19,803	$400,000	48%	$22,073	$440,000	58%
Avoided system CO_2 emissions (tons)	397	7,938	41%	497	9,939	46%

Notes: Assumes community solar project is sized based on the same project expenditures that would be required for 200 individual rooftop solar installations. 20-year savings represent undiscounted sum of annual values in 2017 dollars. Avoided system CO_2 emissions are based on average state emissions profiles. 20-year energy savings rounded to the nearest 10,000 kWh. 20-year resource cost savings rounded to the nearest $10,000.

Note that the cost savings presented in Table 4 and the benefits presented in Table 5 are not additive. They are two different ways of measuring the incremental value of the alternative community solar-based configuration.

SYSTEM IMPACT DETAILS

To better understand the relative system costs and benefits of ZNE homes and the alternative configuration, it is helpful to consider the value per unit of installed PV capacity. Figure 2 summarizes the incremental costs and benefits of the Community Solar project relative to the Rooftop Projects, on a per-megawatt basis.

33 Based the U.S. Environmental Protection Agency's (EPA's) calculation of annual CO_2 emissions for the average U.S. passenger vehicle. EPA website: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#vehicles.

From the system perspective shown in Figure 2, it is clear that the lower installed cost per MW_{DC} of community solar provides the primary financial benefit. Due to current low wholesale energy prices, avoided energy costs are a modest share of the total incremental benefit of community solar, in spite of its greater than 25 percent advantage in total energy output. Avoided capacity costs will vary significantly by region, depending on capacity needs and the ELCC that system planners assign to both types of solar PV.

Figure 2: Incremental System Costs and Benefits of Community Solar-based Configuration Relative to Conventional ZNE Approach, per MWDC of installed Capacity

Note: Costs shown do not reflect reductions due to tax credits or other financial support. Solar PV investment decisions are based on cost discounts and revenue streams not reflected in the "system" perspective taken in this analysis.

IV. Conclusions

Summary of Findings

This study has assessed the potential benefits of an alternative to conventional ZNE configurations, by supplying clean energy to energy efficient homes using a larger community solar project. We have specifically considered a hypothetical new development of 200 homes in non-urban locations in both Minnesota and New Mexico.

Under the market characteristics considered in this study, the economies of scale and technological advantages of the homes configured with community solar provide roughly:

- 13% lower total solar PV project expenditures per watt than ZNE homes
- 25 to 30% greater annual energy output per watt than ZNE homes

As a result of these advantages, a community solar-based approach could serve a development of 200 homes with total solar PV project cost savings of approximately 30 to 35 percent relative to conventional ZNE configurations.

Viewed an alternative way, the same total expenditure on the community solar-based approach that would have been required in the conventional ZNE approach could produce:

- Enough additional electricity production to power another 80 to 90 efficient homes
- 50 to 60% resource cost savings (i.e., avoided generation from the power grid)
- 40 to 45% reduction in average CO_2 emissions (equivalent to 80 to 100 cars off the road, or roughly one car per two ZNE homes)

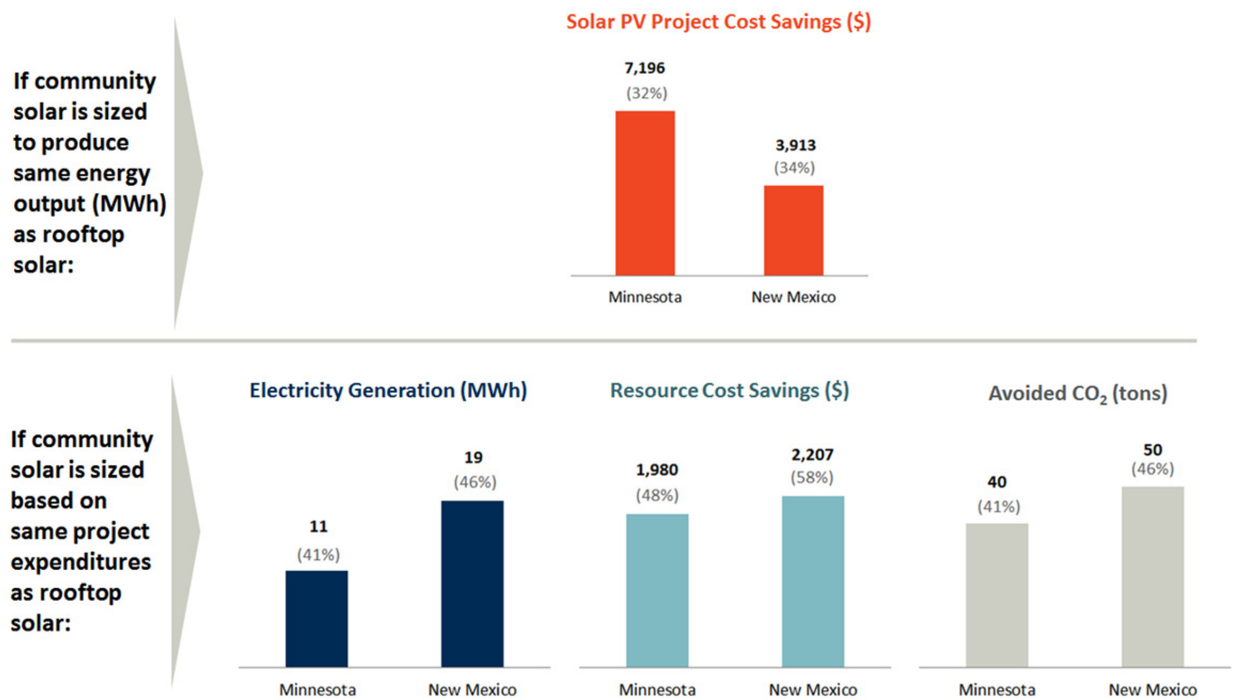
In addition to these financial and environmental benefits, the inclusion of community solar projects would expand the base of eligible customers to include those who would not otherwise be able to participate in ZNE initiatives (e.g., individual tenants of large apartment buildings).[34]

Figure 3 provides a summary of the 20-year cumulative benefits quantified in this study.

---

34 NREL has estimated that 49% of households and 48% of businesses are unable to host PV due to issues such as building leasing constrains and inadequate roof space. Community solar would provide access for these segments of the population.

Figure 3: 20-year Incremental Benefits of Using Community Solar, per Home
(Percent savings relative to conventional ZNE configuration shown in parentheses)



Notes: Bottom panel reflects community solar project sized based on the same expenditures that would be required for 200 individual rooftop solar installations. 20-year savings represent undiscounted sum of annual values in 2017 dollars. Avoided system CO_2 emissions are based on average state emissions profiles.

Policy Considerations

A variety of alternatives to ZNE initiatives may provide improved consumer and environmental outcomes at a lower cost. The community solar configuration described in this study is just one such example.

Where a decision has been made to implement ZNE initiatives, community solar could be incorporated in a variety of forms.[35] For instance, policymakers may wish to explore making the provision of financial support for the development of ZNE homes contingent on the economic evaluation of a range of renewable generation options, including community solar and others.

[35] For example, the California Energy Commission recently proposed language in the state's "Title 24" building efficiency standards that would allow community solar and community storage to count toward the on-site electricity generation of ZNE homes.

The inclusion of community solar provides benefits to a broader pool of potential program participants, so policies that include community solar may garner broader support as well. Such an approach may help to generate consensus in instances where conventional ZNE programs may otherwise be perceived as unfair to customers who would be eligible to participate.

Policymakers may also wish to analyze and quantify the extent to which the deliberate inclusion of community solar or other forms of clean generation in ZNE policies will expand the potential market impact of the policies. The economic and technical advantages of a broader range of generation options should allow for a materially greater level of participation in new ZNE initiatives, by getting more mileage out of existing funding and by including a broader pool of customers.

Since community solar projects are not located directly on homes, building code policies that incorporate community solar would need to consider how to ensure that the community solar project actually gets developed, and that the project's output is tied to the community or development for the long-term.

When moving beyond ZNE initiatives to more broadly include community-based or utility-scale generation projects, careful consideration should be given to the definition of the "boundaries" within which the projects must reside. This will involve an assessment of the tradeoffs between the cost savings of larger, centralized projects and the potential economic and non-monetary benefits of smaller projects that are located nearer to housing developments.

For utilities and solar developers, partnering with ZNE housing developers may serve as a new business model for community solar projects. Doing so could reduce marketing and sales costs that would otherwise be associated with recruiting individual customers into the community solar program.

Similarly, housing developers may wish to explore opportunities to incorporate community solar into new housing developments. As an alternative to rooftop solar, community solar has the potential to provide development cost savings.

Utility service territory-specific analysis of community solar opportunities is recommended. The findings of this study are specific to the underlying assumed system conditions. While we have explored a fairly robust range of conditions, the conclusions could change if analyzing other markets or solar configurations.

From the homeowner's perspective, it would be useful to extend the analysis to consider a range of rooftop and community solar pricing models. This study only accounted for system-level costs and benefits. Customer-oriented analysis would provide valuable insight regarding the effective design of ZNE and community solar programs, and the distributional effects of such initiatives.

The analysis presented in this study should be extended to multi-family dwellings and non-residential buildings, other geographic markets, and other configurations of rooftop and community solar projects. The analysis could also be extended to include a detailed assessment of the impacts of rooftop and community solar on distribution system costs. Such analysis would provide a broader sense of the robustness of the conclusions.

V. Resources

Publications

Ardani, Kristen, Jeffrey J. Cook, Ran Fu, and Robert Margolis, "Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030," National Renewable Energy Laboratory, January 2018.

Barbose, Galen and Naïm Darghouth, "Tracking the Sun 10," Lawrence Berkeley National Lab, September 2017.

Brehm, Kevin et al, "Community-Scale Solar, Why Developers and Buyers Should Focus More on This High-Potential Market Segment," Rocky Mountain Institute, March 2016.

California Energy Commission and California Public Utility Commission, "New Residential Zero Net Energy Action Plan 2015-2020," June 2015.

Clarin, Bienvendio, Ram Narayanamurthy, Rob Hammon, Ian Hammon-Hogan, and William Vincent, "Establishing Feasibility of Residential Zero Net Energy Community Development – Learnings from California's First ZNE Neighborhood," EPRI, BIRA Energy, and SCE, 2016.

DNV GL, "Customer Distributed Energy Resources Grid Integration Study," prepared for the California Public Utilities Commission, October 18, 2017.

Fu, Ran, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani, "NREL U.S. Solar Photovoltaic System Cost Benchmark Q1 2017 Report," National Renewable Energy Laboratory, September 2017.

Garrison, Michael et al, "Zero Net Energy Homes Project," University of Texas at Austin, 2005.

Honeyman, Cory, MJ Shiao, and Sarah Krulewitz, "U.S. Community Solar Outlook 2017," GTM Research, February 2017.

Maclay Architects and Efficiency Vermont (January 30, 2015): Net Zero Energy Feasibility Study.

Net-Zero Energy Coalition, "To Zero and Beyond: Zero Energy Residential Buildings Study," June 2017.

Residential Energy Consumption Survey (RECS). Energy Information Administration, 2009.

Rocky Mountain Institute, "A Review of Solar PV Benefit and Cost Studies," 2nd Edition, September 2013.

Smart Electric Power Alliance, "2017 Solar Market Snapshot," July 2017.

Smart Electric Power Alliance, "Community Solar Program Design Models," 2018.

Tsuchida, Bruce et al, "Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area," July 2015.

U.S. Department of Energy, "A Common Definition for Zero Energy Buildings," September 2015.

U.S. Department of Energy, "A Guide to Community Shared Solar: Utility, Private, and Non-profit Project Development," May 2012.

Websites

California Energy Commission: http://www.energy.ca.gov/releases/2018_releases/2018-05-09_building_standards_adopted_nr.html.

Convert Units: https://www.convertunits.com/from/kwh/to/btu.

EPA: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#vehicles.

Greentech Media coverage: https://www.greentechmedia.com/articles/read/california-wants-all-new-homes-to-be-net-zero-in-2020#gs.1ddpNE8.

HERS Index: http://www.hersindex.com/.

RESNET: https://www.resnet.us/hers-index.

Wikipedia: https://en.wikipedia.org/wiki/Zero-energy_building.

Zero Energy Design Glossary: https://zeroenergy.com/energy-glossary/.

Zero Energy Ready Home: https://energy.gov/eere/buildings/zero-energy-ready-home.

Appendix A: Additional Study Details

Beyond Zero Net Energy?

Alternative Approaches to Enhance Consumer and Environmental Outcomes

Technical Appendix

THE Brattle GROUP

Methodology and Assumptions

Methodology Overview (1 of 2)

The analysis compares two types of solar PV systems for two markets.

- Residential-scale (i.e., rooftop) vs. Community-scale (CS) PV systems
  - Rooftop in the 5 kW to 10 kW range, CS in the 500 kW to 1 MW range.
  - CS systems have single axis tracking.
- Minnesota vs. New Mexico
  - Different resource mix, wholesale market structure, and solar irradiance.

Costs and benefits are compared for the two types of solar PV systems.

- Benefits
  - Energy (including losses), capacity, and carbon emission reduction.
  - Based on 2016 market conditions.
- Costs
  - System installation costs
- Analysis takes a “societal” or “system level” view of costs and benefits.
  - No specific owner perspective (e.g., utility, solar developer, customer, etc.) is assumed; therefore the assessment of costs and benefits excludes tax incentives, renewable energy credits, etc.

Methodology Overview (2 of 2)

Solar Project Evaluation

1 **Define Solar Project:** Establish capacity, define performance specs and calibrate to public data

2 Establish Project Costs

Review public sources to establish equip/install costs

Establish additional costs (e.g., land), if applicable

Total unsubsidized cost of solar project ($/W)

Levelized cost of project ($/MW-yr)

3 Quantify Project Benefits

Establish marginal hourly energy costs

Establish marginal generation capacity costs

Simulate hourly output from solar project using NREL SAM

Total marginal costs for a given market

Gross up to generator level, accounting for line losses and reserve margin

Combine to produce total avoided resource cost from solar project

Project Comparison

4 The steps are implemented for a residential rooftop solar project and a community solar project. Results of those two analyses are compared to identify relative costs and benefits of the projects for a given market.

Two Solar PV Systems

Two types of PV systems (rooftops and CS) were compared.

Parameters	Rooftop PV	Community Solar
Orientation	160°	180°
Tracking	Fixed	Single axis (ground mounted)
Inverter Loading Ratio	1.15	1.15
Inverter Efficiency	94%	96%

The same PV assumptions were used for both markets, but using location-specific irradiance data. See later slide for additional SAM input assumptions.

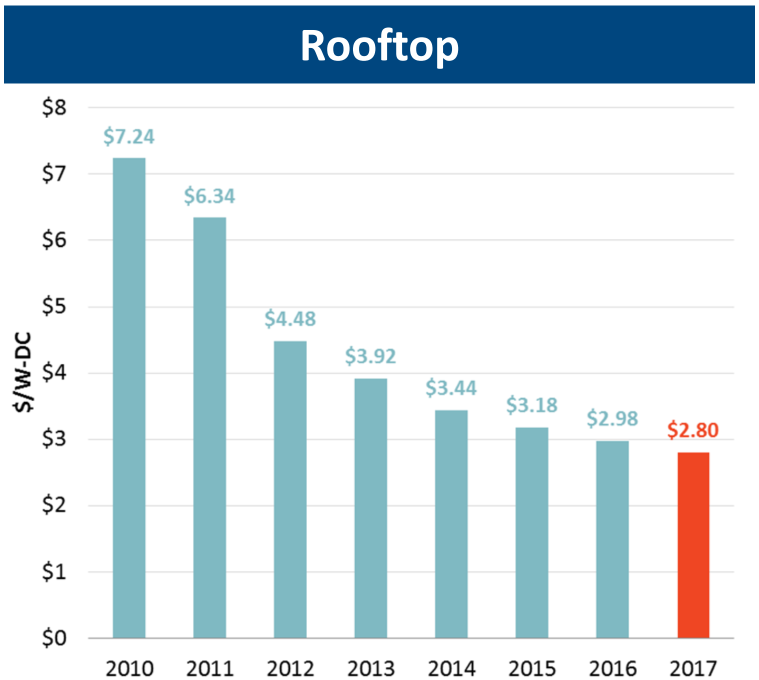
Model and Assumptions

- NREL System Advisor Model (SAM) used to simulate hourly PV output, based on 30-year historical insolation profiles for selected markets.
- Both systems were modeled with a 1 MW_{AC} capacity using standard quality panels.
- Orientation and tilt assumptions were based on default SAM values and validated against historical observations.
- 160° orientation for rooftop PV reflects observation that homes are often not oriented on the lot to maximize PV output (i.e., with rooftops that face due south).

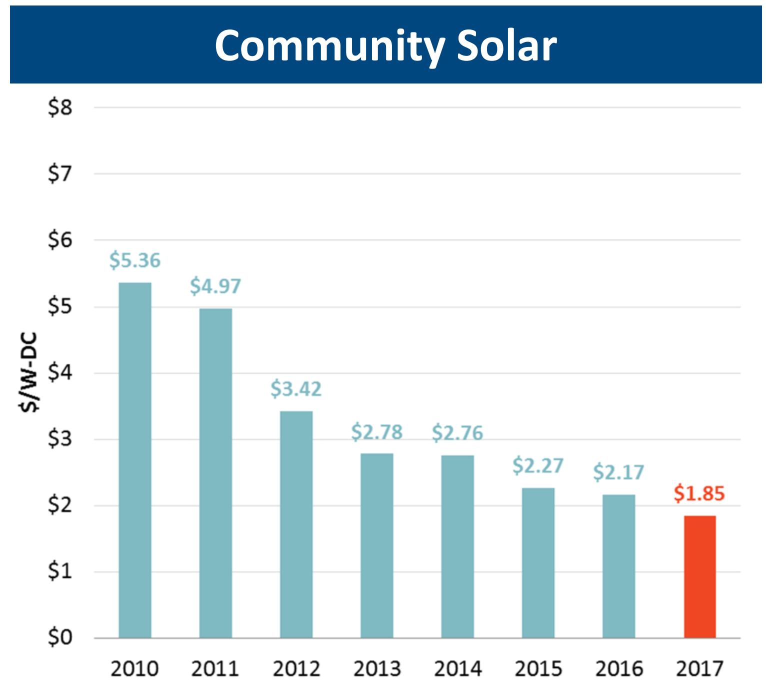
Solar PV Project Cost Assumptions and Trends

NREL data provides the most up-to-date estimates of solar PV costs for both residential rooftop systems and CS-sized systems.

- Rooftop (<10 kW): $2.80/$W_{DC}$
- Commercial (10 kW to 2 MW): $1.85/$W_{DC}$



Source: NREL, U.S. Solar PV System Cost Benchmark: Q1 2017.



Source: NREL, U.S. Solar PV System Cost Benchmark: Q1 2017.

Note: Prices shown are based directly on NREL cost data. We assume CS system costs to be similar to commercial solar systems.
For commercial solar, NREL provides cost estimates for 100 kW ($2.03/$W_{DC}$), 200 kW ($1.85/W_{DC}), 500 kW ($1.77/$W_{DC}$), and 1 MW ($1.74/W_{DC}) installations. We use the 200 kW estimate for this study.

Adjustments to NREL cost data

Brattle Adjustments to NREL Costs

	Rooftop Solar ($/W_DC$)	Community Solar ($/W_DC$)
NREL installed cost	**2.80**	**1.85**
Adjustments		
Sales/marketing	-0.34	0.00
Installation labor	-0.09	0.00
PII	-0.06	0.00
Tracking technology	0.00	0.14
Land lease	0.00	0.01
Modeled installed cost	**2.31**	**2.00**

Rooftop Solar PV adjustments

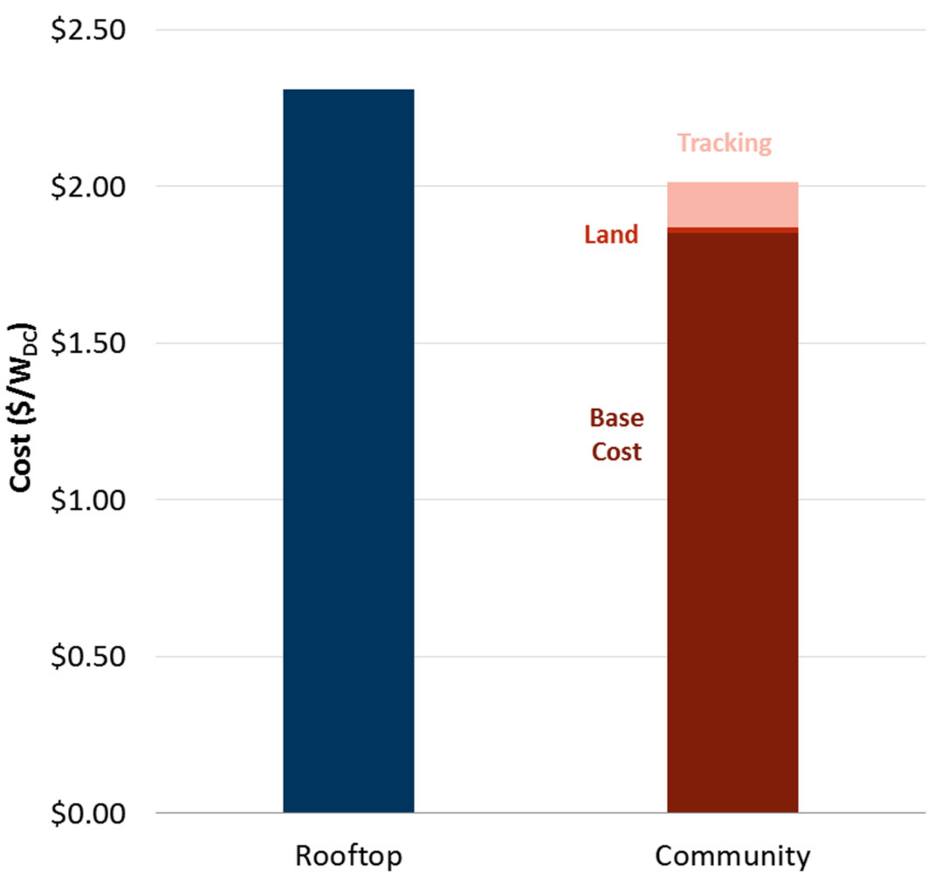
- Sales/marketing cost excluded from analysis for both project types (see next slide)
- Installation labor and permitting, inspection, and interconnection costs (PII) reduced to reflect efficiencies associated with rooftop PV installation at time of housing construction
  - Adjustments based on data in NREL's *Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030.*
- See later slide for detail on CS cost adjustments

Additional Commentary on Solar PV Project Cost Assumptions

- Regional variation in labor/equipment costs is likely modest, particularly with respect to the delta between rooftop and CS.
  - Existing PV cost data does not sufficiently capture these differences, so we have not modeled regional variation in costs.
- Cost analysis is based on best available public data, but is subject to some constraints.
  - NREL data does not reflect customer recruitment/marketing costs that would be associated with solar PV for a new ZNE housing development
    - Given the lack of data, for the best possible comparison of relative total costs between rooftop and CS, we have excluded recruitment/marketing costs from the analysis for both project types.
  - As a ground-mounted system, the CS project would likely have lower O&M costs than a rooftop PV project; this cost advantage to CS is not accounted for in the analysis, though the CS project's tracking equipment would increase O&M costs.
  - We have adopted NREL's cost estimate for a 200 kW system, which is smaller (and therefore more costly) than many larger-sized CS projects, thus overstating CS costs in this regard
- Ultimately, the cost-per-kW advantage of CS is primarily be driven by economies of scope and scale, which are captured in our study. The development and publication of better data on the relative costs of residential rooftop and CS projects of various types and location would be a useful future research activity.

Solar PV Project Cost Components

Solar PV Cost Comparison



CS Cost Assumptions

Tracking

- According to NREL, utility-scale PV systems with single-axis tracking were \$0.08/W_{DC} more expensive than similar fixed systems in Q1 2017.
- As commercial scale PV systems are 80% more expensive than utility-scale systems (\$1.85/W_{DC} vs. \$1.03/W_{DC}), we assume the same cost premium applies to tracking for CS, resulting in a total incremental cost of \$0.14/W_{DC} for single-axis tracking in a CS system.

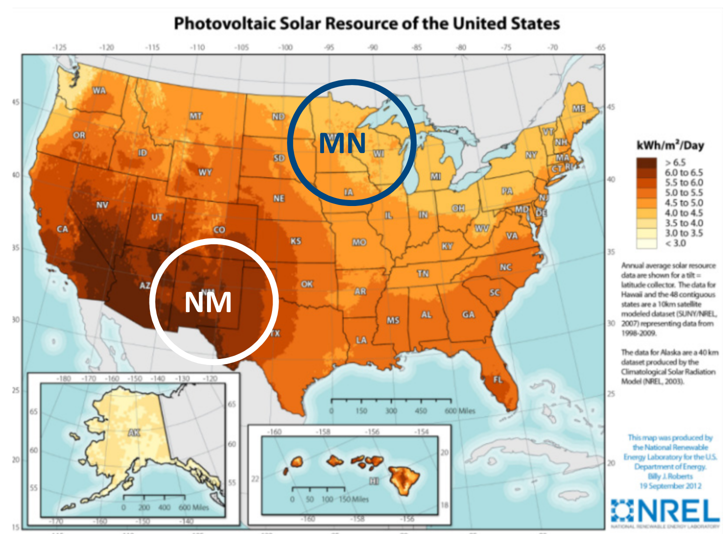
Land lease cost

- Assumed $1/kW-year.
- CS projects are often installed on utility-owned or otherwise very inexpensive land; alternatively, land lease costs for CS projects in urban areas would be significantly higher.

Two Markets

Two markets that present stark contrast across key variables of interest were selected. Neither market is intended to be representative of the national landscape, but rather to illustrate how different system conditions impact our findings. The two markets are compared assuming 2016 market conditions.

	Minnesota	New Mexico
Solar Radiation	Modest	High
Marginal Energy Cost	Average $26.61/MWh	Average $26.32/MWh
Marginal Capacity Cost	Very low market prices (MISO)	New capacity need in 2023 (PNM IRP)
Average CO_2 Emissions Rate	Near US average	8th highest-emitting state
Wholesale Market Structure	Deregulated (MISO)	Regulated

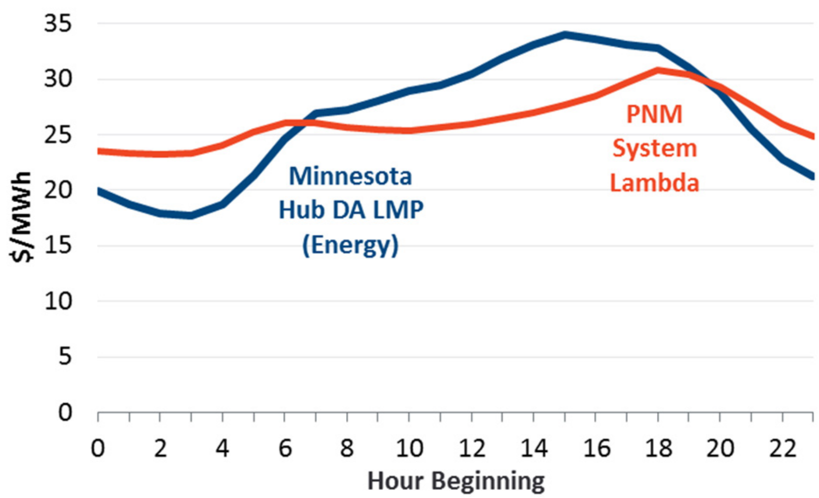


Source: NREL. https://www.nrel.gov/gis/images/eere_pv/national_photovoltaic_2012-01.jpg.

Marginal Resource (Energy & Capacity) Costs

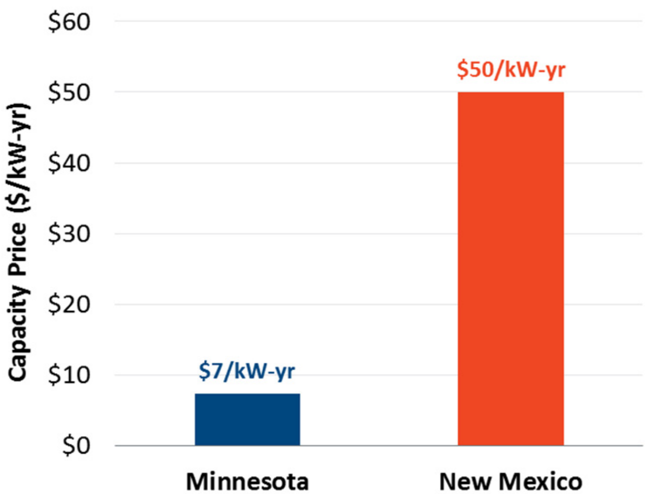
Marginal resource costs are the costs that are avoided by the new rooftop or community solar projects.

Marginal Energy Costs (Average Day)



- Minnesota: Energy component of 2016 MISO Minnesota Hub Day-Ahead LMP.
- New Mexico: 2016 PNM system lambda.
- System lambdas represent the dispatch cost of the marginal generation unit in each hour; a comparison of system lambdas to market prices in MISO confirmed that, in the absence of a wholesale energy market, they are a reasonable approximation of market prices (see next slide).
- We do not model the impact of new solar installations on the marginal energy price; our analysis is limited to avoided fuel and O&M costs.

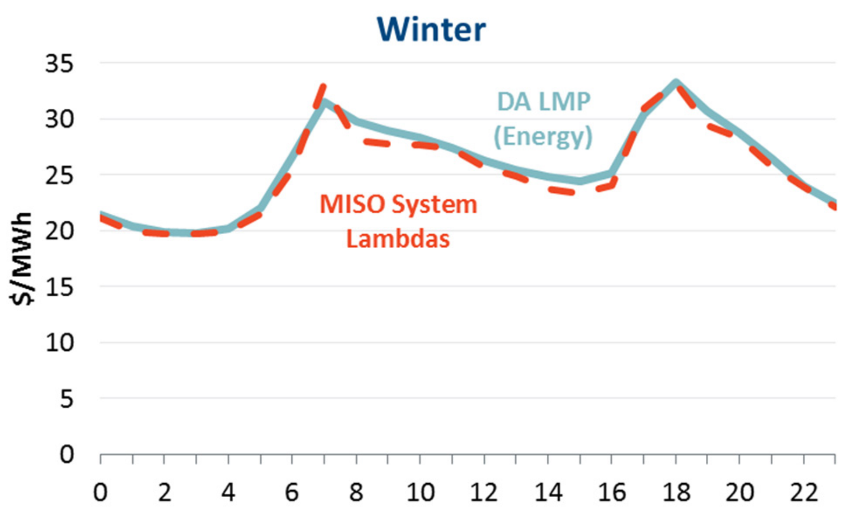
Marginal Capacity Costs

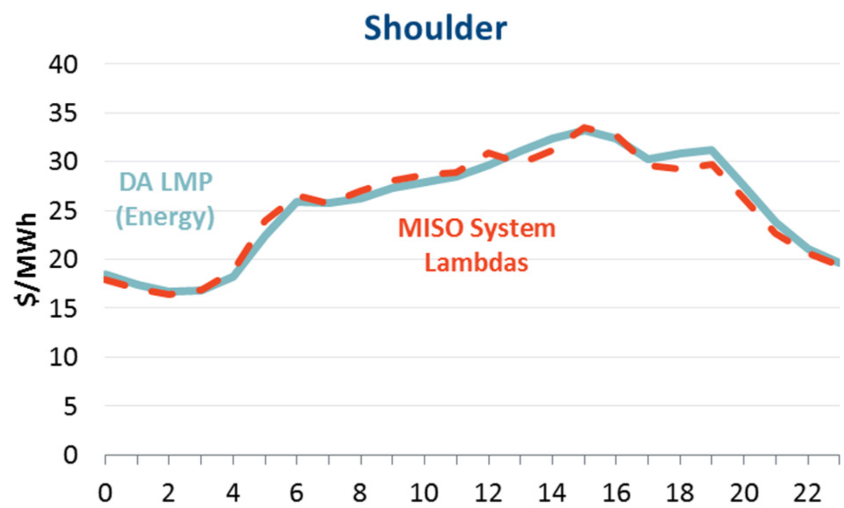


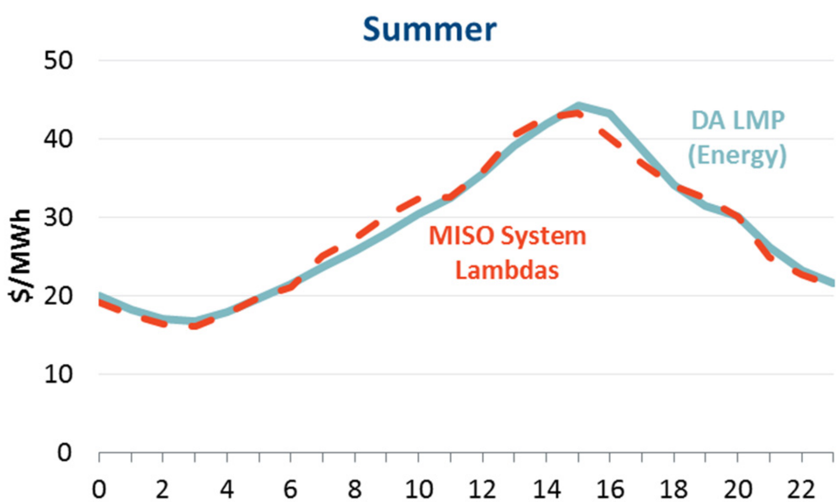
- Minnesota: 2016/2017 MISO capacity auction price (capacity prices in MISO have historically been in this low range).
- New Mexico: Levelized cost of a new peaking unit over 20 years, assuming zero benefits for first 7 years since PNM does not project a need for new capacity until 2023.
- Capacity cost assumptions represent two relevant cases, though it is important to recognize that different utilities in these and other regions will have different capacity needs.

System lambda validation

2016 Minnesota Hub DA Prices and MISO Lambdas





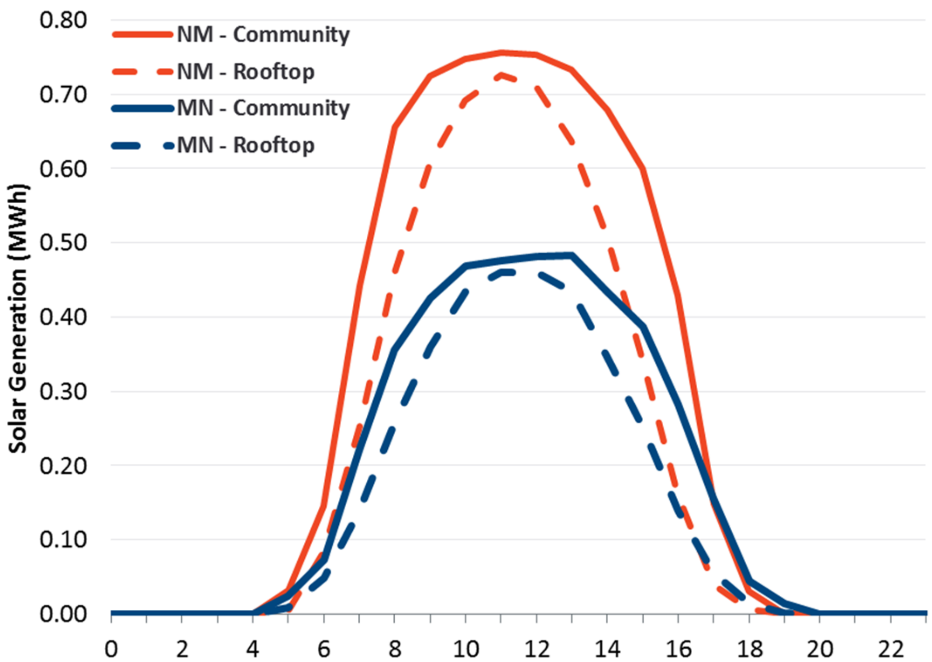


Observations

- System lambdas were used as a proxy for energy prices in New Mexico, where there is no organized wholesale energy market.
- To determine the extent to which system lambdas are an appropriate proxy, we compared lambdas to energy prices in Minnesota, where both are available.
- Lambdas tracked the day ahead energy price reasonably well on a seasonal and daily basis.

Relative Performance of Solar Projects

Average Daily Generation Profiles



Source: Brattle analysis using NREL's System Advisory Model

	Capacity Factor (DC)		Capacity Factor (AC)		ELCC (AC)	
	Rooftop	CS	Rooftop	CS	Rooftop	CS
Minnesota	12.4%	15.7%	14.2%	18.0%	35.6%	50.1%
New Mexico	19.0%	24.9%	21.8%	28.6%	39.9%	60.4%

Observations

- Technical advantages of the CS projects lead to output that is higher than rooftop solar by approximately 27% in Minnesota and 31% in New Mexico.
- Significantly higher solar radiation in New Mexico leads to output that is higher than in Minnesota by 59% for community solar and 54% for rooftop solar.
- Similar advantages are observed in effective load carrying capacity (ELCC), which is one way to measure a solar project's contribution to peak system capacity needs.

Additional System Advisor Model (SAM) Assumptions

Losses and Location

- SAM default loss parameters were used at both locations (see table)

- SAM Locations
  - Minnesota: Brainerd Wieland
    - Station ID: 726555
  - New Mexico: Albuquerque Airport
    - Station ID: 723650

Parameters	Loss (%)
Soiling	2%
Shading	3%
Snow	0%
Mismatch	2%
Wiring	2%
Connections	0.5%
Light-induced Degradation	1.5%
Nameplate	1%
Age	0%
Availability	3%
Total	**14%**

Effective Load Carrying Capability (ELCC)

As noted previously, the capacity contribution of the PV projects can be determined using an ELCC calculation.

There are many established ways to calculate ELCC, with no clear industry standard across utilities and market operators. The method is subject to the objectives and preferences of system planners.

For instance, MISO and PNM use significantly different methods for calculating ELCC.

- MISO ELCC[1]
  - Calculated for each individual resource based on its 3-year historical average output during peak hours.
  - Peak hours: All hours ending 15, 16, and 17 in summer (June - August).
- PNM ELCC[2]
  - Pre-established estimates are used for all resources of a given type (in AC terms).
  - Behind-the-meter solar ("private"): 56%
  - Front-of-meter solar ("universal," fixed tilt): 56%
  - Front-of-meter solar ("universal," w/tracking): 76%
  - Expected by PNM to decrease significantly by 2023 as additional PV penetration shifts net peak later in day.

We have adopted the MISO ELCC calculation methodology for both markets in our analysis to allow for a consistent comparison of capacity value across the two markets. Alternative methodologies could lead to higher or lower capacity value estimates for both PV project types.

Sources:
[1]: MISO Solar Capacity Credit presentation, December 2, 2015
[2]: PNM 2017-2036 IRP, Appendix K, July 3, 2017

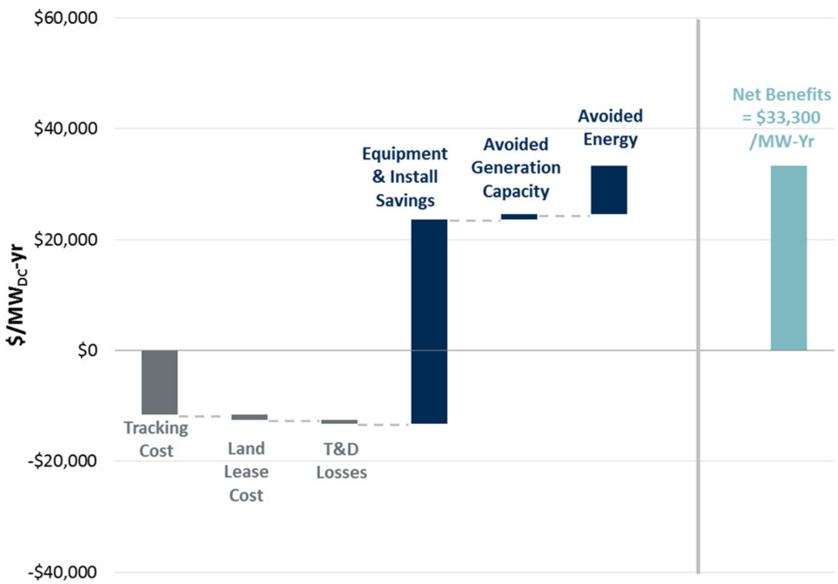
Findings

Relative Economic Advantage of CS

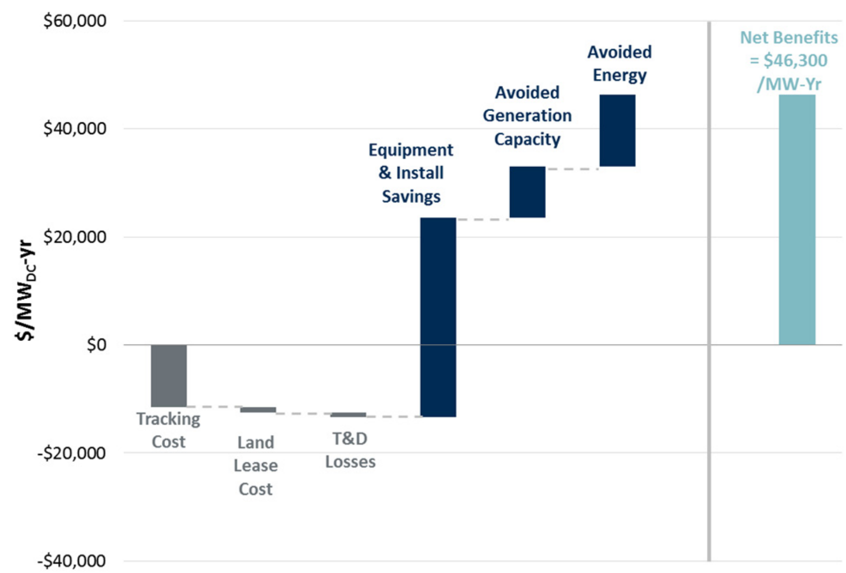
CS systems present comparative benefits relative to rooftop per MW of installed capacity.

Incremental costs and benefits of CS relative to rooftop ($/MW$_{DC}$-year)

Minnesota



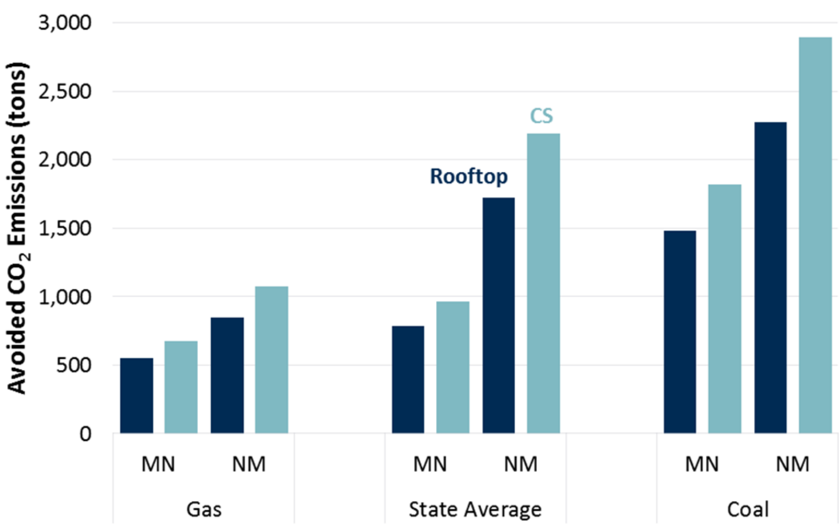
New Mexico



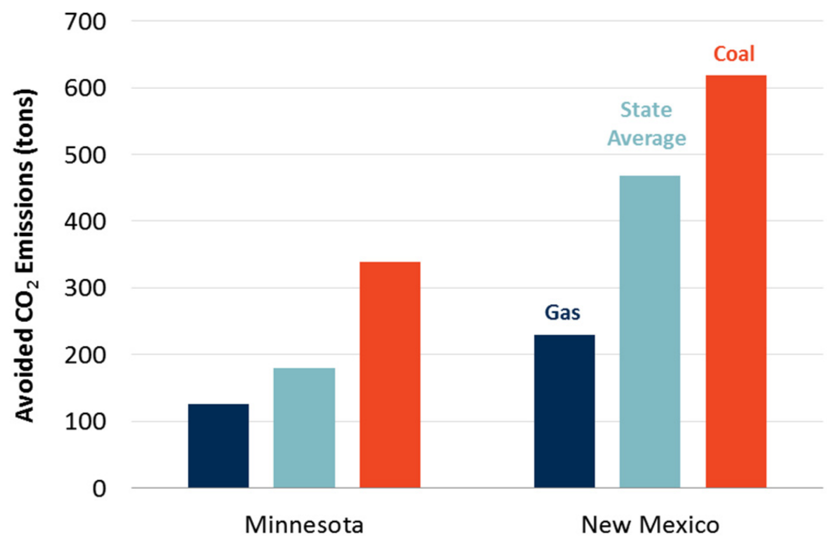
Note: Costs shown do not reflect reductions due to tax credits or other financial support. Solar PV investment decisions are based on cost discounts and revenue streams not reflected in the "system" perspective taken in this analysis.

CO_2 Emissions Reductions

Total Annual CO_2 Emissions Savings for 1 MW Rooftop and Community Solar Projects



Incremental Annual CO_2 Emissions Savings for 1 MW Community Solar, Relative to 1 MW Rooftop



Observations

- The figure shows annual avoided CO_2 emissions for three different scenarios.
  - Navy bar (labeled "gas") assumes the solar PV avoids emissions from a gas-fired combined cycle unit.
  - Red bar (labeled "coal") assumes the solar PV avoids emissions from a coal-fired steam unit.
  - Teal bar (labeled "state average") assumes solar PV avoids the average emissions from the state-wide resource.
- Assuming state average emissions rate, 1 MW of community solar in NM would avoid nearly 470 tons of CO_2 more than 1 MW of rooftop solar.
- 1 MW PV systems could avoid the annual CO_2 emissions of 334 (rooftop) to 425 (CS) vehicles in New Mexico and 152 (rooftop) to 187 (CS) in Minnesota, assuming state average emissions rates.

Benefit Comparison on Per-MW Basis

Summary - Total Costs and Benefits

	Rooftop	Community	Difference (CS - rooftop)
Minnesota			
Unsubsidized cost ($000/$MW_{DC}$-yr)	$185	$161	-$24
Avoided resource costs ($000/$MW_{DC}$-yr)	$34	$44	$10
Energy	*$31*	*$40*	*$9*
Capacity	*$3*	*$4*	*$1*
Avoided CO_2 emissions (tons/MW_{DC}-yr)	786	965	179
New Mexico			
Unsubsidized cost ($000/$MW_{DC}$-yr)	$185	$161	-$24
Avoided resource costs ($000/$MW_{DC}$-yr)	$61	$84	$23
Energy	*$41*	*$54*	*$13*
Capacity	*$20*	*$30*	*$10*
Avoided CO_2 emissions (tons/MW_{DC}-yr)	1,724	2,192	468

Notes:
Table shows avoided CO_2 emissions based on state average emissions rates.
Costs shown do not reflect reductions due to tax credits or other financial support.

Observations

- From a "system benefits" standpoint, the lower installed cost per MW_{DC} of CS is the primary financial benefit relative to rooftop.
- Due to current low energy prices, avoided energy costs are a modest share of the total incremental benefit of CS, in spite of its >25% advantage in total MWh output relative to rooftop (on a per-MW capacity basis).
- The incremental avoided emissions are roughly proportional to the >25% higher relative energy output associated with CS.
- Avoided capacity costs will vary significantly by region, depending on capacity needs and the ELCC that system planners assign to both types of solar PV.

What Do the Findings Mean for ZNE Homes?

ZNE homes generate the same amount of energy that they consume on an average annual basis (by definition).

We have assumed that the typical ZNE home is 70% more efficient than the average residential single family home:

- “Home Energy Rating System (HERS) Index” scores are a measure of a home’s energy efficiency.
- A typical new home has a HERS index of 100, an average home has a HERS of 130.
- By comparison, highly efficient ZNE homes can have a HERS index in the 30 to 40 range.
- An efficiency improvement of 60% relative to new homes and 70% relative to average homes is generally in line with limited data on ZNE home energy use.

The rooftop solar PV capacity of ZNE homes is designed to offset the home’s entire energy consumption (including non-electricity sources). The capacity required to serve the average ZNE homes described above is:

- Minnesota: 6.1 kW_{DC} per home.
- New Mexico: 3.1 kW_{DC} per home.

We have quantified the cost savings associated with providing the same energy from a community solar project rather than from rooftop PV.

For a community of 200 ZNE homes, the following community solar project size would be required:

- Minnesota: 968 kW_{DC} (compared to 1,229 kW_{DC} for rooftops)
- New Mexico: 474 kW_{DC} (compared to 622 kW_{DC} for rooftops)

21-24% reduction in required capacity due to higher output per MW_{DC}

ZNE home assumptions

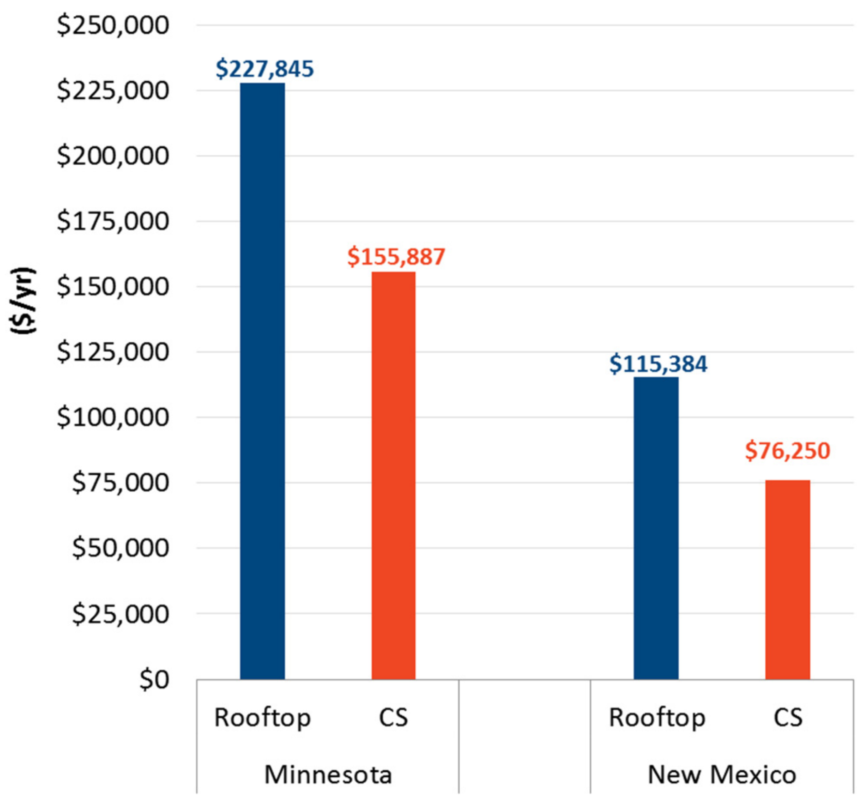
			New Mexico		Minnesota	
			Rooftop	CS	Rooftop	CS
Avg Sub-Region Home Site Energy Consumption	[1]	*MMBtu*	87	87	102	102
Avg Sub-Region Home Source Energy Consumption	[2]	*MMBtu*	158	158	210	210
Single Family Home Consumption Premium	[3]	*%*	17%	17%	13%	13%
Avg Single Family Home Source Energy Consumption	[4]	*MMBtu*	185	185	238	238
ZNE Home Efficiency (Relative to Avg Single Family Home)	[5]	*%*	70%	70%	70%	70%
Avg ZNE Home Energy Consumption	[6]	*MMBtu*	56	56	71	71
Energy Conversion Factor (Btu to kWh)	[7]	*Btu/kWh*	3,412	3,412	3,412	3,412
Source Energy Conversion for Electricity	[8]		3.15	3.15	3.15	3.15
Solar PV Output Required to Serve ZNE Home	[9]	*kWh*	5,167	5,167	6,649	6,649
PV Capacity Factor (DC)	[10]	*%*	19.0%	24.9%	12.4%	15.7%
PV Capacity Required (per ZNE Home)	[11]	*kW*	3.1	2.4	6.1	4.8
PV Capacity Required (per 200 ZNE Homes)	[12]	*kW*	622	474	1,229	968

Sources and Notes:
[1]: 2009 RECS, per-home average, calculated from 2009 RECS, Consumption and Expenditures data.
[2]: 2009 RECS, home energy consumption converted using source energy conversion factors.
[3]: 2009 RECS, Reflects higher consumption of single family home relative to average home.
[4]: [2] x (1 + [3]).
[5]: 12/22/17 interview with NRDC building efficiency expert and https://www.resnet.us/hers-index.
[6]: [4] x (1 - [5]).
[7]: www.convertunits.com.
[8]: 'A Common Definition for Zero Net Energy Buildings,' Sep. 2015, DOE.
[9]: [6] x 1,000,000 /[8]/[7]
[10]: NREL, System Advisor Model (SAM).
[11]: [9] / (8,760 x [10]).
[12]: [11] x 200.

Net Economic Benefits of CS (200 ZNE Homes)

CS presents economic advantages over rooftop to provide power for 200 ZNE homes.

Annual Cost of Solar PV Systems for 200 ZNE Homes



Note: Costs shown are before subsidies (tax credits, etc.)

Observations

On a levelized cost basis, CS saves:

- $72,000/yr in Minnesota
- $39,100/yr in New Mexico

CS avoids additional resource costs (not shown in chart)

- $454/yr in Minnesota
- $1,905/yr in New Mexico

Qualitatively, CS can extend ZNE eligibility to a broader portion of the population (e.g., multi-family dwellings).