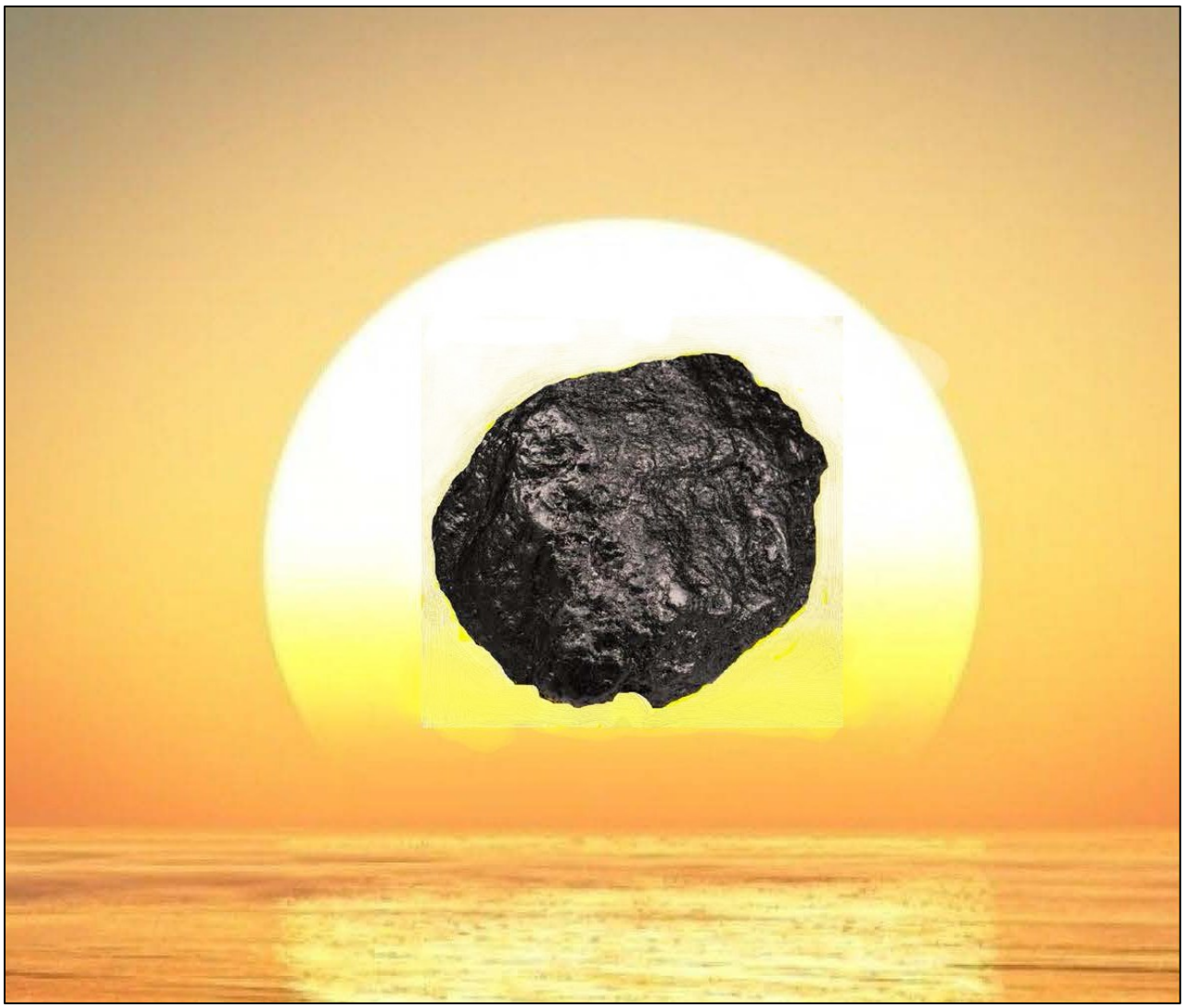
Decarbonizing Land Development Practices

Strategies for Connecticut Planning and Zoning Commissions



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Executive Summary

Land use policies have an important role to play in enabling the future use of solar energy in Connecticut and in achieving the state's goal of a 100% renewable electricity grid by the year 2040. During the last forty years there have been revolutionary changes in the range of solar energy applications that have reached the marketplace. In the 1980s, photovoltaic systems designed to generate electricity were limited to outer space applications managed by the National Aeronautics and Space Administration or to "back to the land" individuals seeking an off the grid way of life. Today, dozens of different applications of solar photovoltaic systems exist that are more economical than petroleum-based products for the generation of electricity, home heating or hot water.

Today, photovoltaic energy applications are no longer limited to solar panels placed on the roof or backyard of a residential or commercial building. Building Integrated Photovoltaics systems (BIPV) include glass that not only lets visible light into a building but also generates electricity at the same time. The range of BIPV products is growing rapidly and includes vertical glass, skylight glass, awning glass, glass-based terraces, and specialty glass for cell phones, computers and other devices that generate electricity. While these products are not as productive as traditional solar collector panels, their value in the marketplace has run parallel with their increasing electrical generation capability. Land use regulations have not kept pace with the evolving technologies of photovoltaics, and this has adversely constrained the optimum use of this technology to meet homeowner and utility grid-level goals of reducing the cost of electricity and using renewable sources for electricity.

Limited adoption of photovoltaic panels for residential or commercial use has prompted the State of Connecticut to emphasize grid-connected solar arrays to meet its renewable energy goals. This state policy has resulted in an inappropriate removal of thousands of acres of farm and forestland without a full assessment of the climate benefits of farms and forests or the climate impacts associated with their destruction. Forest lands are generally less expensive to purchase and develop than similar sized parcels in urban and suburban locations. The lack of financial disincentives and restrictions on the siting of large-scale solar energy systems should be a priority for the state's regulatory community and the state legislature. Reliance on the marketplace for the siting of these systems inevitably fails to factor in the economic and ecosystem values of farm and forest land. A principal reason for the reliance on large, grid-level solar arrays is a failure to develop and implement "solar-conscious" development patterns that make electricity generation via distributed systems – i.e., solar panels on rooftops and/or backyards – efficient and cost-effective. Such regulations would overcome the essentially random orientation of buildings that has occurred during the petroleum era. With most dwellings lacking proper solar design and orientation – and thus energy conservation and on-site generation and storage – a wide range of hybrid strategies have emerged. These options include micro-grids, community solar, and battery systems to modulate the vicissitudes of using PV systems that do not generate electricity at night and energy conservation.

The National Renewable Energy Laboratory estimates 88,217 acres are suitable for grid-connected solar in the rural and urban areas of Connecticut – not nearly enough land to meet the state's electrical needs. The NREL analysis underscores the urgency to 1) diversify its renewable energy options, 2) increase investments in energy conservation strategies to reduce electrical demand and 3) invest in home-based renewable energy strategies that couple energy conservation with behind the meter (BTM) photovoltaic systems. Without an emphasis on energy conservation and solar-conscious land

use practices as discussed in this report, we can expect to see a bias toward renewable energy strategies relying too heavily on grid-connected solar arrays.

Alternatives to grid-connected solar exist. For example, the state's adoption of micro-grids as a means to avoid power failures is a case in point. In 2012 the Connecticut legislature enabled the development of micro-grids to deal with ongoing power outages due to hurricanes, extreme rainfall events, and wintertime wind and snow. Local governments can play an important role in enabling a more resilient electric grid by establishing rights-of-way for buried electrical lines to serve critical infrastructure and facilities that can avoid the threats posed by hurricane force winds, snow loads, and downed trees. Thirteen micro-grids exist in Connecticut, but this concept should be expanded across the state. Similarly, the Connecticut Department of Energy and Environmental Protection has developed a community solar program (virtual net metering) to address the needs of those in higher-density development, including rentals, where building and tree shading or lack of control over utility services pose barriers to photovoltaic systems. While community solar is still getting off the ground, it represents an important strategy to serve those dwellings unable to take advantage of behind the meter PV panels.

Since solar and wind energy are both dependent on the vicissitudes of sunlight and wind respectively, systems that store energy – both thermal and electrical – will be essential. Indoor thermal storage systems, such as thermal mass and buffer tanks, can retain large quantities of heat generated during the day for distribution during the night; subterranean and grid-scale facilities may be able to retain heat generated during the summer into the winter. Likewise, rapid improvements in battery efficiency, longevity and price have occurred in the last ten years. They are now being used at the utility scale as well as for residential applications including as an alternative to gasoline or natural gas generators during power outages. Battery technologies also have land use impacts that must be considered.

Photovoltaic systems are now a viable means of generating electricity, based on the tax credits and incentives. The economics of installing solar energy systems improved dramatically in the period 2014 to 2020, reflecting rapid improvements in the manufacture of photovoltaic panels and efficiencies in converting sunlight into electricity. The result of these improving economics has been an increased focus on electrification of transportation and space heating, via electric vehicles and air and ground source heat pumps. In 2018, the Connecticut General Assembly passed Public Act 18-50, An Act Concerning Connecticut's Energy Future, providing for the use of photovoltaics to support up to two electric vehicles and an electric heat pump per household under the Residential Renewable Energy Solutions (RRES) program effective January 1, 2022. This is an important step in decarbonizing the grid. Yet there are economic consequences. It is anticipated the average Connecticut household will see its total electricity consumption double, with the move to two electric vehicles and an air source heat pump. At the municipal level, an increase in electrical demand places greater importance on solar-conscious land use regulations to enable cost-effective residential photovoltaic systems. Without PV systems, residents will face dramatic increases in electricity costs, especially as investment in petroleum production declines.

Municipal efforts to decarbonize Connecticut's land use practices, where they have occurred, have not been effective. A WestCOG analysis of the state's zoning regulations found that, rather than encouraging its use, 97 of the 103 municipalities that address solar energy in their regulations (94%) impose barriers to its use. Furthermore, a lack of solar access protections may undermine the performance and widespread use of photovoltaic systems. Connecticut is one a small number of states

without solar access or solar easement laws to protect over $1 billion invested in PV systems. Despite these caveats, consumers are investing in PV system due to expanded federal tax credits for their installation. In 2021, the Connecticut legislature, enacted Public Act 21-29, which enabled planning and zoning commissions to adopt six different strategies discussed in this report for promoting solar design and solar energy, and decarbonizing the building and transportation sectors, through land use. Decarbonizing land use practices will lessen the ecological and economic impacts anticipated from the rising costs of electricity and our overdependence on fossil fuels for transportation, heating, and cooling purposes.

Introduction

This report is intended to establish a path forward for the sustainable use of renewable energy resources in the context of land use planning at the municipal level. To understand the potential for solar energy – especially the deployment of photovoltaic technology – requires an understanding of ongoing advances in harvesting energy and generating electricity from the sun and in energy storage. The rapidity of this change is exceeding the ability of government to keep pace, including local land use commissions to understand and address the impacts these technologies are having on land development in Connecticut. Lacking a full public understanding of this emerging technology, photovoltaic applications for residential use have had a limited adoption rate in Connecticut – until just the last ten years. Most planning and zoning commissions did not anticipate its rapid growth and its essential role in curbing greenhouse gas emissions. Because of past limited adoption rates and cost considerations for the installation of photovoltaic panels, it is not surprising that most local governments have failed to fully encourage their use.

In view of limited adoption of photovoltaic panels for residential or commercial use, the State of Connecticut has decided to emphasize the deployment of grid-connected solar arrays to meet its renewable energy goals. This policy has resulted in an inappropriate removal of thousands of acres of farm and forestland for use as grid-connected photovoltaic arrays. A principal reason for the reliance on large, grid-level solar arrays is a failure to develop and implement "solar-conscious" development patterns that make electricity generation via distributed systems – i.e., solar panels on rooftops and back yards – efficient and cost-effective. Such regulations would overcome the essentially random orientation of buildings that has occurred during the petroleum era. With most dwellings lacking proper solar design and orientation – and thus energy conservation and on-site generation and storage – a wide range of hybrid strategies have emerged. These options include micro-grids, community solar, the use of battery systems to address the vicissitudes of using photovoltaics to generate electricity and energy conservation measures necessary to reduce our reliance on fossil fuels for transportation and for home heating and cooling.

While solar-conscious subdivision legislation has been in existence since 1981, this report identifies the limitations of current subdivision practices in the state's 169 municipalities and their impacts on the development of energy efficient patterns of development and the use of solar energy. Similarly, for the last forty-five years the state legislature has enabled zoning commissions to encourage the use of solar energy. However, this report has identified a wide range of land use practices that do just the opposite, creating barriers to the efficient and cost-effective use of solar-conscious design and distributed solar power systems. In addition, the lack of solar access protection for photovoltaic panels anywhere in the state raises questions about the long-term viability of investments in solar power. Solar access is a foundational principle necessary for the long-term growth of renewable energy in Connecticut. Current solar access practices and their limitations are discussed in detail with suggested remedies. This report also reviews the dangers of not having explicit state legislative authority for the protection of solar access when over $1 billion has already been invested in its use.

The last sections of this report review the geographic coverage of residential behind the meter (BTM) photovoltaic panels as well as grid-connected solar arrays and where these distinctly different technologies are being adopted. One of the primary purposes of this report is to urge planning and zoning commissions to incorporate solar-conscious land use practices into zoning regulations as enabled by Public Act 21-29. That law, the most significant legislative effort ever made to expand the

use of solar energy through zoning, will require the state's Office of Policy and Management and its nine regional Councils of Government to provide technical assistance for it to be successfully implemented.

Since one of the stumbling blocks to the wider use of photovoltaic technology has, until recently, been its cost, this report also evaluates the changing economics of this technology. The economic analysis includes payback times for installing PV systems depending upon the size of the photovoltaic panels, the percent of the annual electric load to be provided and the tax credits and incentives that affect the final purchase price for these systems. The adoption of solar energy is now less a function of its economic feasibility and more a function of the land use constraints that stand in the way of its full adoption.

Emerging Solar Energy Technologies and their Land Use Impacts

During the last forty years there have been revolutionary changes in the range of solar energy applications that have reached the marketplace. In the 1980s, photovoltaic systems designed to generate electricity were limited to outer space applications managed by the National Aeronautics and Space Administration or to "back to the land" individuals who wished to get off the grid and live a simple life. Today, there are dozens of different applications of photovoltaic systems that have become more economical than petroleum-based products and can cost-effectively replace these products for the generation of electricity, home heating, or hot water. The pace of product development has inevitably meant that zoning regulations in Connecticut are out of alignment with the types of land use impacts created by photovoltaic products available in the marketplace.

Building Integrated Photovoltaics Systems

Today solar photovoltaic energy applications are no longer limited to solar panels placed on the roof or backyard of a residential or commercial building. Building Integrated Photovoltaics systems (BIPV) include transparent glass that not only serves as a vehicle for letting light into a building but also captures electricity at the same time. The range of BIPV products is growing rapidly and includes vertical glass, skylight glass, awning glass, glass-based terraces, and specialty glass for cell phones, computers, and other devices that generate electricity. While these products are not quite as productive as the traditional solar collector panels, their value in the marketplace has run parallel with their increasing electrical generation capacity.

Instead of having ground-mounted solar collectors in one's backyard, in the future it will be possible to achieve the same energy benefits without any visual clutter. Imagine a landscape that uses specialty glass products that create outdoor patios, terraces, or walkways that generate electricity from sunlight. Glass-based terraces and walkways are already available in the marketplace. The land use implications of this product have yet to be determined, but they could adversely impact groundwater recharge, stormwater runoff, and the amount of impervious surface coverage on a building lot. For municipalities that have already established impervious surface cover standards, glass-based patios, terraces, or walkways will be a new land use consideration.

Changing Photovoltaic Technologies

Because of the increasing efficiencies of PV panels, it is now possible to buy solar panels rated as high as 850 watts, or three to four times as powerful as the solar panels commercially available ten years ago. These bifacial solar panels generate electricity on both their front and backsides. Such systems,

while highly productive, are limited to pole mounted, ground mounted or flat roof mounted solar energy systems where there is sufficient albedo value from the area immediately below the backside of the solar panels. Rooftop applications of bifacial solar panels are ideally suited to flat rooftops that have a white or light-colored surface to reflect light to the backside of the solar panel. Pole-mounted photovoltaic systems can be installed as stationary systems fixed at an optimum tilt for the solar panels to capture sun year-round or with tracking systems that are designed to track the movement of the sun so that the solar panels maximize electricity generation every single day of the year. Tracking systems cost more to install than stationary systems but have the advantage of generating as much as 1.7 times as much solar energy as stationary systems.

Solar shingles are another recent innovation in the photovoltaic industry that could potentially be an important alternative to unsightly solar panels on the roof. However, like rooftop solar panels, the generation potential and payback for this product is limited by the improper solar orientation of most houses in America. To be cost-effective, solar shingles should be placed on houses that are oriented with their long axis perpendicular or within 30 degrees of true south. Because solar shingles are more expensive than traditional solar energy panels, they currently have a limited market which in turn constrains access to a labor force skilled in both electrical and roofing skills. While there are a wide range of solar shingles in the market, only a handful of companies dominate the business. One company that is beginning to establish a foothold in the marketplace is GAF, a major roofing company. A producer like GAF raises the legitimacy of solar shingles as a market-ready product since they already have the expertise in the roofing trades. Solar shingles are one example of Building Integrated Photovoltaics Systems that will impact future building designs in Connecticut. However, their impact will primarily be governed by the state building code, except where these systems impinge on zoning standards for building heights, lot line setbacks, maximum lot coverage, impervious surface cover, or design standards for village districts and historic districts. However, the ability of solar shingles to blend in with traditional architecture should facilitate their use without compromising a community's design standards.

Grid-connected Solar Energy Systems

In 1973, the Connecticut legislature gave sole authority for the management of grid-connected energy systems (which would eventually cover photovoltaic systems) to the predecessor agency of the Connecticut Siting Council.[1] While photovoltaic systems were not economically viable then, in the ensuring years the solar energy industry has steadily reduced its manufacturing costs and improved their generation efficiencies. By 1998, photovoltaics had become a viable means of generating electricity, based on the tax credits and incentives available, making them competitive for the first time with fossil fuels. In 1998, Connecticut established solar energy as a Class I and Class II renewable resource, thereby giving a regulatory impetus to the expansion of this renewable form of electricity.[2] The economics of installing grid-connected solar energy systems improved dramatically in the period 2014 to 2020, reflecting rapid improvements in the manufacture of photovoltaic panels and improved efficiencies in converting sunlight into electricity. Starting in 2013, the Connecticut Siting Council

[1] Legislative Program Review and Investigations Committee, Connecticut Siting Council, December 2000, p. 4
[2] The Center for Energy, Economic, and Environmental Policy and the Rutgers Economic Advisory Service, A Review of Connecticut's Renewable Portfolio Standards, prepared for the Connecticut Energy Advisory Board, July 18, 2011, p. 8; The Connecticut Legislature, An Act Concerning Electric Restructuring, Public Act 98-28, Approved April 29, 1998.

approved the first grid-connected large-scale photovoltaic system in Somers. Since then, sixty-seven other grid-connected photovoltaic systems have been installed in forty-nine Connecticut municipalities, ranging in capacity from 0.9 to 120 megawatts. As of June 2022, grid-connected photovoltaic systems account for 543.4 megawatts of the state's electrical capacity. Yet according to 2021 data provided by the Energy Information Agency (EIA), solar energy accounted for less than 1% of the 44,079,943 megawatt-hours of all electrical generation in Connecticut[3], and grid-connected solar energy arrays represented just 25% of this total. The balance came from rooftop solar under the residential BTM program. Given the land use impacts of grid-connected solar, it is unlikely to be a complete answer to the state's long-term energy needs. Substantial efforts to conserve energy, coupled with expanded use of BTM, will also be critical.

Land Use Consequences of Grid-connected Solar

One of the unfortunate consequences of the vastly improved economics of large-scale solar energy systems is the loss of farm and forest land. These lands are generally less expensive to purchase and develop than similar sized parcels in urban and suburban locations within the state. The absence of appropriate financial incentives and restrictions on the siting of large-scale solar energy systems reflects an early planning focus on near term solutions on the part of the state's regulatory community and the state legislature. Reliance on the marketplace for the siting of these systems fails to factor in the economic and ecosystem values of farm and forest land. The threat to the world's trees is not merely a function of international efforts to expand the use of renewable energy to decarbonize the world economies, through clearance for solar farms and harvesting for biomass. Trees are also facing elevated mortality and removal through climate change, a loss of habitat diversity, and clear-cutting for commercial and industrial purposes. Today, one third of the world's trees are threatened with extinction.[4]

The current state energy strategy prioritizes the use of state farms and forests for electricity over their long-term value for food, fiber, and timber or as a public trust to be held in perpetuity to curb long-term changes to our climate. In the last ten years, grid-connected solar arrays consumed 2,684.2 acres of land, with 94% of these arrays installed on land which had been previously used for agriculture or that was forested (Table 1). The remaining 6% of the land has been sited on landfills, former sand and gravel sites, on the rooftops of commercial or industrial buildings, or as parking lot canopies.[5]

In 2017, the Connecticut legislature recognized the loss of farm and forest land as a matter of public concern by requiring the Connecticut Siting Council to review proposals for grid-connected systems of 2 megawatts or more capacity to determine they do not have a substantial adverse environmental effect on prime farmland or core forests.[6] While this law is a step in the right direction, it placed too little value on farmland not labelled "prime" or forests not defined as "core." In a small state with far fewer large, unbroken tracts of wilderness than most other states in this nation, this excludes much if

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[3] U.S. State Profiles and Energy Estimates for Connecticut, Energy Information Agency, 2010; accessed November 2, 2022.
[4] Aisling Irwin, The loneliest trees: can science save these threatened species from extinction? *Nature*, August 31, 2022, pp. 24-27.
[5] Connecticut Council on Environmental Quality, July 2022 with updates by WestCOG staff, July 11, 2022
[6] Public Act 17-218, An Act Concerning the Installation of Certain Solar Facilities on Productive Farmlands, Incentives for the Use of Anaerobic Digesters by Agricultural Customer hosts, Applications Concerning the Use of Kelp in Certain Biofuels and the Permitting of Waster Conversion Facilities, July 10, 2017.

not most of the state's farm and forests – lands that, despite their size, have important value. Another consequence of this law has been an increase in the number of proposals for grid-connected solar arrays with less than 2 megawatts of capacity to avoid these new review procedures. Since the inception of the Connecticut Siting Council's role in reviewing grid-connected solar arrays, the Council has approved 28 projects under 2 megawatts capacity, with 25 of these projects (89%) approved after the enactment of Public Act 17-28.

WestCOG has evaluated the amount of forest land clear cut merely because of shading impacts upon the grid-connected solar panels. Almost 100 acres of land has been clear cut over the last ten years simply to remove trees that might shade poorly sited grid-connected solar arrays. This finding underscores the need to consider the ecological impacts of siting grid-connected solar on less ecologically valuable land as well as to strengthen the behind the meter use of solar energy to meet the state's renewable energy goals.

The broader point that comes out of the well-intended legislative efforts of Public Act 17-218 is that critical decisions on the future uses of Connecticut's land should not be solely determined by the Connecticut Siting Council. A comprehensive analysis of the best uses of the land for farm, forest, housing, and renewable energy – among other land uses – must be done in a coordinated fashion with equal weight given to the state and municipal agencies responsible for these land use resources.

Table 1: Impacts of Grid-connected Photovoltaic Systems Installed in Connecticut: 2013 to 2022

Type of Land Use Impacted	Land Disturbed by Grid-connected Photovoltaic Systems (Acres)	Megawatt Capacity (AC MW)	Average Number of Acres/MW
Agricultural and Forest	979.6	179.2	5.5
Agricultural Lands	766.9	141.0	5.4
Agricultural Lands & Mining	14.0	2.7	5.2
Forest	763.0	177.2	4.3
Landfill	60.0	22.2	2.7
Parking Canopies	15.8	2.9	5.4
Rooftop Application	14.2	4.5	3.2
Sand & Gravel	50.1	9.0	5.6
Landfill/Grass Land	10.8	2.7	3.9
Stump and Soil Storage	10.0	2.0	5.0
Grand Total	2,684.2	543.4	4.9

The urgency of addressing the climate crisis has contributed to the loss of these natural resources, but this is only part of the story. The state legislature has enacted aggressive goals to phase out fossil fuels for the generation of electricity. These have, if unintentionally, contributed to the conversion of forests and farmlands to electric generating facilities. Other approaches that merit greater priority, include installing grid-connected solar energy systems on commercial and industrial rooftops, as carports in shopping malls, along the right of ways of state or interstate highways (the Massachusetts approach)[7], on top of closed municipal landfills, as dual use shade control and photovoltaic generation systems

[7] Massachusetts Department of transportation, Highway Right of Way Solar Project, Accessed July 6, 2022

elevated above working farmland (another Massachusetts strategy)[8], and even as transparent roofing over highways to serve the dual use of generating electricity while eliminating snow plowing along major highways segments in the state.[9]

Many renewable energy advocates support a less environmentally damaging application of grid-connected solar. These include Mark Scully, Executive Director of People's Action for Clean Energy (PACE). Scully estimates, "…Connecticut could site seven gigawatts of commercial solar on 8,400 canopies, essentially parking lots, across the state generating 37% of our current electricity needs."[10] Similarly, Connecticut could use the hundreds of miles of its limited access highways, including the area over the roadway itself, as a vast zone to install grid-connected transparent photovoltaic panels. Elevating the solar panels at least twenty feet above the roadway would not only enable the panels to collect sunlight without interfering with traffic, it could also eliminate the need for snow plowing in the winter months; German engineers have already designed such a system. These examples illustrate there has been a strong near term focus on the deployment of grid-connected photovoltaic panels, caused in part by statutes that do not account for the negative consequences of losing farmland and forest land. These issues are only now becoming apparent as the cost for long distance transport of food and the loss of the temperature moderating effects of forest canopies (reducing the 'urban heat island effect') are becoming apparent. To its credit, the state now requires grid-connected PV systems of 2 megawatts or more to avoid installations on prime farmland and core forests. Unfortunately, this approach does not consider the value of other agricultural and forest lands. One dual use approach that merits further consideration is the Massachusetts solar farm project, which maintains farming below elevated solar panel arrays. This approach is useful for plants that do not prefer full sun and protects crops from the damaging impacts of high winds and intense rainfall events. In some respects, this approach is similar to an open-air greenhouse – especially when the solar panels covering the fields are semi-transparent.

Achieving 100% Renewable Energy Future: Reaching the Cliff

One of the greatest limitations of grid-connected solar is its intensive reliance on large areas of vacant land in a state that has limited land resources. Based on the current energy performance of grid-connected solar arrays approved by the Connecticut Siting Council over the period 2012 to July 1, 2022, we can expect that it will take 4.9 acres of land to generate 1 megawatt of alternating current photovoltaic electricity. As can be seen in table 2, if the goal is to achieve 100% renewable energy by 2040, and if all of this energy were to be supplied by grid-connected photovoltaic systems, the state will require 217,548 acres of land, or about 6.13% of the entire state's land mass, to accommodate the energy required for two electric vehicles and one whole home air source heat pump for every household in Connecticut.[11]

While mass use of electric vehicles and heat pumps – as envisioned by the Connecticut Public Utilities Regulatory Authority – is unlikely to be achieved anytime soon, the potential land use impacts of such a vision, given current renewable energy development practices, underscores the need for a

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[8] Ellen Rosen, When Solar Panels Share Land with Cows, Lettuce and Blueberries, New York Times, July 5, 2022, B-2.
[9] Zachary Shahan, European Trio Working On Solar Canopy For Highways, September 5, 2020
[10] Jan Ellen Spiegel, Solar program reform efforts likely in Connecticut legislature. They already face hurdles, Hartford Courant, February 14, 2022,
[11] Executive Order 21-3, Governor Ned Lamont, December 16, 2021

reassessment of Connecticut's land use priorities. Who should decide when any given land is devoted to solar energy versus protecting it for open space, farmland, forest land, or land for (affordable) housing? Unlike the latter four categories of land use, which have limited protections, lands chosen for grid-connected solar arrays are exempt from local government land use oversight. For example, the Connecticut Siting Council has the authority to overrule local land use controls – an authority not available for those seeking to protect farm and forest land. Yet each of these four uses of land are critical to the state's economy, environment and public health, safety and general welfare.

If the state wishes to meet all its energy needs through grid-connected solar – not just residential needs but also its goal of two electric vehicles and one heat pump in every household in the state– Connecticut would need to devote anywhere from 217,548 acres to 401,885 acres to large-scale solar arrays to meet anticipated electricity demand forecast for the year 2040 (see Appendix 9 for the detailed forecasting calculations. These land use estimates are more than those in the table below since table 2 does not factor in the energy needs of electric vehicles and heat pumps). While grid-connected solar should not (and realistically cannot) be the sole means of achieving a decarbonized electricity grid, this analysis is meant to emphasize the need to stop unplanned deployments of these systems until a comprehensive, statewide land use plan is formulated that identifies which lands should be allocated to each of these five critical land uses. While goals have been established for the state's energy sector, enabling analysis of needs, locations, and impacts of energy development, no such coordinated goalsetting has been done for these critical land uses, and consequently no comprehensive analysis is possible.

Table 2: Land Area Required to Achieve Residential Renewable Goals with Grid-connected Solar[12]

Meeting the 2040 Renewable Energy Goal through Grid-Connected Solar	**Parameter**
Connecticut Households 2020	1,385,437
Anticipated Whole Home Air Source Heat Pump Electricity/Household (kwh/Year)	3,608
Anticipated EV Electricity Needed/Household for 2 EV Vehicles @ 3,285 kwh/Year/EV	6,570
Total Electricity for Heat Pump and Electric Vehicles (kwh/Year)	10, 178
Annual Added Residential Electric Energy Needed by 2040 for CT Households (MWh)	14,701,400
Acres of Land for 1 MWh of Grid-connected Solar Arrays (current practice)	4.9
Acres of Land Needed for Grid-connected Solar to meet 2040 Goal *Low Range* *High Range*	 170,386 314,760
Size of the entire State of Connecticut (Acres)	3,547,520
Percent of Connecticut Land Required to meet 2040 renewable goal *Low Range* *High Range*	 4.8% 8.9%

Source: Connecticut Public Utilities Regulatory Authority 2021 Clean and Renewable Energy Report, February 2022, p. 48 and WestCOG staff analysis of the PURA Grid-connected Solar Array Dockets, 2012 to 2022.

[12] Eversource, Residential Renewable Energy Solutions Program Manual, Version 2022.2, Effective 06/10/2022, p. 18.

As can be seen in Appendix 9, an upper limit on the deployment of grid-connected solar must be established so farm and forest land are not lost simply because the short-term payback to the development of a grid-connected solar array is greater than the economics and ecosystem values of farm and forest.

The National Renewable Energy Laboratory (NREL) has calculated that only 88,217 acres in Connecticut are suitable for grid-connected solar in the rural and urban areas of the state.[13] This is far short of what would be needed to achieve the state's renewable energy goals with grid-connected solar alone. The implications of this the NREL analysis is that grid-connected solar arrays are not the complete solution. The NREL analysis underscores the urgency to 1) diversify the renewable energy options developed for Connecticut, 2) vastly increase investments in energy conservation strategies to reduce future electrical demands and 3) invest in home-based renewable energy strategies that couple reduced energy demand behind the meter with efficient, cost-effective photovoltaic systems. Without an emphasis on energy conservation and implementation of solar-conscious land use practices at the municipal level, Connecticut will continue to be marked by a bias toward energy development actions that fall within the authority of PURA and the Connecticut Siting Council. Instead, what is needed, as discussed in later sections of this report, are dramatic strengthening of the zoning and subdivision regulations that focus on renewable energy options consistent with affordable least cost housing concepts.

At the household level, the state policy of switching to electric heat pumps and electric vehicles will have profound economic consequences for the average homeowner. According to the Energize CT municipal dashboard, in 2021 the average household in Connecticut used 8,596 kilowatt hours of electricity.[14] Assuming two electric vehicles per household, as anticipated by the Connecticut Public Utilities Regulatory Authority, a switch to heat pumps and electric vehicles would add 10,178 kilowatt hours to the electricity consumed by the average household – representing a doubling of electric energy demand. The economic consequences of this will not be affordable unless the state and federal governments focus on conservation and distributed generation, i.e., "solarizing" the state's housing stock and decarbonizing existing land use practices.

Perhaps the greatest case for minimizing reliance on grid-connected photovoltaic systems is that they are not reducing the cost of electricity to the consumer. Federal Energy Regulatory Commission and ISO-New England policies emphasize low generation costs, which is not the same as low ratepayer costs. While grid-connected solar can reduce greenhouse gas emissions associated with the electricity sector, it does not necessarily provide any cost relief – or additional resiliency – to consumers.[15] Because of this, the Connecticut Department of Energy and Environmental Protection has developed other options to address grid resiliency, affordability and equity issues, and management of peak hour demand unique to photovoltaic systems as discussed below.

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[13] National Renewable Energy Laboratory Report, U.S. Renewable Energy Technical Potentials: A GIS Based Analysis, July 2012, p. 11. It is important to note, potential sites for grid-connected solar are also limited by the availability of electrical capacity within the utility grid – a situation that tends to bias siting decisions to rural areas.

[14] Energize CT, Annual Reports for Aggregated Energy Usage, 2021. Accessed November 22, 2022.

[15] Connecticut Department of Energy and Environmental Protection, Integrated Resources Plan, October 2021, pp. 79-81

Micro-Grid Systems

In 2012 the Connecticut Legislature enabled the development of micro-grids to deal with ongoing power outages caused by hurricanes, extreme rainfall events and wintertime wind and snow.[16] Disruptions are of particular concern for critical infrastructure such as hospitals, fire and police departments, water and wastewater treatment plants, government facilities, school campuses, commercial centers, food and fuel retailers, and emergency operations centers. With that in mind, the Connecticut Department of Energy and Environmental Protection (DEEP) was charged with developing micro-grid pilot projects that could operate independently of the electric grid. Over the last ten years DEEP has awarded contracts for thirteen micro-grid systems in the state serving three universities (Wesleyan – 2 projects, Bridgeport, and Hartford), six municipalities (Bridgeport, Coventry, Fairfield, Hartford, Milford, Windham, and Woodbridge), a New Britain hospital and one social service agency, and the New London submarine base.[17]

Micro-grids operate using renewable energy sources including photovoltaic systems or fuel cells and have battery backup systems that enable long term isolation from the utility grid. By being able to disconnect from the grid, these systems represent a new way of dealing with intense storm events that minimize adverse impacts on public health, safety, and the general welfare. Rather than being an option limited to critical infrastructure, the opportunity now exists to make the electric grid far more resilient by creating a portfolio of micro-grids that cover the entire state. To achieve this vision will require a more secure grid – less susceptible to powerline failures due to falling trees and high winds. It will also require new legislative measures that enable micro-grids to operate beyond the limited critical infrastructure identified by Public Act 12-148.[18] At one extreme, when residential photovoltaic systems have reliable battery backup systems, those in suburban and rural areas can weather the storms without regard for grid failures. At the other extreme, areas of dense development where utilities are underground or more securely protected can benefit from the micro-grid concept. Micro-grids have the potential to offer economies of scale in the use of renewable sources of electrical energy. Indeed, grid-connected photovoltaic systems could be established that not only feed the overall electric grid in fair weather but can become "islands" during an emergency to serve specific clusters of end users. The Connecticut legislature has identified the latter as an opportunity for future grid-connected photovoltaic systems.

From a land use perspective, municipalities should consider establishing local utility corridors to allow networking of critical infrastructure and a wider expansion of self-contained micro-grids. Such corridors will require many municipalities – particularly in suburban and rural areas – to revise their right of way ordinances to reserve space (underground) or an access to utilities in dense areas. The vision should be the development of micro-grids statewide, in all appropriate areas where critical infrastructure exists. Planning and zoning commissions can facilitate the micro-grid concept by increasing densities where sewer and water services exist to make underground infrastructure a more cost-effective option. Unlike traditional buried infrastructure that relied on backhoes and manual labor to dig ditches, the modern use of micro-trenches has revolutionized the laying of telecommunication systems. This same technology may be adapted to enable the laying of electrical lines in a more cost-

[16] Connecticut General Assembly, An Act Enhancing Emergency Preparedness and Response, Public Act 12-148, June 15, 2012.
[17] Connecticut Department of Energy and Environmental Protection, Micro Award Winners, Accessed July 12, 2022
[18] Public Act 12-148, An Act Enabling Emergency Preparedness and Response, June 15, 2012.

effective manner than in any previous period. The traditional reliance on utility poles to carry electricity will need to be replaced by underground service if the micro-grid concept is to deliver on its promise of increased resilience.

Community Solar – A Virtual Net Metering Program

Connecticut is one of twenty states that enable individuals without the ability to install solar energy systems on their roof or backyard to get the financial benefits of solar energy by subscribing to a community solar project.[19] Connecticut is in the incipient stages of developing a community solar program that aims to assist low-income families that might not otherwise be able to afford solar energy. The program is intended to "provide savings to specific categories of customers, particularly customers with low- to moderate-income (LMI), low-income service organizations, and customers who reside in environmental justice communities."[20] However, the program also targets small businesses that might benefit as well.[21] The primary advantage of a community solar project is it reduces electricity costs for those who cannot install solar energy on their home or for those who are renters. In an ideal world, all municipalities in Connecticut should offer incentives for all dwellings oriented to within 30 degrees of south so that solar energy systems can be efficiently installed. Over the last hundred years the orientation of houses in Connecticut and across the nation has been influenced more by aesthetics and road alignment than proper orientation for solar access.[22] Community solar projects offer the opportunity to extend the advantages of reduced electrical costs to those without adequate access to solar energy on their home or rental unit. Community solar projects are limited in scale in terms of the number allowable subscribers and the maximum kilowatt hour generation.[23] Those participating in the program benefit from reduced costs for electricity under what is called a virtual net metering program. Unlike grid-connected solar, community solar reduces the customer's electricity costs and represents an important means to deal with thousands of buildings that are not properly oriented to accommodate solar panels on the rooftop. The Residential Renewable Energy Solutions Program replaces the previous solar program operated by the state's two private utilities with two options; 1) net metering with the value of the energy produced serving as a credit for the customer's bill. In addition, the value of the renewable energy certificates (RECs) earned can be paid quarterly or a portion of it can be assigned to a third party; 2) the buy-all approach where the customer receives quarterly payment for the sale of electricity and the RECs and has the option of assigning some of the electricity to third parties. Whatever remains is applied to the customer's bill as a monetary payment.

Rooftop Non-Residential Solutions

In May 2002 the Connecticut legislature established the Non-Residential Solutions (NRES) program that authorizes commercial and industrial facilities to make full use of their rooftop space for the

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[19] Institute for Local Self-Reliance, National Community Solar Programs Tracker, Accessed October 11, 2022
[20] Public Utility Regulatory Authority, Annual Review of Statewide Shared Clean Energy Facility Program Requirements -Year 3, Docket No. 21-08-04, November 17, 2021, p. 2.
[21] Connecticut State Legislature, An Act Concerning Connecticut's Future, Public Act 18-50, p. 21.
[22] Charles Vidich, Overcoming Land Use Barriers to Solar Access, Central Naugatuck Valley Regional Planning Agency, 1980, p. 34.
[23] Community solar projects is known as the Shared Clean Energy Facilities (SCEF). According the Connecticut Department of Energy and Environmental Protection website, "The statewide SCEF Program seeks the deployment of new or incremental Class I renewable generation projects ranging in size from 100 to 4,000 kW (AC) for a 20-year term.

generation of electricity.[24] Previously solar energy generation for commercial and industrial facilities were limited to 2 megawatt capacity for on-site use. The NRES program expands the generation capacity to 5 megawatts and enables the excess electricity to be sold to other subscribers – thereby providing incentives for the private sector to accelerate the use of solar photovoltaic systems in much more appropriate locations than occurs through grid-connected solar arrays. Based on NRES projects approved by Eversource in the fall of 2022, 97% of the projects have selected the "buy-all" option.

Since the NRES program involves land use issues associated with commercial and industrial facilities, zoning regulations can influence the siting and design of these photovoltaic systems. Only seventeen of the 167 municipalities with zoning regulations currently allow large-scale photovoltaic systems (250 kilowatt capacity or more) as a permitted land use. As a matter of law, the Connecticut Siting Council has jurisdiction over all photovoltaic projects of one megawatt or more. Zoning commissions should become familiar with the NRES program and encourage photovoltaic systems to be placed on rooftops, as carports, or breezeways instead of vacant land.

Battery, Liquid and Solid Storage Systems

It is important to recognize that solar projects must factor in the vicissitudes of sunlight. The only way renewable resources can provide 24/7 electric benefits to individual homeowners is by storing electrical energy in batteries or relying on the grid for electricity at night. Batteries storage systems have been undergoing rapid improvements in efficiency, longevity, and price over the last ten years. Batteries are being used at the utility scale as well as in residential applications. Longer lasting batteries are being used as an alternative for residential gasoline or natural gas generators during power outages or as a tool to disconnect from the grid entirely.

The National Renewable Energy Laboratory (NREL) predicts small scale battery storage systems will increase dramatically as distributed energy systems, such as grid-connected photovoltaics and residential photovoltaic systems, continue to grow in popularity. The Federal Energy Regulatory Commission (FERC) has recently authorized battery storage systems to participate in regional wholesale electrical energy capacity within the United States.[25] Despite the enormous importance of battery storage systems applied to behind the meter applications (i.e., residential applications) the NREL has found the long payback period for residential batteries supporting rooftop solar to be as long as 11 years, thereby dampening the rate at which these systems will be quickly adopted.[26] However, the NREL study found the economics of battery storage are highly sensitive to the backup power it displaces. In the case of Connecticut, which has the highest electricity costs in the continental United States, battery storage systems will have a much better return on investment than similar systems installed anywhere else. Moreover, Connecticut is one of only six states that have reported average outage durations greater than 10 hours.[27] Indeed, in 2020 Connecticut had the third highest System Average Interruption Duration Index in the United States – a measure of the minutes of electricity

[24] Connecticut legislature, Public Act 22-14, An Act Concerning Clean Energy Tariff Programs, Approved May 10, 2022.
[25] Ashreeta Prasanna, Kevin McCabe, Ben Sigrin, and Nate Blair, Storage Futures Study; Distributed Solar and Storage Outlook: Methodology and Scenarios, National Renewable Energy Laboratory, NREL/TP-7A40-79790, July 2021, p. viii.
[26] Ibid, p. x.
[27] Ibid, p. 8. The other five states are Massachusetts, Maine, Vermont, West Virginia, and North Carolina.

interruptions experienced by customers throughout the year.[28] For many Connecticut residents the economics of battery backup systems will be determined by the competing cost for installing gas or natural gas generators to keep the lights on during Connecticut's numerous annual power outages. The NREL study estimates that battery storage systems will be cost effective (based on their positive net present value) as early as 2030.[29]

Mindful of these developments, on July 21, 2021, the Public Utilities Regulatory Authority announced a nine-year plan to demonstrate the value of battery storage systems to bolster the resiliency of the grid.[30] While frequent power outages have contributed to the need for this program, it also will play an important role in modulating the daytime electrical generation provided by grid-connected solar and residential photovoltaic systems operating under the net metering or virtual net metering programs. PURA has stated the goal of this program is "…to develop and implement a program for electric energy storage systems connected to the electric distribution system that provide multiple types of benefits to the grid, including but not limited to: customer, local, or community resilience; ancillary services; peak shaving; and support for the deployment of other distributed energy resources."[31] After Tropical Storm Isaias in 2020, the program was expanded to use battery storage as a means to address environmental justice communities, serve customers on the grid-edge[32], and support critical infrastructure.[33] Other objectives anticipated include maximizing the environmental benefits of battery storage (i.e., they reduce peak electrical generation air pollutant emissions), and to lower barriers for entry of battery storage systems into the utility grid.[34]

The Connecticut state legislature has further promoted battery storage with the enactment of Public Act 21-53 which sets specific goals for the storage of electricity over the near term (i.e., 300 megawatts by 2024) and longer term (1,000 megawatts by 2030).[35] This is an important development that is one of a series of necessary steps to make the grid more resilient and as a tool to better manage the variable electrical generation associated with solar and wind. Grid-connected battery storage supports the resiliency principles associated with micro-grid systems enabled by Public Act 12-148. However, it remains to be seen if battery systems will be cost-effective, and whether they contribute to a reduction in the costs of electricity for the ratepayers. At a minimum, PURA is requiring batteries to have at least a 10-year warranty – a marked improvement over battery systems available a decade ago. To the extent that battery storage systems have a land use footprint and create potential fire hazards, there may also be a role for planning and zoning commissions and other local land use agencies to be actively involved in the deployment of behind the meter solar battery storage systems. The potential fire risks

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[28] United States Energy Information Agency, Table 11.2, Reliability Metrics Using IEEE of U.S. Distribution System by State: 2020-2021.
[29] Ibid p. 39.
[30] Public Utilities Regulatory Authority, PURA Investigation into Distribution System Planning of the Electric Distribution Companies – Electric Storage, DOCKET NO. 17-12-03RE03, July 28, 2021.
[31] Ibid, p. 1.
[32] PURA defines grid edge customers as those "who experience more and/or longer than average outages during major storms." PURA Docket 21-08-05, Annual Review of Electric Storage Program-Year 1, December 8, 2021, p. 31.
[33] Ibid, p. 6.
[34] Ibid, p. 6.
[35] Connecticut General Assembly, An Act Concerning Energy Storage, Public Act 21-53, passed June 16, 2021. However, Docket 17-12-03RE03 limits the initial goals of the battery storage program to 580 megawatts until such time as DEEP, PURA and the electric utilities learn more about the practicalities of battery storage systems.

posed by lithium-ion batteries in the basement of dwellings suggests accessory structures or underground vaults may be appropriate options – both of which fall directly under the authority of zoning commissions.

Solid and Liquid Storage

Energy storage is an important aspect of any renewable energy strategy that relies on solar energy for home heating. Without some form of energy storage, solar heat gain achieved during the daytime is rapidly dissipated during the evening hours. Appropriately sized storage systems are needed to hold the daytime solar energy for release during the nighttime. Several different approaches exist to achieve that objective; one option is to install a thick dark color cement or stone floor in that portion of the dwelling that directly receives solar radiation in the daytime. This approach provides some energy storage but is often constrained by competing uses for floor space; another highly effective option is the installation of a vertical Trombe wall which is a thick dark cement or stone wall from eight to sixteen inches thick that is faced with a single- or double-glazed glass. Heat gained through the Trombe wall is slowly radiated back into the dwelling during the evening hours. By applying a sheet of metal foil to the outside wall surface, the Trombe wall absorbs almost all the visible sunlight. This approach can extend the solar heat gain during the daytime for ten hours into the nighttime. Trombe walls can covert 70 to 80% of the sun's radiation into heat making this an effective heating system. Trombe walls block indoor access to sunlight and therefore must be integrated into the overall passive solar house design so sunlight is available for 1) direct solar heat gain through windows, 2) access to sunlight to meet minimum lumen requirements for health and safety and 3) sunlight dedicated to storage. Numerous passive solar designed houses have integrated Trombe walls into southern exposures without sacrificing aesthetics or functionality of the dwelling. According to the National Renewable Energy Laboratory the heat from Trombe walls takes about eight to ten hours to reach the interior of the house which is ideal for ensuring a more comfortable evening temperature without the use of fossil fuels. Trombe walls can reduce energy consumption by as much as 30% compared to conventional construction.[36] The design of Trombe walls requires sizing the wall mass to achieve sufficient solar heat gain to warm the dwelling throughout the night. By properly calculating the size of double-glazed windows and Trombe wall's thermal storage mass the desired solar storage can achieve the building's heating requirements.[37]

Another Trombe approach is to develop a horizontal slab that incorporates a venting system beneath the slab to accelerate the distribution of heat gained through the solid horizontal cement floor. This approach is similar to the vertical Trombe wall, but it has the advantage of eliminating the delay in daytime heat capture because heat does not have to be driven through the wall to reach the interior air space. It also eliminates the vertical Trombe wall's blockage of direct sunlight into the home where the wall is installed. Since a ventilated horizontal slab can be built as the house foundation it can be less expensive. However, the design would need a layer of concrete-brick air channels to function optimally.

Trombe walls are not the only means of storing heat generated from the sun. Water is an excellent means of storing heat and has been used in lieu of Trombe walls. Water stored in dark plastic containers with direct exposure to sunlight is another means of moderating the normal drop in evening

[36] National Renewable Energy Laboratory, Building a Better Trombe Wall, NREL, Golden, CO, 1998.
[37] J. Douglas Balcomb, Passive Solar Design Handbook: Volume 2, Passive Solar Design Analysis, January 1980, pp. 20-39

temperatures in New England. This approach is used in greenhouses to moderate wintertime temperatures. There are also other energy storage systems that promise significant energy benefits including a new specialized liquid used for capturing solar energy that has a remarkable ability to hold energy for up to 18 years. This new liquid, called "molecular solar thermal", operates like a rechargeable battery in which electricity is stored but this approach puts sunlight in and heat is then stored for extended periods of time. This technology has the capability to convert the stored heat to electricity although its primary and most valuable application is for heating purposes. This is one of the most promising liquid storage systems emerging today and could have important home heating applications in the next ten to fifteen years if it can be commercialized.[38]

Finally, earth-sheltered dwellings are an important means of tapping the energy stored in the ground thereby reducing heat loss in the winter and providing cooling benefits in the summer. Ideally, a super-insulated passive solar dwelling benefits from earth-sheltering on the main floor with a horizontal Trombe wall to add additional heat. Such dwellings have already been constructed in New England requiring no additional heating other than the sun. To achieve 100% heating through renewable energy requires careful attention to solar access, solar orientation, proper fenestration, energy conservation and energy storage – as discussed in later sections of this report.

Expanded Solar Capacity for Residential Customers

In 2018, the Connecticut General Assembly passed Public Act 18-50, An Act Concerning Connecticut's Energy Future, allowing household photovoltaic systems to be sized to serve up to two electric vehicles and electric heat pumps. The result is that, effective January 1, 2022, the energy requirements of any given household can exceed the highest electricity demands over any 12-month period during the last five years to consider the following additional anticipated electricity demands provided the overall limit does not exceed 25 kilowatt hours of alternating current. For the average residential electric user in Western Connecticut, the anticipated electricity required to meet current needs and to plan for the transition from natural gas or petroleum heating would be as follows (Table 3):

Table 3: Residential Renewable Energy Solutions (RRES) Program Kilowatt Allowances

Future Electrification Measure[39]	Estimated Annual Load (kWh)
Electric Vehicle (per vehicle, maximum of two)	3,285
Whole-Home Air Source Heat Pump	3,608
Whole-Home Ground Source Heat Pump	2,458
Average Residential electricity Usage in Western CT	11,530
Total electrification anticipated in Western CT	20,881
Total electrification eligible under RRES Rules	25,000

The capacity limit for any grid-connected residential photovoltaic system installed after January 1, 2022, is 25 kW of alternating current.[40] The state's Residential Renewable Energy Solutions (RRES)

[38] Jessica Miley, Sun in a Box: The Liquid That Stores Solar Energy for Two Decades, Interesting Engineering, June 8, 2021; Accessed December 7, 2022

[39] Eversource, Residential Renewable Energy Solutions Questions and Answers, March 2022, p. 5.

[40] The kilowatt size limits established by the Public Utilities Regulatory Authority are intended to serve as planning guidelines to enable a more effective transition to a more electrified economy. In any given proposal, homeowners will need to demonstrate their specific electricity requirements to obtain approval from their electric utility company.

program does not include incentives for in-ground pool heater and/or hot tubs since these uses can increase consumption significantly and provide no climate change benefits for Connecticut or the world at large.

The example above indicates the typical residence in Western Connecticut will require a large number of solar collector panels to meet the 20,881 kWh of electricity that the state anticipates will be needed for each resident (see Table 3). As an energy audit is required for anyone seeking to install photovoltaic panels under the new RRES program so the actual electrical demand Eversource or United Illuminating (UI) will authorize is usually somewhat less than the 20,881 kilowatt-hours anticipated for the average household in Western Connecticut. Nevertheless, for planning purposes this analysis reveals that current and anticipated electricity consumption levels to support the use of electric vehicles and heat pumps will require an extensive amount of ground level or rooftop real estate if homeowners adopt a net metering strategy to meet their future electric vehicle needs.[41]

The implication of this analysis is that individuals planning to fully transition to the use of heat pumps and electric vehicles to meet their heating and transportation needs may be hard pressed to find enough surface area on their roofs or in their front or backyard to accommodate the required solar panels (Table 4). This challenge will be greatest for those living on lots of one acre or less where setback requirements and lot cover standards may inhibit an appropriate location for photovoltaic panels. Planning and zoning commissions must be mindful of the efficiency and size limitations of current photovoltaic technologies when establishing setback, maximum lot coverage, and height standards for these systems. If the goal is not only to achieve 100% reliance on renewable energy but also to do so cost-effectively by 2040, then the future of solar energy depends on an assessment of land use controls that may limit its installation.[42]

Table 4: Photovoltaic Panels required to meet residential electric needs in Western Connecticut: 2022

Scenario	**Anticipated Annual Kilowatt Hours**	**Solar Panels Required inclusive of Loss Factors***		
		250-watt panels	400-watt panels	450-watt panels
Anticipated Need	20,881	117	73	65
RRES KWh Limit	25,000	140	88	78

**Note: Loss factors include tree and building shading, snow, dust, cloud cover, solar refraction, line loss, and degradation of panel performance over time. As a result, actual solar photovoltaic electrical needs are generally up to 1.4 times greater than the name plate capacity of any given solar photovoltaic panel.*

Table 5: Roof or Ground Area Required to meet Residential Electric Needs with PV Panels: 2022

Scenario for Anticipated 20,881 Annual KWh	**Single Solar Panel Dimension (Square Feet)**	**Number of Solar Panels Required**	**Square Footage of Solar Panels Required**
250-watt Solar Panels	18.03	117	2,019

[41] While these electrical energy needs could be supplied by grid-connected solar arrays, this would not reduce the cost of electricity to the homeowner and would adversely impact farm and forest land. In contrast, community solar project could achieve this objective but the state has inappropriately limited this option for low income households and not all residents of the state with limited solar access.

[42] Connecticut Department of Energy and Environmental Protection, Integrated Resources Plan: Pathways to achieve a 100% zero carbon electric sector by 2040, October 2021, p. 15. Strategy #1 calls for 100% carbon free electricity by the year 2040.

Scenario for Anticipated 20,881 Annual KWh	Single Solar Panel Dimension (Square Feet)	Number of Solar Panels Required	Square Footage of Solar Panels Required
400-watt Solar Panels	21.95	73	1,602
450-watt Solar Panels	24.06	65	1,564

Note: For illustrative purposes, the 250 watt panel reflects the size of the Solar World Sun module panel, the 400 watt panel reflect the size of the Silfab 400 watt solar panel and the 450 watt panel reflects the size of the Canadian Solar 144 bifacial solar panel. Different panel manufacturers have different solar module sizes. Furthermore, the actual size of the solar array will be slightly larger than the square footage indicated since each solar panels must be held in place by a support structure.

Energy Conservation

Another important implication of this analysis is that current building code standards for insulation and energy conservation measures will need to be improved so fewer photovoltaic panels are required to operate residential heat pumps or fuel electric vehicles. On October 1, 2022, Connecticut adopted the 2021 The International Energy Conservation Code (IECC). That code has established maximum *U* factors (the inverse of R values) for new residential construction as shown in table 6.

Table 6: Residential Energy Performance Standards for Connecticut (Climate Zone 5)

Category	*U* Factor	Equivalent R-Value
Fenestration	.300	3.30
Ceilings	.024	41.6
Wood Frame Wall	.045	22.0
Floors	.033	30.0
Basement Walls	.050	20.0

Source: Table R402.1.2, 2021 International Energy Conservation Code adopted by Connecticut State Building Code, October 2021 and WestCOG R-value calculations.

While these *U* factors are an improvement over the previous building code, they still fall short of optimum insulation standards found in super-insulated residences where ceilings achieve R-60 values, basement walls R-30 or more, and wood frame walls are at least R-30. Optimum insulation, well-sealed thermal barriers, and minimal thermal bridging – in excess of the 2022 State Building Code – are the best lifecycle strategy for achieving energy efficiency in the residential sector; energy efficiency is, practically speaking, a prerequisite for the renewable energy transition. Other important conservation measures include transitioning to LED lighting systems, use of motion sensors to turn lights off when rooms are not occupied, installation of energy management systems to regulate heating, cooling, and appliance loads, installation of Energy Star appliances, air sealing, insulation, and installation of energy-efficient windows, doors, and skylights. These measures should precede the installation of photovoltaic panels and, in some cases, are required by electric utilities prior to approval for a residential solar project.

As much as photovoltaic technology has improved, and recognition of the need for renewable energy to address climate change has grown, over the last forty years, corresponding evolution in local regulation has been scant. Back in the late 1970s and early 1980s, the state legislature enacted several important laws to enable municipalities to address solar energy via local land use regulations. These laws, however, have had little impact in changing land use regulations – or development practices. A consequence of the failure to advance solar energy through local regulation has been a greater state-

level effort to address renewable energy at the grid level. Grid-connected solar arrays do not require local land use approvals and for this reason this initiative, which is about ten years old, has become the driving force for current state level renewable energy policies. While doing an end run on local land use regulations has dramatically increased the megawatt capacity of grid supported renewable energy, it has done nothing to reduce the cost of electricity for the consumer and has left local solar-conscious land use planning in no better shape than it was forty years ago. To understand the current state of solar-conscious land use regulation in Connecticut and the state's decision to focus on grid-connected solar installations, the first step is to understand what solar-conscious land use regulations have worked and which ones have not.

Solar-conscious Subdivision Practices in Connecticut: State of the Art

It has been forty-one years since the state legislature enacted Public Act 81-334, "An Act Concerning Passive Solar Design for Subdivisions", and yet no Connecticut legislative, executive, or judicial body has chosen to evaluate whether municipalities have effectively implemented this critical renewable energy land use law. The late seventies and early eighties were a time of intense interest in renewable energy – largely due to the energy crisis that fueled interest in alternative modes of heating homes. Today, with the increasing recognition of the adverse impacts of petroleum combustion on the world's climate, the planet is facing an even greater existential threat that has reinvigorated the importance of maximizing the use of renewable energy resources.

Forty years ago, the number of solar energy applications was far less than today. For example, in 1980 solar hot water systems and passive solar energy designs for homes were considered the most viable options for harnessing the sun. In contrast, today a wide spectrum of solar photovoltaic systems are available that are economically more viable than grid-connected electricity and that can support any use of electricity – not just space heating. Solar photovoltaic systems have become so popular that many state governments have authorized electric utility companies and other private sector developers to install vast solar photovoltaic installations displacing forests, farms, and other natural resources to expedite the transition to a zero-carbon world. One of the reasons these private sector and utility sector initiatives have taken root rests with limited state and local government awareness of the need to integrate solar-conscious land use planning into local zoning and subdivision regulations. This section of the report analyzes solar land use planning in Connecticut and recommends revisions to the regulations and procedures used to encourage solar energy use in the residential, commercial, and industrial sectors.

In 1981 the Connecticut General Assembly retained the Central Naugatuck Valley Regional Planning Agency to implement Public Act 81-334. Working in concert with the state's other regional planning organizations, 141 of the 169 municipalities adopted passive solar subdivision regulations from 1981 through 1988. Public Act 81-334 enabled municipalities to adopt cost effective passive solar concepts but did not specify the criteria or standards needed to achieve solar access. Nor did the state legislature provide technical guidance on 1) what constitutes adequate solar access for a residential lot, 2) how that solar access should be protected, and 3) what documentation requirements developers must provide to verify solar energy techniques were properly considered and determined feasible. For these reasons, it is not surprising there is not a uniform understanding across the state's 169 municipalities on how solar access can be protected through land use regulation.

In 1988, the Connecticut legislature made the provisions of Public Act 81-334 mandatory for all municipalities. However, this mandate did not provide any technical assistance to planning and zoning commissions. As a result, it achieved very little, if any change, in compliance with solar-conscious land use planning.[43]

As the law was implemented, emphasis was on encouraging 1) street orientations along an east/west axis to enable more houses to face south; 2) lots to be oriented with their long axis along a north/south axis to increase the distance between buildings and trees to the south of solar energy equipment, 3) minimizing the planting of "late leaf dropping" deciduous trees to the south of solar collectors to avoid shading problems, 4) locating septic system leaching fields on the south side of new home construction as this obviated the need for additional tree removal for solar purposes, and 5) identifying standards for what constitutes adequate solar access to any given residential development.

State of Passive Solar Design Concepts in 2022

A recent review of the subdivision regulations for the state's 169 municipalities revealed inconsistent and ineffective implementation of the 1981 and 1988 laws. While Public Act 88-263 required all municipalities to revise their subdivision regulations to address solar access and solar orientation issues, twenty-eight municipalities (17% of all municipalities) have not complied with this mandate. Of the 141 municipalities that have adopted solar-conscious subdivision regulations, 89% have addressed the importance of orienting streets along an east/west axis, and 84% have regulations that address lot orientation and solar access. Unfortunately, the mere inclusion of guidance on the importance of street and lot orientation and solar access by itself accomplishes very little without specific standards for orientation and solar access, let alone for what constitutes a design that does not significantly increase the cost of housing after tax credits, subsidies, and exemptions.[44] Only 62% of all municipalities that have adopted passive solar subdivision regulations (i.e., the 141 municipalities with regulations) require developers to document how they have applied the principles of orientation and solar access in a proposed development. The result is that about seven out of every ten Connecticut municipalities have no explicit requirements that passive solar be considered in the subdivision of land. (28 municipalities have no regulations at all; of the 141 that do, 88 do not require developers to prove they have considered solar; together these groups total 116 municipalities).

Table 7: Solar Subdivision Practices in Connecticut Municipalities, July 2022

Local Regulations Include	Number of Municipalities	% of Munis. with Solar Considerations in Subdivision Regulations	% of Munis. with Subdivision Regulations
No solar access provisions	28	20%	17%
Solar-oriented street policies	125	89%	74%
Solar-oriented lot and solar access policies	118	84%	70%

[43] Connecticut General Assembly, An Act Requiring Municipal Planning Commissions to Adopt Subdivision Regulations that Encourage Energy Efficient Land Use, Public Act 88-263, 1988. Unlike PA 81-334, Public Act 88-263 did not provide technical support or guidance on how to implement its mandatory provisions.

[44] Since tax credits and subsidies are periodically changing, this suggests a need to routinely review land use regulations to address the changing economics of solar energy applications.

Local Regulations Include	Number of Municipalities	% of Munis. with Solar Considerations in Subdivision Regulations	% of Munis. with Subdivision Regulations
No required documentation of solar subdivision policies	88	62%	52%

Fiscal Impacts of Passive Solar Subdivision Design

One of the most significant issues raised by municipalities that adopted solar access regulations forty years ago was the impact these regulations would have on the cost of housing. At several public hearings for solar access regulations held in Connecticut in the 1980s, residents and engineers felt the increased cost for meeting the mapping requirements for a solar subdivision might add several hundred dollars to the cost of the lot. This was an apparent stumbling block for planning commissions at that time, but in reality it was largely an education issue. In 1981, less than a quarter of all Connecticut municipalities had town planners and therefore were reliant on the expertise of lay commission members who may not have had experience with trigonometry (the basis for all solar access calculations) or an understanding of the energy benefits offered by orientation and access to sunlight as tools to reduce the cost of home heating. At that time, it was argued that mapping requirements should be kept to a minimum so as not to increase the cost of development.

The cost to build zero energy houses, passive solar houses, or houses that rely on photovoltaic panels to provide electricity were not the main fiscal concerns raised by Public Act 81-334. In 1981, a concern raised by builders and developers was the anticipated costs to design and get planning commission approval for solar-conscious subdivisions. At that time, calculating the length of a shadow cast by a building or tree was more cumbersome since this was the pre-computer age where maps were done by hand without the aid of drafting software. Today, software has made designing a solar subdivision, including the proper position of streets, lots, houses, trees, and fences to ensure proper solar access, a straightforward process that has no significant impact on the cost of development. More importantly, the energy benefits of solar access for home heating and electricity are clearly economical when the land planning goal is merely access to the sun – not installing building components or building technologies. Indeed, even in 1980, a study done of California subdivisions by the California Energy Commission found no economic hurdles for orienting buildings or lots to maximize the use of solar energy.[45] However, the Connecticut state legislature has yet to update Public Acts 81-334 and 88-263 to reflect the dramatic improvements in the economic feasibility of solar or to leverage lessons learned by the developers of solar subdivisions in Connecticut and in other states. There is a clear need for the Office of Policy and Management and the Connecticut Department of Energy and Environmental Protection to educate land use commissions on the state of the art concerning solar subdivision design and its favorable economics.[46]

Making solar affordable remains a critical goal not only for the initial cost associated with site planning and construction but the long-term energy benefits that accrue to homes properly oriented to the south with adequate solar access. Unlike 1981 when 1) photovoltaic technology was limited to NASA

[45] Ed West, *Site Planning for Solar Access*, Project Report No. 11, California Energy Commission, June 1980.
[46] It is worthy to note the Office of Policy and Management did promote passive solar subdivision design concepts in 1981 but these efforts were a one-time affair. See *Passive Solar Subdivision Design: A Planner's Guidebook*, Connecticut Office of Policy and Management, 1982.

space projects and "back to the land" survivalists and 2) passive solar designed houses were considered fringe concepts in the building trades, the economics of passive solar homes and photovoltaic panels have now become internationally recognized sustainable building concepts. Solar-powered utility grids are now outcompeting petroleum-based fuels as a cost-effective means of providing electricity to the home.[47] Furthermore, advances in passive solar design technologies now play a significant role in reducing home heating and cooling costs in Connecticut. It is not simply access to solar energy that drives the economics of solar-conscious land development but the cost of the competing options. With home heating oil selling at $5.20 a gallon during the fall of 2022 and utility based electrical costs priced at over 26 cents a kilowatt hour in Connecticut (the highest rate in the continental United States), the economics of solar energy has become a "no brainer" (see Chart 7 for heating oil price trends in the Appendix). And yet more than 90% of the state's 169 municipalities still live with regulations that do not recognize these economics and climate change realities.

One way to avoid creating costly regulations is to evaluate the provisions of solar access regulations for consistency with the "Least Cost Housing" concept. Without an emphasis on a "least cost" approach to solar-conscious land use regulations, the benefits of solar access and solar orientation policies may be inconsistent with Connecticut's legislation on solar subdivision design. The 1988 Act Concerning Passive Solar Design for Subdivisions stipulates that a developer must "demonstrate to the commission that he has considered, in developing the plan, using passive solar energy techniques which would not significantly increase the cost of the housing to the buyer, after tax credits, subsidies and exemptions."[48]

Fiscal Benefits of Street and Lot Orientation

Since the passage of Public Act 81-334, numerous studies have quantified the fiscal benefits of proper street, lot, and house orientation in reducing home heating and cooling costs. Street orientation is one of the primary drivers that influence the orientation of lots and houses. For this reason, subdivision regulations that promote proper solar orientation through street layout standards play an outsize role in creating a viable renewable energy future. Perhaps one of the most important studies documenting the energy benefits of street and house orientation is that prepared by Brandt Anderson and colleagues at the Lawrence Berkeley Laboratory at the University of California. Anderson evaluated the total residential energy load impacts (i.e., heating and cooling loads) for twenty-five different cities in America for a rectangular house size of 1,176 square feet with R-10 insulation for the foundation slab, R-19 for the walls, R-38 for the ceiling, and 176 square feet of double-glazed windows (with 144 square feet of that glazing facing the south). The analysis revealed the same house in each of the twenty-five cities would have the lowest heating and cooling loads when the house faced due south compared to east or west orientations. The analysis addressed heating and cooling loads in the Boston and New York climate zones, finding that the modeled house when facing east or west would have an 18% and 19% respectively greater heating and cooling load compared to the same house facing due south (see Appendix 8).[49] At today's heating oil prices the model house oriented east or west spends about $250 more to heat and cool than the same house facing due south. For larger houses of 3,000 square feet or

[47] Ravi Manghani, Total Eclipse: How Falling Costs Will Secure Solar's Dominance in Power, Wood Mackenzie, January 2021. Accessed on November 2, 2022.
[48] Connecticut General Assembly, An Act Requiring Municipal Planning Commissions to Adopt Subdivision Regulations that Encourage Energy Efficient Land Use, Public Act 88-263, 1988.
[49] Anderson, Brandt, et al., The Impact of Building Orientation on Residential Heating and Cooling, Lawrence Berkeley Laboratory, University of California, April 1983, pp. 5-7.

more typically found in Western Connecticut, the savings from proper solar orientation would be more than double those in the Anderson study.

Proper solar orientation, while a fundamental element of any well-designed building, is not the only variable that affects the overall energy costs of a home. Super-insulated houses can achieve enormous energy savings when insulation (R values) used in walls, roof, and foundation exceed the state building code as well as those used in the baseline study prepared by Anderson. Super-insulated homes work well in the New England climate, especially when there is enough thermal mass or storage within the building to absorb daytime solar energy for release throughout the evening hours. Ideally in the New England climate zone, a super-insulated house should have triple-glazed windows on the north, east, and west sides of the house and double-glazed windows on the south wall.[50] In the northern climate zone, the Energy Star program calls for windows with U values ranging from .27 to .30 depending on the solar heat gain coefficient of the glass.[51] Windows with high solar heat gain coefficients (SHGC) and low U factors are best for south facing windows since a high SHGC rating lets in more heat from the sun.[52]

A 2019 study by the U.S. Green Building Council (USGBC) of Massachusetts found some zero energy houses being built in Massachusetts have been completed with zero additional upfront costs, although these examples were not the norm. Zero energy ready (ZER) buildings are so energy-efficient they can meet their total energy needs through renewable resources. From a lifecycle perspective, the USGBC study found a one to eight year payback for the additional upfront costs for zero-energy single-family house compared to a typical single-family residence (although in some cases, depending on the cost of building materials and labor, payback could take up to 15 years).[53] Despite these longer paybacks, the study suggested zero-energy houses can be built for the same cost as typical residential construction when special attention is paid to purchase lower cost building materials – however these cases are the exception to the rule. The assumption that inexpensive building materials can be used to achieve these results may temper the applicability of the study's findings given recent inflation in building material costs, which have made construction – including building upgrades – more expensive. However, these costs may be mitigated by several factors, including the 1) space-efficient design and "right-sizing" of new homes to meet household needs (i.e., building a well-designed 1,200 square foot house rather than one of 3,000 square feet), 2) expanded incentives for the retrofit or creation of zero energy and renewable energy housing under the Inflation Reduction Act of 2022[54] and 3) the favorable economics of renewable and zero energy concepts in an era of high costs for heating oil, natural gas, electricity, and other fuels used for home heating and cooling.

Zero energy houses are not a new phenomenon. Indeed, zero energy houses were built in the late 1970s by 1) sizing residences to meet household needs, 2) super-insulating residences (e.g., improved roof, wall, and foundation insulation, reduction in thermal bridging, elimination of air leaks, and

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[50] Nigel Maynard, The Latest Highly Insulating Windows Are Almost as Efficient as a Wall, The Journal of the American Institute of Architects, December 20, 2011. Accessed November 2, 2022; Nathan Holladay, Choosing Triple Glazed Windows, Balancing U Factor and Solar Heat Gain, Green Building Advisor, 2010: Accessed November 2, 2022.
[51] Window Performance Criteria, EPA Energy Star Program. Accessed November 2, 2022.
[52] U.S. Department of Energy, Guide to Energy Efficient Windows, 2010. Accessed November 2, 2022.
[53] Marshall Duer-Balkind, et al., Zero Energy Buildings in Massachusetts: Saving Money from the Start, U.S. Green Building Council, Massachusetts Chapter, 2019, p. 39.
[54] Public Law No: 117-169, Inflation Reduction Act of 2022. Accessed November 2, 2022.

recycling heat with energy and heat recovery ventilators) optimum use of high transmittance glazing on south walls, 3) earth sheltering of habitable space[55], and 4) energy-conscious landscape planning. These conservation principles can still be used to eliminate or dramatically reduce the need for fossil fuels for home heating.

Micro-Climate and Energy Benefits of South Facing Slopes

South facing slopes are the equivalent of energy resource zones since they provide a greater BTU value per square foot than flat land or north facing slopes. A landmark study prepared by Victor Olgay found solar radiation striking a south facing slope of 17.6% (equivalent to a 10 degree inclination) generated 21% more BTUs per square foot than flat land during the heating season months (October to February) at 40 degrees north latitude (Appendix 12).[56] Perhaps more significantly, a north facing slope of 17.6% will generate 58% less BTUs per square foot than south facing slopes of 17.6%. The improved micro-climate of south facing slopes means the additional 21% greater radiation compared to a level site means the south slope site will be two weeks ahead in the arrival of spring. Using Olgay's analysis, north sloping land of 17.6% will be four weeks behind the arrival of spring. The implications of this analysis are that south facing slopes provide an energy advantage for all dwelling units simply because of the beneficial advantages of the micro-climate.

While south facing slopes provide an energy benefit, not all municipalities have considered these lands buildable. A 2022 WestCOG analysis of the state's 167 zoning regulations identified 71 municipalities with town-wide buildable lot standards and 35 with district specific standards limiting development on steep slopes. Among the municipalities with town-wide standards, the definition of steep slope varies with nine municipalities prohibiting development on slopes of 15 percent or more; twenty-one municipalities prohibiting on slopes of 20% or more and forty-one prohibiting development on slopes of 25% or more. While steep slopes require greater attention to erosion and sedimentation controls during construction, there are no technical reasons that should pre-emptively prohibit development on slopes less than 30 percent without a specific analysis of the soil types and erosion and sedimentation controls measures appropriate for any given site. Fragile and unstable soils should not be used for development but, slope by itself, is not the determinant of fragile or unstable slopes. Slopes have energy benefits that must be considered as Connecticut moves toward greater reliance on solar energy for home heating and electricity.

Solar Access Best Practices

There is no right to sunlight in America nor in the state of Connecticut.[57] States that have developed solar access protections (e.g., California, Massachusetts) have done so through state enabling legislation that establishes the right to use solar energy when a solar energy system is installed and protected through a solar access permit. Connecticut has never established a system to protect solar access through a special permit process (e.g., the approach taken in Massachusetts), nor has it enabled the use of solar easements to protect solar access privately. The result is that a homeowner could make significant investments in passive or active solar energy systems without any guarantee that his or her system will have adequate solar access in the future.

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[55] The Groton Connecticut Public Library, a facility with 24,800 square feet of space, is an excellent example of an earth sheltered building that has provided significant energy benefits for the town since its dedication in 1977.
[56] Vivtor Olgay, Design with Climate: Bioclimatic Approach to Architectural Regionalism, 2015, pp. 44-52
[57] This topic is discussed in more detail infra under the section "There is no Right to Sunlight in America."

While virtually all the state's 141 municipalities with passive solar subdivision regulations use the term solar access, only twenty-six of these municipalities define it in sufficient detail for a developer to determine whether solar access is available. There are four solar access definitions extant in Connecticut. The limited number of municipalities that address solar access define it based on 1) shadow projections on the worst day of the year for sunlight, 2) specific levels of protection applicable to ground, wall or roof mounted solar energy systems, 3) a goal for full solar access protection year-round or 4) solar access protection based on a first come first served approach. These approaches are described below. It is important to note that, regardless of how solar access is defined, no municipalities in Connecticut provide for enforcement mechanisms to protect it.

Solar Access Based on December 21st Sun Angles

Because access to sunlight is most likely to be obstructed when the sun is at its lowest altitude, eighteen municipalities have adopted December 21st as the key date to evaluate the availability of solar radiation. Municipalities that have adopted this approach have selected 9 AM to 3 PM or the equivalent solar times in Western Connecticut (e.g., 8:35 AM to 3:08 PM to compensate for when the sun is truly due south, coinciding with the sun at a 45-degree angle from true south in the morning and afternoon hours). It is generally assumed that if solar access is available on December 21st from 9 AM to 3 PM, then it will also be available for the balance of the year.[58] Defining the "time window" for solar access is the first of two key factors required to protect the feasibility of solar energy systems. The second factor is the maximum amount of shading acceptable for a solar energy system to be economically feasible. Only six of the eighteen municipalities have defined the maximum acceptable shading that can occur on December 21st with no more than 25% shading allowed on that day. Defining maximum shading standards is an important land use control in a state with about 60% tree coverage.[59]

Solar Access Based on Specific Roof, South Wall, or Lot Protections

The second approach recognizes that different lot sizes have different solar access potential. Three municipalities have declared that solar access may be protected at the roof level, the south wall, or to the open space on the south side of the lot based on the developer's determination of what is feasible. This approach assumes that solar access objectives should be specified by developers based on the solar energy systems incorporated into the design and layout of a residential development. For example, ground-level photovoltaic systems may not achieve adequate solar access protections when serving homes on small lots. In this instance, solar access may only be feasible when photovoltaic panels are installed on south facing roofs or when pole-mounted above obstructing shadows. This approach has merit but should be supplemented with specific dates and times when solar access is to be evaluated so that there are publicly recognized standards for what constitutes an acceptable level of solar access.

Requiring 100% access to solar radiation for 365 days of the year is not realistic in Connecticut. Based on solar access legislation in other parts of the United States, a 10% shading of solar panels is an acceptable compromise, as long as the time that shadows obstruct the functioning of the solar energy system are during the early morning or late afternoon hours where some loss of radiation has the least

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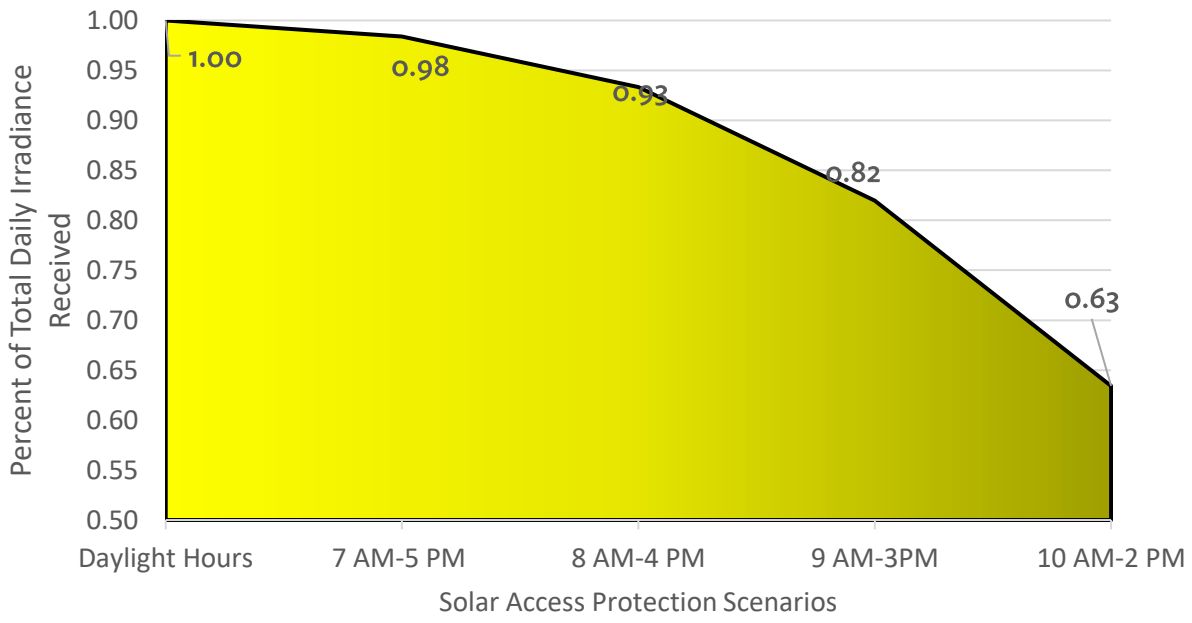
[58] The exceptions to this rule are late leaf dropping trees (e.g., Oak trees) that can interfere with solar access in the fall season.

[59] Bureau Natural Resources. Forestry Division, CTDEEP, Connecticut's Forest Action Plan 2020 Update. Accessed November 3, 2022

impact on system performance.[60] In Connecticut, 93% of the solar energy needed to power photovoltaic systems on a year round basis is available between the hours of 8 AM and 4 PM solar time (Figure 1).[61] Protection of solar access during the period 8 AM to 4 PM is even more important in the winter months (December through February) when about 99% of all solar direct normal radiation occurs in Western Connecticut. The only shortcoming of a longer solar window is that shadow lengths are much longer. For example, the shadow cast by a 65-foot tree when the sun is 11 degree above the horizon (i.e., the 45 degree morning and afternoon azimuths) is 337 feet long (see Appendix 13). In contrast, that same 65-foot tree only casts a 187 foot shadow when the sun is 19 degrees above the horizon (i.e., the 30 degree morning and afternoon azimuths). For this reason, municipalities may wish to consider solar access protection that recognizes a time between the 8 AM to 4 PM window (solar time) and the 9 AM to 3 PM window (solar time) for unobstructed sunlight. The appropriate standard of protection must be sufficient to maximize daily solar radiation for a cost-effective application of photovoltaic panels while minimizing tree shading issues on an annual basis.

Figure 1: Percent of Total Solar Irradiance Received on Solar Panel with 42 Degree Tilt: Newtown, Connecticut Under Five Solar Access Protection Scenarios



Source: WestCOG staff analysis, December 2022

Solar Access Based on Full Protection

The third approach is to declare that solar access must be unobstructed on all lots. Four municipalities have declared that solar access must be unobstructed on lots in residential subdivisions (Brookfield, Cheshire, Naugatuck, and Portland). Unlike option 2 above, this approach sets completely unrealistic expectations for solar access protection. Taken literally, these four municipalities require access to sunlight from dawn to dusk – an improbable strategy given the topography, tree canopies and lot sizes that exist in Connecticut. Dawn to Dusk solar access protection simply does not work. Hypothetically,

[60] This is the standard established by the California Shade Control Act of 1978.
[61] Global Solar Atlas, https://globalsolaratlas.info/map?s=41.117597,-73.407897,10. Accessed, May 12, 2022

if this approach were adopted analysis of impediments to solar access on a lot-by-lot basis would quickly reveal dawn to dusk protection is a pipe dream. While solar access standards are essential to ensure that solar energy continue to perform over the long term, the range of current and future objects that could cast a shadow anywhere on a lot is large – especially when the sun is less than 10 degrees above the horizon. Shading from buildings, fences, and trees can be significant and can interfere with the functioning of photovoltaic panels, domestic hot water solar collectors, and passive solar heating systems. The lesson for these four municipalities is to define a solar access protection window that takes into consideration topography, tree canopies and a realistic level of solar access for the proper functioning of solar panels or passive solar designed houses. Several municipalities, including Goshen, require a demonstration of what level of solar access (and thus electric generation) can be attained on a lot. This is a useful approach but may only succeed if solar easements are incorporated into the deeds of the adjoining lots that could create future shading impacts. Since the Connecticut legislature is one of twenty states whose statutes and court precedent are silent on solar easements, the specific deed restrictions to be applied should rely on tested easement language adopted in other states.

Solar Access Based on the Right of Prior Appropriation

The last approach in use in Connecticut is that of the City of Hartford. Hartford's zoning regulations establish solar access as a right of prior appropriation analogous to how riparian water rights have been allocated in the western United States. Neighbors who install solar energy systems have a right to solar access that cannot be impeded by trees that are planted after the installation of an approved solar energy system. However, the shortcoming of this approach is that it does not address the possibility that new building construction or other manmade objects may be installed after the approval of the solar energy system. While use of the prior appropriation doctrine can work in principle, the City of Hartford has not provided administrative procedures to adjudicate conflicts between a property owner and neighbors concerning tree planting and trimming. This shortcoming can be remedied by developing a solar permit procedure adopted by various municipalities in other parts of the United States that have robust administrative procedures for such land use conflicts (see later sections of this report).

Technological Innovations for Minimizing Shading

During the last twenty years, the efficiency and economics of solar panels have improved dramatically. The ability to convert a higher percentage of received solar energy into electricity has made it possible to increase the performance of solar panels – measured in watts ratings per panel – and thereby reduce the impacts of shadow obstructions. Similarly, the adoption of micro-inverters within solar photovoltaic panels has helped minimize the impact of shadows on the overall performance of the panels. In-panel micro-inverters limit the loss of solar to just that portion of the panel that is shaded, whereas the wiring of a solar panel in series means the entire panel loses power when any portion of the panel is shaded. Twenty years ago, photovoltaic panels were typically rated at 250 watts. Today, solar panels of comparable size are achieving 450- to 600-watt ratings – resulting in the need for fewer than half the panels – and less than half the roof or ground-level real estate – required to generate the same amount of electricity. Smaller arrays in turn make it easier to avoid shadows in siting panels.

While technological innovations have made it possible to live with some shading on solar panels without adversely impacting their overall performance, this does not solve the fundamental lack of

"right to sunlight" in Connecticut or anywhere in the United States. In contrast to Connecticut, seventeen states have adopted solar access protections ranging from solar easements to special permits that guarantee access to sunlight.[62] Because access to sunlight is a land use issue, Connecticut's municipal planning and zoning commissions are in the best position to provide a modicum of solar access protection for those investing in passive or active solar energy systems. Yet, as this analysis points out, lack of solar access remains a critical infrastructure vulnerability that has yet to be properly addressed by any municipality in Connecticut. Back in 1978, the Connecticut legislature did not address this issue when it authorized zoning commissions to consider solar and other forms of renewable energy. The result has been a hodgepodge of zoning regulations that speak to solar energy but provide no concrete protections for it – a fact that tends to discourage its use.

Solar Access and Zoning

Solar access is not merely a concern to be addressed in the subdivision of land. Solar access issues arise in existing and new development even without land subdivision. The Connecticut legislature recognized this issue in 1978 with Public Act 78-314, "An Act concerning inclusion of energy considerations in local planning and zoning functions." With the passage of this act, the Connecticut legislature authorized zoning commissions to "encourage energy-efficient patterns of development, the use of solar and other renewable forms of energy, and energy conservation." [63] As of July 2022, 103 of the state's 167 zoning commissions (62%) have availed themselves of this authority to incorporate solar provisions of any nature into their regulations (Figure 2).

Solar provisions vary significantly by municipality. Thirty of the state's zoning commissions require extensive reviews as part of the zoning approval depending upon the type of solar energy system installed. Requiring review procedures beyond those in the state building code does not reduce the cost of solar energy systems. Indeed, according to the National Renewable Energy Laboratory, an average of 18% of the cost of photovoltaic installations, on a per watt basis, are attributable to permitting, inspections, and interconnection requirements.[64] Since the NREL study reflects average costs, jurisdictions with more cumbersome approval procedures may create greater costs for solar energy systems. The use of a zoning permit or conditional zoning permit strategy with specific, clear, and workable approval standards is an important means of reducing transaction costs associated with land use approvals that impose special permits, site plan approvals, and similar procedures.

Fifty-seven municipalities allow solar energy systems simply by obtaining a zoning permit (see Figure 2). Seventy-six municipalities, or 45% of all Connecticut municipalities, do not require a zoning permit, instead deferring to the building code to determine how photovoltaic systems are installed. As will be discussed in later sections of this report, simplified permitting reduce costs with one exception; in the case of solar access protections a site plan review may be a valuable benefit to homeowners who have concerns about shading of their solar collectors. For this reason, some form of formal or informal site plan review could play an important role in the future expansion of solar energy in Connecticut. Absent a state solar access law like that adopted in California, only zoning can address the issues of solar

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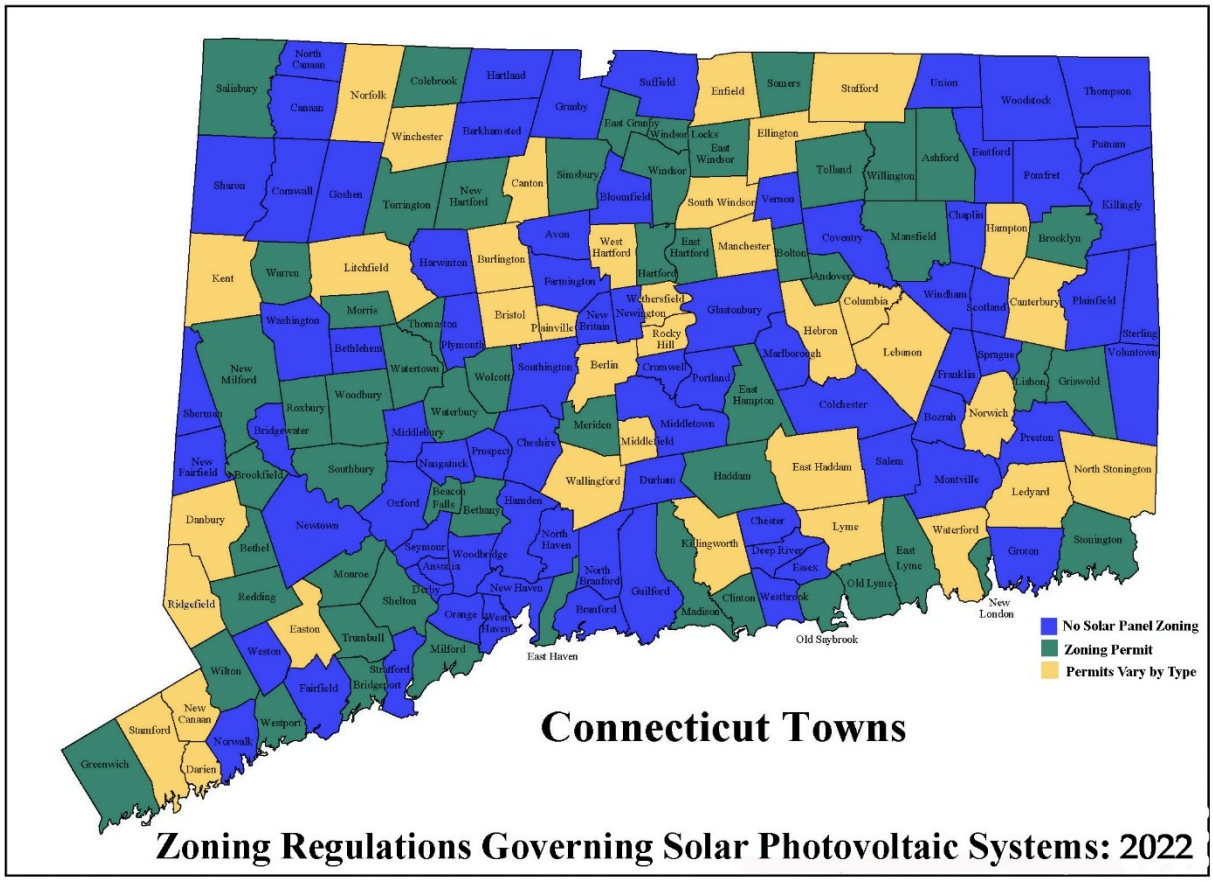
[62] National Conference of State Legislatures, Solar Policy Toolkit – Solar Access and Rights. Accessed June 14, 2022

[63] Public Act 78-314, "An Act Concerning Inclusion of Energy Considerations in Local Planning and Zoning Functions", Connecticut State Legislature,

[64] Vignesh Ramasamy, et al., U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2021, National Renewable Energy Laboratory, November 2021. Accessed November 3, 2022, p. 6.

access and solar orientation of buildings – a critical need to protect the right to sunlight for future solar energy systems installed in Connecticut.

Figure 2 Solar Zoning Regulations in Connecticut



Without at least 90% unobstructed access to sunlight, there is less economic value – and less incentive –to install photovoltaic panels. Yet few municipalities speak to sunlight: 26 Connecticut municipalities address solar access through subdivision regulations and just five through zoning regulations (Beacon Falls, East Hartford, Hartford, Stonington, and Wolcott). Solar access zoning regulations have been conspicuous by their absence. While five Connecticut municipalities have adopted solar access regulations, their standards are silent with respect to 1) how solar access is to be protected, 2) which, if any, height and setback standards apply, and 3) whether large-scale solar installations should be allowed in the municipality. The broader challenge is the development of explicit standards for solar access in the 162 municipalities that do not address solar access. In many cases, these municipalities have not only overlooked the importance of protecting sunlight to solar collectors; they may have created unintentional barriers to its wide deployment through zoning requirements and review procedures that limit where and how solar photovoltaic panels can be installed. For example, twenty-four municipalities encourage the use of solar energy, yet only ten require a site plan review of solar access; in contrast, eighty-three (50% of all municipalities with zoning regulations) require solar energy systems to comply with building setbacks (building setbacks may create a barrier to solar panels that are inappropriate on the roof of the building).

Of concern is the degree to which municipalities have created regulatory constraints on the use of solar energy. These constraints often restrict the locations where solar panels may be installed or set forth complicated approval procedures (Table 8). A total of 97 of the 103 municipalities with solar energy regulations have imposed between 6 and 11 requirements limiting the use or siting of on-site solar energy systems. See Appendix 10 for a town-by-town analysis of key solar regulations in Connecticut. These constraints can act as barriers to the installation of solar rooftop and ground-level solar systems, adding delay and cost, and limiting the options for solar installations and slowing the overall transition to renewable energy and greater energy resilience.

Table 8: Zoning Regulations Governing Use of Solar Energy in Connecticut Municipalities: 2022

Zoning Requirements for Solar Energy Systems	**103 Municipalities**	**% of Munis. with Solar Provisions**	**% of Munis. with Zoning**
Solar Access Not Protected through Zoning	96	93.2%	57.5%
Must Comply with Lot Setback Requirements	93	90.3%	55.7%
Solar Panels must Comply with Building Height Limits	67	65.0%	40.1%
Limit Ground Mounted Solar Panel locations	49	46.2%	29.3%
Define Non-Roof Mounted PV Panels as Structures	35	34.0%	21.0%
Limit the Height of Ground Mounted Solar Panels	39	37.9%	23.4%
Restrictions placed on Roof Mounted Solar Panels	31	30.1%	18.6%
Buffers if Ground Mounted Panels (Non-Res. Zones)	20	19.4%	12.0%
Rooftop Solar Panels must be Recessed	14	13.6%	8.3%
Solar Panels Can't Be Visible from Adjacent Property	15	14.6%	9.0%
Solar Collectors count toward Building coverage Stds.	15	14.6%	9.0%
Solar Panels removed after ceasing operation	11	10.7%	6.6%
Allow Large Scale Solar Energy Systems (250KW+)	17	16.5%	10.2%
Restrictions placed on wall mounted panels Restrictions	7	6.8%	4.2%
Prohibit Ground Mounted Panels in Front Yard	14	13.6%	8.3%
Define Solar Energy Systems	30	29.1%	18.0%
Adopted policy to encourage solar energy use	45	43.7%	26.9%

Flexible Height and Setback Standards

Requiring photovoltaic panels and similar solar energy collection equipment to comply with height and setback standards imposed upon the principal buildings on any given lot, may be a disincentive to the use of solar energy. This is especially true on small lots in urban and suburban neighborhoods where side, rear, and front yard setbacks can make it difficult to find a suitable shade-free location. Rather than imposing building setbacks standards upon solar photovoltaic panels, it may be more appropriate to establish less restrictive setbacks for ground-mounted panels. As long as the setback standards that are adopted are administered uniformly within each zoning district – consistent with the state's zoning enabling legislation and Connecticut case law – they remain an important strategy to support solar energy development.[65] Solar energy system setback standards can be less restrictive than those imposed upon the principal structure on the lot. The real issue will always be whether the added flexibility will result in greater solar access options for the homeowner.

Similarly, if the state of Connecticut wishes to enable the rapid development of solar energy for electricity, zoning regulations need to provide appropriate height exemptions for photovoltaic panels. Virtually all Connecticut municipalities exempt certain building elements (e.g., cupolas, church spires, antennas, weathervanes) from building height restrictions. This practice should be extended to include solar panels as well. A 2022 review of building height exemption practices in the state's 167 municipalities with zoning found only thirty-nine municipalities, (23% of municipalities with zoning) have exempted solar panels from height restrictions. In many instances, where lot sizes are small or mature trees exist due south of a building, the only viable location for solar panels will be on the roof or slightly elevated above the roof peak.

Overly Restrictive Siting Standards for Photovoltaic Panels

While Public Act 78-314 was designed to encourage solar energy, many municipalities have spent more time restricting than promoting their use. For example, twenty-eight municipalities control where on the roof solar panels can be installed, thirteen municipalities prohibit the placement of solar panels in locations that might be visible by adjacent property, another thirteen municipalities require solar panels placed on the roof to be recessed so as not to overlap the roofline, and five municipalities restrict the placement of solar panels on vertical walls. These aesthetic driven standards do not encourage the use of solar energy and, arguably, have little basis in the protection of public health, safety, and the general welfare. The only exception where these standards may apply are within historic districts or Section 8-2j village districts, where architectural review boards are responsible for evaluating the compatibility of new development on village design and its physical character. However, in these instances it is important to recognize the existence of a multiplicity of photovoltaic systems that can be installed that are compatible with historic district aesthetics.[66]

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[65] The requirement that setback standards be regulated as an administrative duty and not a legislative duty of zoning commissions has been upheld by the Connecticut Supreme and Appellate Court in the Mackenzie decision of 2013. Donna Mackenzie et al. v. Planning and Zoning Commission of the town of Monroe, et al. (AC 34919), released October 15, 2013.

[66] For example, photovoltaic transparent glass is now available in the marketplace that not only provides the direct benefits of passive solar heating to south facing windows but can also convert solar radiation into electrical energy.

Lot Size and Setback Challenges for Solar Access

Connecticut's zoning regulations were not initially established to protect solar access as a means to provide electricity, hot water, or home heating. It is only in the last forty-five years that the value of solar access and solar energy as an important purpose of zoning has emerged. As a result, there are significant conflicts between lot size, setback, building height, and fence height standards and the need to provide unobstructed access to sunlight during the critical winter months when solar energy is most needed. WestCOG has evaluated the impact of tree and building shading originating from neighboring properties to the south of any given solar collector and found that homes located in areas zoned for small lots often have limited access to unobstructed sunlight. Building lots of less than 20,000 square feet in area oriented on a north-south axis have very limited opportunity to install ground-mounted solar panels when mature oak trees of 65 feet or higher in height are located immediately to the south. The analysis addressed shadows cast on December 21st at noon solar time. A similar analysis of shadows cast by trees in Western Connecticut when the sun is 45 degrees on either side of true south (i.e., when the sun is about 11 degrees above the horizon) reveals even longer shadow projections than those at solar noon. Since the altitude of the sun in Western Connecticut is much lower on the horizon in the early morning and late afternoon hours (coincident with the 45-degree azimuth from true south) than the midday sun at solar noon time (i.e., 25 degrees above the horizon), there is a greater likelihood that trees or other obstructions will pose threats to unimpeded solar access.

In contrast, areas zoned for larger lots (i.e., where lots are one acre in area or more) are less affected by off-site shading issues caused by trees or buildings. The slope of the land also affects shadows, creating varying shadow lengths depending upon whether a lot is on a north facing or south facing slope or on flat land. A house located on a north slope of 5 degrees will have shadow lengths that are almost 15% greater than those located on flat land in the Western Connecticut region. Indeed, there are even slight differences in the shadows cast in the northern tier municipalities of the region compared to those along the coastline – simply because of differences in latitude (see Appendix 3). However, minor differences in slope do not have a significant impact on solar access for ground-mounted photovoltaic systems where lots are larger (Table 9).

Table 9: Tree Shading on Small & Large Lots From Adjacent Property: Noon on December 21

Municipality	**Minimum Required Lot Size (Sq. Ft.)**		**% of Lot Depth Shaded by 65 ft. Mature Oak Tree on Smallest Lot: Noon, December 21 (North-South Oriented Lot)**			**% of Lot Depth Shaded by 65 ft. Mature Oak Tree on Largest Lot: Noon, December 21 (North-South Oriented Lot)**		
	Smallest Lot	Largest Lot	5% North Slope	5% South Slope	0% Slope	5% North Slope	5% South Slope	0% Slope
Bethel	10,000	80,000	124%	100%	111%	31%	25%	28%
Bridgewater	87,120	174,240	27%	22%	24%	22%	18%	20%
Brookfield	7,000	100,000	111%	90%	99%	31%	25%	28%
Danbury	8,000	80,000	97%	78%	86%	10%	8%	9%
Darien	8,712	87,120	105%	85%	94%	35%	28%	31%
Greenwich	7,500	174,240	122%	99%	109%	11%	9%	10%
New Canaan	7,500	174,240	153%	124%	137%	31%	25%	27%

Municipality	Minimum Required Lot Size (Sq. Ft.)		% of Lot Depth Shaded by 65 ft. Mature Oak Tree on Smallest Lot: Noon, December 21 (North-South Oriented Lot)			% of Lot Depth Shaded by 65 ft. Mature Oak Tree on Largest Lot: Noon, December 21 (North-South Oriented Lot)		
New Fairfield	43,560	87,120	45%	36%	40%	28%	22%	25%
New Milford	5,000	160,000	125%	101%	112%	20%	16%	17%
Newtown	21,780	130,680	71%	58%	64%	33%	26%	29%
Norwalk	5,000	43,560	153%	124%	137%	53%	43%	47%
Redding	21,780	174,200	71%	57%	63%	27%	21%	24%
Ridgefield	7,500	130,680	103%	83%	92%	24%	19%	21%
Sherman	80,000	160,000	39%	32%	35%	24%	20%	22%
Stamford	5,000	130,680	152%	123%	136%	23%	19%	21%
Weston	87,120	87,120	30%	24%	27%	30%	24%	27%
Westport	5,000	87,120	153%	124%	137%	35%	28%	31%
Wilton	43,560	87,120	53%	43%	47%	35%	28%	31%

Note: This analysis assumes a north-south lot orientation for the longest dimension of small and large lot zones. Lots oriented with their long axis along an east-west axis would have significantly greater restrictions on solar access caused by off-site tree shading.

Building height and fence height regulations can also affect solar access when solar collectors are installed near a neighbor's existing fence or when houses are only separated by side yard setbacks of 5 or 10 feet. In these instances where houses are closely spaced, solar access protections may only be feasible as a rooftop option and only when the orientation of the roof lies within 30 degrees of true south (See Appendices 5 and 6). To determine the relative significance of street, lot, and house orientation on solar access, WestCOG analyzed three development scenarios to determine their impact on solar access; 1) south-facing houses separated by a municipal street; 2) south-facing houses abutting rear lots of equal size and 3) south-facing houses on north-south oriented streets (Figure 3). As can be seen in Appendix 6, it is far more difficult to provide solar access at 9 AM on December 21 than it is at noon on that same day. This underscores the critical role that planning and zoning commissions must play to enable future use of solar energy whether that be on the rooftop, the south wall, or a yard with good solar exposure.

Large lot zones have the advantage of greater separations between houses and trees on adjoining lots, and, for this reason, solar access issues are less severe. Nonetheless, when street and lot orientations are not designed to encourage the use of solar energy, even large lot zones can face significant shading issues especially in the early morning and late afternoon hours during the winter season. Appendix 7 contains the results of the shading impacts created in large lot zones in Western Connecticut.

One of the lessons revealed by this analysis is that on small lots (i.e., 20,000 square feet or less), access to solar energy for electricity, domestic hot water, or space heating purposes will be limited in most cases to south wall or rooftop options depending on the type of solar energy system planned (Figure 4). Solar easements can address the shading challenges of small lots in proximity to off-site obstructions; however, this solution is unlikely to be scalable, especially in existing neighborhoods, where getting neighbors voluntarily to cede an easement may be unlikely. Zoning commissions, which can impose uniform rules on a zone, are authorized to regulate solar access in the public interest, may

be better positioned to address this underappreciated challenge facing the long-term expansion of solar energy in Connecticut and the nation as a whole.[67]

Figure 3: Street and Lot Orientation and Lot Alignment Scenarios

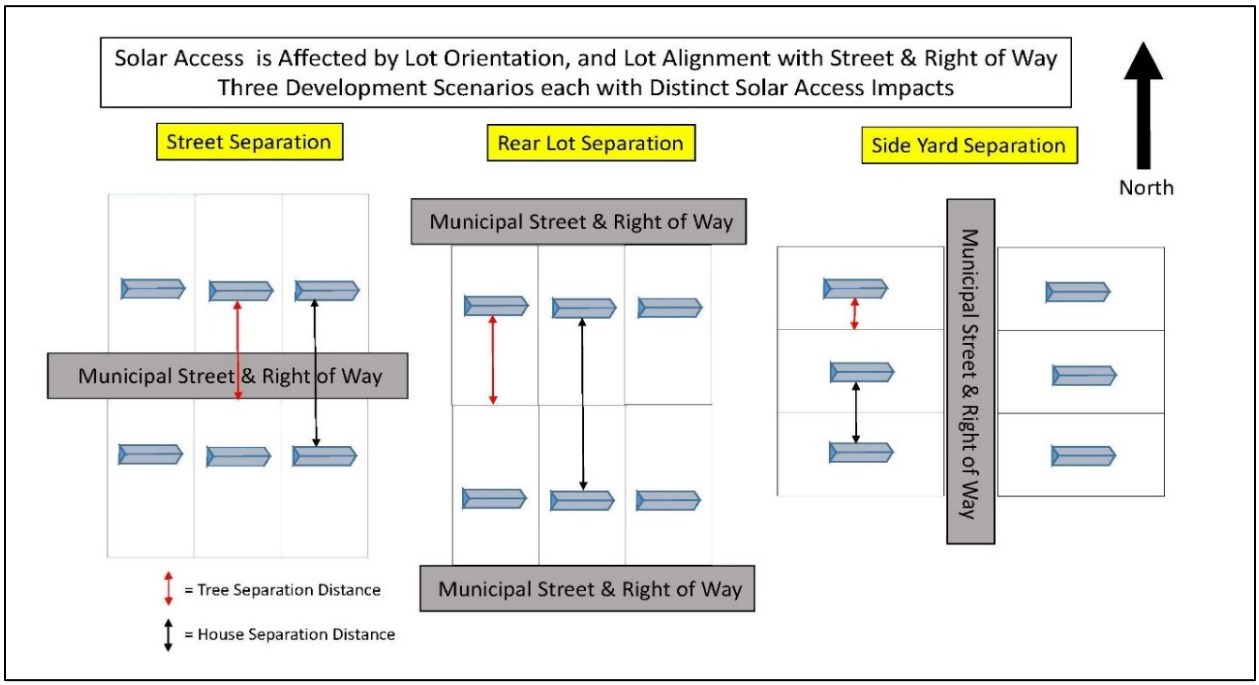
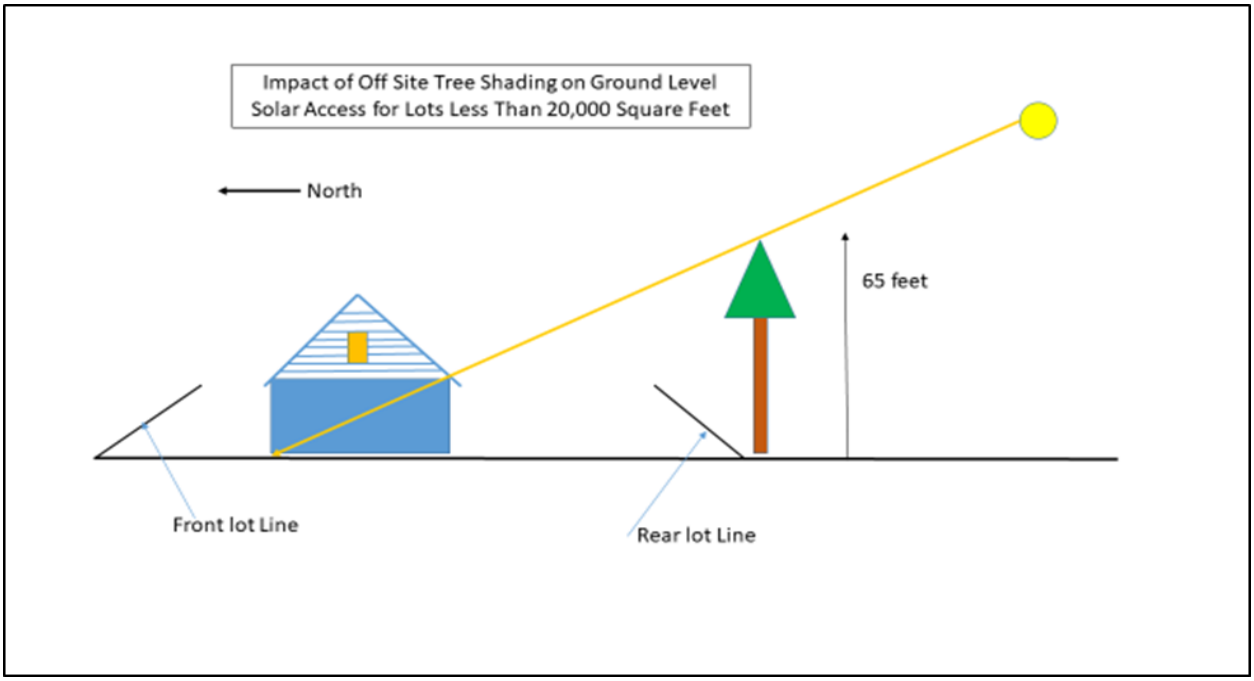


Figure 4: Off-Site Tree Shading on Lots of 20,000 Square Feet



[67] Robert L. Thayer, *Solar Access Control Strategies for Vegetation in Existing and New Developments, Journal of Architectural and Planning Research, Vol. 3, No. 3 (August 1986), pp. 199-217.*

Solar Access Protection Options

Several strategies can address the shading caused by trees. These include 1) the use of solar easements, 2) the adoption of solar envelope zoning for designated areas where solar energy is most favorable (this is equivalent to the concept of variable solar access depending on whether roof, south wall, or ground access is to be protected), 3) solar access permit programs, and the 4) adoption of subdivision performance standards that enable optimum access to sunlight for new developments. A study from Portland, Oregon found that 55% of shading impacting roofs and south walls were caused by trees; only 45% was caused by buildings.[68] The shadows created by trees and other vegetation is influenced by the tree canopy characteristics of the tree, its fall leaf drop time, the mature height of the tree, and the location of the tree with respect to the solar access zone to be protected. Several guidebooks have been prepared that identify the most appropriate tree species most compatible for solar access protection in different bioclimatic zones of the United States.[69] Reducing tree shading to south walls and roof areas is particularly important in the northern states, where the need to maximize winter heat gains from the sun is of far greater relevance than in the southern states (where keeping buildings cool in the summer may be more important). In brief, where annual heating requirements exceed cooling requirements, south wall and south roof solar access should be high priorities.

Due to the wide array of slopes, development densities and tree canopies in Connecticut, there will not be one approach that works for every community or even every building. Solar applications located in existing neighborhoods must deal with existing buildings, trees, and foliage on neighboring properties. In contrast, new developments can be designed to optimize solar access by siting and orientation of buildings for the best exposure to the sun and by planting and trimming trees that complement the solar access needs of buildings within the development.

Solar Access and Trees

The solar access experiences of other states have shown that tree planting and trimming strategies are important components of a sound solar access policy. Trees are not only the most common constraint to the protection of solar access; they are also the most likely reason that solar easements or solar access protections are needed. However, not all trees can be trimmed in existing neighborhoods, especially those on a neighbor's property. In these instances, a solar access policy must inevitably "grandfather" existing shadow casting trees found on adjoining properties from municipal solar access controls.

Tree maintenance for solar access purposes must be accomplished with an understanding of the role of trees in reducing energy use and their potential compatibility with solar design (trees cool buildings in the summer and act as a windbreak in the winter, reducing heat loads), as well as their positive impacts on aesthetics and property values, and their valuable ecological functions. Other benefits of trees include 1) mitigating climate change through carbon sequestration and its impacts through reductions in heat islands and droughts, 2) preventing erosion and water pollution from stormwater runoff, 3) reducing air pollution, and 4) providing habitat for terrestrial and avian species. Trees provide a range of ecosystem services and must be protected where possible. Where trees interfere with solar access, tree trimming should take precedence over removal (see table 8). To the extent that

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[68] Ibid p. 200.

[69] Michael Douglas Fotheringham, Guide to Residential Landscape Development for Logan, Utah, University of Utah, 1978, pp. 86-96; Gary O. Robinette, Plants, People, and Environmental Quality: a Study of Plants and their Environmental Functions, U.S. Department of the Interior, Washington DC., 1972, pp. 67-95.

photovoltaic systems are mounted on rooftops of new buildings, many of the shading concerns posed by trees can be overcome.

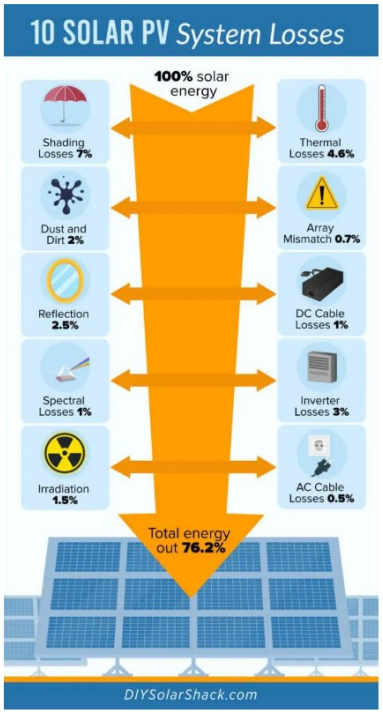
It is important to recognize that even homeowners who do not use solar energy to generate electricity from photovoltaic panels benefit from access to sunlight for heating in the northern climate. A study conducted by Gregory McPherson modeled the energy impacts of a completely shaded 1,539 square foot house in Madison, Wisconsin (a climate zone comparable to New England) and found that heating costs were 28% higher than the same house when it had full solar access. The lesson here is simple: all houses in Connecticut benefit from solar access for home heating even if photovoltaic systems are not installed on the dwelling or passive design concepts are not explicitly incorporated into the building. McPherson's worst case shading scenario was found to be associated with evergreen trees since they do not drop their leaves in the winter months.[70]

Ideally, as previously discussed, trees should be located outside of 45-degree azimuths on either side of true south since this is the sky space most critical for generating solar energy during the winter months of New England. In new development, trees should be selected that either are placed outside of the solar sky space or have maximum heights at maturity that fall below the altitude of the sun on December 21st between the hours of 8 AM and 4 PM.

Solar Access Protection as a Foundational Principle

How much solar energy should be protected to make solar energy systems viable – regardless of whether the application is photovoltaic panels, solar thermal domestic hot water, and/or passive solar for home heating? Forty years of research has made clear that unobstructed to solar access is required for at least six to eight hours per day to make financial investments in these technologies cost-effective. This underscores the critical need for zoning commissions to determine that at least 90% of the maximum daily solar access be unobstructed by the building height and lot setback standards adopted within their zoning regulations. To achieve that objective beyond the theoretical analysis contained in Table 9, each municipality should consider undertaking a shading analysis for each residential, commercial, and industrial zone to determine if the maximum building heights allowed or the minimum setback standards adversely impact the ability to control solar access to south-facing roofs and walls and ground to the south of the building. Without such an analysis, there is no guarantee that existing land use controls protect solar access.

Figure 5: Solar PV Sysrtem Losses



Similarly, state and utility investments in large scale solar photovoltaic systems must consider whether solar access can

[70] McPherson, E. Gregory, Lee P. Herrington and Gordon M. Heisler, Impacts of Vegetation on Residential Heating and Cooling, Energy and Buildings, Vol. 2. 1988, pp. 41-51.

be protected before major fiscal investments are made.[71] As this report has shown, some of the concerns with potential shading of solar collectors are influenced by zoning regulation standards for maximum building heights, while others are associated with tree shading that generally falls outside of the authority of zoning commissions.[72] However, zoning commissions can influence the impacts of shading on future development by landscaping standards established for land subdivisions, planned developments, and for buffer zones between incompatible land uses.

Non-Shading Factors Influencing Panel Performance

Shading by trees and buildings is not the only impediment to the maximum use of photovoltaic panels for electrical generation. Other factors that affect a panel's ability provide its full wattage rating include 1) line losses associated with conduit connecting the panels to the point of use, 2) the percentage of cloudy days commonly associated with any given geographic area of the United States, 3) inverter power losses from converting direct current (DC) to alternating current (AC), 4) whether the panels are connected in parallel or in series, 5) whether the panels have micro-inverters that limit the impact of shadows to the shaded area, 6) the amount of dirt, dust, ice, or snow covering the panel, 7) solar reflection caused by panel tilt angles less than perpendicular to the sun, 8) reduced energy performance caused by excessive heat load on the backside of the panels, 9) spectral losses attributable to the limited wave lengths captured by any given solar panel, and 10) the age of the panel since energy performance deteriorates slowly over the rated life of some panels. These ten factors can reduce solar photovoltaic panel performance by 20% or more. If the cumulative impact of these factors on panel output are substantial, the economics of solar energy can be adversely impacted. The result of significant shading obstructions will be increased costs per delivered kilowatt hour of energy, longer payback times for the initial investment, and a reduced ability for property owners to meet their electrical needs themselves. Figure 5 above provides an example of the energy losses that must be factored into any analysis of the performance of photovoltaic systems. Note that the figure does not specifically address snow or ice as limiting factors to panel performance nor does it address the loss of wattage over time due to the aging process. With those caveats, Figure 5 underscores the importance of designing any photovoltaic installation to account for these losses in the overall planning of the rated capacity of the installed system. A rule of thumb is that solar energy required for any given photovoltaic system must be at least 1.4 times the annual energy requirements of the dwelling unit to account for these energy losses (i.e., 100% of solar needs divided by 76% performance due to wattage losses = 1.4 factor required to meet electrical load).

Solar Easements

When passive solar or photovoltaic installations take place on houses within an existing neighborhood, homeowners must also consider the potential need to negotiate solar easements with their neighbors. Solar easements are designed to limit the planting of new trees or to require neighbors to trim trees that may block sunlight to solar collectors. While Connecticut has not established a standard solar

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[71] It is instructive to note that several grid-connected solar projects in Connecticut have had significant shading issues attributable to trees. For example, see Connecticut Siting Council Docket 1348 for the West Farms Mall in West Hartford that included the removal of 39 trees that would have shaded PV panels installed on the parking lot canopies. Similarly, Docket 1310A for the grid-connected solar project in Brooklyn, CT would require clear cutting 19 acres of forest simply to eliminate shading issues.

[72] However, street trees located in the street right of way fall within the authority of local governments and can be addressed within a municipal solar access ordinance.

easement, Connecticut law does not prohibit solar easements.[73] A solar easement requires an agreement between the owner of the solar energy system and the abutting property owners. The agreement must identify the solar access protection zone and how that impacts the neighbor's property rights with respect to trees, buildings, fences, and other shadow casting objects. Such easements must be recorded on the deeds of each impacted property and must include the conditions upon which actions can be taken by each party when shading issues emerge or the solar energy system becomes nonfunctioning due to retirement or becomes inoperable for a specified period of time. Since the abutting property owners must relinquish certain property rights for the easement to function, there will be costs incurred for this form of protection to succeed. It may be challenging to persuade existing property owners to cede rights in this way. A more workable approach may be to attach easements as a condition of sale to units in new developments – whether they be single-family residential subdivisions, condominiums, or planned unit developments – especially when the development has been designed to maximize solar potential and thus the interest that future property owners will have on protecting solar access. Solar easements applied in existing developments will be harder to negotiate, will likely involve financial compensation to the impacted property owner and will require explicit procedures for addressing and remedying violations of the easement.

Solar-conscious Land Planning

With the array of topographic, density and tree canopy conditions that exist across the state, there is no one strategy that will work across all 169 municipalities. Depending upon the presence of existing trees, housing densities, and whether solar is to be installed in new developments or as a retrofit option in an existing neighborhood, will influence the solar access protection strategies that work best (table 10). Beyond the four solar access best practices currently used by zoning commissions in Connecticut, there are other legal measures to protect sunlight relevant to homeowners.

Five basic solar access protection strategies are available that each provide varying levels of protection including 1) solar easements, 2) a solar access permit program, 3) solar subdivision or planned development solar protections, 4) solar envelope or solar setback protections (whether based on rooftop, wall, or ground-level protection) and 5) as a last resort, the use of public or private nuisance law (i.e., through litigation). Some or all of these five strategies will require state enabling legislation to ensure consistent guidance on how these options should be implemented as discussed below.[74]

[73] Kevin McCarthy, Protection of Solar Access, Report No. 2007-R-0498, Office of Legislative Research, August 27, 2007. Accessed June 16, 2022.

[74] These five strategies assume that full solar access protection and the prior appropriation strategies discussed supra are not viable long term strategies. Specifically the administrative burdens created by the prior appropriation strategy and the unreasonable solar protection standards associated with full solar access protection explain why they are not included in the five strategies discussed here.

Table 10: Factors Influencing Control of Vegetation Impacting Solar Access

	Private Nuisance	Public Nuisance	Private Solar Easement	Solar Setback Fence	Solar Envelope Overlay	Subdivision Performance Standards	Solar Access Permit
Existing vegetation	●	●	●	○	○	○	
New Vegetation	●	●	●	●	●	●	●
Existing Neighborhood	●	●	●	●	○		●
New Neighborhood	○	○		●	●	●	●
High Density Development			○	●	●	●	○
Low Density Development	●	●	●	●	○	●	●

● = Optimal Application of Solar Access Protections
○ = Positive Application of Solar Access Protections
Blank = Not a Likely Application of Solar Access Protections
Source: WestCOG staff work adapted from Robert Thayer in "Solar Access Control Strategies for Vegetation in Existing and New Development," Journal of Architectural and Planning Research, Vol. 3, No. 3 August 198, pp. 199-217.

States with Alternative Protections for Solar Access

There are no state level protections for solar access in Connecticut; however, state-level protections do exist in California, Massachusetts, New Mexico, Wisconsin, and Wyoming. These five states have developed permitting procedures to protect solar access that can serve as potential models for state level protections in Connecticut.[75] Local governments have also developed programs to protect solar access; exemplars include the Village of Prairie du Sac Wisconsin, Boulder Colorado, Los Alamos County New Mexico, Laramie, Wyoming, and Santa Barbara, California.

Massachusetts has long been a leader in solar access protections. Its law concerning the protection of solar access through zoning is perhaps the most relevant to Connecticut of all solar access protection strategies in the United States. Under Chapter 40A, Section 9B, Solar Access of Massachusetts state law, zoning commissions may establish special permits to protect solar access. The law states:

> *"Such ordinances or by-laws may provide that such solar access permits would create an easement to sunlight over neighboring property. Such ordinances or by-laws may also specify what constitutes an impermissible interference with the right to direct sunlight granted by a solar access permit and how to regulate growing vegetation that may interfere with such right. Such ordinances or by-laws may further provide standards for the issuance of solar access permits balancing the need of solar energy systems for direct sunlight with the right of neighboring property owners to the reasonable use of their property within other zoning restrictions. Such ordinances or by-laws may also provide a*

[75] Protecting Solar Access. San Francisco Department of the Environment. December 2012. Accessed: June 13, 2022

process for issuance of solar access permits including, but not limited to, notification of affected neighboring property owners, opportunity for a hearing, appeal process and recordation of such permits on burdened and benefited property deeds. Such ordinances or by-laws may further provide for establishment of a solar map identifying all local properties burdened or benefited by solar access permits. Such ordinances or by-laws may also require the examination of such solar maps by the appropriate official prior to the issuance of a building permit."[76]

Solar access issues may not be perceived as important when only a limited number of households have installed photovoltaic systems or built or retrofitted their homes for passive solar energy. However, today there are over 46,000 photovoltaic systems on residential, commercial, and industrial properties in Connecticut.[77] While this is small in relation to the state's 1.4 million households, these property owners have spent over $1 billion on the installation of photovoltaic panels during the last twenty years. Investments of this magnitude underscore the importance of creating robust solar access protections. These concerns are greatest in some of the state's most densely developed municipalities. Small lots create greater potential for solar shading due to the relatively shorter distances between abutting property owners, and this geographic constraint will become more apparent as the demand for solar energy continues to expand. Rather than deal with solar access through a crisis management approach, state legislators should consider a pro-active system of solar access protections to complement the significant fiscal investments made by homeowners, businesses, and utilities in Connecticut.

The Right to Sunlight in America: A Status Report

Striking as it may be, there is no right to sunlight in the United States. The leading case on the subject is Fontainebleau Hotel Corp. v. Forty-Five Twenty-Five, Inc. (1959), where the Florida District Court of Appeals declared a landowner has no legal right to the free flow of light and air across the adjoining land of his neighbor.[78] While this Florida court decision is not binding on other states' courts, it remains one of the cases most cited by solar industry experts concerned with the nation's massive investments in solar energy. In Connecticut, the legislature eliminated any right to light and air by prescription in 1875 and as a result, there is very little right to solar access except where local governments have established some zoning provisions as mentioned above.[79] Investments in solar energy carry great risks when nearly all zoning regulations in Connecticut enable neighbors to obstruct sunlight onto adjoining properties.[80]

The Geography and Demographics of Solar Energy

WestCOG analyzed the location of all the photovoltaic systems installed in Connecticut under the Certified Renewable Portfolio Standard. As of June 15, 2022, the database contained 46,480 behind the meter installations all of which have been registered with the Public Utilities Regulatory Authority and the Independent System Operator (ISO) of New England. While there are photovoltaic systems that have not been enrolled in this program, the Renewable Portfolio database represents most of the

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[76] Massachusetts General Law Part 1, Title VII, Chapter 40A, Section 9B, Solar Access.
[77] WestCOG analysis of the Public Utilities Regulatory Authority Renewable Energy Portfolio database, August, 2022.
[78] Fontainbleau Hotel corp. v. Forty-five Twenty-Five, Inc., 114 So. 2d 357, 359 (Fla. Dist. Ct. App. 1959).
[79] Kevin E. McCarthy, Principal Analyst, Solar Access Protection, Office of legislative Research Report No. 2007-R-0498, August 27, 2007.
[80] Alan S. Miller, Gail Boyer Hayes, Grant P. Thompson, Solar Access and Land Use: State of the Law, 1977, Environmental Law Institute.

residential installations in Connecticut. This program creates renewable energy credits, a valuable commodity for the state's electric utilities in complying with the state's Renewable Portfolio Standards and in becoming more sustainable. The state's non-municipal electric utilities comply with this program by purchasing Renewable Energy Certificates (REC):

> *"A REC is a tradable certificate that represents all the positive environmental attributes of electricity generated from a residential solar electric system, separate from the actual electricity itself. Each time a clean energy system generates 1,000 kilowatt hours of electricity, a REC is metered that can be sold or traded as a transferable commodity. When a buyer makes an environmental claim based on a REC, the REC is considered used."*[81]

There has been a rapid growth of photovoltaic systems under the Renewable Portfolio Standard enabled by Public Act 98-28, An Act Concerning Electric Restructuring and further strengthened in 2013 with the enabling authority provided by Public Act 13-303, An Act Concerning Connecticut's Clean Energy Goals.[82] A total of 772 megawatts of behind the meter capacity has been created in the last twelve years under the certified Renewable Portfolio Standard (Figure 6). This capacity, being generated at the site of consumption, reduces demand for off-site electricity generation. As this report has emphasized, residential photovoltaic systems (behind the meter) require energy audits and conservation measures as part of the approval process. In contrast, no energy audit or energy conservation measures are associated with grid-connected solar arrays since the latter installations feed electricity directly into the grid without any direct connection to any given home or commercial or industrial facility. Ideally, Connecticut should prioritize the installation of behind the meter photovoltaic systems over grid-connected systems. Past trends reveal market forces are pushing behind the meter applications faster than grid-connected solar arrays – an encouraging development for energy conservation (Figure 7).

The geographic distribution of behind the meter photovoltaic systems is not evenly distributed across the state. This may reflect heterogeneity in income levels, housing types, aesthetic preferences, and solar access limitations. A WestCOG analysis of the 46,480 behind the meter installations reveals the highest density of installations on the I-91 corridor, the I-84/691 corridor from Waterbury to Middletown and Vernon, and the I-95/Route 15 corridor between Bridgeport and New Haven. Smaller hotspots are also visible in the Danbury, Norwalk, and New London areas. The size of the dots represents the kilowatt capacity of the system. Larger dots are generally associated with commercial and industrial installations (Figure 8).

[81] Clean Energy Finance Investment Authority, Solar Home Renewable Energy Credits (SHRECs) Growing Connecticut's Solar Market, 2015. Accessed November 7, 2022.
[82] Connecticut General Assembly, Public Act 13-303, An Concerning Connecticut's Clean Energy Goals, Approved June 5, 2013

Figure 6: Megawatts of Photovoltaic Electricity Approved Behind the Meter: 2010-June 15, 2022

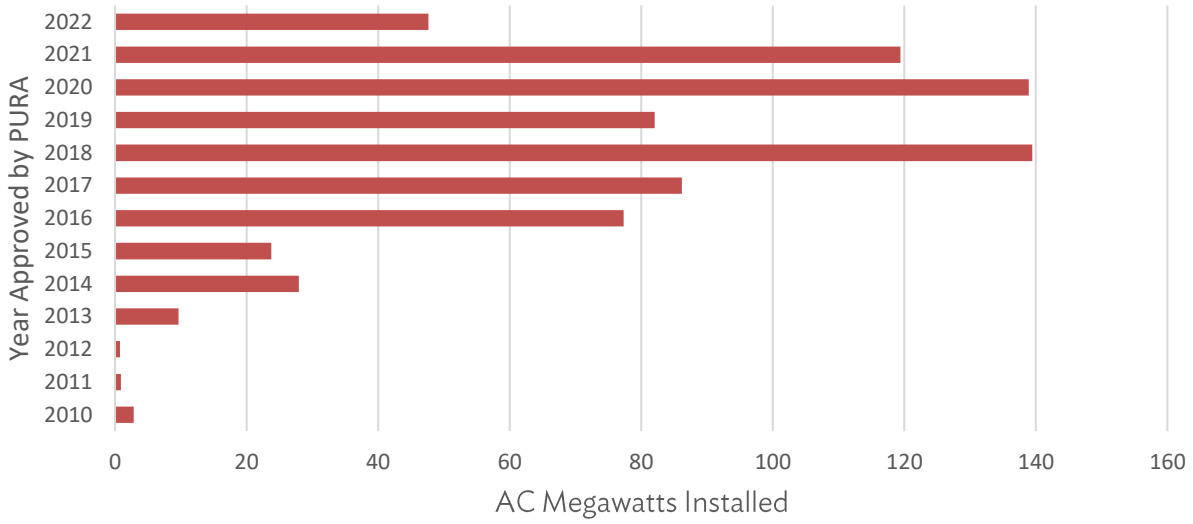
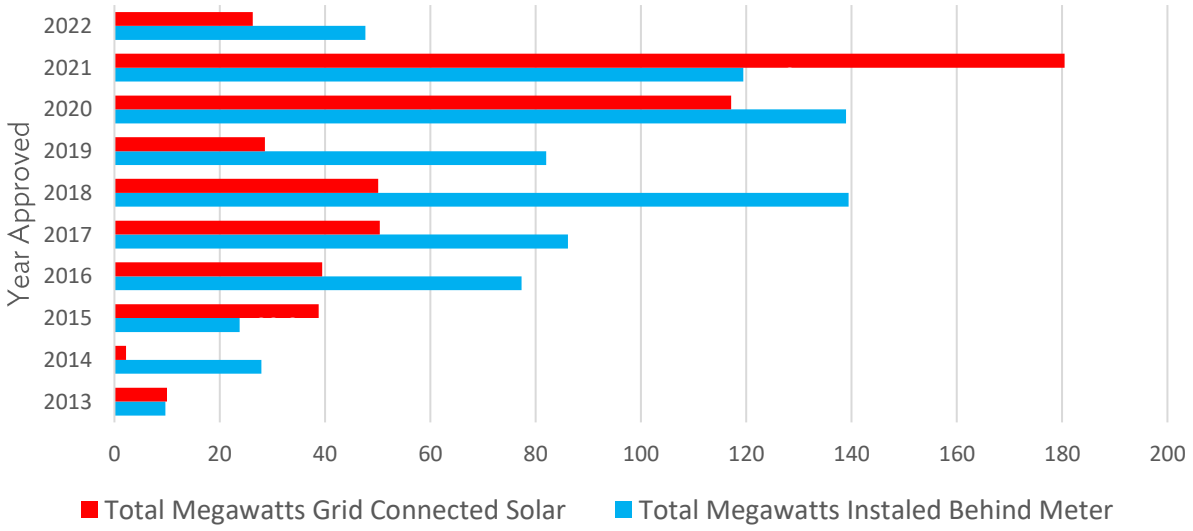


Figure 7: Comparison of Behind the Meter and Grid-connected Photovoltaic Systems Based on Megawatts of Approved Power: 2013 to June 15, 2022



Source: Public Utility Regulatory Renewable Energy Portfolio Database and Grid-connected Solar Docket Decisions, June 2022

Figure 8: Photovoltaic Installations in Connecticut, June 15, 2022, Derived from PURA Renewable Portfolio Database

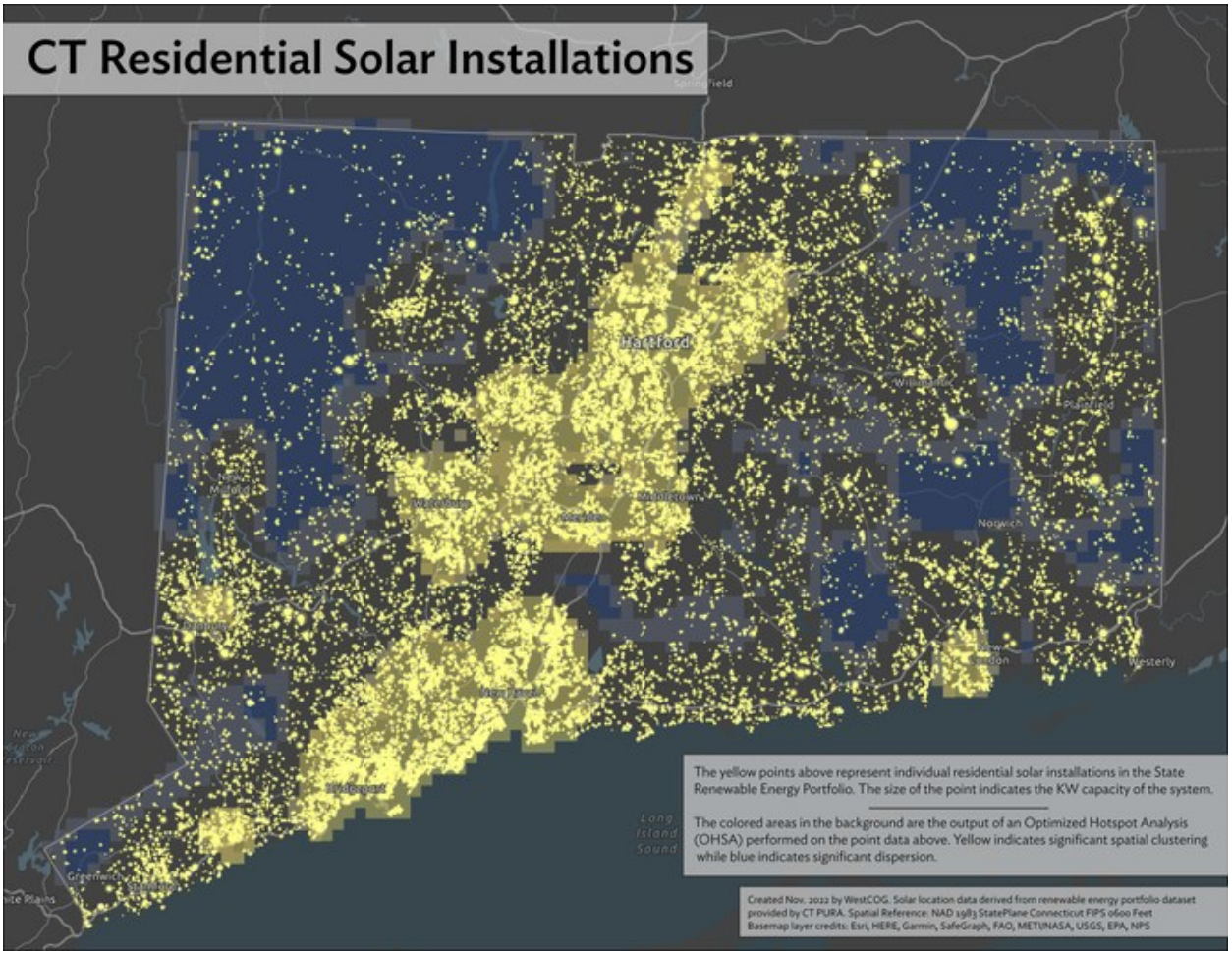
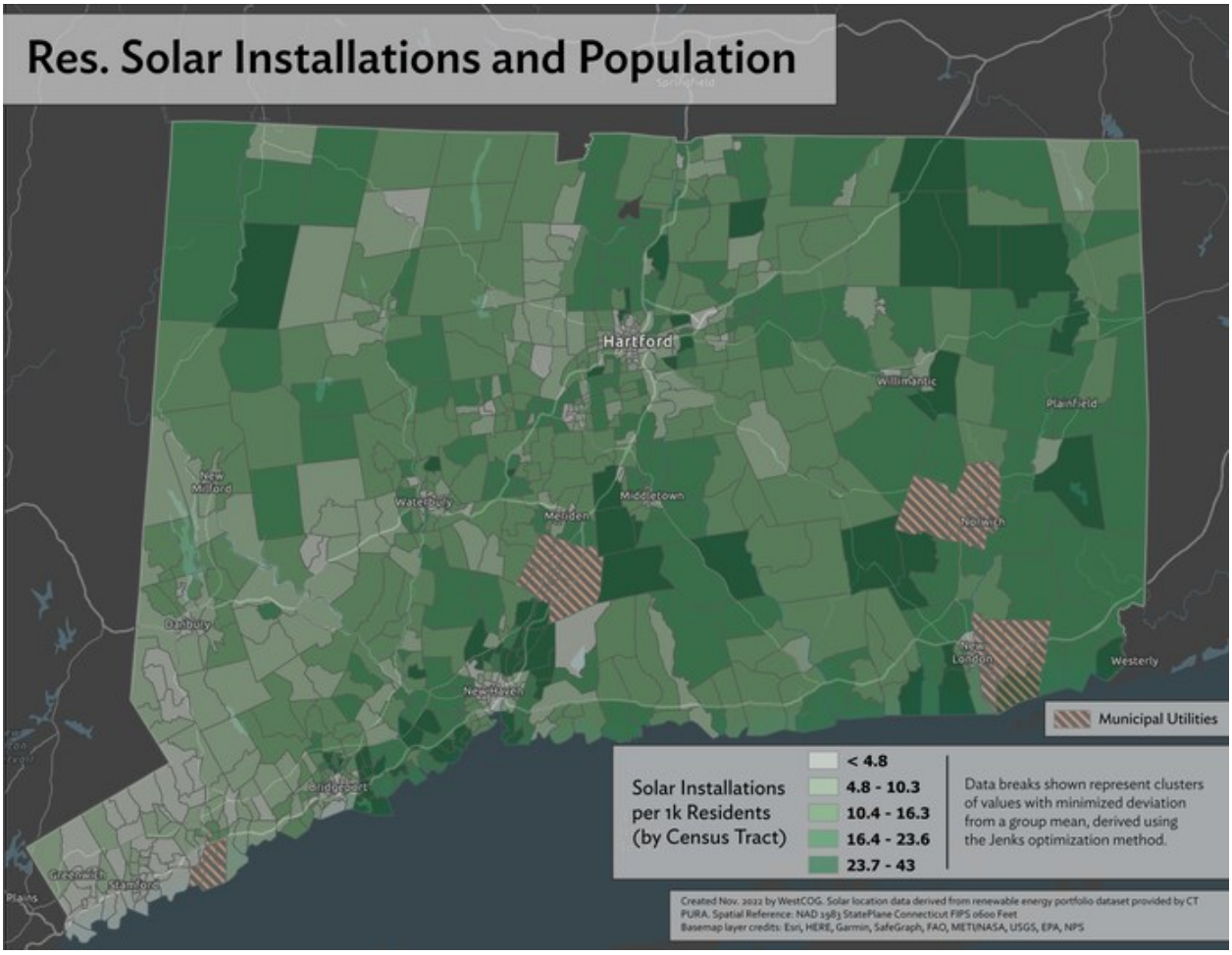


Table 11: Photovoltaic Solar Installations Installed in Connecticut under the Renewable Portfolio Standard: As of June 15, 2022

Planning Region	2020 Population	Photovoltaic Systems Installed	Percent of Photovoltaic Systems	Total Megawatt Capacity	Percent of Megawatt Capacity	Photovoltaic Systems Per 1,000 Residents
Capitol Region	976,248	12,862	27.7%	242	31.3%	13.17
Greater Bridgeport	325,778	4,261	9.2%	50	6.5%	13.08
Lower CT River Valley	174,225	3,153	6.8%	46	5.9%	18.10
Naugatuck Valley	450,376	6,097	13.1%	89	11.6%	13.54
Northeastern	95,348	1,845	4.0%	57	7.4%	19.35
Northwest Hills	112,503	1,643	3.5%	36	4.7%	14.60
South Central	570,487	8,774	18.9%	111	14.4%	15.38
Southeastern	280,430	4,033	8.7%	80	10.3%	14.38
Western CT	620,549	3,812	8.2%	61	8.0%	6.14
Grand Total	**3,605,944**	**46,480**	**100.0%**	**772**	**100.0%**	**12.89**

Figure 9: Photovoltaic Systems Installed per Thousand Residents: 2022



As can be seen in Table 11, the greatest concentration of behind the meter photovoltaic systems can be found in the Capital Region, representing 27.7% of all the systems participating in the state's Renewable Portfolio Standard. However, normalizing the photovoltaic installations based on population densities, the most frequent locations where these systems have been installed are, in rank order, the Northeastern, Lower Connecticut River Valley, South Central, and the Northwest Hills regions. Similarly, Figure 9 identifies the census tracts in Connecticut where photovoltaic systems have the greatest level of market penetration.

The Western Connecticut region has the fewest photovoltaic installations per capita. Higher household incomes in the region may account in part for the relatively low adoption rate of photovoltaic panels. However, the most important points revealed in table 11 and Figure 9 are the extremely low adoption rates for photovoltaic panels across the state. On average only 1.3% of all residents (i.e., 12.89 persons per thousand Connecticut residents) live in a house with photovoltaic panels. That said, the rate at which photovoltaic systems are being installed is expected to accelerate in the next ten years. A major reason is the improving economics of solar systems, with higher panel capacities and lower costs per watt, decreasing the space needed for panels and increasing the return on investment. (Chart 2). The growth of Power Purchase Agreements (PPA) has also helped expand the solar energy market since homeowners need not own solar panels on their roof to get the

economic benefits of this technology. Finally, the 30% tax credit enabled by the 2022 Inflation Reduction Act will spur additional solar photovoltaic market growth for the next ten years (Figure 10).[83]

Despite these important developments, questions remain about the accessibility of solar energy for many households, including those whose properties do not lend themselves to solar and for those who do not have the ability to install solar (e.g., renters and those of limited financial means). A recent Lawrence Berkley Laboratory analysis of the users of photovoltaic systems found that a broad range of income groups have installed solar panels across the United States.[84] If Connecticut is to maximize the generation of renewable energy, households that cannot install their own solar energy systems will need to be part of the program. One strategy to do this should be expansion of the community solar program, where virtual net metering substitutes for rooftop or ground-mounted solar.

If Connecticut intends to achieve its goal of 100% renewable energy by 2040, the economics of solar energy must continue to improve, barriers to their use must fall, and households at all income levels must have financial and technical means to facilitate their transition to solar power.

New Zoning Enabling Authorities for Solar Energy

Effective June 10, 2021. Connecticut's zoning commissions are authorized to require the use of energy efficient patterns of development, the use of distributed or freestanding solar, wind and other renewable forms of energy, combined heat and power and energy conservation. This is a new and significant expansion of the authority of zoning commissions over energy efficiency and renewable energy, beyond the provisions for incentives that had previously existed (and continue to exist).

Typically, incentives used by zoning commissions in Connecticut include 1) density bonuses, 2) reduced infrastructure requirements for roads, sidewalks and other utilities when consistent with recognized performance standards; 3) simplified permitting procedures replacing special permits with conditioned zoning permits; 4) waiver of setback, height limits, building coverage standards, and floor area ratios for specific types of solar energy equipment; 5) special floating zones that eliminate traditional zoning standards for lot size, setbacks and other limitations on land development to more effectively create solar energy zones regulated under performance zoning standards and 6) creation of renewable energy use zones designed to encourage shared community solar energy systems and large-scale applications of solar energy for community use. These are not new ideas; all these concepts have been adopted in one or more Connecticut municipalities for other purposes during the last forty-five years. What is needed is a handbook of these best practices and lessons learned that can be applied to renewable energy and made available to all 169 municipalities in the state. Appendix 1 provides six solar and energy conservation strategies enabled by Public Act 21-29.

While growth in solar energy should be driven through land use incentives, some solar energy objectives may require action beyond incentives if the state is to meet its goal of 100% renewable energy by 2040, improve energy resilience, and reduce household energy costs. Without unobstructed access to sunlight guaranteed by local zoning regulations, the development of solar energy as a tool for

[83] Homeowner's Guide to the Federal Tax Credit for Solar Photovoltaics, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. 2022. Accessed November 16, 2022.
[84] Barbose, Galen, Sydney Forrester, Eric O'Shaughnessy, and Naïm Darghouth, Residential Solar-Adopter Income and Demographic Trends: 2022 Update, Electricity Markets & Policy Group, Lawrence Berkeley Lab, Berkeley, CA, March 2022, p. 11.

distributed or standalone electrical generation could literally be cast into shadow – or become mired in litigation as neighbors argue about their disparate interests concerning the right to sunlight.

To avert this, two land use regulations are needed: one; requiring developers to include solar easements as part of planned residential subdivisions so prospective homeowners are not burdened with the legal and financial challenges of negotiating such agreements on their own. Secondly, the Connecticut General Assembly should explicitly authorize zoning commissions to administer solar access permits for existing developments where long-term access to sunlight could be obstructed by trees and other vegetation. This latter strategy would benefit from adopting a version of the Massachusetts solar access permitting law. Furthermore, solar access will be meaningless if solar design is not a fundamental zoning requirement. Specifically, solar access is premised on the proper orientation of buildings to make maximum use of solar energy for heating and/or electricity. Solar design must be required for zoning permits and projects requiring site plan review.

A lack of protection for solar access is not the only issue that may limit to a more widespread use of photovoltaic systems. Public Act 21-29 empowers zoning commissions to develop solar regulations. While this may lead to policy innovation and peer learning, it also may presume a level of technical expertise with conservation, energy efficiency, solar access, trigonometry, and solar easement practices that may not exist on volunteer commissions. If the state remains committed to achieving 100% de-carbonization of the electric grid by 2040, the Connecticut legislature will need to establish statewide standards for acceptable levels of solar access. Furthermore, the Office of Policy Management should be directed to provide technical support to address specific measures required to achieve solar access goals across municipalities with varying densities, varying latitudes, and varying levels of professional expertise in solar access issues.

While PA 21-29 provides a range of land use opportunities to promote renewable energy, the most cost-effective options continue to be photovoltaic systems and passive solar design concepts associated with solar orientation, solar access, earth-sheltered housing, energy-conscious landscaping and the energy efficiencies associated with higher density and clustered development. In the case of solar orientation and solar access, these two renewable energy concepts are not only technically feasible; they are cost-effective techniques to enable the future installation of photovoltaic panels and the use of solar-aided home heating from passive solar designed or retrofitted housing. These two strategies are discussed below from a life cycle perspective.

The Economics of Solar Energy

To appreciate the benefits of new zoning authority under Public Act 21-29, it is necessary to understand the economics of solar energy to ensure that regulatory strategies are not inconsistent with housing affordability. The cost of a home to a household do not end with a mortgage or rental payment, and discussions about housing affordability must go beyond construction, financing, and sale expenses to include lifecycle costs. These include the energy needed to heat and cool a home, provide hot water, and operate appliances and lighting, as well as maintenance associated with HVAC and electrical systems. Properties that are developed with proper solar design and that use solar energy systems can dramatically lower energy demands and produce enough power to cover their own needs, relieving households of the high, unpredictable, and never-ending costs associated with grid-sourced electrical power and fossil fuels.

By integrating lifecycle costs for home heating and cooling, hot water, and electricity into regulation, solar design will be built into new developments during construction – when it is relatively inexpensive to do so – rather than left up to future property owners to retrofit efficiency later – when it is expensive if not impossible to do so. If the economics of solar energy are favorable to the homeowner or developer over 1) the lifecycle of a home mortgage or 2) over a five-year period typically used in the business world to determine a short-term return on investment, then there is a strong environmental *and economic* basis for a zoning commission to require the use of solar energy concepts that fall within the purview of zoning commissions in Connecticut. Given the lifespan of buildings, investments made in efficiency tend to be durable – photovoltaic systems are expected to last 50 years and buildings often outlast 100 years – so the net benefits of requirements for efficiency and distributed generation will significantly exceed even the initial payback period.

The Economics of Various Types of Solar Energy Applications

There are six basic types of solar energy applications that fall within the purview of zoning commissions under the authority granted under PA 21-29. Under this law, zoning commissions may, at their discretion, encourage, incentivize, or require 1) solar photovoltaic systems, 2) solar domestic hot water systems, 3) solar design (passive solar) concepts including building and roof design and orientation and fenestration, thermal mass based on optimum southerly oriented fenestration – all to create solar ready dwellings 4) solar access protections, 5) energy conservation landscaping including earth sheltering and summer shade trees and winter windbreaks and 6) embodied energy concepts associated with the selection of materials, equipment and other resources that have the least overall energy impacts to the environment and over the life of the proposed development. These six concepts and the specific factors influencing the viability of solar energy and energy conservation are presented in Appendix 1.

As can be seen in Appendix 1, many of the concepts that should be required are simply changes to zoning regulations that require good solar access and solar orientation at the outset of a planned development. Without community design standards that enable the use of solar energy through adequate solar access and orientation it will be impossible to cost effectively promote or require solar energy for electrical generation, domestic hot water use, or for the construction or retrofit of homes to maximize the use of passive solar energy for home heating.

Economics: The Payback Analysis

The decision to require, incentivize, or encourage solar design through land use regulations must consider the economics of each solar energy application before instituting policies or regulations for their use. To address this issue, WestCOG has evaluated the economics and payback times for the purchase of a photovoltaic system by the average household living in each of the eighteen municipalities of Western Connecticut (see economic payback discussion below). Similarly, the economics of passive solar design concepts, as influenced exclusively by land use regulations (i.e., solar access, solar orientation) have been evaluated in comparison to other northern latitude cities that benefit from the wintertime solar heat gains.

Photovoltaic Economics

The twelve basic factors required to determine the economic analysis of installing photovoltaic panels in the region's eighteen municipalities are as follows. The detailed analysis supporting the economic analysis is contained in Appendix 11.

Twelve Basic Factors for PV Economic Analysis

1. Annual average electricity use by household by municipality
2. Annual Average Direct Normal Incident Irradiation (watts/m²)
3. Annual Electricity Use Adjustment for electrical losses through shading, etc. (1.4 X item 1)
4. Solar Panels required to meet adjusted annual electrical use
5. Selection of solar panel wattage rating to meet demand
6. Installation cost for Solar Panels (based on NREL cost study)
7. Current cost of electricity for residential Customers in Connecticut
8. Federal Tax credits for Solar Photovoltaic systems
9. Eversource/United Illuminating Solar Incentives
10. Reductions in electrical demand over baseline use through conservation measures
11. Calculation of total cost for photovoltaic system
12. Calculation of Payback time in years

The high cost for Connecticut electricity is a strong incentive for homeowners tied to major utility rates to switch to solar. As previously mentioned, Connecticut has the highest cost for electricity in the continental United States at 26.48 cents per kilowatt hour for residential users as of February 2022 (see Chart 1 in the Appendix). During the period 2001 to 2022 the price of residential electricity purchased from Eversource (including its predecessor organization, Northeast Utilities) increased 147% (from 10.7 cents a kilowatt hour to 26.48 cents – see Chart 1).

However, electricity costs are not the only variable that affects the economics of photovoltaic systems. Connecticut is not blessed with the same level of annual direct normal irradiation as states in the southwest. For example, the average municipality in western Connecticut receives about 40% less annual direct normal irradiation (KWh/m²) than that experienced in Santa Fe, New Mexico.[85] The result is that more solar panels are required in Connecticut compared to Santa Fe to achieve a comparable electrical delivery performance. Yet the greater cloud cover and more limited annual solar insolation received in Connecticut has recently become less relevant to the economics of photovoltaics systems as manufacturing and installation costs for solar photovoltaic systems have rapidly declined. During the last ten years the cost to install residential solar photovoltaic systems in the United States, as measured on a delivered watt basis, has dropped from $7.83 in 2011 to $2.65 in 2021 for a 22-panel residential solar array.[86] Major factors for these reduced costs are attributable to the decrease in the manufacturing costs for solar panels over the last fifty years (and to the increase in generation per panel) (see Chart 2). Between 1975 and 2020, the equipment cost per watt for solar panels declined from about $105 a watt to 30 cents a watt (see Chart 2). As a result of these

[85] Global Solar Atlas reports for Western Connecticut municipalities compared to Santa Fe, Mexico. Accessed May 20. 2022: https://globalsolaratlas.info/map?s=35.68761,-105.938457&m=site&c=35.687697,-105.938416,11

[86] David Feldman, Vignesh Ramasamy, Ran Fu, Ashwin Ramdas, Jal Desai, and Robert Margolis, U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020, January 2021, p. 61.

efficiencies, other costs such as those associated with government permitting and approvals now represent a greater share of the cost for photovoltaic installations than in previous years.[87]

Another important factor that has a long-term favorability rating for photovoltaic systems are steadily improving efficiencies in converting sunlight to electricity over the last forty-five years. In the case of crystalline silica cells, efficiencies have increased from 13.9% to 24.4% between 1977 and 2020, or a 75% increase in performance in forty-three years (Chart 3). The less expensive thin film technology has had even higher efficiency improvements during this period, increasing from 8.9% in 1976 to 23.4% in 2018, when the latest testing data was released by the National Renewable Energy Lab (NREL). These improvements have enabled greater electrical generation for the same sized solar panels. Indeed, based on recent innovations in multi-layered solar cells that capture different wave lengths of light, industry experts have already field-tested photovoltaic panels with 40% efficiencies. These innovations will eventually reduce the number of solar panels needed to provide 100% of the electricity for any given home, business, or industry.[88] This in turn helps to reduce – but not eliminate – the potential solar access concerns that exist with photovoltaic systems that require greater space on the roof or ground to meet a given home's energy needs.

Solar Panel Efficiencies versus Solar Panel Size

As photovoltaic panels become more efficient, the number and size of the panels required to provide 100% of the electrical power needed for any given household will decline. All else equal, a house meeting its electrical needs with 300 watt rated photovoltaic panels will need nearly twice as much roof or ground level space as the same house served by 600 watt rated photovoltaic panels. Why is this important? For homeowners with limited roof or ground level space for solar collectors, the increased efficiency of 600 watt rated panels means solar access issues can be minimized. The only drawback of the more efficient solar panels is they cost more and therefore may not be the most cost-effective when solar access is not an issue and space is available to install the requisite number of lower cost solar panels.

String Inverters versus Micro-inverters

There are other ways to improve the economics of solar besides substitution of higher efficiency panels for lower efficiency ones. As discussed previously, solar photovoltaic systems are often connected in series using string inverters that control the maximum electrical output of the panels based on the worst performing panel. Using this approach, if one solar module is 50% shaded, then the output of the other panels is reduced to that level as well. The result is that a small shadow on one solar panel affects the performance of the other panels. In contrast, panels with micro-inverters operate differently. The electrical performance of the panel that is shaded 50% has no impact on the performance of the remaining solar panels. While micro-inverters are more expensive than string inverters they are an important option for those households that may have significant shading at certain times in the early morning or late afternoon at different times during the year.[89] Reducing

[87] Ibid, pp. 6-8.
[88] Will solar panels ever reach 50 percent efficiency?, Energyusage.com; Accessed June 9, 2022.
[89] Pros and cons of string inverters vs micro-inverters, Solar Reviews.com September 24, 2021; Accessed June 13, 2022

shading increases the solar radiation reaching the PV panels, which in turn improves the economics of photovoltaic systems.

Photovoltaic Panel Orientation

The number of photovoltaic panels required to meet 100% of the electricity for a dwelling is also influenced by the orientation of the roof. Photovoltaic panels installed on a roof oriented due south at a 42.5 degree pitch will generate 26% more solar energy (as measured in kilowatt hours per square meter per day) than the same panels installed on a roof oriented due east or west. Installing photovoltaic panels on east or west facing roofs – or a similar orientation for ground mounted photovoltaic panels – increases the number of panels required by a factor of 1.35 in the Connecticut climate zone compared to ones installed on south facing roofs. In turn, the additional cost lengthens the payback period for the project after federal tax credits by 2.5 years. Proper roof orientation for new construction is like putting money in the bank.

Payback Period for Photovoltaic Systems

To determine whether an investment in photovoltaic panels is cost effective for homeowners in Western Connecticut, WestCOG evaluated the kilowatt hours of electricity consumed by the average household in 2021 to determine the size of the photovoltaic panels that would be required to meet 100% of the annual electricity used in each of the eighteen municipalities within the region. The analysis determined that, even with the dramatic reduction in the cost to install photovoltaic systems in the last ten years, the average homeowner in Western Connecticut would have about a nine-year payback from the outright purchase of a photovoltaic system meeting 100% of household needs. This analysis did not include the time value of money. Assuming a 7.3% annual inflation in the cost of electricity, homeowners in Western Connecticut could pay back their investments in eight years. However, when energy conservation measures are incorporated into the home prior to the installation of the panels, the payback period can be as low as four years if measures are taken to reduce total electricity consumption by as much as 25%.

Furthermore, when federal rebates and tax credits and utility financial incentives are utilized, along with a 25% reduction in electricity consumption, the payback for photovoltaic systems is three to four years. Normally, investments that pay for themselves within a three- to five-year period are good business decisions. Indeed, the payback period may even be better than modeled in this analysis if heating oil and natural gas prices remain high, and the average costs for the installation of photovoltaic panels continues to decline. Finally, when the present value of money is incorporated into the analysis and increases in grid-supplied residential electricity continues – following the trends seen for the last twenty years – then photovoltaic systems that are installed with a robust effort to reduce electricity consumption can be paid off in about 2.5 years. Even if efforts to reduce electricity demand only amount to a 10% reduction over past usage levels, the average homeowner in Western Connecticut could see a payback of less than three years by taking advantage of federal tax rebates and tax credits and utility incentives.

Electric Vehicles and Electric Heat Pumps

An analysis of photovoltaic systems for home use would not be complete without considering the emerging market for electric vehicles as an alternative to gas-powered vehicles and the use of electric heat pumps as a supplement or replacement for fossil fuels used for home heating. Electric vehicles and heat pumps require considerable amounts of electricity and therefore anyone considering these options will need to forecast the electricity required to meet these needs. Based on data provided by

PURA (Table 2), an additional 10,178 kilowatt-hours of electricity will be required for the average home with two electric vehicles and a heat pump. If the aim is 100% use of renewable energy, the installation of more solar panels to cover the costs for EV charging and the heat pump will affect the payback period. Fortunately, the Inflation Reduction Act of 2022 provides incentives and tax credits for these options. However, the tax credits for the purchase of electric vehicles and incentives for the use of heat pumps do not have any bearing on the electricity costs associated with these items. The increased electricity required for these items means a larger number of solar panels will be required, and that in turn means larger costs for the installation and a longer payback period.

For many Connecticut households, there will be obstacles to choosing photovoltaic panels including, as discussed previously, solar access problems caused by trees on neighboring properties and lack of funds to invest during a high inflationary period – especially for low- and moderate-income households. Similarly, renters will not be able to use solar unless the landlord finds it in his or her self-interest to install solar panels. A fourth obstacle reflects market uncertainty concerning the acceptability of electric vehicles including their range, their cost, access to charging stations and reliable service stations to repair and maintain these vehicles. These factors continue to drive market hesitation and clearly point to federal and state renewable energy programs that are barely staying abreast of industry developments and public opinion.

Summary of Market and Economic Issues

In summary, the rising costs for electricity, heating oil and natural gas coupled with the federal tax credits offered through the Inflation Reduction Act of 2022 and declining costs for the installation of photovoltaic panels creates ideal conditions for a transition to solar powered electricity for many Connecticut homeowners. Yet Connecticut homeowners will need to give a great deal of thought to planning for future electrical needs as the nation transitions to electric vehicles. Electric vehicles are being strongly marketed by the federal government as well as many of the automobile manufacturers. For example, the General Motors has made a public commitment to transition fully to electric vehicles; this will affect the purchasing options of the public.[90] Of course, homeowners do not need to generate all their electricity from photovoltaic systems if the economics are not favorable. Even meeting 75% of one's electricity needs with solar is a major step toward a more sustainable future. At a governmental level, the transition to a renewable energy future will require a 'Marshall Plan' that drives investments and focuses public actions on achievable short- and long-term goals. The public must be able to understand the choices available, and why the economics of renewable energy systems – especially photovoltaic systems – are foundational concepts in the best interest of individuals and to society. These foundational principles enable the de-carbonization of the Connecticut economy but rest on solar-conscious land use practices that fall under the jurisdiction of the state's planning and zoning commissions.

The real challenge will not be explaining the economic advantages of photovoltaic derived electricity but the ability to find qualified contractors available to meet the demand for their services. The Connecticut labor force does not have the skilled manpower to ramp up photovoltaic installations – nor of electric HVAC systems and vehicles – to meet Governor Lamont's executive order 21-3 calling

[90] Mary T. Barra, Chair, Chief Executive Officer, General Motors, Sustainability Strategy. Accessed November 9, 2022

for 100% of the state's energy to come from renewable sources.[91] With less than 5% of all electrical energy derived from renewable sources in 2022 (indeed solar energy represents even less than that – about 2%), achieving 100% renewable energy by 2040 represents massive technological forcing. The State of Connecticut is placing its hopes of achieving the 2040 goal on the installation of large offshore wind energy systems in the next ten years. However, wind turbines – while an important component of an energy strategy – alone are insufficient for an energy transition. As this report has emphasized, neither photovoltaic panels behind the meter, grid-connected solar arrays, or offshore wind are likely in combination to reach the 2040 goal of decarbonized electric grid without significant zoning incentives for energy conservation, passive solar design, and photovoltaic panels.[92]

Consistency with the Regional Plan of Development

The Western Connecticut Council of Governments unanimously endorsed the infrastructure goals and policies of the 2020-2030 Regional Plan of Development that included renewable energy infrastructure policies. The five policies listed below are intended to assist municipal governments with the development of renewable energy strategies and regulations that achieve the goals of reducing our dependence on fossil fuels.

2020-2030 Renewable Energy Goals and Policies

1. Adopt zoning regulations that facilitate the installation of renewable energy systems including photovoltaic systems, super-insulated and net zero energy dwellings, earth sheltered housing, and ground source and air source heat pump technologies.
2. Consider the creation of renewable energy zones like that established in Bethel, as a means to direct the locations where the Connecticut Siting Council places grid-connected solar energy systems within the region.
3. Adopt subdivision regulations that give greater consideration to solar access and solar orientation of buildings in new residential developments.
4. Participate in the Clean Energy Communities Program to facilitate adoption of long-term sustainable approaches to the installation and use of renewable energy sources.
5. Avoid the placement of grid-connected solar energy systems in areas that will destroy core forests, adversely affect riparian corridors, or destroy critical agricultural lands.

Strategies and Next Steps

To respond to the legislative measures contained in Public Acts 88-263, 21-29 and 22-5, enabling planning and zoning commissions to actively promote the use of solar energy and other renewable resource, municipalities should consider the following strategies within the context of the Region's adopted renewable energy goals and policies:

Goal 1: Adopt zoning regulations that facilitate the installation of renewable energy systems including photovoltaic systems, super-insulated and net zero energy dwellings, earth sheltered housing, and ground source and air source heat pump technologies.

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[91] Public Act 22-5, An Act Concerning Climate Change Mitigation, Connecticut General Assembly, approved May 10, 2022. Since enactment of Governor Lamont's greenhouse gas goals contained in Executive Order 21-3, the Connecticut General Assembly recently codified the goals as state law.
[92] Connecticut Department of Energy and Environmental Protection. "Integrated Resources Plan." Hartford, CT: CTDEEP, 2021, pp. 29-39.

Strategy 1: Incentivize the adoption of solar access and solar orientation standards for new construction to enable the most efficient application of a wide range of photovoltaic technologies.

Strategy 2: Develop zoning review procedures that address the need for solar access in the siting of all new construction including expedited permit procedures for those in compliance with municipal solar access standards.

Strategy 3: Consistent with Public Act 88-263, revise subdivision regulations to specify the use of solar orientations for streets and lots unless developers can document how such requirements significantly increase the cost of housing.

Strategy 4: Review zoning regulations to eliminate barriers to earth sheltered housing and facilitate the use of finished basements that serve as living areas consistent with the recently amended State Building Code.

Strategy 5: Develop zoning incentives for super-insulated housing and net zero housing consistent with the mandates of Public Act 21-29 and with the principles of least cost housing contained in this report.

Goal 2: Consider the creation of renewable energy zones, like that established in Bethel, as a means to encourage the Connecticut Siting Council to place greater priority on locations where grid-connected solar energy systems are most appropriate within the region.

Strategy 1: Identify business and industrial lands, closed landfills and parking lots that could be used for grid-connected solar arrays in lieu of their installation on forest and farmland. Consider zoning selected parcels as renewable energy zones to ensure the Connecticut Siting Council has more acceptable siting options for grid-connected solar arrays.

Strategy 2: Encourage the Connecticut Siting Council to place greater emphasis on siting grid-connected solar arrays on lands that do not result in the loss of farm or forest land as urged by Governor Lamont in Executive Order 21-3.

Strategy 3: Municipalities should encourage community solar, virtual net metering or micro-grid projects that meet the energy needs of those without solar access, low and moderate income families and businesses unable to meet their renewable energy goals on site. Such facilities could be located on lands identified as renewable energy zones as discussed in strategy 1.

Goal 3: Adopt subdivision regulations that provide more robust solar access and solar orientation standards for buildings in new residential developments.

Strategy 1: Public Act 88-263 mandates the use of solar access and solar orientation unless it significantly increases the cost of housing. Provide technical assistance to planning commissions on the economic advantages of solar access and solar orientation as a means to minimize new housing construction costs and reduce the life cycle costs of home heating.

Strategy 2: The Councils of Governments in Connecticut should establish land use training that provides the basic tools and techniques needed by planning and zoning commissions to comply with the mandates of Public Act 88-263.

Goal 4: Participate in the Clean Energy Communities Program to facilitate adoption of long-term sustainable approaches to the installation and use of renewable energy sources.

> **Strategy 1:** Since Clean Energy Communities Program was a Connecticut Green Bank initiative, municipalities interested in renewable energy strategies should leverage its wide range of resources in developing municipal renewable energy strategies.

Goal 5: Avoid the placement of grid-connected solar energy systems in areas that will destroy core forests, adversely affect riparian corridors, or destroy critical agricultural lands.

> **Strategy 1:** To achieve energy independence without loss of farm or forest land, planning and zoning commissions should facilitate the installation of behind the meter solar installations, improved energy efficient patterns of development including energy conscious landscaping in new developments.

> **Strategy 2:** Chief elected officials and/or planning and zoning commissions should consider establishing hierarchies for the proper location of grid-connected solar arrays that are consistent with good land use planning, the protection of open space, farm and forest land based on the same principles developed for local governments wishing to guide telecommunication facilities governed by the Connecticut Siting Council.

Appendices

Charts on Electricity Trends, Photovoltaic Costs and Efficiencies

Chart 1: Connecticut Residential Electricity Costs: Cents/ Kilowatt Hr. 2001-2022

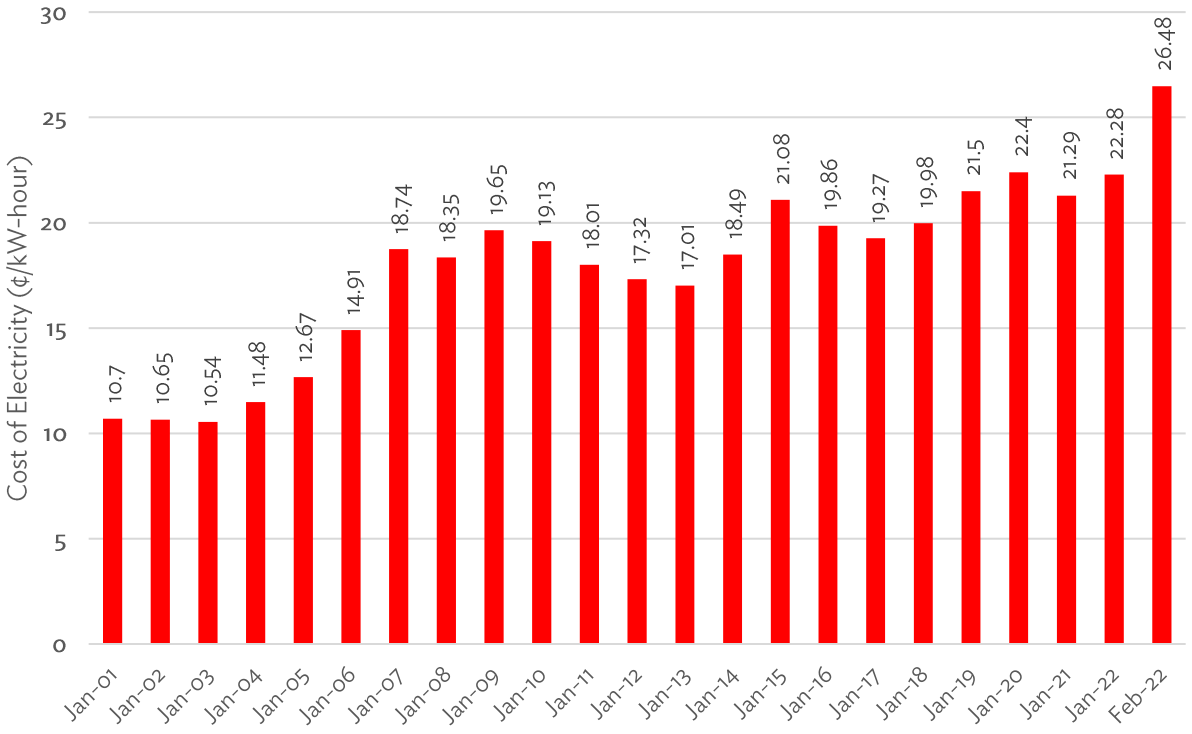
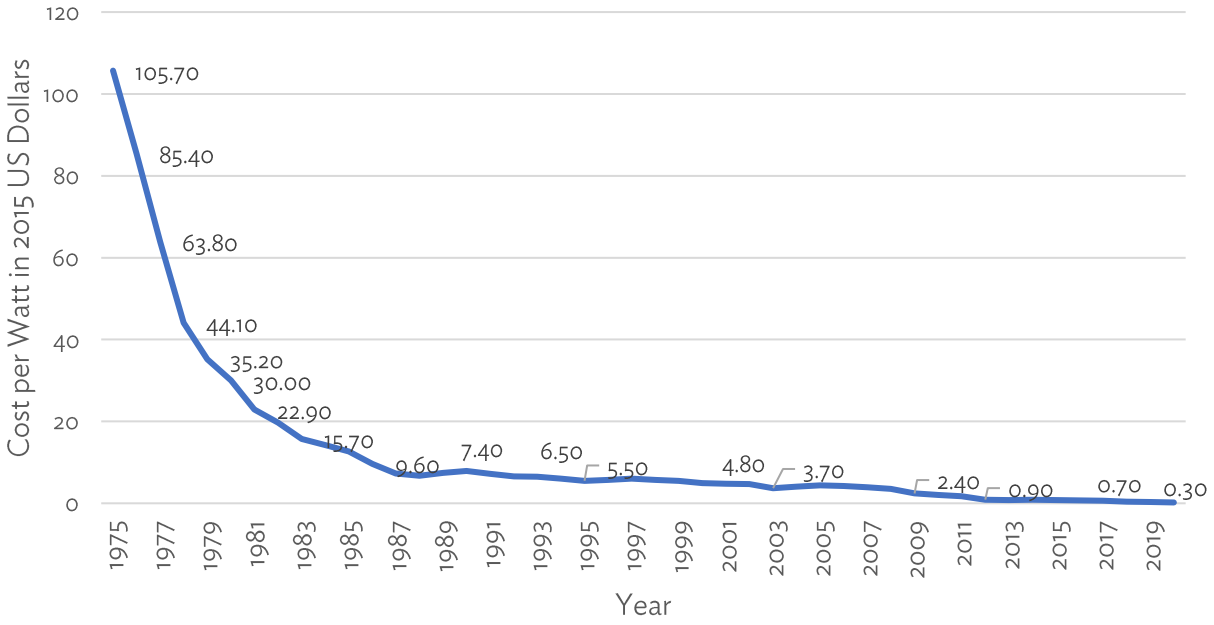
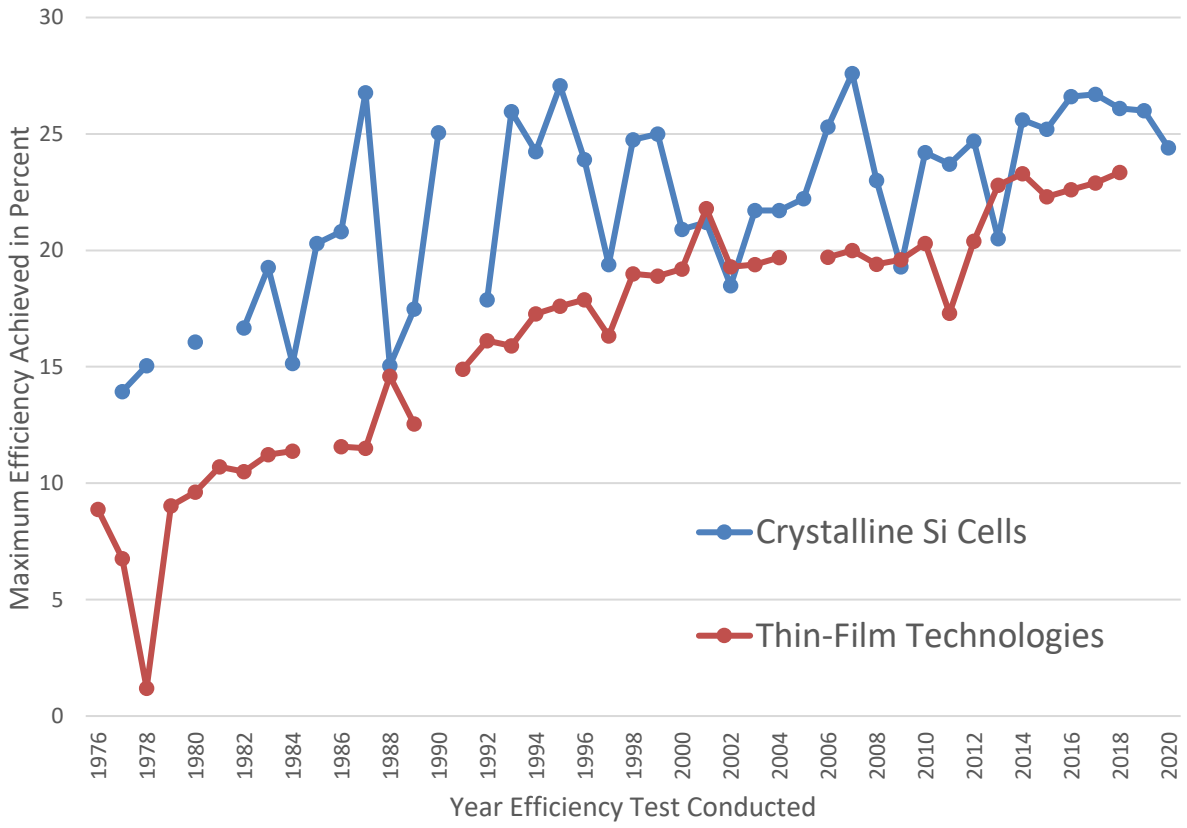


Chart 2: Solar Photovoltaic Module Costs: 1975- 2020



Source: International Energy Agency, 2020.

Chart 3: Comparison of Tested Photovoltaic System Efficiencies for Crystaline Silica Cells and Thin Film Technologies: 1976-2020



Source: National Renewable Energy Laboratory, Golden, CO.

Appendix 1: Solar and Energy Conservation Strategies Enabled by Connecticut Public Act 21-29

Strategy	Require	Incentivize	Cost and Other Considerations
Solar Photovoltaic Systems (distributed or free standing)			
1. Flexible setbacks for ground mounted solar	Yes		Zoning setback revisions
2. Roof orientation and pitch for solar access	Yes		Zoning Bldg. Siting revisions
3. Flexible height limits for solar photovoltaic systems	Yes		Zoning Bldg. Height revisions
4. Photovoltaic systems to meet full building electrical loads	No	Yes	Payback Analysis required
5. Photovoltaic systems to meet partial electrical loads with 5-year ROI	Yes		Payback Analysis required
6. Electric vehicle charging stations in new construction	Yes		New Zoning BMP Standards
Solar Domestic Hot Water Systems			
1. Roof orientation and pitch for solar access	Yes		Zoning Bldg. Orientation Standards
2. Solar Domestic Hot water to meet full building hot water loads	No	Yes	Payback Analysis required
Passive Solar House Design Concepts			
1. Building Orientation for solar Access	Yes		Energy Economics of Orientation
2. Locating septic system to the south of the building	Yes		Where feasible
3. Building fenestration/orientation for solar energy/ reduce heat loads	Yes		Energy Economics of Orientation
4. Development on south facing slopes		Yes	Energy Economics of slope
5. Avoid development on north facing slopes		Yes	Energy Economics of slope
Solar Access Protections			
1. Solar Access protections through zoning permit system	Yes		Zoning permit to protect solar access
2. Solar easements	Yes		Applies to Planned developments
3. Building setbacks from south lot line to reduce shadow threats	Yes		Zoning setback revisions
4. Tree type & placement consistent with solar access protection	Yes		Create Solar compatible tree guide
5. Revise building height limits for better neighborhood solar access	Yes		Zoning Bldg. Height revisions
6. Revise fence height limits for better ground mounted solar access	Yes		Zoning fence height revisions
Energy Conservation Conscious Landscaping			
1. Tree placement for wind breaks	Yes		Minimal cost for proper tree types
2. Tree placement for reduced Bldg. cooling loads	Yes		Minimal cost for proper tree types
3. Berms and natural landscapes for wind load reduction	Yes		Cost varies by application
4. Site design concepts to reduce energy in the micro-climate	Yes		Cost varies by application
Embodied Energy Concepts			
1. Use of materials that reduce embodied energy in site development	Yes		Key is procurement planning
2. Use of green infrastructure solutions to stormwater management	Yes		Payback Analysis recommended
3. Minimalist and xeriscaping concepts in landscape design	Yes		Payback Analysis recommended

Appendix 2: Examples of Current Solar Access Practice:

Three examples of solar access protection regulations in Connecticut are found in Beacon Falls, Wolcott and Hartford. The solar access definitions each of these municipalities has adopted identify the nature of solar access and the times during which it should be protected. However, what is missing in all of these examples are the specific procedures for ensuring solar access is protected in the event a conflict emerges with an adjoining property owner.

Suburban and Rural Example of Solar Access

Beacon Falls Zoning Regulations

Minimum Solar Access: No dwelling shall be constructed and no building shall be expanded or enlarged if said construction, expansion or enlargement would cast a shadow upon the south wall of an existing building or a proposed building for which a building permit has been issued for more than 25% of the time between 8:34 a.m. and 3:08 p.m. local time on December 21st. Minimum setbacks for buildings required to protect solar access shall be based upon the shadow length table available from the Planning and Zoning commission. Where solar access protection precludes development of any portion of the lot, then the minimum solar access requirements of this section shall not apply.

Wolcott Zoning Regulations:

Solar Access: The term solar access means access to unobstructed direct sunlight to the south wall of the principal building. Solar access shall be considered adequately available if the south wall of the principal building has unobstructed access to direct sunlight for 75% of the time between 8:34 a.m. and 3:08 p.m. local time on December 21st of any year. Note: The maximum height limitation shall not apply to the following, unless such structures or facilities would interfere with solar access for an existing solar collector or wind access for an existing wind energy conversion system: church spires and belfries, pole type T.V. antennas and chimneys; roof parapets and turrets of less than three (3) feet; and cupolas and domes not used for human habitation, clock towers, bell towers, elevator penthouses, roof ventilators and similar facilities.

Setbacks for Solar Access: No building or structure shall be sited, constructed, altered or enlarged if the effect of such construction, siting, alteration or enlargement would be to cast a shadow upon the south wall of an existing principal building or a proposed principal building for which a building permit has been issued, for more than 25% of the time between 8:34 a.m. and 3:08 p.m. local time on December 21st. For purposes of this regulation the south wall of a principal building shall mean any wall which faces within 30 degrees of true south. In order to achieve compliance with these provisions the following setback standards shall be adhered to and supersede other setback requirements listed in these regulations.

Minimum Setbacks: For every foot of height above the mean grade, any building or structure due south of the south wall of a dwelling unit shall be setback the following distance per foot of height, based on slope conditions at the site: land slopes east, west or is flat: 2.2 feet - land slopes 5% to the north: 2.4 feet: - land slopes 10% to the north: 2. 7 feet: - land slopes 5% to the south, southwest or southeast: 2.0 feet: - land slopes 10% to the south, southwest or southeast: 1 .8 feet: - land slopes 5% to the northwest or northeast: 2.3 feet - land slopes 10% to the northwest or northeast: 2.5 feet.

Steep Terrain: When land slope conditions significantly vary from those listed in Par. 25.4.13a, then reference shall be made to a Shadow Length Table from a source approved by the Commission.

Solar Access Exemptions: Where solar access protection to the south wall precludes development within the buildable portion of the lot to the south, then the minimum solar access requirements of Par. 25.4.13 shall only apply to that portion of the south wall located 10 feet above the natural grade of the building as far as practical or feasible. The provisions of Par. 25.4.13 shall not apply to existing buildings that are shaded for greater than 25% of the time between 8:34 a.m. and 3:08 p.m. local time on December 21st and shall not prohibit construction to the property line by mutual agreement of the property owners.

Urban Approaches to Solar Access:

It is important to understand that solar access protections will vary according by the density of development within any given community. Therefore, what might work in the less dense communities of Beacon Falls and Wolcott might not be appropriate for Hartford. Hartford has taken a simpler approach that applies the principle of "prior appropriation" of solar access as a means to protect against future shading problems caused by trees. It is noteworthy that Hartford's zoning regulations do not extend this same right of prior appropriation when new tall buildings are planned to the south of an existing solar collector. Similar to Beacon Falls and Wolcott, Hartford does not provide administrative procedure for the adjudication of solar access conflicts. Here is Hartford's approach to solar access protection:

Hartford Zoning Regulations

"No new tree shall have a significant negative impact on any adjacent or nearby property owner. A property owner may not plant any tree which, when fully grown, will shade a solar collector existing at the time of the planting of the tree."

With the exception of the homeowners living in the five municipalities that have defined solar access protection through zoning, the balance of Connecticut homeowners has no guarantee that their photovoltaic panels or passive solar designed house will have uninterrupted access to sunlight throughout the year or in the future. Indeed, even the five municipalities that have identified specific solar access standards do not require solar easements or impose a permit program that establishes a homeowner's right to the use of sunlight. With millions of dollars being invested in solar technologies, the state legislature and municipal zoning commissions need to develop explicit land use controls that protect these significant investments and guarantee some level of solar access protection across the state. The state level solar access protection strategies adopted by California, New Mexico and Oregon should be the starting point for similar efforts in Connecticut. Without explicit state level guidance on what constitutes an acceptable level of solar access, the means for its protection and procedures for arbitrating disputes, the future of photovoltaic systems in Connecticut has a shaded future.

Appendix 3: Solar Access Laws and Easements

#	State	Type of Law	Date Issued	Details
1	California	Easement	September 25, 1978	Enables use of Solar Easements
1	California	Solar Shade Control	1978	Enables protection of solar access from new tree plantings
2	Utah	Restrict Prohibitions	May 9, 2017	Restricts community associations from prohibiting solar energy systems
3	Iowa	Easement	May 19, 1981	Creates Board to regulate the creation of solar easements
4	Virginia	Easement	1978	Enables use of solar easements
5	Maryland	Easement	April 24, 2008	Enables use of solar easements
6	Florida	Easement	June 16, 1978	Enables use of solar easements
7	Rhode Island	Easement	1981	Enables use of solar easements
8	Tennessee	Easement	April 23, 1979	Enables use of solar easements and through zoning controls
9	South Dakota	Easement	February 15, 2017	Enables use of solar easements – very detailed
10	Ohio	Easement	February 20, 1979	Enables use of solar easement
11	Colorado	Easement	May 25, 1979	Enables use of solar easement
12	Indiana	Zoning	April 7, 1981	Enables solar access protections thru zoning
12	Indiana	Easement	February 27, 1980	Enables use of solar easement
13	New Mexico	Easement	1983	Enables use of solar easement
14	Arizona	Zoning	April 20, 1979	Enables solar access protections thru zoning
15	Massachusetts	Zoning	December 23, 1985	Enables solar access protections thru zoning permits for solar access and solar easements
16	New Hampshire	Zoning	June 30, 1982	Enables solar access protections thru zoning and enables solar easements
17	Vermont	Zoning	April 28, 1980	Enables solar access protections thru zoning
18	Maine	Easement	1981	Enables use of solar easement
19	New York	Zoning	1979	Enables solar access protections thru zoning
19	New York	Easement	1979	Enables use of solar easement
20	New Jersey	Easement	1979	Enables use of solar easement
21	North Carolina	Land Use	2007	Protects solar energy systems from unreasonable restrictions
21	North Carolina	Land Use	2009	Extends 2007 law to residential development types beyond single family housing.
22	Arkansas	None	NA	None
23	South Carolina	None	NA	None
24	Florida	Easement	June 16, 1978	Enables use of solar easement
25	Alabama	None	NA	None
26	Mississippi	None	NA	None
27	Oregon	Easement	August 19,. 1981	Enables solar access protections thru zoning and solar easements – This is the most focused on solar access ordinances of any in the USA
28	Washington	Easement	May 11, 1979	Enables solar access protections thru zoning and solar easements
29	Texas	None	NA	None
30	Idaho	Easement	May 29, 1978	Enables use of solar easement

#	State	Type of Law	Date Issued	Details
31	Montana	Easement	April 10, 1979	Enables use of solar easement
32	North Dakota	Easement	March 12, 1977	Enables use of solar easement
33	Minnesota	Zoning/Easement	April 15, 1978	Enables solar access protections thru zoning and enables solar easements
34	Wisconsin	Zoning/Easement	May 6, 1982	Enables solar access protections thru zoning and solar easements – a model approach.
35	Indiana	Easement	February 27, 1980	Enables use of solar easement
36	Kentucky	Easement	April 1, 1982	Enables use of solar easement
37	Wyoming	Solar Rights	March 5, 1981	Enables solar access and solar easements - one of the most innovative of all solar regulations
38	Michigan	None	NA	None
39	West Virginia	None	NA	None
40	Louisiana	None	NA	None
41	Pennsylvania	None	NA	None
42	Nebraska	Easement	April 27, 1979	Enables use of solar easement
43	Kansas	Easement	April 5, 1977	Enables use of solar easement
44	Oklahoma	Easement	June 6, 2010	Enables use of solar easement for commercial applications of solar and wind
45	Delaware	Restrictive Covenants	July 9, 2009	Addresses restrictive covenants that limit use of solar energy systems
46	Georgia	Easement	April 16, 1978	Enables use of solar easement
47	Missouri	Easement	June 28, 1979	Enables use of solar easement
48	Connecticut	Zoning	June 16, 1981	Enables solar access protection thru subdivision Regulations. (In 2012 required consideration)
49	Alaska	Easement	1980	Enables use of solar easement
50	Hawaii	None	NA	None

Appendix 4: Shadow Projections Cast on December 21st in Western Connecticut

ZIP Code	Municipality	State	Latitude (North)	Longitude (West)	Solar Altitude on December 21 (degrees)	Solar Noon	1 Meter pole Shadow at Solar Noon 12/21 on flatland (meters)
06801	Bethel	CT	41.3759	73.3933	25.19	11:51:37	2.13
06752	Bridgewater	CT	41.5211	73.3597	23.03	11:51:29	2.14
06804	Brookfield	CT	41.4668	73.3928	25.09	11:51:40	2.14
06810	Danbury	CT	41.3768	73.4601	25.17	11:51:51	2.13
06811	Danbury	CT	41.4236	73.4845	25.14	11:52:00	2.13
06820	Darien	CT	41.0804	73.4823	25.49	11:51:53	2.10
06830	Greenwich	CT	41.0502	73.6235	25.55	11:52:31	2.09
06831	Greenwich	CT	41.0864	73.6612	25.55	11:52:41	2.09
06870	Greenwich	CT	41.2234	73.3353	25.55	11:52:17	2.09
06878	Greenwich	CT	41.5364	73.3517	25.54	11:52:23	2.09
06807	Greenwich	CT	41.4641	73.3644	25.54	11:52:28	2.09
06840	New Canaan	CT	41.1589	73.4989	25.42	11:52:00	2.10
06812	New Fairfield	CT	41.4862	73.4974	25.11	11:51:58	2.13
06776	New Milford	CT	41.6202	73.4053	24.99	11:51:40	2.15
06470	Newtown	CT	41.3932	73.3201	25.15	11:51:15	2.13
06850	Norwalk	CT	41.1272	73.4433	25.45	11:51:40	2.10
06851	Norwalk	CT	41.1388	73.4037	25.42	11:51:37	2.10
06853	Norwalk	CT	41.0695	73.4379	25.51	11:51:38	2.10
06854	Norwalk	CT	41.0941	73.4328	25.48	11:51:42	2.10
06855	Norwalk	CT	41.1001	73.3971	25.47	11:51:36	2.10
06856	Norwalk	CT	41.6145	73.2455	25.47	11:51:41	2.10
06877	Ridgefield	CT	41.3064	73.5024	25.29	11:52:01	2.12
06896	Redding	CT	41.3054	73.393	25.27	11:51:33	2.12
06784	Sherman	CT	41.5795	73.4985	24.99	11:52:00	2.15
06901	Stamford	CT	41.0531	73.5379	25.52	11:52:11	2.09
06902	Stamford	CT	41.061	73.5493	25.50	11:52:13	2.10
06903	Stamford	CT	41.1356	73.571	25.43	11:52:12	2.10
06904	Stamford	CT	41.0537	73.539	25.51	11:52:10	2.10
06905	Stamford	CT	41.0876	73.5444	25.51	11:52:09	2.10
06906	Stamford	CT	41.0697	73.522	25.50	11:52:07	2.10
06907	Stamford	CT	41.1005	73.521	25.47	11:52:06	2.10
06883	Weston	CT	41.2268	73.373	25.37	11:51:33	2.11
06880	Westport	CT	41.1454	73.3462	25.43	11:51:27	2.10
06897	Wilton	CT	41.207	73.4401	25.37	11:51:46	2.11

For precise latitude and longitude, see *https://www.esrl.noaa.gov/gmd/grad/solcalc/* and *https://keisan.casio.com/exec/system/1224682331*.

Appendix 5: Fence Height Requirements in Zoning Regulations of Western Connecticut

Municipality	Fence Height When Located In or Outside Residential Setback Standards				Fence Height Abutting Commercial or Industrial
	Front Yard	Side Yard	Rear Yard	Outside Setback	
Bethel[1]	4	6	6	8	8
Bridgewater[2]	4	6	6	NS	NS
Brookfield	12	12	12	12	NS
Danbury[9]	NS	15	15	15	NS
Darien	4	6	6	NS	8
Greenwich	6.5	6.5	6.5	NS	NS
New Canaan[3]	4	6	6	8	NS
New Fairfield	6	6	6	6	NS
New Milford	8	8	8	8	8
Newtown	NS	NS	NS	NS	8
Norwalk[4]	6	6	6	6	NS
Redding[5]	6	6	6	NS	NS
Ridgefield	NS	NS	NS	NS	NS
Sherman[6]	6	6+	6+	NS	NS
Stamford[7]	6	6	8	NS	NS
Weston	6	6	6	6	NS
Westport	8	8	8	8	NS
Wilton[8]	6+	6+	6+	NS	NS

Notes:

1. Where there are horses the front yard fence height can be 6 feet
2. Front yard fence must be between building line and street line.
3. An 8 foot fence is allowed outside required yard areas except in front yard. A 6 foot fence is allowed in front yard only if located behind front yard setback. Otherwise, only a 4 foot fence allowed in front yard between property line and front yard setback line. New Canaan allows deer fencing up to 8 feet high in front yard provided it meets aesthetic and visual standards.
4. Norwalk only has fence height standards for 6 foot fences to screen refuse and recycling receptacles without regard to location or setback considerations.
5. Redding allows 8 foot fence poles although the fence is limited to 6 feet.
6. Sherman allows fences to exceed 6 feet in the side or rear yards. Those exceeding 6 feet in the front yards must have a percentage of open construction.
7. Stamford allows higher fence heights as long as it doesn't adversely impact adjacent property or the public street.
8. Fences over 6 feet in height are allowed but must be 75% open construction for that portion of the fence that exceeds 56 feet.
9. Danbury has no height limit for fences specified but accessory structures are limited to 15 feet only in side and rear yards.

NS is no setback.

Appendix 6: Shadows Cast on December 21: Three Small Lot Building Scenarios

Municipality	**Maximum Allowable Residential Bldg. Height Smallest Lot (feet)**	**Smallest Lot Separation Distances for Buildable Area Setbacks (Three Scenarios)**			**Maximum Building Shadow Projections on December 21st at Noon and 9AM**	
		Street Separation (feet)	Rear Lot Separation (feet)	Side Yard Separation (feet)	Bldg. Shadow at Noon 12/21	Bldg. Shadow at 9AM 12/21
Bethel	35	70	70	10	74.4	140.2
Bridgewater	35	130	80	50	75.0	141.1
Brookfield	30	70	20	20	64.0	120.7
Danbury	35	70	70	16	74.4	138.1
Darien	30	80	50	20	62.9	118.4
Greenwich	35	80	50	15	73.2	138.3
New Canaan	35	80	50	16	73.6	138.8
New Fairfield	35	110	100	40	74.7	141.3
New Milford	35	50	40	10	75.1	141.7
Newtown	30	100	40	40	63.9	120.0
Norwalk	38	90	30	10	79.8	150.0
Redding	40	110	60	30	84.8	159.5
Ridgefield	40	80	16	16	84.7	159.8
Sherman	35	130	50	50	75.1	142.3
Stamford	30	80	60	12	62.8	118.6
Weston	35	130	60	60	73.9	138.8
Westport	30	90	12	12	63.1	118.4
Wilton	35	110	80	60	73.8	138.8

Note: This analysis assumes lots are aligned on a north south axis

Source: WestCOG analysis of local zoning regulations concerning maximum allowable height of height of buildings, minimum side, rear and front yard setbacks and minimum municipal street widths.

Appendix 7: Shadows Cast on December 21st: Three Large Lot Building Scenarios

Municipality	**Maximum Allowable Residential Building Height - Largest Lot Zone (Feet)**	**Largest Lot Separation Distances for Buildable Area Setbacks (Three Scenarios)**			**Maximum Building Shadow Projections on December 21st at Noon and 9AM**	
		Street Separation (feet)	Rear Lot Separation (feet)	Side Yard Separation (Feet)	Bldg. Shadow at Noon 12/21	Bldg. Shadow at 9AM 12/21
Bethel	35	130	80	50	74.4	140.2
Bridgewater	35	180	100	100	75.0	141.1
Brookfield	30	130	100	100	64.0	120.7
Danbury	35	130	70	50	74.4	138.1
Darien	30	130	100	70	62.9	118.4
Greenwich	50	180	150	100	104.6	197.6
New Canaan	45	130	100	100	94.7	178.5
New Fairfield	35	180	120	70	74.7	141.3
New Milford	35	230	160	120	75.1	141.7
Newtown	30	130	50	50	63.9	120.0
Norwalk	40	110	60	30	84.0	157.8
Redding	40	150	120	100	84.8	159.5
Ridgefield	45	130	100	100	95.2	179.8
Sherman	35	130	80	80	75.1	142.3
Stamford	35	150	140	70	73.3	138.3
Weston	35	130	60	60	73.9	138.8
Westport	40	130	100	100	84.2	157.8
Wilton	35	130	100	80	73.8	138.8

Note: This analysis assumes lots are aligned on a north south axis

Source: WestCOG analysis of local zoning regulations concerning maximum allowable height of height of buildings, minimum side, rear and front yard setbacks and minimum municipal street widths.

Appendix 8: Energy Loads for South vs. East or West Oriented Residential Buildings

		South Orientation		East-West Oriented Building Energy Load Increase over South Oriented Building			
City	State	Heating, % of Total	Total Mbtu	Heating Mbtu	Cooling Mbtu	Total Mbtu	% of Total
Caribou	ME	99	45.7	4.9	24.0	5.3	12%
Seattle	WA	97	19.1	2.0	0.3	2.3	12%
Ely	NV	94	18.8	5.73	1.7	7.4	39%
Bismarck	ND	93	43.1	6.0	0.9	6.9	16%
Great Falls	MT	93	30.2	5.2	0.7	5.9	20%
Madison	WI	92	33.3	4.8	1.3	6.1	18%
Boston	MA	92	27.4	3.9	1.0	4.9	18%
New York	NY	87	23.5	3.7	0.8	4.5	19%
Medford	OR	78	16.6	2.4	1.2	3.6	22%
Columbia	MD	74	26.3	4.2	3.5	7.7	29%
*Dodge City**	KS	71	23.5	5.7	4.3	10	43%
Washington	DC	69	23.2	3.6	2.2	5.8	25%
*Santa Maria***	CA	65	2.7	1.6	-0.1	1.5	56%
*Albuquerque**	NM	61	11.6	4.3	3.8	8.1	70%
Nashville	TN	53	22	2.7	2.9	5.6	25%
Cape Hatteras	NC	37	18.8	2.9	3.4	6.3	34%
*Fresno**	CA	34	14.9	2.3	5.4	7.7	52%
Fort Worth	TX	27	22.7	2.5	5.2	7.7	34%
Charleston	SC	23	18.3	2.4	3.2	5.6	31%
*El Paso**	TX	20	14.5	2.0	7.1	9.1	63%
Lake Charles	LA	15	21.7	1.1	4.1	5.2	24%
Apalachicola	FL	8	21.3	1.1	4.9	6.0	28%
Brownsville	TX	4	26.7	0.3	6.3	6.6	25%
Phoenix	AZ	3	27.7	1.0	7.3	8.3	30%
Miami	FL	0	22.7	0.0	2.7	2.7	12%

Note: Table 1a in the Anderson report had several minor rounding errors and one miscalculation. This table corrects for those minor errors.

* Figures for the desert climate are often much higher than comparable areas because the cold nights and hot sunny days are ideal for reduction of both heating and cooling loads by proper orientation and appropriate levels of thermal mass.
** The percentage increase for Santa Maria is unexpectedly high only because of the extremely low baseline loads in the mid California coastal climate. These are treated as anomalous points in the Anderson study.
Source: The Impact of Building Orientation on Residential Heating and Colling, Brandt Anderson, et al, Lawrence Berkley Laboratory, April 1983, Table 1a

Appendix 9: Land Needed for 100% Grid-connected Solar in Connecticut: 2021 & Forecast 2040

Item	Grid-connected Solar (GCS): Analysis of Land Use Impacts	Units	Option 1 NREL Method	Option 2 PURA Method	Option 3 CEQ Method
1	2021 Grid-connected Solar Capacity (MW)	MW	543	543	543
2	Annual Hours of Performance	Hours	8760	8760	8760
3	Solar Capacity Factor	Efficiency	0.1867	0.169	0.1337
4	Total Load Served by Grid-connected Solar	MWH	888,072	803,879	635,968
5	Acres per Megawatt	Acres	10	4.9	5
6	1 Megawatt Capacity Converted to MWH/Year	MWH	1,635	1,480	1,171
7	Megawatts per Acre	MW	0.100	0.204	0.200
8	MWH per Acre	MWH	163.5	302.1	234.2
9	Total Electricity Generated in CT 2021	MWH	44,079,943	44,079,943	44,079,943
10	Total Electricity Consumed in CT 2021	MWH	27,737,606	27,737,606	27,737,606
11	Size of Connecticut	Acres	3,547,520	3,547,520	3,547,520
12	MWH/Year generated if CT covered in Solar Panels	MWH	580,194,058	1,071,814,390	830,979,599
	Calculation Procedure A: MWh Analysis to Determine Land for GCS to Meet Generation & Consumption				
13	Land to meet 100% of Elect. Generation (2021)	Acres	269,521	145,897	188,181
14	% of CT Land for 100% of Elect. Generation (2021)	Percent	7.60%	4.11%	5.30%
15	Land to meet 100% Elect. Consumption (2021)	Acres	169,598	91,807	118,414
16	% of CT Land to Meet 100% Elect. Consumption	Percent	4.78%	2.59%	3.34%
	Calculation Procedure B: Land Analysis to Determine Land for GSC to Meet Generation				
17	MW Capacity if Connecticut Covered in Panels	MW	354,752	723,984	709,504
18	MWh Potential if CT 100% Covered in PV Panels	MWH	580,194,058	1,071,814,390	830,979,599
19	% of CT Land for 100% Electric Generation (2021)	Percent	7.60%	4.11%	5.30%
20	Land to Meet 100% Electric Generation (2021)	Acres	269,521	145,897	188,181
21	Land to meet 100% Elect. Consumption 2021	Acres	169,598	91,807	118,414
22	% of CT Land to Meet 100% Elect. Consumption	Percent	4.78%	2.59%	3.34%
	Calculation Procedure C: Land Deficit to Meet 100% of 2021 Electric Load with Grid-connected Solar				
23	Maximum of Rural & Urban Land Suitable for Solar	Acres	88,216	88,216	88,216
24	MWh PV Potential for Rural & Urban Land in CT	MHW	14,427,656	26,652,754	20,663,928
25	Land Deficit to Meet 100% of 2021 Electric Load	Acres	181,305	57,681	99,965
	Scenario 1: Grid-connected Solar Land Needed Based on Current Trends in Electricity Consumption to Meet 2040 Projected Electrical Loads				
26	2040 Electricity Demand @.82% annual increase	MWH	51,478,774	51,478,774	51,478,774
27	% of CT Land to Meet 100% Elect. Generation (2040)	Percent	8.9%	4.8%	6.2%
28	Land Area to Meet 100% of Elect. Generation (2040)	Acres	314,760	170,386	219,767
	Scenario 2: Grid-connected Solar Land Needed Based on Current Trends in Electricity Consumption and 100% adoption of Electric Vehicles (2 Per Household) and One Air Source Heat Pump (One/Per Household) to Meet 2040 Projected Electrical Loads				
29	2040 Electricity Demand @.82% annual increase; 2 EVs/HH; 1 Air Source Heat Pump/HH	MWH	65,727,974	65,727,974	65,727,974
30	% of CT Land to meet 100% of 2040 Electricity Load	Percent	11.33%	6.13%	7.91%
31	Land Area to Meet 100% of Load in 2040	Acres	401,885	217,548	280,598

Sources for Solar Capacity factor: The Solar Capacity Factor is the average amount of energy produced by an energy source versus its nameplate capacity. For example, a solar installation with a 10 MW capacity that produces an average pf 1.3 MWh over each hour has a capacity factor of .13 or 13%. The capacity factors used in this analysis are based on data supplied by the Connecticut Public Utilities Regulatory Authority 2021 Clean and Renewable Energy Report, February 2022, p. 48; The National Renewable Energy Laboratory Report, U.S. Renewable Energy Technical Potentials: A GIS Based Analysis, July 2012, pp. 10–11 and the Connecticut Council on Environmental Quality 2019 Annual Report.

Sources for Grid-connected Land Use Impacts: The National Renewable Energy Laboratory established a conservative standard of 10 acres required for each 1 megawatt for photovoltaic panels. See NREL report, Solar Development on Contaminated and Disturbed Lands, December 2013, p. iv; The Connecticut Council on Environmental Quality 2019 Annual Report, and Western Connecticut Council of Governments Analysis of land required for Grid-connected Solar Arrays in Connecticut, November 2022 (unpublished).

Source for Total Electrical Load: The Energy Information Agency (EIA) maintains electrical generation data for Connecticut accessible on the EIA website

Source: For Amount of Land Suitable for Solar: The National Renewable Energy Laboratory Report, U.S. Renewable Energy Technical Potentials: A GIS Analysis, July 2012, pp. 10–11.

Methodology: The analysis of future photovoltaic electricity evaluated the three extant methodologies for determining electric energy requirements based on land needed to achieve a one-megawatt capacity grid-connected solar array. Since Connecticut generates more electricity than it consumes the analysis identifies both the land needed to generate all the electricity by the state's electric utilities as well as the amount needed to meet that portion of the electricity consumed in Connecticut. The calculation of land needed to achieve these objectives was done using two methods: one based on an analysis of the Megawatt hour needs of the state and the second based on the land needed to achieve the electricity needs of the state. Both calculations arrive at the same conclusions. The second part of the analysis determined, based on a study conducted by the National Renewable Energy Laboratory, that Connecticut will not be able to meet all its electricity needs solely through grid-connected solar arrays if these projects are limited to land deemed suitable for its use. Indeed, based on the NREL study no more than 23% of the state's electric energy needs can be supplied by grid-connected solar IF these projects are limited to lands suitable for such projects. The third level of analysis evaluated projected electrical consumption in the year 2040 based on anticipated .82% increase in the use of electricity between 2021 and 2040. Finally, the 2040 forecast was modified to include the electricity needed to meet the state's goal of encouraging the transition to electric vehicles and the use of either air source heat pumps or ground source heat pumps. This strategy is intended to wean the state away from non-renewable forms of energy but creates significant new electric consumption that will require enormous amounts of the state's land IF grid-connected solar is perceived as the fastest means to achieve 100% renewable electric grid by 2040. That analysis revealed the state would need to devote anywhere from 6.13% of its land at the low end of the scale (Option 2 the PURA Method) to 11.33% of its land to grid-connected solar at the high end (Option 1 NREL Method).

Appendix 10: Municipal Solar Energy Regulations in Connecticut: July 2022

Municipality	Have Solar Panel Regs?	Encourage Solar Energy Use	Rooftop Panels Recessed	Panels Not visible from adjacent property	Height Exceptions for Panels	Comply with Lot Setbacks	Right to Solar Access	Flexible Setbacks for Solar Access	No Ground Mounted Panels in Front Yard	Limit Ground Mounted Panel Sites	Restrictions on Roof Mounted Panels	Restrictions on Wall Mounted Panels	Panels Count for Building Coverage	Restrict Ground Mounted Panel Height	Panels Removed after ceasing operation	Allow Large Scale Solar 250 KW+	Define Solar Energy Systems
Andover	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	NS	Yes	No	No	No
Ansonia	No																
Ashford	Yes	No	No	No	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Avon	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Barkhamsted	No																
Beacon Falls	Yes	No	No	No	Yes	Yes	Yes	No	No	No	No	No	NS	No	No	No	No
Berlin	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	Yes
Bethany	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	No	No	No	Yes
Bethel	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No
Bethlehem	No Zoning																
Bloomfield	No																
Bolton	Yes	Yes	Yes	No	No	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	No	Yes
Bozrah	No																
Branford	No																
Bridgeport	Yes	No	No	Yes	No	Yes	No	No	No	No	Yes	No	No	Yes	No	No	No
Bridgewater	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Bristol	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No
Brookfield	Yes	Yes	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No	No	No	No
Brooklyn	Yes	No	No	No	Yes	Yes	No	No	Yes	No	No	No	No	Yes	No	No	No
Burlington	Yes	No	No	Yes	No	Yes	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes
Canaan	No																
Canterbury	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes
Canton	Yes	Yes	No	Yes	No	Yes	No	No	Yes	Yes	No	No	No	Yes	No	No	No
Chaplin	No																
Cheshire	No																
Chester	No																
Clinton	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Colchester	No																
Colebrook	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Columbia	Yes	Yes	No	No	No	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	No	No	No
Cornwall	No																
Coventry	No																
Cromwell	No																
Danbury	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	No	No	Yes
Darien	Yes	No	No	No	Yes	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No
Deep River	No																
Derby	No																
Durham	No																
East Granby	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
E. Haddam	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No
East Hampton	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No

Municipality	Have Solar Panel Regs?	Encourage Solar Energy Use	Rooftop Panels Recessed	Panels Not visible from adjacent property	Height Exceptions for Panels	Comply with Lot Setbacks	Right to Solar Access	Flexible Setbacks for Solar Access	No Ground Mounted Panels in Front Yard	Limit Ground Mounted Panel Sites	Restrictions on Roof Mounted Panels	Restrictions on Wall Mounted Panels	Panels Count for Building Coverage	Restrict Ground Mounted Panel Height	Panels Removed after ceasing operation	Allow Large Scale Solar 250 KW+	Define Solar Energy Systems
East Hartford	Yes	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes
East Haven	Yes	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No
East Lyme	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
East Windsor	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes
Eastford	No Zoning																
Easton	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Ellington	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes
Enfield	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Essex	No																
Fairfield	No																
Farmington	No																
Franklin	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Glastonbury	No																
Goshen	No																
Granby	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Greenwich	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	No	No
Griswold	Yes	No	No	No	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Groton	No																
Guilford	No																
Haddam	Yes	No	Yes	No	No	Yes	No	No	No	Yes	No	No	NS	No	No	No	No
Hamden	No																
Hampton	Yes	Yes	No	No	No	Yes	No	No	No	Yes	No	No	NS	No	No	No	No
Hartford	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No
Hartland	No																
Harwinton	No																
Hebron	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Yes	Yes	NS	No	No	No	No
Kent	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Yes	No	NS	No	No	No	No
Killingly	No																
Killingworth	Yes	No	No	No	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes
Lebanon	Yes	No	No	No	No	Yes	No	No	No	Yes	No	No	NS	No	No	No	No
Ledyard	Yes	No	No	No	No	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes
Lisbon	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Litchfield	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes
Lyme	Yes	No	No	No	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Madison	Yes	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	NS	No	No	No	No
Manchester	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	No	No	Yes
Mansfield	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	NS	No	No	No	No
Marlborough	No																
Meriden	Yes	No	No	No	No	No	No	Yes	No	No	No	No	NS	No	No	No	Yes
Middlebury	No																
Middlefield	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	NS	No	No	Yes	No
Middletown	No																

Municipality	Have Solar Panel Regs?	Encourage Solar Energy Use	Rooftop Panels Recessed	Panels Not visible from adjacent property	Height Exceptions for Panels	Comply with Lot Setbacks	Right to Solar Access	Flexible Setbacks for Solar Access	No Ground Mounted Panels in Front Yard	Limit Ground Mounted Panel Sites	Restrictions on Roof Mounted Panels	Restrictions on Wall Mounted Panels	Panels Count for Building Coverage	Restrict Ground Mounted Panel Height	Panels Removed after ceasing operation	Allow Large Scale Solar 250 KW+	Define Solar Energy Systems
Milford	Yes	No	No	No	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Monroe	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	NS	No	No	No	No
Montville	No																
Morris	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	No	Yes	No	No	No
Naugatuck	No																
New Britain	No																
New Canaan	Yes	No	No	No	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	No	No	No
New Fairfield	No																
New Hartford	Yes	No	No	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	No	No
New Haven	No																
New London	Yes	Yes	No	No	Yes	No	No	Yes	No	Yes	No	No	No	No	No	No	No
New Milford	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	NS	No	No	No	No
Newington	No																
Newtown	No																
Norfolk	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	No	No	Yes
North Branford	No																
North Canaan	No																
North Haven	No																
North Stonington	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No
Norwalk	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Norwich	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	No
Old Lyme	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	Yes
Old Saybrook	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Orange	No																
Oxford	No																
Plainfield	No																
Plainville	Yes	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Plymouth	No																
Pomfret	No																
Portland	No																
Preston	No																
Prospect	No																
Putnam	No																
Redding	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Ridgefield	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	No	No	Yes	No	Yes	Yes
Rocky Hill	Yes	No	No	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No	No
Roxbury	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes
Salem	No																
Salisbury	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Scotland	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	No
Seymour	No																
Sharon	No																

Municipality	Have Solar Panel Regs?	Encourage Solar Energy Use	Rooftop Panels Recessed	Panels Not visible from adjacent property	Height Exceptions for Panels	Comply with Lot Setbacks	Right to Solar Access	Flexible Setbacks for Solar Access	No Ground Mounted Panels in Front Yard	Limit Ground Mounted Panel Sites	Restrictions on Roof Mounted Panels	Restrictions on Wall Mounted Panels	Panels Count for Building Coverage	Restrict Ground Mounted Panel Height	Panels Removed after ceasing operation	Allow Large Scale Solar 250 KW+	Define Solar Energy Systems
Shelton	Yes	No	No	No	No	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No
Sherman	No																
Simsbury	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Somers	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
South Windsor	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Southbury	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Southington	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	Yes
Sprague	Yes	No	No	No	No	Yes	No	No	No	Yes	No	No	No	No	No	Yes	Yes
Stafford	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Stamford	Yes	No	No	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No	No
Sterling	No																
Stonington	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No	No	Yes	Yes	No	No	Yes
Stratford	No																
Suffield	No																
Thomaston	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No	No
Thompson	Yes	Yes	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	No
Tolland	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	No	No	Yes	No	Yes	yes
Torrington	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Trumbull	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Union	No																
Vernon	No																
Voluntown	No																
Wallingford	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	No	No	No	Yes	No	No	No
Warren	Yes	No	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	No	No	No	No
Washington	No																
Waterbury	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Waterford	Yes	No	No	No	No	Yes	No	No	No	Yes	No	No	No	No	No	Yes	No
Watertown	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
West Hartford	Yes	No	No	No	No	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	yes	Yes	yes
West Haven	No																
Westbrook	Yes	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No
Weston	No																
Westport	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	No	No	No	Yes	No	No	No
Wethersfield	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	NS	No	No	No	No
Willington	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Wilton	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	NS	No	No	No	No
Winchester	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes
Windham	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No
Windsor	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	No	No	Yes	No	Yes	Yes
Windsor Locks	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	NS	No	No	No	No
Wolcott	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	No	No	NS	Yes	No	No	Yes
Woodbridge	No																

Municipality	Have Solar Panel Regs?	Encourage Solar Energy Use	Rooftop Panels Recessed	Panels Not visible from adjacent property	Height Exceptions for Panels	Comply with Lot Setbacks	Right to Solar Access	Flexible Setbacks for Solar Access	No Ground Mounted Panels in Front Yard	Limit Ground Mounted Panel Sites	Restrictions on Roof Mounted Panels	Restrictions on Wall Mounted Panels	Panels Count for Building Coverage	Restrict Ground Mounted Panel Height	Panels Removed after ceasing operation	Allow Large Scale Solar 250 KW+	Define Solar Energy Systems
Woodbury	Yes	No	No	No	No	Yes	No	No	No	No	No	No	NS	No	No	No	No
Woodstock	No																
Yes	103	45	14	15	37	92	6	12	14	49	31	7	15	64	12	17	30
No	64	58	89	88	66	11	97	91	89	54	72	96	63	39	91	86	73
No Specified													25				
Total	**167**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**	**103**

Source: WestCOG staff analysis of the solar energy regulations for the 167 Connecticut municipalities with zoning, July 2022.

Appendix 11: Payback for Photovoltaic Electricity for Households in Western Connecticut in 2021

Step 1: Electricity Demand in Western Connecticut in 2021 (Megawatt Hours)

Municipality	**Households**	**Residential (MWh)**	**Business (MWh)**	**Total Electricity (MWh)**	**Residential Electricity Used Per Household (MWh)**	**Total Municipal Electricity Normalized Per Household (MWh)**	**Residential Electricity Used Per Household Per Day (kWh)**
Bethel	6,595	71,019	57,584	128,603	10.77	19.50	29.5
Bridgewater	738	11,135	1,018	12,153	15.09	16.47	41.3
Brookfield	5,941	71,248	53,949	125,197	11.99	21.07	32.9
Danbury	28,070	266,115	318,942	585,056	9.48	20.84	26.0
Darien	6,616	109,844	52,111	161,955	16.60	24.48	45.5
Greenwich	22,804	365,136	248,635	613,771	16.01	26.92	43.9
New Canaan	6,792	129,423	39,247	168,670	19.06	24.83	52.2
New Fairfield	4,675	60,053	9,337	69,390	12.85	14.84	35.2
New Milford	10,585	116,931	63,097	180,028	11.05	17.01	30.3
Newtown	8,704	105,848	59,497	165,346	12.16	19.00	33.3
Norwalk	32,503	230,927	238,474	469,401	7.10	14.44	19.5
Redding	3,294	43,469	13,474	56,943	13.20	17.29	36.2
Ridgefield	8,342	109,373	95,911	205,284	13.11	24.61	35.9
Sherman	1,429	20,692	2,077	22,769	14.48	15.93	39.7
Stamford	46,469	444,454	658,390	1,102,843	9.56	23.73	26.2
Weston	3,289	59,701	6,734	66,435	18.15	20.20	49.7
Westport	9,459	157,374	90,223	247,596	16.64	26.18	45.6
Wilton	6,058	87,230	84,384	171,614	14.40	28.33	39.4
Region	**212,363**	**2,459,973**	**2,093,082**	**4,553,056**	**11.58**	**21.44**	**31.7**

Step 2: Solar Radiation, Photovoltaic Performance Goals to Meet Residential Electricity

Municipality	**Direct Normal Solar Radiation (Watt Hours/M2) Annual Average**	**Specific PV Power Output Per Day (kWh/Day)**	**Direct Normal Solar Radiation (kWh/M2) Per Day**	**Direct Normal Solar Radiation (kWh/M2) Per Year**	**Adjust Daily kWh to account for Various Losses (1.4 *Electricity Use by HH/Day)**	**Adjust Annual kWh to account for Various Losses (1.4 Adjustment Factor)**	**Solar System Size (in Kw Capacity) to meet Annual Electricity Needs**
Bethel	4253	3.907	4.198	1532	41.3	15,076	9.839
Bridgewater	4277	3.932	4.212	1537	57.9	21,123	13.739
Brookfield	4206	3.844	4.145	1513	46.0	16,790	11.098
Danbury	4291	3.929	4.217	1539	36.4	13,273	8.623
Darien	4372	4.010	4.312	1574	63.7	23,244	14.769
Greenwich	4333	3.988	4.275	1560	61.4	22,417	14.366
New Canaan	4321	3.979	4.269	1558	73.1	26,677	17.121
New Fairfield	4238	3.894	4.146	1513	49.3	17,984	11.884
New Milford	4191	3.876	4.125	1506	42.4	15,466	10.272
Newtown	4289	3.932	4.221	1541	46.6	17,025	11.051
Norwalk	4369	3.998	4.312	1574	27.3	9,947	6.320
Redding	4321	3.954	4.246	1550	50.6	18,475	11.921
Ridgefield	4325	3.957	4.258	1554	50.3	18,356	11.811
Sherman	4207	3.861	4.129	1507	55.5	20,272	13.451
Stamford	4355	3.990	4.297	1568	36.7	13,390	8.538
Weston	4331	3.979	4.274	1560	69.6	25,413	16.290
Westport	4342	3.981	4.293	1567	63.8	23,292	14.865
Wilton	4308	3.951	4.237	1547	55.2	20,159	13.035
Region	**4296**	**3.942**	**4.231**	**1544**	**44.4**	**16,217**	**10.500**

Step 3: Costs, Savings and Payback Periods to Install Photovoltaic Panels to Meet Existing Electricity Needs

Municipality	**Number of 300-Watt Solar Panels Required to Meet Annual Electrical Need**	**Number of 600-Watt Solar Panels Required to Meet Annual Electrical Need**	**Installation cost @ $2.65 per Watt**	**Connecticut Electricity Cost (Cents per Kilowatt Hour)**	**Yearly Savings through Solar (in Dollars)**	**Number of 300-Watt Solar Panels Required to Meet Annual Electrical Need**
Bethel	32.8	16.4	$26,073.52	$0.265	$2,851.54	9.1
Bridgewater	45.8	22.9	$36,409.43	$0.265	$3,995.21	9.1
Brookfield	37.0	18.5	$29,408.44	$0.265	$3,175.66	9.3
Danbury	28.7	14.4	$22,850.94	$0.265	$2,510.41	9.1
Darien	49.2	24.6	$39,136.67	$0.265	$4,396.42	8.9
Greenwich	47.9	23.9	$38,070.47	$0.265	$4,239.96	9.0
New Canaan	57.1	28.5	$45,369.99	$0.265	$5,045.82	9.0
New Fairfield	39.6	19.8	$31,492.35	$0.265	$3,401.51	9.3
New Milford	34.2	17.1	$27,220.54	$0.265	$2,925.21	9.3
Newtown	36.8	18.4	$29,284.00	$0.265	$3,220.20	9.1
Norwalk	21.1	10.5	$16,747.65	$0.265	$1,881.35	8.9
Redding	39.7	19.9	$31,590.30	$0.265	$3,494.38	9.0
Ridgefield	39.4	19.7	$31,298.04	$0.265	$3,471.84	9.0
Sherman	44.8	22.4	$35,645.94	$0.265	$3,834.35	9.3
Stamford	28.5	14.2	$22,624.49	$0.265	$2,532.68	8.9
Weston	54.3	27.1	$43,168.43	$0.265	$4,806.60	9.0
Westport	49.5	24.8	$39,391.97	$0.265	$4,405.60	8.9
Wilton	43.5	21.7	$34,543.12	$0.265	$3,812.91	9.1
Region	**35.0**	**17.5**	**$27,825.56**	**$0.265**	**$3,067.39**	**9.1**

Step 4: Payback for Photovoltaic Panels Based on Federal Tax Credits

Municipality	**Installation cost @ $2.65 per Watt**	**Federal Tax Credit of 30% in 2022**	**Value of Tax Credit**	**Net Cost After Tax Credit**	**Yearly Savings through Solar (in Dollars)**	**Years for Payback with Federal tax Credits**
Bethel	$26,073.52	0.30	$7,822.06	$18,251.46	$2,851.54	6.4
Bridgewater	$36,409.43	0.30	$10,922.83	$25,486.60	$3,995.21	6.4
Brookfield	$29,408.44	0.30	$8,822.53	$20,585.90	$3,175.66	6.5
Danbury	$22,850.94	0.30	$6,855.28	$15,995.66	$2,510.41	6.4
Darien	$39,136.67	0.30	$11,741.00	$27,395.67	$4,396.42	6.2
Greenwich	$38,070.47	0.30	$11,421.14	$26,649.33	$4,239.96	6.3
New Canaan	$45,369.99	0.30	$13,611.00	$31,758.99	$5,045.82	6.3
New Fairfield	$31,492.35	0.30	$9,447.70	$22,044.64	$3,401.51	6.5
New Milford	$27,220.54	0.30	$8,166.16	$19,054.38	$2,925.21	6.5
Newtown	$29,284.00	0.30	$8,785.20	$20,498.80	$3,220.20	6.4
Norwalk	$16,747.65	0.30	$5,024.30	$11,723.36	$1,881.35	6.2
Redding	$31,590.30	0.30	$9,477.09	$22,113.21	$3,494.38	6.3
Ridgefield	$31,298.04	0.30	$9,389.41	$21,908.63	$3,471.84	6.3
Sherman	$35,645.94	0.30	$10,693.78	$24,952.16	$3,834.35	6.5
Stamford	$22,624.49	0.30	$6,787.35	$15,837.14	$2,532.68	6.3
Weston	$43,168.43	0.30	$12,950.53	$30,217.90	$4,806.60	6.3
Westport	$39,391.97	0.30	$11,817.59	$27,574.38	$4,405.60	6.3
Wilton	$34,543.12	0.30	$10,362.93	$24,180.18	$3,812.91	6.3
Region	**$27,825.56**	**0.30**	**$8,347.67**	**$19,477.89**	**$3,067.39**	**6.3**

Step 5: Payback for Photovoltaic Panels with Energy Conservation but NO Federal Tax Credit

Municipality	Energy reduced by Conservation over Baseline (kWh/Year)	Adjust kWh/Year Various Losses (1.4 Times Column H)	Solar System Size (in kWh) to meet Annual Electricity Needs (kWh)	300-Watt Solar Panels to Meet Annual Electrical Need (#)	600-Watt Solar Panels to Meet Annual Electrical Need (#)	Energy Conservation Installation Cost @ $2.65 per Watt	Electricity Cost (Cents per Kilowatt Hour)	Yearly Savings through Solar (in Dollars)	Yearly Savings Through Conservation @ 25% kWh Reduction	Years for Payback
Bethel	9,692	13,568	8.86	29.5	14.8	$23,466.17	$0.265	$2,566.38	$2,799.85	4.4
Bridgewater	13,579	19,010	12.37	41.2	20.6	$32,768.48	$0.265	$3,595.68	$3,922.78	4.4
Brookfield	10,793	15,111	9.99	33.3	16.6	$26,467.59	$0.265	$2,858.09	$3,118.09	4.4
Danbury	8,532	11,945	7.76	25.9	12.9	$20,565.84	$0.265	$2,259.37	$2,464.90	4.4
Darien	14,943	20,920	13.29	44.3	22.2	$35,223.01	$0.265	$3,956.78	$4,316.73	4.3
Greenwich	14,411	20,175	12.93	43.1	21.5	$34,263.42	$0.265	$3,815.96	$4,163.10	4.3
New Canaan	17,150	24,010	15.41	51.4	25.7	$40,832.99	$0.265	$4,541.24	$4,954.36	4.3
New Fairfield	11,561	16,185	10.70	35.7	17.8	$28,343.11	$0.265	$3,061.36	$3,339.85	4.4
New Milford	9,942	13,919	9.24	30.8	15.4	$24,498.48	$0.265	$2,632.69	$2,872.19	4.5
Newtown	10,945	15,323	9.95	33.2	16.6	$26,355.60	$0.265	$2,898.18	$3,161.83	4.3
Norwalk	6,394	8,952	5.69	19.0	9.5	$15,072.89	$0.265	$1,693.21	$1,847.25	4.3
Redding	11,877	16,627	10.73	35.8	17.9	$28,431.27	$0.265	$3,144.95	$3,431.04	4.3
Ridgefield	11,800	16,520	10.63	35.4	17.7	$28,168.24	$0.265	$3,124.66	$3,408.91	4.3
Sherman	13,032	18,245	12.11	40.4	20.2	$32,081.34	$0.265	$3,450.92	$3,764.85	4.4
Stamford	8,608	12,051	7.68	25.6	12.8	$20,362.04	$0.265	$2,279.42	$2,486.77	4.3
Weston	16,337	22,871	14.66	48.9	24.4	$38,851.59	$0.265	$4,325.94	$4,719.47	4.3
Westport	14,974	20,963	13.38	44.6	22.3	$35,452.77	$0.265	$3,965.04	$4,325.74	4.3
Wilton	12,959	18,143	11.73	39.1	19.6	$31,088.80	$0.265	$3,431.62	$3,743.80	4.3
Region	**10,425**	**14,596**	**9.45**	**31.5**	**15.8**	**$25,043.00**	**$0.265**	**$2,760.65**	**$3,011.79**	**4.3**

Step 6: Payback with Energy Conservation, Federal Tax Credit & Eversource Incentives Applied

Municipality	**Energy Conservation Installation cost@ $2.65 per Watt**	**Installation Cost after Federal Tax Credit & Conservation Applied**	**Yearly Savings through Solar ($) with Tax Credits**	**Yearly Savings Through Energy Conservation @ 25% kWh Reduction**	**Annualized Eversource net Incentives @.0318 kWh**	**Yearly Saving Solar, Conservation, and Incentives Option (in Dollars)**
Bethel	$23,466.17	$17,364.96	$2,566.38	$2,851.54	$308.20	$5,674.43
Bridgewater	$32,768.48	$24,248.68	$3,595.68	$3,995.21	$431.81	$7,950.28
Brookfield	$26,467.59	$19,586.02	$2,858.09	$3,175.66	$343.23	$6,319.41
Danbury	$20,565.84	$15,218.72	$2,259.37	$2,510.41	$271.33	$4,995.60
Darien	$35,223.01	$26,065.03	$3,956.78	$4,396.42	$475.17	$8,748.69
Greenwich	$34,263.42	$25,354.93	$3,815.96	$4,239.96	$458.26	$8,437.32
New Canaan	$40,832.99	$30,216.41	$4,541.24	$5,045.82	$545.36	$10,040.95
New Fairfield	$28,343.11	$20,973.90	$3,061.36	$3,401.51	$367.64	$6,768.84
New Milford	$24,498.48	$18,128.88	$2,632.69	$2,925.21	$316.16	$5,821.04
Newtown	$26,355.60	$19,503.15	$2,898.18	$3,220.20	$348.04	$6,408.05
Norwalk	$15,072.89	$11,153.94	$1,693.21	$1,881.35	$203.34	$3,743.80
Redding	$28,431.27	$21,039.14	$3,144.95	$3,494.38	$377.68	$6,953.67
Ridgefield	$28,168.24	$20,844.50	$3,124.66	$3,471.84	$375.24	$6,908.80
Sherman	$32,081.34	$23,740.20	$3,450.92	$3,834.35	$414.42	$7,630.18
Stamford	$20,362.04	$15,067.91	$2,279.42	$2,532.68	$273.74	$5,039.93
Weston	$38,851.59	$28,750.18	$4,325.94	$4,806.60	$519.50	$9,564.91
Westport	$35,452.77	$26,235.05	$3,965.04	$4,405.60	$476.16	$8,766.95
Wilton	$31,088.80	$23,005.72	$3,431.62	$3,812.91	$412.11	$7,587.52
Region	**$25,043.00**	**$18,531.82**	**$2,760.65**	**$3,067.39**	**$331.53**	**$6,103.97**

Step 7: Payback Based on Present Value of Money for Conservation, Tax Credits & Eversource Incentives

Municipality	**Years for Payback with Federal tax Credits & Energy Conservation**	**Installation Cost after Federal Tax Credit & Energy Conservation**	**Years for Payback with Federal Tax Credits, Energy Conservation & Net Incentives from Eversource Without Considering Increasing Electric Costs**	**Savings at Year Three Based on Electricity Inflation Factor Derived from Past Eversource Trends in Rate Increase**	**Years for Payback Based on Inflation Factor for Electricity Costs**
Bethel	3.0	$17,364.96	3.1	$19,694.04	2.6
Bridgewater	3.0	$24,248.68	3.1	$27,592.75	2.6
Brookfield	3.1	$19,586.02	3.1	$21,932.56	2.7
Danbury	3.0	$15,218.72	3.0	$17,338.06	2.6
Darien	3.0	$26,065.03	3.0	$30,363.76	2.6
Greenwich	3.0	$25,354.93	3.0	$29,283.11	2.6
New Canaan	3.0	$30,216.41	3.0	$34,848.79	2.6
New Fairfield	3.1	$20,973.90	3.1	$23,492.39	2.7
New Milford	3.1	$18,128.88	3.1	$20,202.89	2.7
Newtown	3.0	$19,503.15	3.0	$22,240.20	2.6
Norwalk	3.0	$11,153.94	3.0	$12,993.48	2.6
Redding	3.0	$21,039.14	3.0	$24,133.85	2.6
Ridgefield	3.0	$20,844.50	3.0	$23,978.15	2.6
Sherman	3.1	$23,740.20	3.1	$26,481.82	2.7
Stamford	3.0	$15,067.91	3.0	$17,491.90	2.6
Weston	3.0	$28,750.18	3.0	$33,196.60	2.6
Westport	3.0	$26,235.05	3.0	$30,427.16	2.6
Wilton	3.0	$23,005.72	3.0	$26,333.76	2.6
Region	**3.0**	**$18,531.82**	**3.0**	**$21,184.85**	**2.6**

Appendix 12: Total Daily Solar Radiation: Average BTU per Square Foot at 40° N. Latitude

0 Degree Inclination

Month	South	SE/SW	East/West	NE/NW	North
21-Dec	463	463	363	463	463
January 21 or November 21	512-536	512-536	512-536	512-536	512-536
February 21 or October 21	809-866	809-866	809-866	809-866	809-866
March 21 or September 21	1105-1258	1105-1258	1105-1258	1105-1258	1105-1258
April 21 or August 21	1546-1622	1546-1622	1546-1622	1546-1622	1546-1622
May 21 or July 21	1851-1873	1851-1873	1851-1873	1851-1873	1851-1873
21-Jun	1920	1920	1920	1920	1920
	10 Degree Inclination (17.6% Slope)				
Month	South	SE/SW	East/West	NE/NW	North
21-Dec	583	572	455	377	342
January 21 or November 21	634-666	600-630	507-530	438-457	394-408
February 21 or October 21	952-1022	908-975	810-867	707-754	600-702
March 21 or September 21	1236-1409	1200-1369	1102-1254	1008-1144	965-1094
April 21 or August 21	1618-1698	1570-1645	1536-1611	1473-1544	1418-1486
May 21 or July 21	1848-1869	1884-1906	1843-1864	1805-1826	1700-1781
21-Jun	1912	1937	1916	1899	1842
	20 Degree Inclination (Slope 36.3%)				
Month	South	SE/SW	East/West	NE/NW	North
21-Dec	695	595	419	291	216
January 21 or November 21	741-780	674-708	471-494	352-363	260-265
February 21 or October 21	1079-1160	1001-1075	759-813	598-635	496-524
March 21 or September 21	1318-1506	1253-1430	1073-1270	890-1004	803-901
April 21 or August 21	1680-1762	1632-1712	1479-1551	1344-1409	1281-1341
May 21 or July 21	1871-1893	1866-1888	1775-1796	1705-1725	1663-1682
21-Jun	1898	1903	1830	1790	1773
	90 Degree Inclination				
Month	South	SE/SW	East/West	NE/NW	North
21-Dec	904	694	292	149	118
January 21 or November 21	894-944	722-759	316-326	162-163	136
February 21 or October 21	1037-1116	873-934	511-539	246-252	190
March 21 or September 21	941-1066	900-1017	714-801	371-396	249
April 21 or August 21	847-881	943-983	849-884	546-562	329-331
May 21 or July 21	674-679	901-909	984-994	725-730	460-472
21-Jun	648	872	980	777	521

Source: Victor Olgay, Design with Climate: Bioclimatic Approach to Architectural Regionalism, 2015, p.47

Appendix 13: Tree Shadows Cast at 30° & 45° Azimuths from True South: December 21

	Municipality	AM Sun Elevation (Degrees)	AM Local Time (Hr:Min:Sec)	Solar Noon Local Time (Hr:Min:Sec)	PM Local Time (Hr:Min:Sec)	PM Sun Elevation (Degrees)	Shadow Cast by 65 Foot Tree on 12/21 (Feet)
30° azimuth	Bethel	19.15	9:47:50	11:51:35	13:55:50	19.15	187.18
	Bridgewater	19.00	9:47:28	11:51:23	13:55:46	19.00	188.77
	Brookfield	19.06	9:47:42	11:51:33	13:55:54	19.06	188.13
	Danbury	19.14	9:48:02	11:51:49	13:56:06	19.14	187.29
	Darien	19.44	9:48:18	11:51:50	13:55:52	19.44	184.17
	Greenwich	19.47	9:48:50	11:52:11	13:56:10	19.47	183.86
	New Canaan	19.36	9:48:16	11:51:53	13:55:58	19.36	184.99
	New Fairfield	19.06	9:47:59	11:51:51	13:56:12	19.06	188.13
	New Milford	18.96	9:47:40	11:51:35	13:56:00	18.96	189.20
	Newtown	19.12	9:47:20	11:51:08	13:55:56	19.12	187.50
	Norwalk	19.40	9:48:00	11:51:34	13:55:38	19.40	184.58
	Redding	19.25	9:47:56	11:51:37	13:55:48	19.25	186.13
	Ridgefield	19.23	9:48:14	11:51:55	13:56:08	19.23	186.34
	Sherman	18.96	9:47:59	11:51:55	13:56:20	18.96	189.20
	Stamford	19.46	9:48:32	11:52:03	13:56:04	19.46	183.96
	Weston	19.29	9:47:46	11:51:26	13:55:36	19.29	185.71
	Westport	19.37	9:47:44	11:51:21	13:55:26	19.37	184.89
	Wilton	19.32	9:48:00	11:51:26	13:55:46	19.32	185.40
	Average	19.22				19.22	186.40
45° azimuth	Bethel	10.85	8:34:56	11:51:35	3:08:46	10.85	339.13
	Bridgewater	10.73	8:34:36	11:51:23	3:08:38	10.73	343.02
	Brookfield	10.78	8:34:50	11:51:33	3:08:46	10.78	341.39
	Danbury	10.84	8:35:08	11:51:49	3:09:00	10.84	339.45
	Darien	11.10	8:35:24	11:51:50	3:08:46	11.10	331.31
	Greenwich	11.12	8:35:50	11:52:11	3:09:13	11.12	330.70
	New Canaan	11.03	8:35:22	11:51:53	3:08:52	11.03	333.46
	New Fairfield	10.78	8:35:08	11:51:51	3:09:05	10.78	341.39
	New Milford	10.69	8:34:48	11:51:35	3:08:54	10.69	344.33
	Newtown	10.82	8:34:26	11:51:08	3:08:20	10.82	340.10
	Norwalk	11.06	8:35:06	11:51:34	3:08:34	11.06	332.54
	Redding	10.95	8:35:08	11:51:37	3:08:42	10.95	335.96
	Ridgefield	10.93	8:35:20	11:51:55	3:09:02	10.93	336.59
	Sherman	10.69	8:35:08	11:51:55	3:09:14	10.69	344.33
	Stamford	11.11	8:35:38	11:52:03	3:08:38	11.11	331.00
	Weston	10.97	8:34:53	11:51:26	3:08:46	10.97	335.33
	Westport	11.04	8:34:50	11:51:21	3:08:20	11.04	333.15
	Wilton	11.00	8:35:53	11:51:26	3:08:41	11.00	334.40
	Average	10.92				10.92	337.03

Source: WestCOG staff analysis based on NOAA Solar Calculator, December 12, 2022

Websites with Useful Solar Calculators and Energy Data for Renewable Energy Planning

PVWatts® Calculator: This website calculates the amount of photovoltaic energy generated by location for various sized PV panels at various tilt angles anywhere in the United States. It is a service provided by the National Renewable Energy Laboratory. Based on your specific latitude and longitude, you select the size of the PV panels to be installed and it will determine the total amount of electricity generated by month for the orientation and tilt angle selected.

Sustainable by Design: This website provides a tool to determine panel shading based on various input variables. Based on the panel spacing, orientation, height, thickness, tilt and surface slope the calculator determines one of three monthly outputs; the amount of shading; the amount of solar energy or the amount of power generated. It is particularly useful for those installing multiple rows of ground mounted solar panels. This same website also has several other valuable tools including a sun angle calculator, sun position calculator, six window shading tools including a tool to evaluate the appropriate overhang for shading windows from excessive summertime sun and a window heat gain calculator. The Sun angle calculator can be used to determine the exact angles of the sun at your proposed solar installation based on either your latitude or longitude or your zip code. The outputs from the sun angle calculator are the altitude and azimuth of the sun for any day or time of the year and the clock time and solar time for each day of the year. The window heat gain calculator is useful as a means to determine solar heat gain based on the U value of the windows, the solar heat gain coefficient, window orientation and ground reflection factors.

NOAA Solar Calculator: This website allows users to Find Sunrise, Sunset, Solar Noon and Solar Position for Any Place on Earth. It also can be used to determine the azimuth angles for the sun at any time of day for any location on earth. For this reason, this is an important tool for determining worst case sun altitude angles on December 21st of any year that in turn can be used to determine shadow lengths.

Calculation of Solar Insolation: This website provides the maximum amount of solar insolation on a surface at a particular tilt angle based on the equation of the sun's position in the sky throughout the year. It calculates the sun's position as a function of latitude and day of the year. These calculations are also used in experimental data from sunshine hour recorders. The website animations calculate the daily solar irradiance, the solar insolation and the number of hours during the day which the sun is shining. The graphs do not include local weather effects and so these theoretical graphs are not used in system sizing or prediction of operation.

Degree Days Calculated Accurately for Locations Worldwide: This website provides the number of degree days for heating and cooling based on Centigrade or Fahrenheit measurements for daily, weekly or monthly periods of time or custom measurements. Base temperature can be set by the system user. The website uses data from weather stations throughout the world and these can be inserted into the search engine or the user can search for the weather station nearest to the project.

Energize CT: This website contains annual electricity consumption data for every municipality in Connecticut. The data is useful in estimating the anticipated photovoltaic electricity required to meet current consumptions levels for the average household in each of the 169 municipalities of Connecticut.

U.S. States Profile and Energy Estimates: The U.S. Energy Information Administration provides the most comprehensive summary of energy data for the fifty states. Data includes electric generation, consumption, renewable energy profiles, retails sales, revenues and average price by sector of the electricity industry, and dozens of other sector level reports on the electricity sector. The database provides state level comparisons of performance and also the reliability of electricity as measured by various power interruptions.

Glossary of Terms

Battery Storage System is a device that reserves energy for later consumption that is charged by a connected solar system. The stored electricity is consumed after sundown, during energy demand peaks, or during a power outage. Most common on residential or commercial buildings. However battery storage is also being developed at the utility scale as well. Source: Sunrun

Behind the Meter Solar refers to energy production and storage systems that directly supply homes and buildings with electricity. Residential and commercial solar panels are considered to be behind-the-meter, as are residential and commercial solar batteries. The energy that is produced and/or stored by these systems is separate from the grid and does not need to be counted by a meter before being used, so they are positioned behind the meter. Source: Boston Solar

Bi-Facial Solar Panels create photovoltaic power from both sides of a bifacial module, increasing total energy generation. They're often more durable because both sides are UV resistant, and potential-induced degradation (PID) concerns are reduced when the bifacial module is frameless. Source: Solar Power World.

Building Integrated Photovoltaic Systems (BIPC) are solar power generating products or systems that are seamlessly integrated into the building envelope and part of building components such as façades, roofs or windows. Source: Government of Canada

Community Solar is as any solar project or purchasing program, within a geographic area, in which the benefits of a solar project flow to multiple customers such as individuals, businesses, nonprofits, and other groups. In most cases, customers are benefitting from energy generated by solar panels at an off-site array. Source: U.S. Department of Energy.

Decarbonize the energy system means replacing the fossil fuel energy sources currently being used (such as coal, oil/petroleum, and natural gas) with energy sources that emit far less carbon dioxide (such as wind, solar, and nuclear energy). Source: Proceedings of the National Academy of Sciences

Distributed Generation of Electricity refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels and combined heat and power. Distributed generation may serve a single structure, such as a home or business, or it may be part of a micro-grid such as an industrial facility or a large college campus. When connected to the electric utility's lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines. Source: U.S. Environmental Protection Agency

Grid-connected Solar Energy Systems refers to photovoltaic panels that are used to generate electricity for an electric utility company without any direct connection to residential, commercial or industrial customers. Grid-connected solar energy systems are to be distinguished from Behind the Meter (BTM) Solar Energy Systems since the latter directly serve the electricity needs of individual customers and, if there is a surplus, export the balance to the electric grid.

Micro-Grids a small network of electricity users with a local source of supply that is usually attached to a centralized national grid but is able to function independently. U.S. Department of Energy

Micro Inverter is a device used with solar arrays to convert the energy that is generated (Direct Current) to usable electricity for a home (Alternating Current). Each micro-inverter is connected to a

single solar panel for maximum control and reliability. The advantage of micro inverters is that they reduce the shading associated with inverters functioning for an entire array of solar panels since each panel's performance is independent of every other solar panel. Source: Sunrun

Power Purchase Agreement is a contract between two parties, one which generates electricity (the seller) and one which is looking to purchase electricity (the buyer). The PPA defines the terms for the sale of electricity between two parties, including when the project will begin commercial operation, schedule for delivery of electricity, penalties for under delivery, payment terms, and termination. Source: Wikipedia

Photovoltaic Materials and devices convert sunlight into electrical energy. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. These cells are made of different semiconductor materials and are often less than the thickness of four human hairs. In order to withstand the outdoors for many years, cells are sandwiched between protective materials in a combination of glass and/or plastics. Source: U.S. Department of Energy

Renewable Portfolio Standards (RPS), also referred to as renewable electricity standards (RES), are policies designed to increase the use of renewable energy sources for electricity generation. These policies require or encourage electricity suppliers to provide their customers with a stated minimum share of electricity from eligible renewable resources. U.S. Energy Information Administration

Renewable Energy Certificates (RECs) are an accounting system used by utilities and states to track clean energy. Every megawatt hour generated by a clean energy source (such as a wind turbine) creates one Renewable Energy Certificate. RECs let us measure our progress on clean energy by giving utilities a way to buy and sell renewable power. They also ensure that states can track Renewable Portfolio Standard targets, which are an important tool for combatting the worst effects of climate change and bringing new clean energy jobs to New England. Source: Conservation Law Foundation.

Solar Access means providing unobstructed access to sunlight throughout the year for the critical periods each day to capture the maximum amount of solar energy for home heating or the generation of electricity from photovoltaic panels.

Solar Orientation is placing a building to maximize the amount of heat gained from solar radiation during the coldest months, or it may be oriented to minimize the amount of heat gained in the warmest months. In the Connecticut climate buildings should have the long side of a building oriented within 30 degrees of true south.

Solar Easements means a right, expressed as an easement, restriction, covenant, or condition contained in any deed, contract, or other written instrument executed by or on behalf of any landowner for the purpose of assuring adequate access to direct sunlight for solar energy systems. Source: Law Insider

Solar Shingles are a solar panel that is configured as roof shingles that are integrated into a conventional asphalt type shingle roof. Recent advances in the efficiency of solar shingles or tiles have also led to the development of solar shingles that will integrate into shake, concrete, tile and slate roofs as well. They look a lot like a normal asphalt type shingle and protect your roof from rain like a conventional shingle but have the bonus of being able to convert solar energy into electrical energy for your home. Source: My Solar

Zero Energy Ready home is a high-performance home which is so energy efficient, that a renewable energy system can offset all or most of its annual energy consumption. U.S. Department of Energy

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