Vermont Solar Market Pathways

Volume 1

Summary Report

December 2016

Powered by SunShot
U.S. Department of Energy

Vermont Energy Investment Corporation

RAP®

VERMONT

Vermont Solar Market Pathways

Becoming an Advanced Solar Economy by 2025

David Hill, Damon Lane, Kate Desrochers, Frances Huessy, and Rabi Vandergon

The Vermont Solar Market Pathways project began in late 2014 and will continue through the end of 2017. It is funded through an award from the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (Award No. DE-EE-0006911), to the Vermont Energy Investment Corporation, David G. Hill, Ph.D., Principal Investigator. Subrecipients are the Regulatory Assistance Project and the Vermont Department of Public Service—both of Montpelier, Vermont.

Preface

This Summary Report for the Vermont Solar Market Pathways project is the product of two years of stakeholder engagement, data gathering, and analysis, the specific aims of which are to answer the question: What does it take to advance a state's solar economy sufficiently to meet one of the nation's most ambitious energy goals?

Vermont has such a goal: meeting 90 percent of the state's total energy needs with renewable energy resources by 2050, with several milestones at 2025 and 2035. In particular, this project sought to determine the policy actions necessary to meet 20 percent of that 90 percent goal with solar resources only.

The project's data gathering, research, and analysis depended on comprehensive stakeholder engagement, described throughout this report. With funding from the U.S. Department of Energy (DOE), this work supports the objectives of the Solar Market Pathways program of DOE's SunShot Initiative. In particular, it informs current and future efforts in demonstrating the increasing affordability and advisability of solar energy from the perspective of policy makers.

Acknowledgements

We wish to thank the stakeholders, who supplied a wide range of perspectives, drawn from their own fields and from their willingness to consider other stakeholder interests. **Appendix A, Stakeholder List,** provides the full list of participants in the work.

The team has worked extensively with the Long Range Energy Alternatives Planning System (LEAP), developed and supported by the Stockholm Environment Institute. We would like to thank Charlie Heaps and Taylor Binnington for their expert support and guidance on the use of the LEAP system.

Carl Linvill of the Regulatory Assistance Project led the study's investigation of net metering and alternative rate structures, presented in Volume 2. Critical assistance and guidance on Vermont's Statewide Energy Goals and the Comprehensive Energy Plan were received from Asa Hopkins, Andrew Perchlik, John Woodward, and Anne Margolis. Kim Jones of Green Mountain Power and Steve LeTendre of Green Mountain College provided helpful peer review comments.

We greatly appreciate the support and guidance from the staff of the Department of Energy's SunShot Initiative, including Angela Crooks, Elaine Ulrich, and Michele Boyd. Nicole Enright, Deb Perry and their colleagues at The Institute for Sustainable Communities provided overall coordination for the national Solar Market Pathway awardees. We would also like to thank our peers on the other Solar Market Pathway study teams for their feedback and insights.

Other staff at VEIC who contributed to the project and writing of the report include: Stephanie Baer, Christine Donovan, Suzanne Elowson, Allison Fode, Ethan Goldman, Nick Lange, Ingrid Malmgren, Dave Roberts, and Peter Schneider.

We look forward to continuing work with these and other stakeholders going forward. Any errors or omissions in the report are the responsibility of the primary authors.

Foreword: A Message from Senator Sanders

To my mind, climate change is the single greatest threat facing our planet. Virtually the entire scientific community agrees that human activity is a significant driver of global warming. The United Nation's Intergovernmental Panel on Climate Change warns that if we don't drastically reduce greenhouse gas emissions, the already serious effects of global warming will get much worse by mid-century — including more extreme weather, crop failures, increasing hunger and illness, and mass migrations of people.

While this prognosis is dire, most scientists also agree that we *can* avoid the worst consequences of climate change *if we act boldly*. That means radically transforming our energy system away from fossil fuels and toward renewable and sustainable sources of energy like solar. And that is why efforts like Vermont's Solar Market Pathways project are so important.

Funded through the U.S. Department of Energy's innovative SunShot Initiative and organized by the Vermont Energy Investment Corporation, the Solar Market Pathways project identifies various opportunities and challenges for the widespread adoption of affordable solar energy in Vermont.

I am proud that the state of Vermont has set ambitious sustainable energy goals, including getting 90% of its energy from renewables by 2050. With this report, VEIC and its partners are showing us how to get to that goal. What is more, Vermont's Solar Market Pathways shows that going solar will not only have enormous environmental benefits, but also will provide affordable energy for Vermonters, create new energy sector jobs, and ensure that more energy dollars stay in our state.

Vermont has already seen significant growth in solar. Our installed capacity has increased nearly tenfold over the past five years, and we now rank third in the nation in terms of solar jobs per capita. However, we must do more, and now that we have a roadmap, we must redouble our efforts to make it happen. After all, we have a moral responsibility to do everything possible to ensure our children and grandchildren inherit a planet every bit as habitable as the one we now enjoy.

Sincerely,

Bernie Sanders

United States Senator

Table of Contents

List of Figures

List of Tables

Executive Summary

Vermont is on its way to becoming an advanced solar economy—one in which solar power meets at least 20 percent of the total electric generation needs, statewide, by 2025. Current market trends and State policy both lead toward this level of solar saturation. This is a visible benchmark for considering the challenges and opportunities associated with increased solar, and with increased distributed energy resources.

Over the last two years, we have conducted in-depth scenario analyses and stakeholder engagement to examine the technical, economic, and regulatory policy issues and requirements for reaching this target. The findings clearly indicate that becoming such an advanced solar economy is possible, and that solar is likely to play an important role in Vermont's future economic and energy portfolio.

Solar Is Part of the Total Energy Economy

The work described here investigates the transition from a developed solar economy to an advanced one, across the full energy economy. We do not approach solar in isolation. Our research considers all energy supply and demand resources, across all sectors of the economy. Like any energy economy, Vermont has distinguishing characteristics not commonly shared by other jurisdictions. However, in considering the transition to an advanced solar economy, Vermont can offer insights on innovative policy and business models that make high amounts of solar and other renewable energy economically viable. These emerging features merit policy and business attention in other states and regions, and at the federal level. Vermont can add its own evidence of higher penetration to that of other leading jurisdictions—to prove solar's feasibility and to counter skepticism among lagging jurisdictions.

Challenges and Opportunities

Generating 20 percent of the projected electricity consumption in Vermont by 2025 will require an estimated 1,000 MW (1 gigawatt) of installed solar capacity. This represents an increase of over 10 times the capacity installed at the start of this research. Proper, careful siting of this much solar statewide will be informed and influenced by land use, existing structures and land improvements, aesthetics, natural and cultural resources, location of energy demand, and proximity and capacity of existing electricity infrastructure.

The planning scenarios presented in this study assume significant in-state investments in solar, energy efficiency, and electrification of transportation and space heating. Compared to the business-as-usual (or "Reference") scenario, the advanced solar scenario invests $850 million in efficiency and electrification across 15 years, and an additional $500 million in solar and other renewable generation, and grid infrastructure enhancements. These investments help Vermont avoid significant imports of fossil fuels and electricity, saving more than $1.2 billion over 15 years.

Vermont Solar Market Pathways: Key Findings

SOLAR IS WIDELY AVAILABLE TO HELP MEET VERMONT'S ENERGY NEEDS.
Vermont has sufficient solar resources well-dispersed across the state to meet 20 percent of electricity needs with solar by 2025. Careful planning and siting are important for lower cost and impact. To host enough solar to meet the 2025 target requires about 0.1 percent of Vermont's land area.

MEETING THE VERMONT SOLAR MARKET PATHWAYS TARGET CREATES SIGNIFICANT ECONOMIC BENEFITS.
Through 2025, the total investments and energy expenditures for the Reference (business as usual) scenario and the Solar Development Pathways scenario (SDP; the solar needed to achieve the advanced solar economy target) vary by less than 1 percent. The SDP scenario has higher investments in energy efficiency, solar, and new electric end uses. It also has much lower imports of electricity and fossil fuels. By 2050, the SDP scenario is estimated to create $8 billion in net benefits to Vermont compared to outcomes of the Reference scenario.

THE ELECTRIC GRID CAN HANDLE THE INTEGRATION OF HIGHER AMOUNTS OF SOLAR GENERATION.
To meet the target, Vermont must integrate 1 GW of solar capacity into Vermont's electric grid (which currently peaks at 1 GW). This will require more planning, investment, and upgrades to hardware and operations systems. Technologies and strategies available today can safely and reliably meet these challenges. Many initiatives, collaborations, and new business approaches in Vermont and elsewhere will help the state meet these challenges.

SOLAR CAN HELP LOW- AND MODERATE-INCOME HOUSEHOLDS AFFORD ENERGY.
Great opportunity exists for projects that combine solar and efficiency in increasing energy affordability for low- and moderate-income households. Applying social and energy justice in every project is critical for VEIC. Vermont already has business models, financial strategies, and philanthropic initiatives to support this segment of market growth.

SOLAR INTERACTS WELL WITH OTHER ENERGY TECHNOLOGIES AND EMERGING MARKETS.
Solar and energy efficiency are the most common examples of distributed energy resources (DERs). DERs can also be energy storage, electric load shaping, and demand response. DERs are reshaping energy markets and delivery infrastructure in Vermont and elsewhere. Technical and market advances in Vermont are making electrification of vehicles and space conditioning more attractive. As they accelerate, they will help drive the growth of solar energy, and be driven by it.

THE VERMONT SOLAR PATHWAYS TARGET WILL HELP THE STATE MEET ENERGY, ENVIRONMENTAL, AND OTHER POLICY GOALS.
Vermont has policy targets for meeting 90 percent of the state's total energy needs with renewable resources by 2050 ("90 x 2050"). Vermont Solar Pathways indicates solar is an important contributor for meeting this target in economically and socially equitable ways. Moreover, installing solar energy in Vermont keeps energy expenditures in the state, and reduces dependence on imported fuels. These economic benefits are consistent with Vermont's policy objectives and public opinion. Meeting these targets offers opportunities for Vermont's utilities and businesses to continuously improve and to innovate—and positions them to influence energy markets outside the state.

A Prudent Investment

The net costs for the advanced solar scenarios are only a small fraction of the state's annual energy expenditures and investments. In fact, through 2025, total expenditures in the Reference scenario and in the SDP scenario are within 1 percent of each other. Given variability in energy prices, and the minimal cost difference between the two scenarios, the results indicate that it is economically viable, and prudent for Vermont to invest in a cleaner and a more diverse energy portfolio, based on renewable resources, highly efficient end uses, and a de-carbonized electric supply.

The research results indicate that investments that support high amounts of solar energy generation in Vermont promise significant future economic return. Extending the analysis through 2050, the investments in solar and efficiency result in almost $8 billion of net savings to Vermont consumers. The SDP scenario also reduces greenhouse gas and other emissions, while securing energy resources with less volatile prices, resulting in a more robust and reliable energy system.

Accommodating Solar Generation This High Is Feasible

Solar is an intermittent and variable resource for an electricity grid that must meet the demand for power 24 hours a day, under all conditions. Issues arise from the distribution system, which delivers electricity to the customer, and at the bulk power system level, which interconnects Vermont to the larger regional power markets. Integrating 1 GW of solar capacity into Vermont's electric grid (peaks at 1 GW) will require ongoing research, investment, and upgrades to operations and planning systems. Today's technologies and strategies can safely and reliably meet these challenges, with the help of many initiatives, collaborations, and new business approaches.

Buildings that combine improved energy performance from efficiency with appropriately sited solar installations can lower and stabilize monthly costs for limited-income households. Traditional electricity markets see homes and businesses as energy loads. DERs, on the other hand, can shape and shift consumer energy demand to provide energy generation and storage. The markets, business models, and regulatory policies to expand DERs are still developing. Nevertheless, DERs are clearly reshaping energy markets and energy delivery infrastructure. Vermont's technical and market advances are making electrification of vehicles and space conditioning more attractive, trends that are likely to accelerate.

As the economics of solar continue to improve—through reductions in hardware and installation costs, and with evolving improvements in controls and storage—technical solutions for effective grid integration increase. With increased durability of business models for solar and related technology, more states will likely consider a high-saturation solar future. In addition, with more public attention paid to the social and environmental impacts of energy use, more states might adopt climate goals similar to Vermont's 90 x 2050 target. Helping to meet these targets will reduce serious environmental challenges and provide economic opportunity.

Vermont Solar Market Pathways: Consumer Perspectives from 2025

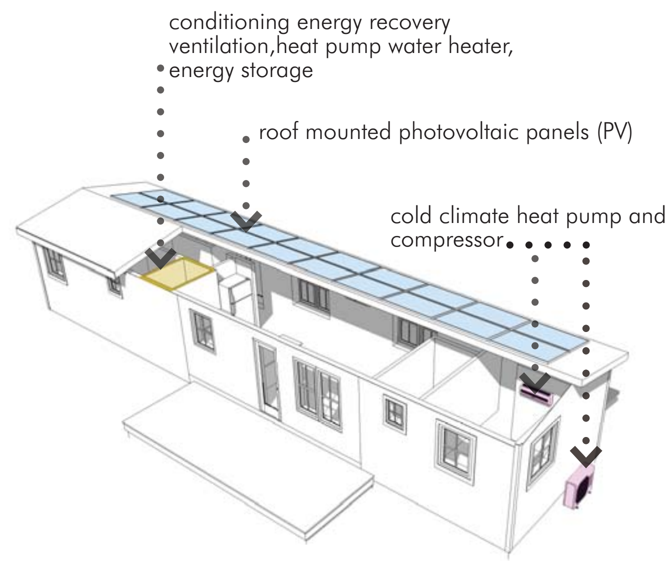
This Summary Report envisions the possible pathways to get to Vermont's advanced solar economy, with 20 percent of electric generation supplied from solar by 2025. Before presenting analysis and research results, we start with a visit to the future, looking at two types of Vermont household. These are imaginary examples, but they are grounded in market trends and possibilities that are emerging today.

The consumer perspective highlights how the value, benefits, and demand for solar and other energy services will drive many of the changes to come. Supported by strong policy and regulatory structures discussed in this report, solar and other energy services can respond to consumer demand and provide lasting value to Vermont in new and original ways.

We look first at the kinds of spaces Vermont households are occupying in this imagined future. One household resides in a relatively new home; the other occupies a classic Vermont farmhouse. What they have in common is that they are looking at energy in a different way from how households in 2016 Vermont look at energy. They are both paying less than their 2016 counterparts are, and they are engaged in new ways with the communities in which they reside.

High Performance and Affordable New Homes

It is a clear day, in summer 2025. You are sitting on the porch of your house, enjoying a cold lemonade. The porch is located at the back of the high-performance modular home you had a local company build and install in 2020. Back then, it was still an unusual concept: a house so efficient, its rooftop solar panels could supply all of the energy the household would need. It is called a *zero energy modular* (ZEM) home. Design and building practices in 2025 are increasingly bringing zero energy performance to modular homes and to other segments of the market. Today, almost all new homebuyers have the ability to compare design options and specify the benefits they want to receive from zero energy homes. The number of modular homebuilders and other builders of efficient housing has risen to meet demand.



Source: Pill Maharam Architects

That ZEM market began as an effort to replace housing damaged by flooding from Tropical Storm Irene in 2011. With a decade-long expansion of the high-performance modular housing market in Vermont, you are not alone in expecting to have as part of your investment: superior energy efficiency, on-site renewable energy generation, and advanced controls that reduce wasted energy in your home. In fact, the ZEM housing segment has been growing particularly rapidly. It is popular with a broad range of people, from first-time homebuyers to empty nesters who are downsizing their living spaces. Families and a large number of single-parent households are also drawn to the affordability, low maintenance, and superior indoor air quality of these units.

What began with one builder of these homes in 2012 has grown to more than a dozen in Vermont. The range for pricing and style choices has grown. Some options closely resemble traditional manufactured homes on the outside. Others are more cottage-like. A third, “modernist” style has also become popular.

Common to all these options are their superior thermal envelope performance, continuous indoor air quality monitoring, and heat recovery ventilation. They also have all been built with durable and non-toxic building materials; electric heat pumps for heating, cooling, and domestic hot water; and on-site or community solar generation with advanced inverters and controls. Since 2024, several senior living communities have invested in new clusters of independent units.

Enhancing Energy Performance for Vermont’s Older Homes

Down the road from you is a 200-year-old house that a young family of four has bought and renovated. Their energy related upgrades included replacing the oil boiler with a new pellet boiler, returning to the homes original wood fuel. They considered investing in solar on their own property, but instead decided to participate in a community solar installation located on a nearby farm. This family is also a customer-member of a community-supported agriculture “farm share” program. They decided to join the community solar group associated with their farm share membership after comparing it to another community solar option hosted by the couple’s employer (both of them work for the local school district). Neither community solar option required up-front payments, and both offered shares that would cover roughly 75 percent of the family’s annual electricity consumption.

Solar array vegetation managed by Prairie Restorations Inc.

The family joined the farm share community solar program primarily because it was easy to sign up. When picking up their farm share, they have always been able to see the vegetables growing, and now they have seen the installation of the solar array. The farmer explained that instead of mowing around the panels, she is going to plant a field with wildflowers and other native plants that will attract bees and other pollinators that will then benefit the vegetable fields. The family has also enjoyed the camaraderie they share with other community members and the farm's owners.

Once burdened with a way of living that typified most family life just 10 years earlier, with unpredictable utility costs from air conditioning in the summer and high utility costs from heating fuels in winter, this family decided to invest some of their own savings in a "deep energy retrofit" a few years ago. They supplemented their savings with low interest financing through their credit union. These funds made it possible for them to complete the retrofit: sealing and insulating the walls, basement, and attic of their house, and installing high-efficiency appliances. The retrofit project also enabled them to enhance and repair some structural features, while fully retaining the centuries-old New England character of their home.

Pathways to the Solar Future

The transition to becoming an advanced solar economy is already under way and is contributing to Vermont meeting the broader target of obtaining 90 percent of the state's total energy from renewable resources by 2050.[1] In this study, we investigate requirements for reaching 20 percent of the total electric generation by 2025, and we present these results and analysis in the context of Vermont's progress toward the longer-term goals for 2050. **Table 1** presents a snapshot of how the advanced solar economy compares to Vermont today.

Table 1. Total energy and electricity consumption in Vermont's advanced solar economy

Total energy		Electricity		Solar		
Total energy demand (TBtu)		Electricity demand (GWh)	Electricity share of total energy demand	Solar generation (GWh)	Share of electricity from solar	Installed capacity (MW)
2015*	116	5,700	17%	280	4.9%	225
2025	106	6,200	20%	1,300	20%	1,000
2050	69	8,800	44%	2,500	28%	2,000

* 2015 values are estimates used in scenario modeling, using the best available data; they are not historic actuals. Vermont's Certificate of Public Good data show just over 250 MW permitted by the end of 2015.

Table 1 shows that solar generation must grow by more than four times the amount produced in 2015 to meet the goal this decade. When this project was conceived, some observers considered the goal of 20 percent of total generation by 2025 to be beyond reach. However, continuing growth trends in Vermont and other jurisdictions with favorable regulatory and market conditions suggest this level of solar saturation can reasonably be expected. Through stakeholder engagement, scenario modeling, and market analysis, the findings indicate that such sustained market growth is technically and economically achievable.

Becoming an Advanced Solar Economy by 2025 Helps Meet Vermont's 2050 Goals

Referenced in this report as *90 x 2050,* this target addresses the electric generation sector, transportation, and space heating, which are the largest consumers of fossil fuels in the state. Research and analysis confirm the findings of the State's *Total Energy Study*[2] and Vermont's *Comprehensive Energy Plans,*[3,4] and reiterate the following as key elements required to meet the 90 x 2050 target:

---

[1] The goal is articulated in "2016 Comprehensive Energy Plan - Executive Summary" (Montpelier, VT: Vermont Department of Public Service, 2016), http://legislature.vermont.gov/assets/Legislative-Reports/Executive-summary-for-web.pdf.

[2] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals" (Montpelier, VT: Vermont Department of Public Service, December 8, 2014),http://publicservice.vermont.gov/publications-resources/publications/total_energy_study.

[3] "2011 Comprehensive Energy Plan" (Montpelier, VT: Vermont Department of Public Service, December 2011),http://publicservice.vermont.gov/publications-resources/publications/energy_plan/2011_plan.

[4] "2016 Comprehensive Energy Plan" (Montpelier, VT: Vermont Department of Public Service, December 2015),http://publicservice.vermont.gov/publications-resources/publications/energy_plan/2015_plan.

- Energy efficiency across all sectors and end uses;
- Fuel switching from fossil fuels (particularly for space heating and transportation) to electricity and biomass; and
- Decarbonization of the electric grid through increased solar and other renewables.

Reflecting these trends, the SDP scenario estimates total energy demand decreasing by 8.6 percent from 2015 to 2025, and by 32 percent by 2050, as shown in **Figure 1**. Some savings are expected to happen through federal standards and changing costs, but the graph also shows additional avoided energy use because of ongoing efficiency and a transition from fossil fuels to electricity in supplying energy for transportation and heating. Given the inherent efficiency of electric drive propulsion and heat pump technology, less primary energy is needed; therefore, the SDP avoids energy that would be required in the Reference scenario.

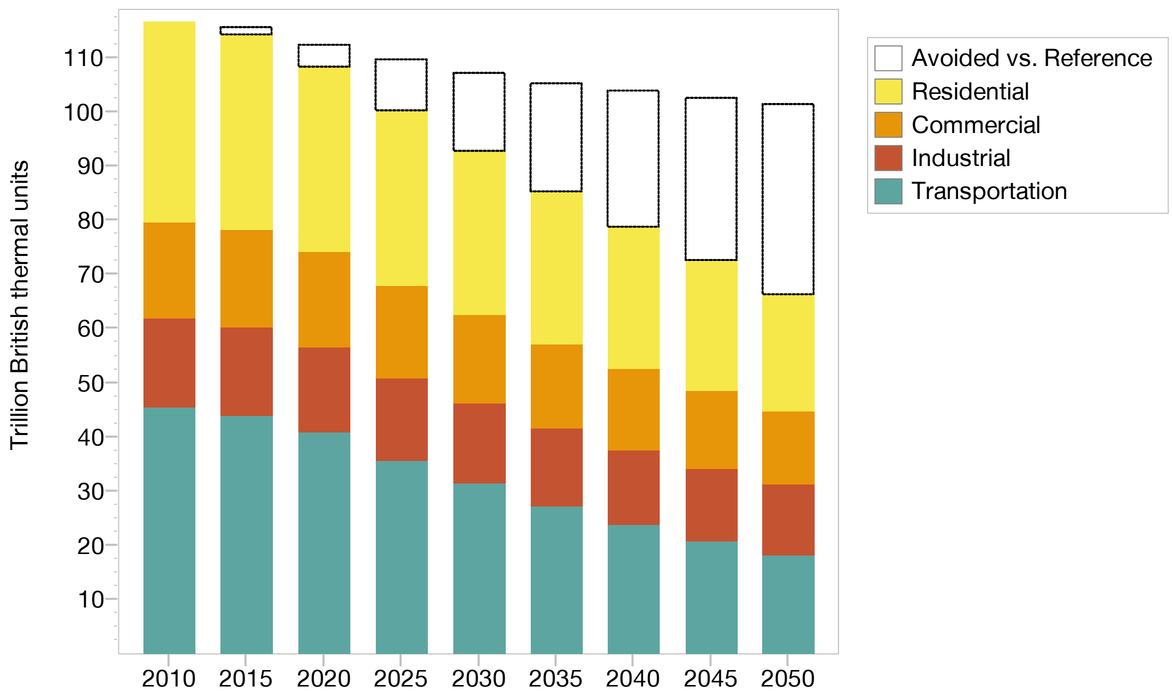


Figure 1. Vermont site energy demand, by 5-year increments, and by market sectors, showing the effect of more aggressive efficiency and fuel switching in the SDP scenario. The white indicates the net gains in the amount of energy not needed ("avoided" energy supply) under the efficiency and fuel-switching SDP scenario, relative to the Reference scenario (business as usual).

Figure 2 illustrates the transition away from fossil fuels toward electricity and renewables that is required to meet the 90 x 2050 goal under the SDP scenario. Reaching the 2050 targets will mean that Vermont has fully transitioned to a renewable energy economy. **Figure 2** also illustrates that as total energy demand will fall, electricity consumption will rise as people switch from fossil fuels to electricity for heating and transportation.

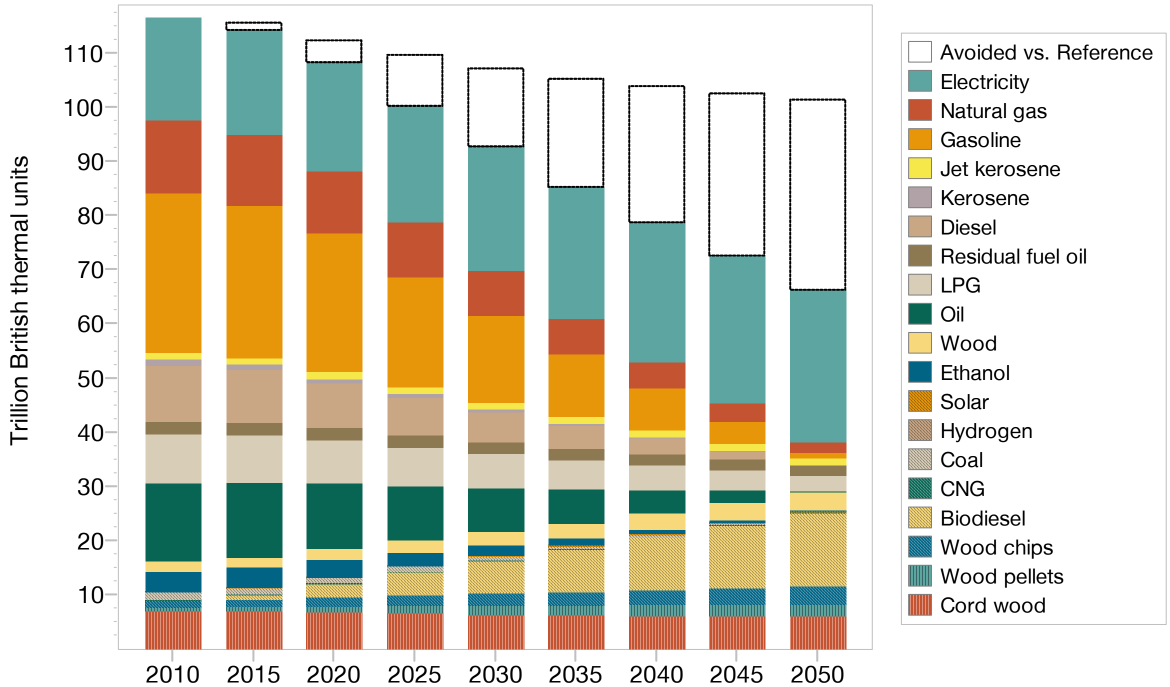


Figure 2. Progress in Vermont toward meeting the 90 x 2050 renewable energy target, by fuel.

Figure 3 shows the growing supply and the increasing mix of renewable resources used to meet that growth in electricity consumption. **Figure 3** also demonstrates the effects of the 2014 retirement of the Vermont Yankee nuclear power station, seen in the drop between 2010 and 2015. In the projection, Vermont moves steadily toward renewables. This will take place through coordinated efforts by residents, businesses (including industry and agriculture), environmental organizations, the utilities, and the State.

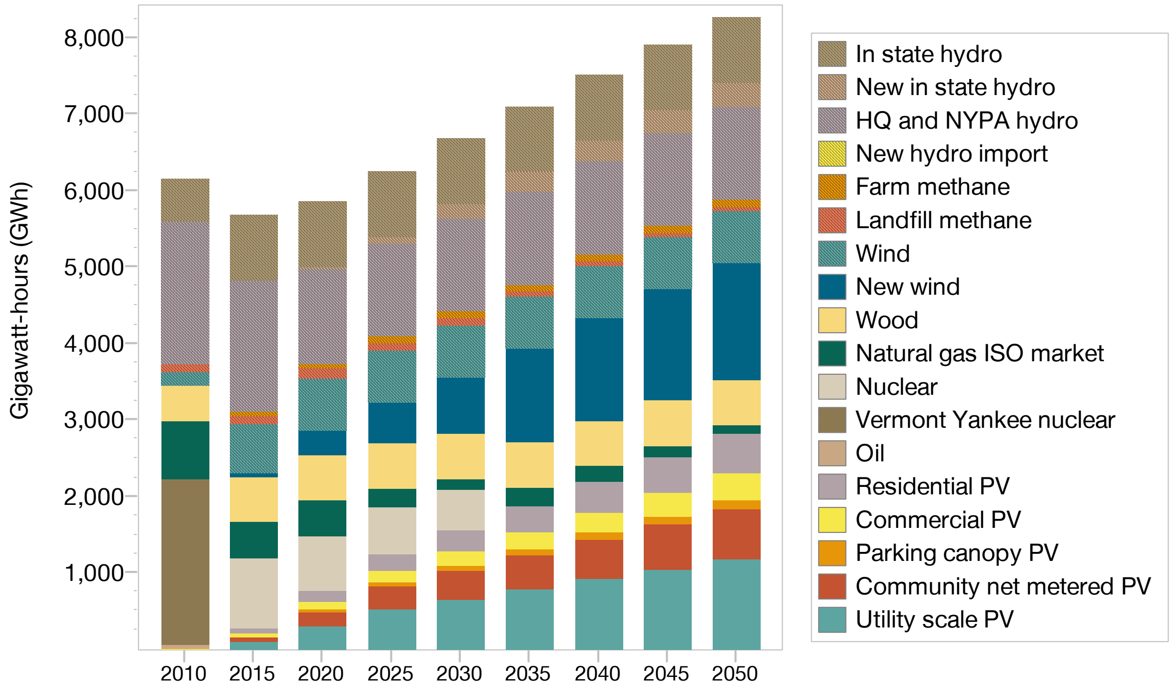


Figure 3. Actual and projected Vermont electricity supply in the SDP scenario, in 5-year increments, and by energy source.

The changes that occurred between the inception of this Solar Market Pathways project in late 2014 and today in early 2017 show that Vermont is moving quickly toward achieving these targets. The changes reflect (1) the Vermont General Assembly's 2014 decision to increase the net metering cap from 4 percent to 15 percent of peak load, (2) the achievement of state's largest city (Burlington) in meeting 100 percent of its electricity needs with renewables, (3) the legislative approval of a renewable portfolio standard, and (4) several of the utilities' reaching the net metering cap ahead of schedule.

High Solar Penetration in Vermont Is Achievable

The level of solar and renewable penetration in the SDP scenario requires careful planning. Although Vermont is a solar leader in many ways, it benefits from the experience of other regions that are achieving high penetration sooner: Germany, Hawai'i, and California are examples. Other places have not gone so far as Vermont has in targeting their solar capacity to equal the grid's peak demand. Thus, Vermont might be breaking new ground by 2025 with its requirement of 1 GW of solar to meet the 20 percent goal, although other energy leaders will likely have made significant progress by then, too. It is worth reiterating that the 1 GW does not count the electrification of transportation and heating systems.

To determine how to reach that target, the Vermont Solar Market Pathways Project Team has evaluated the technical, economic, business model, and regulatory implications of 1 GW of solar. For example, the technical analyses have considered, at a high level, the state's bulk power mix and strategies for integrating solar electricity into the energy distribution system.

Economic Outcomes

Transitioning to an advanced solar economy requires shifts in the types and magnitude of expenditures on energy by Vermont consumers and service providers. Overall, our analyses of the SDP scenario indicate that during the next ten years a total net annual cost for the transition will be approximately $21 million annually. This net cost is much less than 1 percent of expected annual energy expenditures. **Table 2** summarizes the comparative economic results between the SDP and Reference scenarios.

Thus, a transition to the advanced solar economy is economically viable, with a relatively minor difference between the total net costs and benefits, relative to the advanced solar economy under the SDP scenario (and its variants) and the Reference scenario through 2025. Note that these results do not put a value on environmental benefits from reduced emissions, nor on enhanced building durability and occupants' health impacts associated with energy efficiency investments. If a value were put on those factors, the benefits would be even greater.

Table 2. Cumulative costs and benefits of the SDP scenario, relative to the Reference scenario, 2010-2025, discounted at 3 percent to 2015

	SDP vs Reference $ million (2015)
Demand	**$ 851**
Residential	$ 416
Commercial	$ 261
Industrial	$ 58
Transportation	$ 115
Transformation	**$ 498**
Transmission and distribution	$ 13
Electricity generation	$ 485
Resources	**-$ 1,140**
Production	$ 83
Imports	-$ 1,222
Exports	-
Unmet requirements	-
Environmental externalities	-
Non-energy sector costs	-
Net present value	**$ 209**
GHG savings (million tonnes CO_{2e})	**7.1**
Cost of avoiding GHGs	**$ 29**

The largest distinction between the Reference and SDP scenarios is the investment in efficiency, illustrated by the net costs in the demand section of **Table 2**. Over $400 million of net investment in residential efficiency and over $250 million of net investments in the commercial sector will enable the reductions in total energy consumption, shown in **Figure 1** and **Figure 2**. There are also shifts in the production and distribution of electricity, which are represented in the Transformation section of **Table 2**. The present value of the net costs in the transformation sector for the SDP scenario is $498 million. The benefits from these shifts in expenditures and investments are reflected in a significant reduction in net resource imports, more than $1.2 billion.

By extending the analysis through 2050, the net benefits of the transition to an advanced solar economy far outweigh the costs, providing close to $8 billion of economic benefits to the state.

In the advanced solar economy, significantly less of Vermont's energy expenditure will go to energy providers outside the state. The SDP reduces money spent on fuel imports (money sent out of state) by approximately $1.2 billion from 2015-2025, compared to the Reference scenario. Additional economic results are presented in **Section 3.3** of this volume and in **Volume 4**.

Environmental Outcomes

The SDP scenario reduces greenhouse gas emissions by roughly 20 percent by 2025, and by more than 80 percent by 2050. **Figure 4** illustrates these effects.

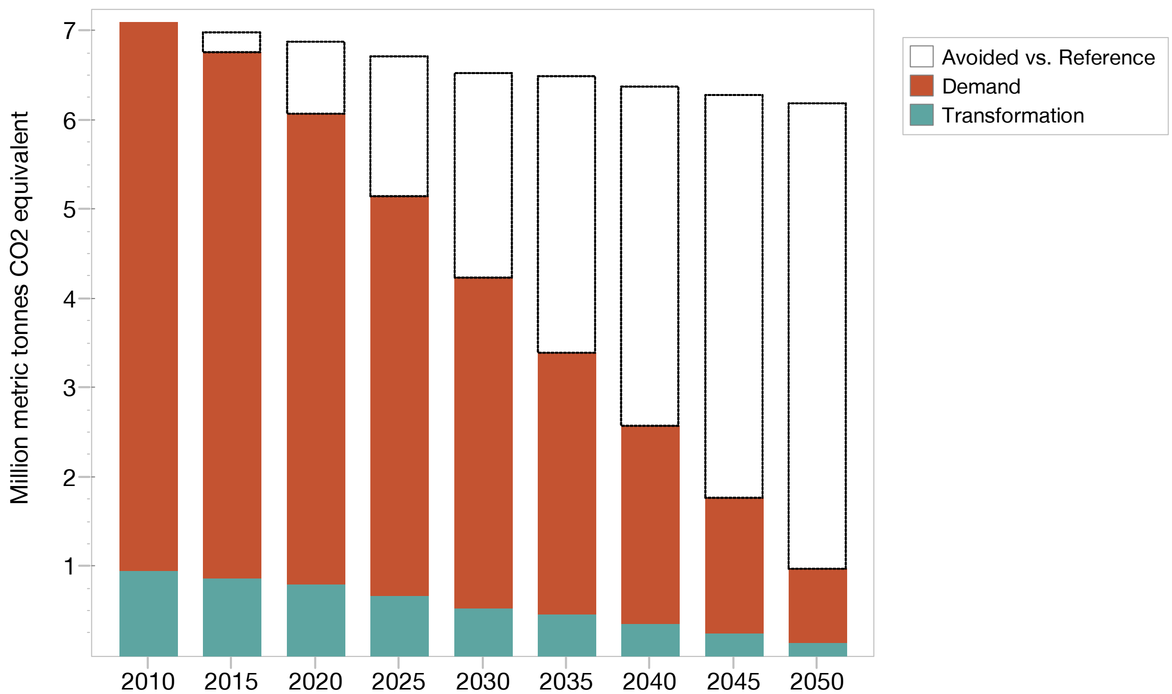


Figure 4. Emissions of the SDP scenario, compared to the Reference scenario.

By 2050, Vermonter's emissions per person fall below 2 metric tonnes per person, a limit suggested for mitigating climate change. Vermonters will see much more of the energy system as in-state renewable projects replace imported energy. Careful siting and project design can limit the impact.

Questions Answered by This Report

There are many issues and factors for states or a region to consider in becoming an advanced solar economy. **Table 3** lists some of the questions that are addressed in the Vermont Solar Market Pathways Report and refers to where in this document and other volumes more detail can be found.

Table 3. Questions answered by the Vermont Solar Market Pathways research

Question	Quick answer	Where to look in this report
Does Vermont have enough solar resource and sites to meet the target?	Yes, Vermont has plentiful solar resource.[5] By 2050, up to 0.2% of the state's land area could be used to meet close to 1/3 of total generation. Siting constraints for land use, and physical and cultural considerations, leave plenty of suitable "prime solar" siting areas for meeting energy needs. Results can support regional and local planning and siting guidance.	**4.1** Siting and System Integration **4.1** Space Requirement
How much will be ground versus roof mounted?	It depends. There is good flexibility to be able to meet targets with a mix of ground- and roof-mounted systems. Roof-mounted solar is not likely to account for more than 300 MW or 1/3 of the 1,000 MW required to meet the target of 20% by 2025.	**4.1** Business Models
Can this much solar be integrated into distribution system?	Yes. Individual sites will continue to need to be evaluated to determine possible distribution grid impacts. However, many sites can host additional PV without costly modifications. Options for storage, load shifting, demand response, and curtailment exist and are emerging to complement traditional solutions of distribution utility hardware upgrades.	**4.1** Distribution System
What about integration with the regional market and transmission system?	It can also be done. Mismatch of supply and demand in 2025 in the SDP is not unlike what utilities manage today. In addition to the distribution tools, utilities can use time-of-use rates and possible regional trading to balance the system. The value of trading will diminish as neighboring states add similar levels of renewable energy.	**4.1** Smart Grid, Demand Management, and Storage **4.1** Bulk Power System Integration
Will business models change?	It is likely. New approaches and business models will emerge across utility, building services, transportation, and solar industries. Innovation relying on advances in information technologies and systems integration will create new value and enable higher saturation solutions.	**4.1** Business Models **4.1** Utility Business Model
What about changes to regulatory and tariff structures?	These will also evolve and change. Rates and regulations enable and catalyze growth of integrated distributed energy resources. There is a mix of more and less regulated elements supporting businesses and consumers in making long-term investment decisions.	**4.1** Smart Grid, Demand Management, and Storage **4.2** Regulatory Considerations

5 National Renewable Energy Laboratory, "Photovoltaic Solar Resource: Flat Plate Tilted South at Latitude" (U.S. Department of Energy, November 2008),http://www.nrel.gov/gis/images/map_pv_us_annual10km_dec2008.jpg.

Question	Quick answer	Where to look in this report
Does the solar future make economic sense?	Yes, the net costs of an advanced solar scenario equal to an annual investment of ~1% of Vermont's total energy expenditures through 2025. By 2050, present value of net benefits is almost $8 billion.	**3.3** Economic Outcomes
Can solar be socially equitable?	Yes, for example, high-performance housing with solar options combine to lower total housing costs, while enhancing occupant health and building durability.	**4.1** Addressing Low-Income People: A Societal Imperative
What about environmental impacts?	The Solar Development Pathways scenario reduces greenhouse gas emissions by ~20% by 2025, compared to the Reference scenario, and 90% by 2050.	**3.4** Environmental Outcomes

The Team further documents these issues, analyses, and potential solutions in **Volume 2, Net Metering and Focus Area Briefs, Volume 3, Barriers and Integration Brief,** and **Volume 4, Methods and Detail Tables**.

1. Introduction

1.1 SunShot Objectives.

This project is one of 15 receiving U.S. Department of Energy (DOE) Solar Market Pathways Program support, within DOE's SunShot Initiative. The specific aim of the SunShot Initiative is to reduce the levelized cost of solar energy systems to $.06 per kWh by 2020. As of the halfway point in the timeline for achieving this goal, SunShot officials estimate that approximately 70 percent of this goal has been met. Since SunShot's launch in 2011, the average price per kWh of energy from a utility-scale photovoltaic (PV) project has dropped from about $0.21 to $0.11.

A major goal of the Solar Market Pathways Program is to make solar deployment faster, easier, and less expensive than it was in 2011, across the United States. The case studies and lessons learned from the 15 awarded Solar Market Pathways projects will provide examples that can be replicated in other jurisdictions—in support of this goal.

1.2 Vermont Solar Market Pathways Objectives

The essential objective of this Vermont Solar Market Pathways project is to examine what is required to attain 20 percent solar generation by 2025, and what the effects of a transition to such an advanced solar economy would be.

Comprehensive solar planning can contribute to lower solar costs through specific mechanisms. By taking a long-term planning perspective and integrating the growth of the solar market into the state's overall energy economy, Vermont Solar Market Pathways will help policy makers, local planning commissions, and the market understand both the potential and the potential barriers to an advanced solar market. This understanding will improve the chances for sustained market growth and investment.

Comprehensive solar strategies and plans can provide greater certainty to businesses, institutions, and utilities investing in solar. This certainty is expected to help lower the soft costs associated with solar energy. By sharing experience and approaches to identifying and addressing barriers to achieving high levels of solar, plans such as this one will also help lower the costs of addressing these barriers.

Moreover, Vermont Solar Market Pathways supports general objectives of regional planning, public discourse, and decision making on increasing the use of solar energy by individuals and businesses.

1.3 Vermont Background

Strong Policy Supports an Advanced Solar Economy

The Vermont Department of Public Service undertook its *Total Energy Study* (TES) in 2014, publishing the results in December of that year. Its primary conclusion was that "Vermont can achieve its greenhouse gas emission reduction goals and its renewable energy goals to do so will require significant changes in energy policy, fuel supply, infrastructure, and technology." [6]

In 2015, the Vermont General Assembly passed the state's first renewable portfolio standard, known as the Renewable Energy Standard (Act 56), which encourages increases in renewable energy supply as a way to reduce total energy use and costs.[7] The Renewable Energy Standard does not contain a carve-out for solar credit. Because of this, the Standard did not create solar renewable energy certificates (SRECs), a common mechanism for advancing accompanying renewable portfolio standards. Nevertheless, the Standard requires 10 percent of electricity to come from distributed generation; we expect solar to provide most of that requirement. Vermont's Renewable Energy Standard is unique in compelling distribution utilities to support the reduction of fossil fuel consumption through actions like weatherization, thermal efficiency measures, and electrification of energy uses traditionally powered by fossil fuels such as heat pumps and electric vehicles.

Vermont's Demographics

Vermont has a small population (626,000 inhabitants), occupying 326,000 housing units, most of which (71 percent) are owner-occupied housing units—primarily single-family houses.[8] Excepting Burlington area, the U.S. Department of Agriculture considers the state's population to be rural. Winters are relatively long, and energy burden is a challenge for many Vermont households. The median Vermont household income is $54,000, only slightly higher than the national average of $53,000.[9] Nevertheless, with a state goal of meeting 90 percent of total energy needs from renewable sources by 2050 (90 x 2050), Vermont policy makers have an advanced vision for achieving energy security and environmental benefits for its inhabitants.

Over 130 MW of net metered solar supplies energy to homes, farms, businesses, and communities.[10] Further, the presence of renewable energy in the supply mix has kept electricity costs at or below the rate of inflation.[11]

The Vermont Department of Public Service estimates that nearly 5 percent of Vermont's workforce (16,000 jobs) is in the clean energy sector.[12]

A Recent History of Energy Supply and Use in Vermont

Vermont has a single transmission system operated by the Vermont Electric Power Company (VELCO). Seventeen local distribution utilities (municipalities, rural electric cooperatives, and an investor-owned utility) provide retail service.

---

[6] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."
[7] General Assembly of the State of Vermont, *An Act Relating to Establishing a Renewable Energy Standard*, 2015,http://legislature.vermont.gov/assets/Documents/2016/Docs/ACTS/ACT056/ACT056%20As%20Enacted.pdf.
[8] "Quick Facts: Vermont," *U.S. Census Bureau*, 2015, www.census.gov/quickfacts/table/PST045215/50.
[9] Ibid.
[10] Department of Public Service, Certificate of Public Good data: VT Generator Data 7-25-16 HC.xlsx
[11] "2016 Comprehensive Energy Plan."
[12] Ibid.

Prior to 2000, all of Vermont's electric utilities (at the time, there were 22) delivered energy efficiency programs to their customers. This well-intended policy had consequences, because investor-owned utilities were caught in a conundrum: To ensure good returns for their shareholders, they needed to sell more electricity; but to ensure compliance with regulators, they needed to promote investments that would reduce electricity sales. Further, energy efficiency program administration was difficult to accomplish effectively for the customers of each of the 22 utilities. Accurate accounting for each utility's contribution to saving energy via retail sales of energy-efficient products in their service territories was also elusive. That is, a store in one utility's location could easily have customers from other utilities buying and installing products—giving the other utilities no information to support a claim to regulators for energy savings.

The Vermont General Assembly created a new entity in 2000, a statewide energy efficiency utility (EEU) for all territory outside the City of Burlington (which maintains its own EEU through the Burlington Electric Department (BED)). The Vermont Energy Investment Corporation (VEIC) has operated the statewide entity, known as Efficiency Vermont, ever since. A 12-year Order of Appointment began in 2010, replacing the earlier 3-year contract cycles, and allows for better planning, greater stability in program offerings, and more strategies for achieving more clean-energy potential than was possible under the shorter cycles.

Throughout Efficiency Vermont's tenure as the statewide EEU, avoided costs of energy supply have been an essential metric in demonstrating the efficacy of energy efficiency. Helping customers use less electricity—through efficient products and appliances, air-sealing and insulation of houses and other buildings, improvements in commercial building energy performance, and many other measures—has a lower average levelized cost than all other new power supply options.[13]

Sustainable energy advisors frequently refer to "efficiency first, then renewables" as a smart path for customers who want to lower their energy costs and carbon footprints. With such a strong and lengthy background in statewide electrical energy efficiency, Vermont has been well positioned to advance its renewable energy economy.

The growth of renewable energy is accelerating: As of late July 2016, 412 MW of wind and solar capacity were online or permitted—of which 70 percent is from solar. Net metering of solar energy to local utilities and the grid has seen a 25 percent increase. It now accounts for 167 MW of solar, compared to 134 MW at the end of 2015.[14] These data signal not only a net increase in renewably supplied energy, but also a disproportionately large jump in energy supply from solar sources.

Figure 5 illustrates the rapid growth of solar and particularly net metering. This market expansion has been propelled by liberal policy toward group net metering; simple permitting; and strong financial performance from a regulated, solar credit adder on utility bills for net metered generation; and the feed-in tariff.

[13] "How Much Does Energy Efficiency Cost?" (American Council for an Energy-Efficient Economy, March 17, 2016), http://aceee.org/how-much-does-energy-efficiency-cost.

[14] Department of Public Service, Certificate of Public Good data: VT Generator Data 7-25-16 HC.xlsx

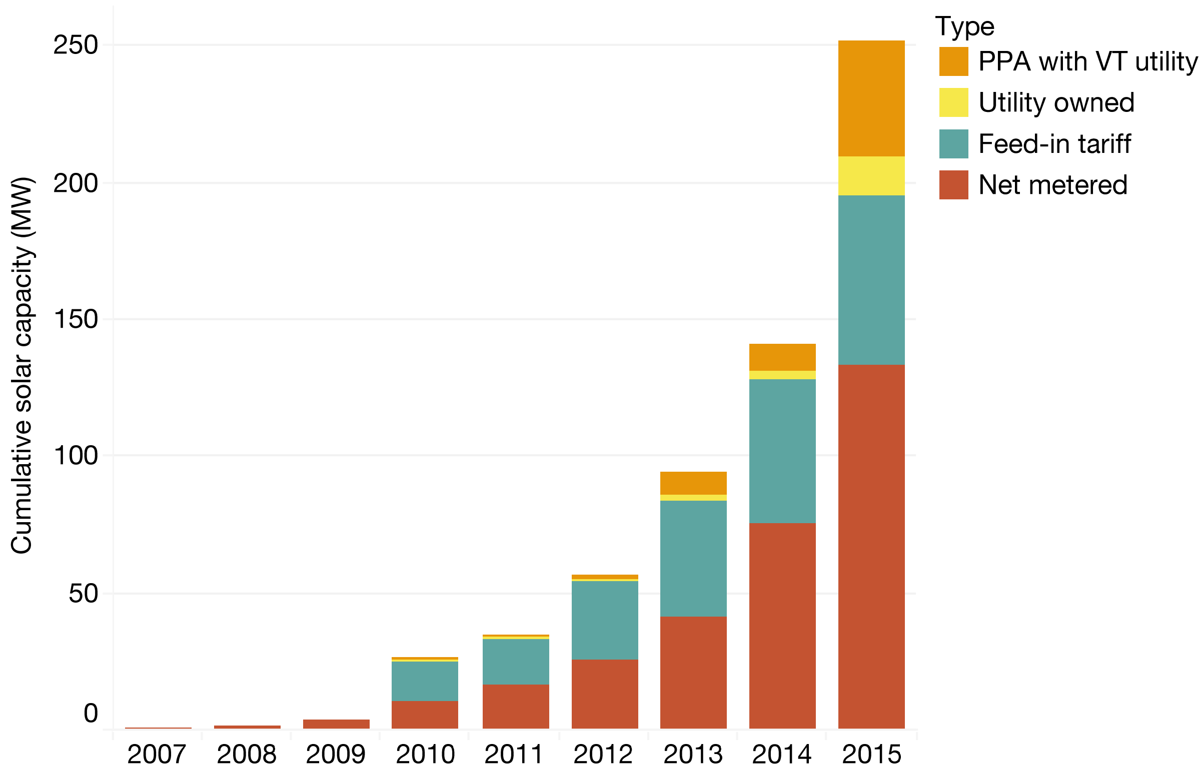


Figure 5. Cumulative permitted solar capacity in Vermont has grown quickly in the last five years, reaching 251 MW by the end of 2015.

Vermont has put a priority on environmental stewardship and energy self-sufficiency for decades. The political decision to commit quickly to an energy mix dominated by renewables is just one of the latest events in a long history of progressive policy decisions on energy. Some highlights of this ongoing effort:

- Land use planning regulation (Act 250, passed in 1970).
- Community-level incentives and technical assistance for revitalization of downtowns (Downtown Designation, administered by the Agency of Commerce and Community Development).
- Statewide EEU concept created via legislation in 1999 (see the beginning of this section).
- Small Scale Renewable Energy Incentive Program (2003) offered upfront rebates for residential, small commercial, and non-profit installations. The administration of this program ceased for most systems at the end of 2014.
- Greenhouse gas reduction goals set in 2005: 25 percent by 2012, 50 percent by 2028, 75 percent by 2050, compared to 1990 baseline (Vermont did not meet the 2012 goal. Actual emissions were very similar to 1990, not 25 percent below).[15]

[15] "Vermont Greenhouse Gas Emissions Inventory Update 1990 – 2012" (Department of Environmental Conservation Air Quality and Climate Division, June 2015), http://climatechange.vermont.gov/sites/climate/files/documents/Data/Vermont_GHG_Emissions_Inventory_Update_1990-2012_June-2015.pdf.

- Sustainably Priced Energy Enterprise Development (SPEED, 2005) feed-in tariff for new utility scale renewable energy projects.
- Streamlined solar registration provided a permit in 10 days for small systems.
- A solar adder, a credit on electric bills for each kWh a solar installation produces, began to pay 19 to 20 cents per kWh for net-metered solar generation.
- In 2011, the Vermont Department of Public Service set a 90 percent renewable total energy target by 2050.
- Standard Offer annual auctions replaced SPEED for new utility scale renewable energy projects (2012).
- *Total Energy Study* (Department of Public Service, 2014) considered paths and viability of 90 x 2050 target.
- Act 56 (2015) established a renewable portfolio standard: energy supply from renewables must be at least 55 percent by 2017, 75 percent by 2032.

Vermont is capitalizing on this foundation to transition away from the use of imported fossil fuels to locally owned renewable energy for electricity, transportation, and thermal needs. The state's consumption and generation is small compared to its neighbors, consuming 4 percent of the electricity on the New England grid, and using less than 1 percent of Hydro Québec capacity.

Vermont could rely on imported electricity, or use these resources to balance in-state renewables. However, many Vermonters are unwilling to export the impact of their energy use and want to model local sustainability, with a high penetration of renewables, balanced and managed with the state's own resources.

Fast growth of wind and solar power drew opposition in the early 2010s. The General Assembly responded with a Siting Task Force. The State also funded the Regional Planning Commissions to account for energy in their regional plans. This can help site renewable energy projects where locals want them, because it gives towns a voice in Vermont's permitting process if they create town energy plans that help support the state's renewable energy goals.

The changes that have occurred between the inception of this Solar Market Pathways project in late 2014 and today in late 2016 show how quickly Vermont is moving toward achieving these targets:

- The General Assembly raised the cap for net-metered renewable capacity from 4 percent to 15 percent of the connected utility's peak load, in 2014.
- Later in 2014, Burlington Electric Department, the state's third-largest utility and operating its own EEU, acquired a 7.4 MW hydropower station to complete its efforts to supply 100 percent of its energy from renewable sources.
- In June 2015, the General Assembly passed a renewable portfolio standard that allows credit for reducing fossil fuel use in building and transportation sectors, and is among the

most aggressive policies in the United States.[16] It requires 75 percent of electricity to come from renewable sources by 2032.

- In November 2015, Green Mountain Power (GMP), an investor-owned utility (IOU) serving 71 percent of the state's utility accounts, reached the net metering cap, 15 percent of peak. It decided to continue to allow small systems to interconnect, as well as 7.5 MW of strategic larger systems. The utility created a map to guide new solar to areas of the grid that have ample capacity to accept it.[17]
- By the close of 2015, Vermont Electric Cooperative (VEC; the second-largest utility), Washington Electric Cooperative (WEC; the fourth-largest utility), and three smaller municipal utilities reached, or were approaching the 15 percent net metering cap.
- In August 2016, The Public Service Board issued new net metering rules that removed the program cap, added incentives for preferred siting and REC treatment, and slightly lowered the total incentive most systems would get.[18]

1.4 Implications for Broader Applicability

Vermont is ahead of the curve in becoming an advanced solar economy. Because it is a small state and operates—even at the policy level—on a community scale, issues that arise as solar saturation increases are frequently addressed quickly and with well-informed deliberations. The State and its stakeholders typically seek options for mitigating issues relating to net metering or siting, for example. The state also enjoys good working relationships among the utilities, and has explored many different approaches for modifying rate structures and incentives. For example, regulators, the statewide energy efficiency utility, and distribution utilities, are discussing concepts around distributed energy resources (DERs) and fuel switching under Tier III of the new Renewable Energy Standard.[19]

The approach in this report is to use scenario analyses to help provide a framework for stakeholders to examine options and implications for alternative pathways towards becoming an advanced solar economy. This approach, the structure of the analyses, and the process of stakeholder engagement are all exportable to support solar market growth in other markets and jurisdictions.

1.5 Structure of This Report

This report is the outcome of the first 24 months of the project work. A "peer review" draft of this volume and volumes 2 and 3 were circulated to stakeholders and external experts for comments

---

[16] Cara Marcy, "Hawaii and Vermont Set High Renewable Portfolio Standard Targets," *U.S. Energy Information Administration*, June 29, 2015, http://www.eia.gov/todayinenergy/detail.cfm?id=21852.

[17] "Solar Map," *Green Mountain Power*, accessed September 21, 2016, http://www.greenmountainpower.com/innovative/solar/solar-map/.

[18] Vermont Public Service Board, *Revised Rule 5.100 Pursuant to Act 99*, 2016, http://psb.vermont.gov/statutesrulesandguidelines/proposedrules/rule5100.

[19] Vermont Public Service Board, Order Implementing the Renewable Energy Standard, IV, pp. 20 – 80. http://psb.vermont.gov/sites/psb/files/8550%20Final%20Order.pdf.

and review in June 2016. This is the final Vermont Solar Market Pathways document (with a fourth volume and a condensed version for the public).

The Vermont Solar Market Pathways Report results comprise four volumes:

Volume 1: Summary Report. Objectives, background, approach, high-level findings, and strategies for becoming an advanced solar economy

Volume 2: Net Metering Brief and Focus Area Briefs. Narrative and analysis on key market segments and strategies related to solar market growth: net metering and alternatives; electric vehicles; heat pumps; storage, load shifting, and demand response; high-performance manufactured housing; and incentives. This volume also contains a broad analysis of pathways to an advanced solar economy, submitted as a Phase II Roadmap for the Smart Electric Power Alliance (SEPA) 51st State initiative.[20]

Volume 3: Barriers and Integration Brief. Investigation and analysis of technical, market, and policy barriers and strategies. Analysis of distribution and bulk power system implications for high-saturation solar.

Volume 4: Methods and Detail Tables. Methodology, assumptions, and results from scenario modeling, using the Long Range Energy Alternatives Planning System and other tools.

[20] "The 51st State," *Smart Electric Power Alliance*, accessed September 26, 2016, http://sepa51.org/phaseII.php.

2. Investigation Methods and Approach

The general approach for this study is the investigation of the implications of becoming an advanced solar economy within the context of the total energy economy. We start by defining, and then refining, various scenarios where solar can provide 20 percent of total electric consumption. With stakeholder review and feedback, we then use those scenarios to investigate the implications across technical, economic, regulatory, and business models. Undoubtedly, transitioning to an advanced solar economy will require shifts for consumers, utilities, solar companies, and other businesses. Transitioning will create those shifts, too. The transition will also require and create shifts for regulators and policy makers. The point of this Summary Report and the analyses is not to predict or define each of these, but to use the scenario modeling and the ensuing discussions to encourage dialogue and innovation.

2.1 Stakeholder Engagement

The project was defined by, and has benefited greatly from, an active, non-binding stakeholder engagement process. This process informed the creation of the Reference scenario, the initial SDP scenario analyses, revisions to those scenarios, and alternative advanced solar scenarios discussed in **2.2 Scenario Modeling**. As of this report, the Team has conducted nine stakeholder meetings, with participants from Vermont distribution utilities, the transmission operator, public service regulators, state agencies (economic development, transportation, agriculture, and natural resources), the statewide energy efficiency utility, solar vendors, environmental activists, the Vermont Law School, and universities and colleges with active environment and energy programs. (See a list of **Stakeholders** at the end of this document).

Figure 6. Second stakeholder meeting, April 2015 in Rutland, VT.

The original list of invited participants contained more than 100 names, and grew to over 150 through referrals and forwarded invitations. Meeting attendance varied; on average, 18 stakeholders attended each meeting. The Team also invited stakeholders to comment on documents and modeling results as they became available. Over 100 individuals have attended a meeting, provided written comments, or have otherwise participated in the project.

2.2 Scenario Modeling

LEAP, the Long-range Energy Alternatives Planning System, is energy policy analysis software developed at the Stockholm Environment Institute. LEAP offers a framework for energy supply and demand accounting, enabling users to work with existing data sets to construct and compare future energy scenarios. Its flexible energy accounting capabilities help create models of different energy systems and scenarios. It is demand driven: The user models energy consumption within the system before adding supply, which is matched to the demand. Users can examine graphic and tabular results on energy flows, costs, and environmental impacts and modify them at multiple levels from end use devices, up to the limits of a total energy economy.

Software specialists have refined LEAP for more than 20 years. It has been used to conduct integrated energy and environmental planning in more than 190 countries (further LEAP modeling information is in **Volume 4** of this report).[21] LEAP modeling typically begins with the development of a demand tree that represents energy demand across various devices, end uses, subsectors, and sectors within an economy. **Figure 7** offers an example of a demand tree structure. The Team used recent data to create “current accounts,” which then became the basis for forecast changes in the Reference and alternative SDP scenarios.

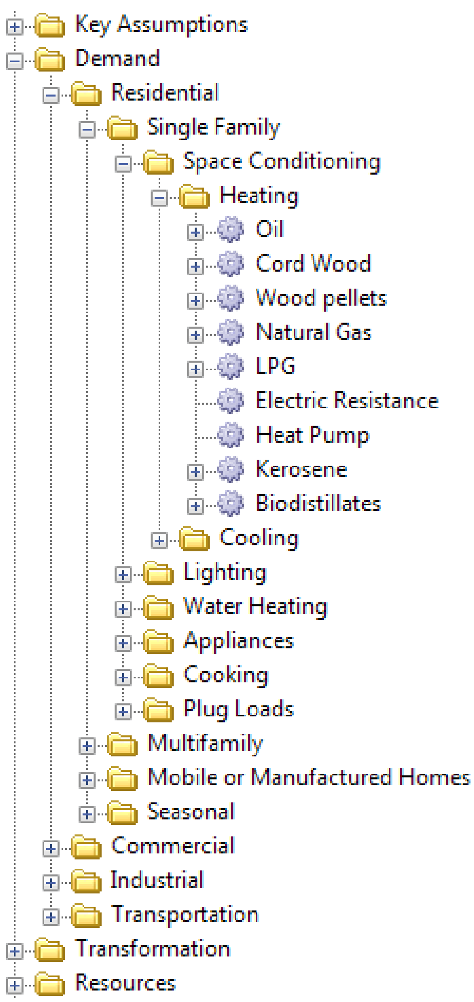


Figure 7. Sample demand tree structure in the LEAP system.

The Team entered current and projected energy use in the demand tree, across all of its branches, to calculate the energy demand by fuel type and sectors. Examples of the type of embedded and analyzed information within the structure are: projected changes in energy

[21] Heaps, C.G., *Long-Range Energy Alternatives Planning (LEAP) System*, version 2015.0.24 (Somerville, MA, USA: Stockholm Environment Institute, 2016), https://www.energycommunity.org/default.asp?action=introduction.

efficiency for end use devices, the demand for specific end uses, and shifts between different devices for a specific end use (for example, greater use of electric or plug-in hybrid vehicles). The structure also reflects fundamental demographic and economic levels as activity drivers; examples are population, household size, commercial area, and vehicle miles traveled.

Once the demand for various types of energy is determined, LEAP calculates the necessary resources to meet that demand, and includes other real-world factors such as transmission losses. For electricity, the time of demand and available supply also comes into play. **Figure 8** shows how resources at the left in the SDP scenario in 2025 move through one or more transitions to serve end uses at the right. This Sankey diagram shows only the energy that ends up being used. There are losses at each step that add up to more than half of the original resources in most fossil fuel economies.

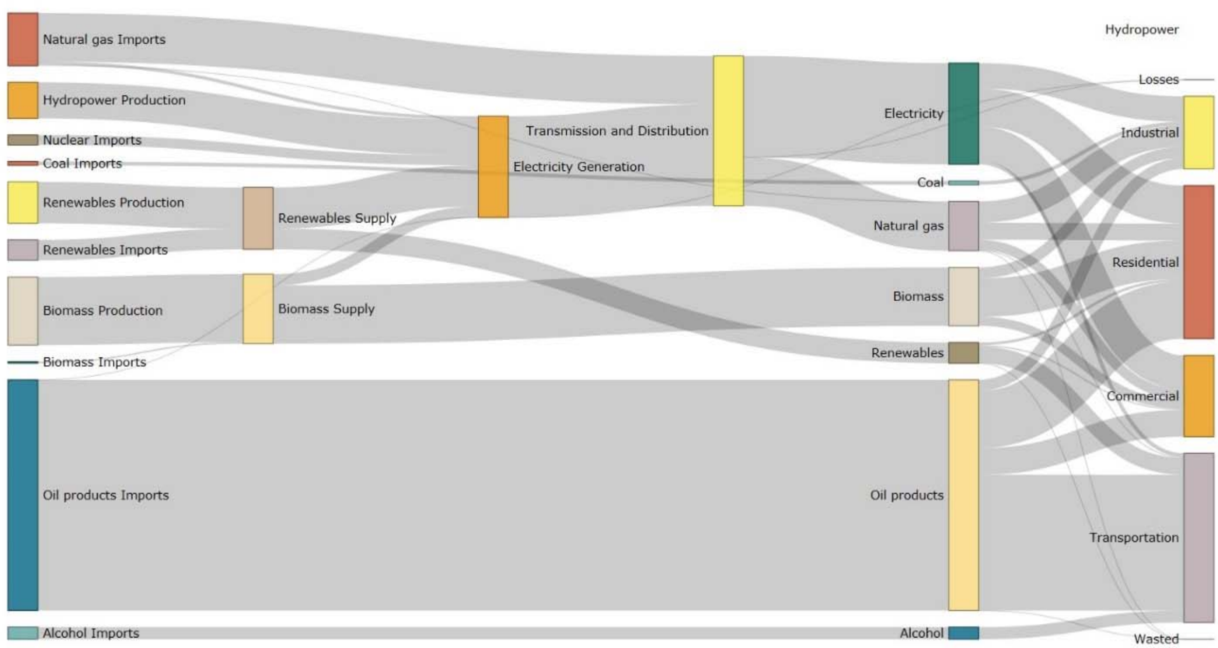


Figure 8. A Sankey diagram representation of how LEAP uses energy resources to meet total energy demand.

The Team drew historic information primarily from the Public Service Department's *Utility Facts 2013* [22] and U.S. Energy Information Administration (EIA) data to fill in the demand tree. The Team used projections from the Department's TES, the utilities' committed supply from their Integrated Resource Plans, and stakeholder input. The Department provided the data from selected Integrated Resource Plans filed by Vermont distribution utilities for the "Committed Resources" graph on page E.7 of *Utility Facts 2013.* [23]

---

[22] "Utility Facts 2013" (Vermont Department of Public Service, 2013), http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Utility_Facts/Utility%20Facts%202013.pdf.
[23] Ibid.

Demand Drivers

Each sector has a unit that measures activity in the sector. That unit is the "demand driver." LEAP multiplies it by the energy intensity of the activity to calculate energy demand.

The population is assumed to grow at 0.35 percent per year.[24] The number of people per household is assumed to decrease from 2.4 in 2010 to 2.17 in 2050.[25] These assumptions combine to give the number of households, the model's basic unit for **residential energy consumption.**

The Team based the projected change in the **energy demand from the commercial sector** on data in the TES. The demand driver for the commercial sector is commercial building square feet.

The Team entered total **industrial consumption** by fuel estimates directly from the TES into the model.

Transportation energy use is based on vehicle miles traveled (VMT). This metric has risen throughout most of American history.[26] In Vermont however, VMT peaked in 2006 and has since declined slightly.[27] Given this trend, and Vermont's efforts to concentrate land development and to support alternatives to single-occupancy vehicles, VMT is assumed in the model to remain flat, while population and economic activity grow slightly.

The Team based **electricity supply** on the TES,[28] the utilities' Committed Supply, and other necessary sources to meet the demand projected in the model and the 90 x 2050 goal, and to supply 20 percent of annual electricity from solar. The Department provided the data from selected Integrated Resource Plans filed by Vermont distribution utilities for the "Committed Resources" graph on page E.7 of *Utility Facts 2013.*[29]

2.3 Scenarios

Once the Team entered historic data into the demand, transformation, and resources modules, it could build scenarios on Reference projections, and on alternative scenarios. For example, the Team examined the implications and requirements for meeting 20 percent of all electricity generation from solar by 2025, and the broader 90 x 2050 total energy targets. **Table 4** summarizes the scenarios derived from the research and informed by stakeholder feedback, review, and further analysis. The SDP is further refined into Low Net Metering and Delayed Deployment versions.

---

24 Ken Jones, Ph.D. and Lilly Schwarz, "Vermont Population Projections – 2010 - 2030" (State of Vermont, August 2013), http://dail.vermont.gov/dail-publications/publications-general-reports/vt-population-projections-2010-2030.
25 Dr. Ken Noble, "Vermont Data_DSM.xlsx" (Vermont Department of Public Service, 2012).
26 "Annual Vehicle Miles Traveled in the U.S.," Alternative Fuels Data Center, August 2016, http://www.afdc.energy.gov/data/10315.
27 "Vermont Annual Vehicle Miles of Travel (AVMT) and Highway Fatalities" (Vermont Agency of Transportation), accessed November 16, 2016, http://vtrans.vermont.gov/docs/highway-research.
28 "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."
29 "Utility Facts 2013."

Table 4. Scenarios for the Vermont Solar Market Pathways, with major data sources, and showing the progression from current accounts to the SDP scenario

Scenario	Represents	Data sources
Current accounts	Description of current energy supply and demand balance. Historic information is from 2010-2015 depending on available data. Basis for all other scenarios.	*Utility Facts 2013*, EIA, *Vermont Residential Fuel Study,* device-specific data from various sources
Reference	Business as usual. Involves expected baseline levels of energy efficiency such as continued Efficiency Vermont operations and improvements in vehicle efficiency through Federal Standards. Renewable generation and natural gas growth continues.	*Total Energy Study* BAU scenario
90 x 2050_{VEIC}	Meeting the 90 x 2050 target. Based on the economic modeling done for the TES.	Adapted from *Total Energy Study* TREES Local scenarios
SDP[30]	Solar Development Pathways scenario. Reaches the 20%-of-generation target by 2025 and also the 90 x 2050 goals for 2050	Based on 90 x 2050: Demand is the same, supply is shifted toward solar

The **Reference scenario** contains energy use values and assumptions as they are today, but it assumes increases in vehicle efficiency, because of updated Corporate Average Fuel Economy (CAFE) standards,[31] and some increased use of natural gas—which, although a cleaner fuel to burn, is still a fossil fuel. The Reference scenario is based on the business-as-usual (BAU) scenario of the Vermont TES. The Vermont Solar Market Pathways Team revised the model to reflect less growth in natural gas use, after the cancelation of the planned second phase of a pipeline project.

The **90 x 2050_{VEIC} scenario** has stronger efficiency, quicker fuel switching, and accelerated renewable energy adoption to achieve the State's goal of meeting 90 percent of total energy needs with renewable sources by 2050. This scenario is based on the TES Total Renewable Energy and Efficiency Standard (TREES; local energy) scenario.[32] The TREES Local scenarios consist of two pricing outcomes, one that assumes a high cost of biomass and biofuels, and one that assumes a low cost. These scenarios test policies requiring all Vermont energy distributors to source an escalating percentage of their supply from in state, Vermont renewables or energy efficiency resources. The 90 x 2050_{VEIC} scenario combines the high and low biomass cost versions of TREES Local.

The Team created **SDP scenarios** for this project to meet the SDP goal to supply 20 percent of annual electric generation from solar by 2025. The demand side is exactly the same as that of

[30] The SDP scenario is further refined into Low Net Metering and Delayed Deployment versions.
[31] "CAFE - Fuel Economy," *National Highway Traffic Safety Administration (NHTSA)*, accessed September 22, 2016, http://www.nhtsa.gov/fuel-economy.
[32] "Total Energy Study: Final Report on a Total Energy Approach to Meeting the State's Greenhouse Gas and Renewable Energy Goals."

the 90 x 2050_{VEIC} scenario, but supply shifts more toward solar, and away from imported hydropower and wind.

The initial draft of this scenario was completed during the first six months of the project. Presenting the draft inputs and results to various audiences elicited feedback from participants who collectively offered many different perspectives. The stakeholders undertook detailed reviews of the scenario, which led to many improvements to the model. The Team presented the results and model in the following ways:

- Webinar for the U.S. Department of Energy (DOE), SunShot systems integration, June 25, 2015
- Regional Planning Commissions (RPCs) webinar, June 25, 2015
- Bennington RPC, July 13, 2015
- American Solar Energy Society “Solar 2015” conference, July 28, 2015
- Stakeholder meetings, May 19 and October 6, 2015
- Northwest Regional Planning Commission, October 7, 2015

The results did not change radically from the initial review and feedback sessions, but the model became more accurate, flexible, and robust:

- Added hourly production data for solar, wind, and hydro to the dispatch model.
- Smoothed forecasted changes in consumption to avoid unrealistic step changes.
- Aligned heat pump efficiency projections with updated, more aggressive estimates.
- Reduced the assumed number of homes using natural gas.
- Made small changes to residential shell and heating equipment efficiency expectations, to more closely align with TES consumption projections.
- Changed the transportation model from top-down to bottom-up, which allowed the team to use stronger and more detailed assumptions.

These changes were the basis for a revised SDP scenario, a high solar model that the Team has continually refined. A significant issue came up from using more data with greater temporal detail. The Team used the LEAP model to dispatch electricity to meet the demand in the first version of the model. Although it contains many detailed data, and can concurrently calculate several regions and scenarios, the model cannot handle high levels of temporal detail. The Team sought greater detail about the times of over-generation and unmet need, so that it could investigate load shifting, curtailment, storage, and electricity trading. To address the temporal data limit in the LEAP model, the team created a script that uses simple logic to “dispatch” generation for each hour of the year, giving the Team a chance to model 8,760 (hourly) time slices—365 times more than LEAP was using.

Additional scenarios. The SDP scenario is one way to reach 20 percent solar penetration by 2025, just as the 90 x 2050_{VEIC} scenario is one way to meet Vermont’s 90 percent total-energy-from-renewables goal by 2050. The Team encouraged stakeholders to suggest alternatives that would be worthy of investigation. Stakeholders suggested the following:

- **Low Net Metering.** The SDP scenario assumes solar grows with a similar distribution pattern of residential, commercial, and utility capacity as it has to date. However, Vermont has a higher proportion of net-metered solar than most other states with advanced solar markets. The lower net metering scenario offers more typical distribution, with much more utility capacity. This scenario addresses concerns expressed by some utilities about the rate impact of a 10-fold increase in solar generation under the current reimbursement model. This scenario might also reflect a new reality. Although no systems larger than the 2.2 MW limit of the Standard Offer had been built in Vermont by 2016, several larger systems have been proposed. **Figure 9** shows the distribution of system types in the low net metering scenario compared to the SDP.

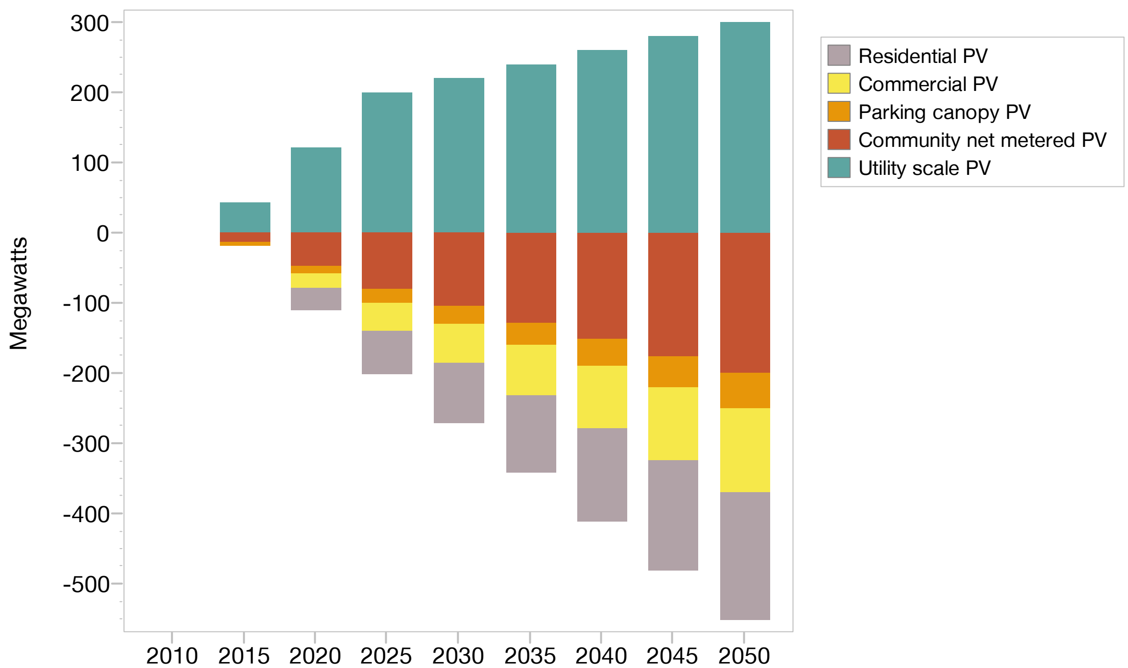


Figure 9. Difference in solar capacity by sector over time in the Low Net Metering scenario, compared to the SDP scenario.

- **Delayed Solar Deployment.** One utility stakeholder suggested this scenario to see the effects of installing more solar capacity in the future, when costs are likely to be lower. A delay would also allow time for the new standard for advanced inverters and time for planning and updates to the grid and to policy. Conversely, it would move more of the investment beyond the phase out of the federal Investment Tax Credit. The scenario is identical to the SDP except that the capacity installation is shifted later by 10 years. Capacity currently installed is the same, but 2025 targets become 2035 and 2050 targets shift to 2060. **Figure 10** shows the solar capacity added in this scenario alongside solar added in the SDP scenario. The SDP installs more in the first 15 years while the Delayed Deployment scenario continues adding solar beyond 2050.

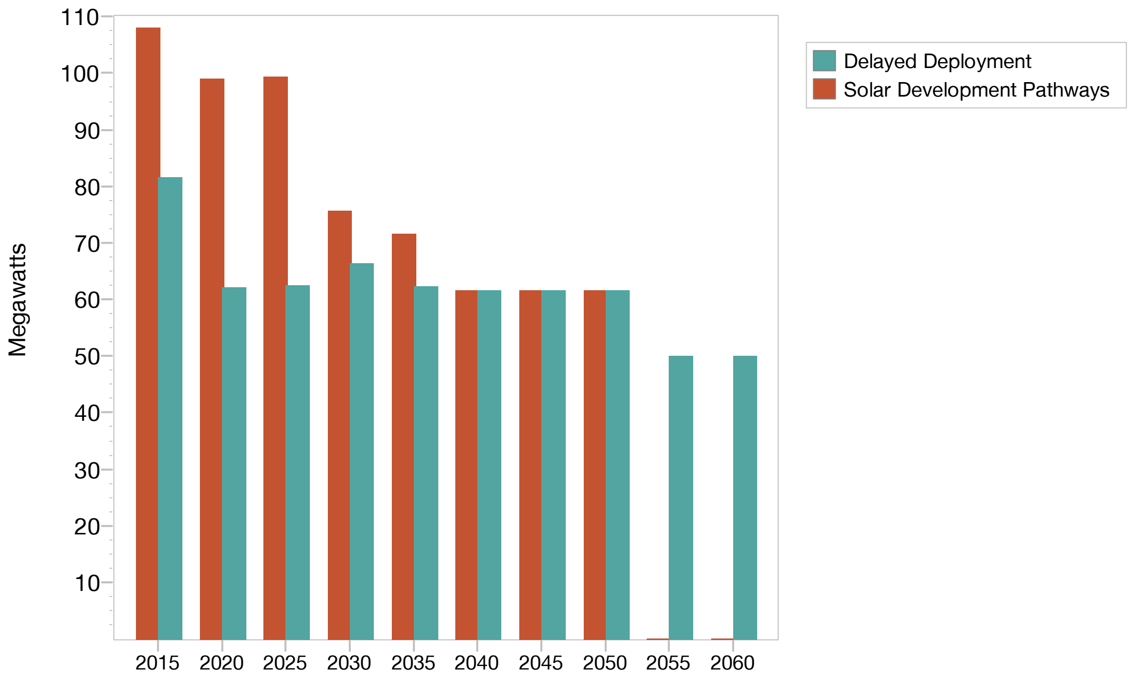


Figure 10. Difference in solar capacity added by year in the Delayed Solar Deployment scenario, compared to the SDP scenario.

- **Act 56, the Renewable Energy Standard.** Now that Vermont has an RPS to move toward the 90 x 2050 goal, the State suggested a scenario to reflect the new law. This scenario will be very similar to the 90 x 2050_{VEIC} scenario, but it will benefit from a few years of new information and market trends.
- **Poor Siting.** This scenario was suggested to reflect the additional grid upgrade costs that would be required if solar systems were sited poorly. The SDP scenario includes integration costs, but at a level that assumes relatively thoughtful siting and smaller investments. The Team and stakeholders decided this would be an appropriate sensitivity analysis, rather than a scenario.

2.4 Costs

The Project Team added costs to the model to estimate the investment required to transform the energy system and to estimate the resulting change in annual energy spending. Each part of the model has a cost: efficiency in all sectors of the demand side, new generation that is added during the model timeframe, grid updates to host high-penetration renewables, and the cost of fuel used directly or in power plants. The sources and assumptions used for cost projections are:

- The Team estimated costs from Vermont-specific data if available, and the best regional or federal estimates otherwise.

- Initial solar costs are from the 2016 *Vermont Solar Cost Study* by the Clean Energy States Alliance (CESA).[33]
- Future solar costs use that baseline and decrease according to a profile VEIC previously developed using national trends. These are shown in **Figure 11**.

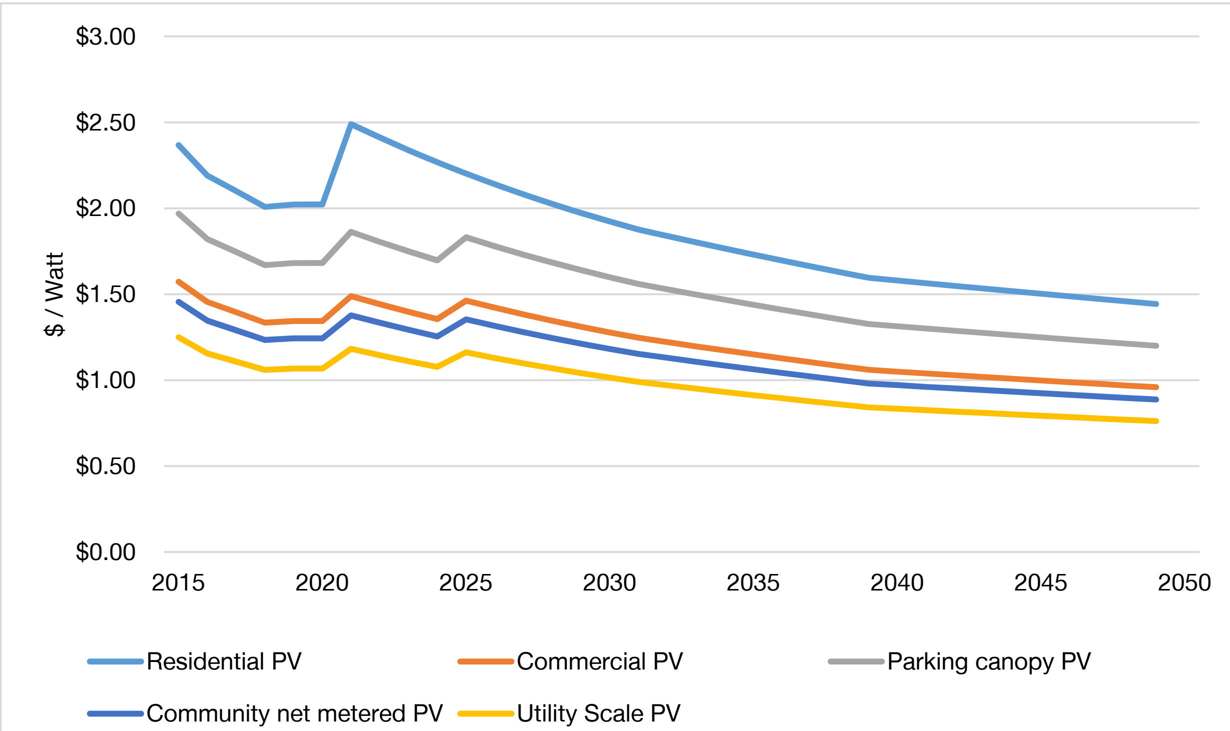


Figure 11. Projected future after-tax installed cost of solar PV in Vermont. Assumes the Investment Tax Credit fully expires in 2025.

- The Team derived efficiency costs from the 2013-2014 Vermont Demand Resources Proceeding, as approved by the Vermont Public Service Board.
- Fuel costs, delivery costs, and capital costs for energy generation and supply reflect costs estimated by Open Energy Information (OpenEI), EIA, CESA, the National Renewable Energy Laboratory (NREL), and the DOE's *Clean Cities Alternative Fuel Price Report.*

Details of cost sources and other assumptions are presented in **Volume 4**.

[33] Leigh W. Seddon and L.W. Seddon, LLC, "Vermont Solar Cost Study: A Report on Photovoltaic System Cost and Performance Differences Based on Design and Siting Factors" (Clean Energy States Alliance, Vermont Department of Public Service, and the Clean Energy Development Fund, February 2016), http://www.cesa.org/resource-library/resource/vermont-solar-cost-study-a-report-on-photovoltaic-system-cost-and-performance-differences-based-on-design-and-siting-factors.

3. Results

This section discussed the primary results from the Team's work to date. For greater detail on the scenario results, see **Volume 4**.

3.1 Changes in Energy Use and Supply

Energy efficiency is a key resource for meeting the high renewable energy goals. In each of the high renewable scenarios (90 x 2050_{VEIC} and the SDP scenarios) total consumption by sector declined through 2050. Vermont has mature energy efficiency programs, so the Team assumed an appropriate amount of baseline energy efficiency in the Reference scenario as well. The Team projected growth in population and commercial space as a base assumption, but total energy consumed declines in all scenarios. This efficiency comes from many places, including ambitious home weatherization, national automotive efficiency standards, and—most significantly—electrification of heating and transportation. As explained in Vermont's 2016 Comprehensive Energy Plan, "heat pump and electric vehicle technology is capable of supplying the same level of energy service as its combustion-based counterparts, with a third or less of the site energy requirements." The impacts of electrification and the extent of efficiency improvements are detailed below.

The savings from thermal shell improvements, more efficient end use equipment, and more efficient vehicles combine to reduce total energy consumption by roughly 10 percent by 2025, and 40 percent by 2050, compared to 2010.

Efficiency Is a Key Resource in All Scenarios

Figure 12 shows the results of investment in efficiency across all sectors of the economy. The costs and savings for efficiency improvements in the building sectors are based on historical experience with Vermont's efficiency efforts, and are consistent with projections from the State's forecasting Demand Resources Plan and its Comprehensive Energy Plan targets.

Figure 13 shows the forecasted cumulative SDP scenario's investments in efficiency and fuel switching, relative to the Reference scenario. This graph reflects only the efficiency investment, not the fuel savings. The transportation segment goes below zero because electric vehicles, which are simpler than combustion-powered vehicles, have lower maintenance costs and are expected to become less expensive to purchase in the second half of the analysis period. The additional savings from gasoline and other fuels is shown within the "Resources" in **Table 7**.

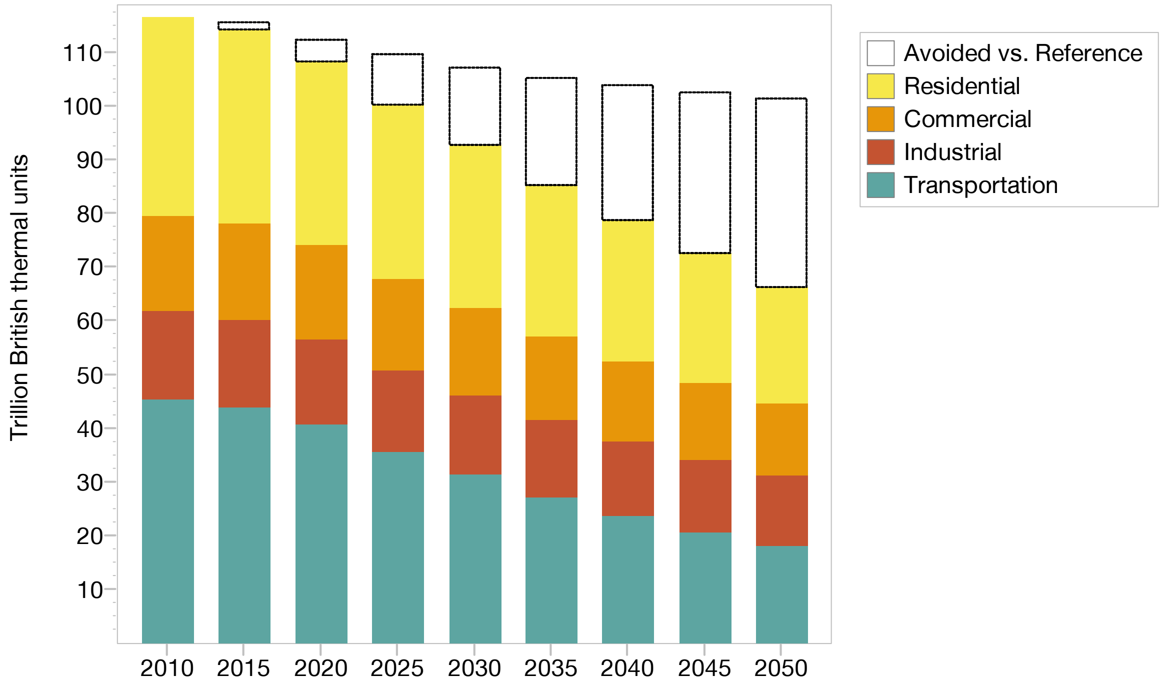


Figure 12. Vermont site energy demand, by 5-year increments, and by market sectors, showing the effect of more aggressive efficiency and fuel switching in the SDP scenario, compared to the Reference scenario.

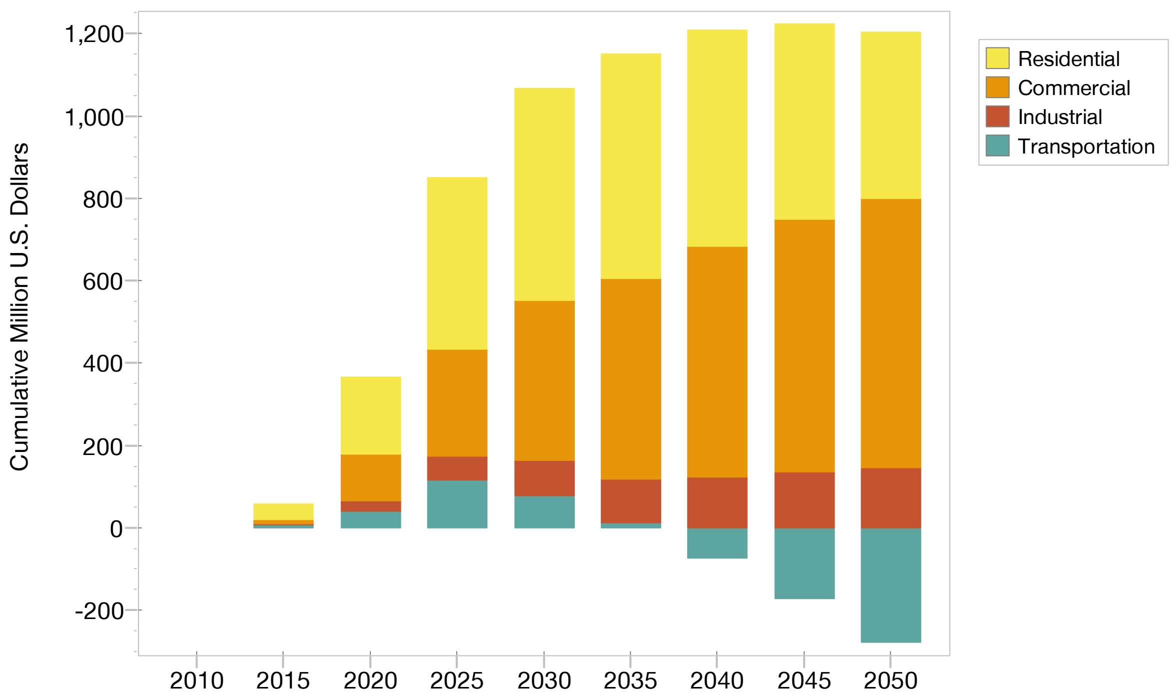


Figure 13. Cumulative discounted investments under the SDP scenario, compared to the Reference scenario.

The costs for these savings represent a significant investment by Vermont in more efficient buildings, equipment, and vehicles, amounting to approximately 1 percent of annual energy spending. The benefits include avoided energy resource costs, mostly from imported fuels, with a present value through 2025 of more than $1.2 billion. Across time, the long-lasting investments in efficiency result in significant positive net benefits.

Strategic Electrification – Heat Pumps

Heat pumps use electricity to move heat. There are many variations of the technology, but the attention here is on air source heat pumps that use energy in outdoor air to provide space heating and cooling. Heat pump water heaters work in a similar way and are another product that is contributing to growth in "smart" electrification in Vermont.

The customer economics are most compelling for homes using electric resistance, propane, or kerosene for heating, as described in **Table 5.** For homes with more expensive heating fuels, a heat pump could be paid off in as little as four or five years. Operating costs are nearly the same as those for natural gas and wood, so people are not likely to rush to switch, but might consider heat pumps when replacing failed systems.

Table 5. Annual savings from heat pumps, for a typical home (75 MMBtu / year), assuming 80 percent fuel offset, and fuel prices in Table 6

Fuel	Savings / year
Natural gas	-$206
Fuel oil	-$142
Wood	-$66
Pellets	$172
Kerosene	$364
Propane	$758
Electric resistance	$1,508

Heat pumps are least efficient when outdoor temperatures are very high or low, so they pose a challenge for utilities by possibly increasing demand during peak periods. Currently in Vermont, summer peak typically causes the most concern to utilities. However, there are areas that experience winter peak concerns. With additional solar, utilities are seeing many localized summer peaks shift from mid-day to after sunset. There are also circuits, where solar is causing the peak to shift from summer to winter. Both equipment controls and solar supply can help lower the summer peak, though storage or other means are necessary to deal with peak demand after sunset. Winter peak issues can be addressed with controls that pre-heat during time of solar output or shift heating to existing fossil systems during peak conditions.

Heat Pump Market Conditions. Vermonters generally are enthusiastic about heat pumps for displacing fossil fuel heating, as shown in Efficiency Vermont and GMP data:

- The most common search term on www.efficiencyvermont.com is *heat pumps.*
- The fourth most common search term on that site is *heat pump* (the singular form).
- In 2014-2015, VEIC's Customer Support group reported 200 customers who have contacted them and are waiting for Efficiency Vermont to launch a heat pump program.

- Customer support staff for Green Mountain Power's (GMP's) lease program took more than 600 calls in the first few days of its announcement. The utility had to stop accepting calls because it could not satisfy the high volume of requests.

Technical Advances. Cold-climate heat pumps are advancing quickly in the marketplace. Initially only available as single-head units, there are now multi-zone and multi-head systems. These systems come with more installation options for the indoor units that address some of the barriers listed below. Soon, heat pumps designed to connect to conventional duct and water pipe distribution systems will be available, as will be combined space and water heating systems. These improvements increase the number of homes and businesses that can use the technology.

Efficiency is also increasing. Researchers are now designing systems that can use carbon dioxide as a highly efficient and low-impact refrigerant. Solid-state heat pumps are another area of research. In Vermont, heat from heat pumps currently costs less than all fuels except cordwood, fuel oil, and natural gas, as shown in **Table 6**. Fuel oil has a higher historical average, but has recently dropped in price. With increasing efficiency, electric heat pumps might overtake these three fuel sources.

Table 6. Relative cost-effectiveness of electric heat pumps, compared to other fuel types

Fuel type	Unit	Btu / unit	Efficiency	$ / unit	$ / MMBtu
Natural gas	CCF	100,000	80%	$1.41	$14.88
Fuel oil	Gallon	138,200	80%	$2.10	$15.96
Wood (green)	Cord	22,000,000	60%	$227.00	$17.21
Electricity (heat pump)	kWh	3.412	250%	$0.15	**$18.32**
Pellets	Ton	16,400,000	80%	$278.00	$21.19
Kerosene	Gallon	136,600	80%	$2.67	$24.40
Propane	Gallon	91,600	80%	$2.27	$30.96
Electric resistance	kWh	3.412	100%	$0.15	$43.46

Source: Adapted from Vermont Fuel Price Report[34]

Figure 14 illustrates the growth of heat pumps as a share of space conditioning for single-family homes.

[34] "Vermont Fuel Price Report" (Vermont Department of Public Service, October 2016), http://publicservice.vermont.gov/sites/dps/files/documents/Pubs_Plans_Reports/Fuel_Price_Report/2016/October%202016%20Fuel%20Price%20Report.pdf.

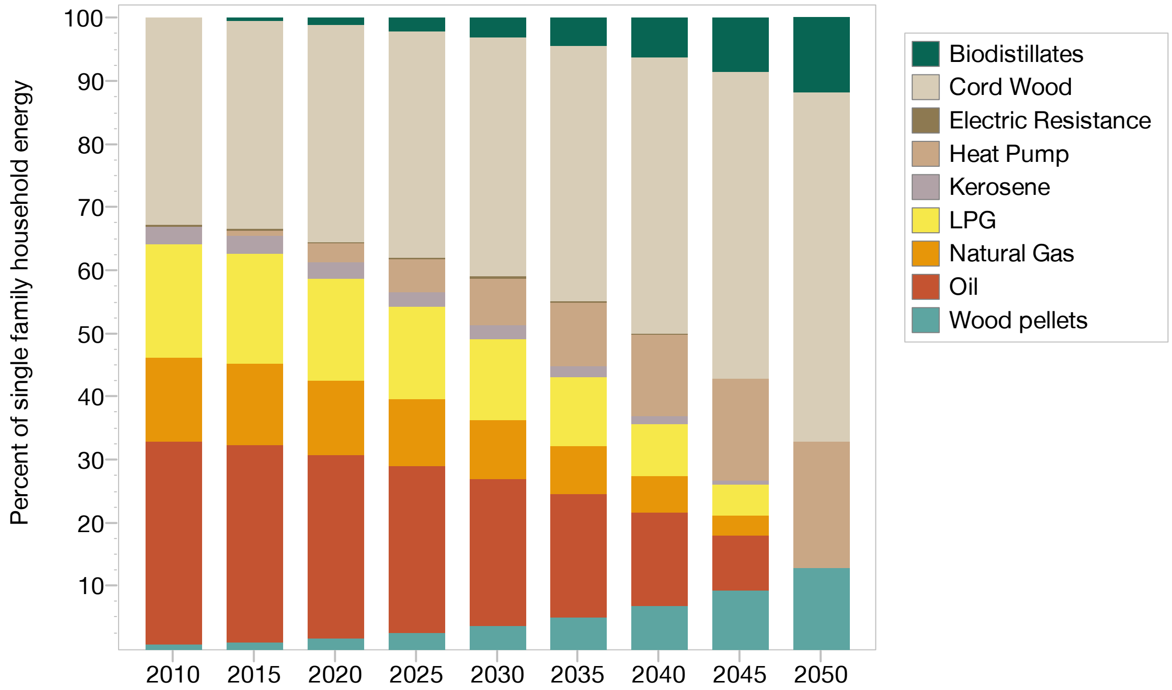


Figure 14. Share of heating energy in single family homes, by five-year increments, and fuel, with electricity and biofuels growing to displace fossil fuels.

Strategic Electrification – Electric Vehicles

The development of an advanced solar market in Vermont will provide significant opportunities for increasing the number of renewably powered vehicles in the state. The primary benefits of renewably powered transportation are reduced emissions of greenhouse gases and other harmful pollutants, reduced cost and volatility in transportation energy expenditures, and support for economic development by shifting monies from fuel expenditures to capital for investment or spending. Further, electric vehicles (EVs) can support the electric grid by boosting demand side management (DSM) through controlled charging and distributed energy storage using EV batteries. Both controlled charging and the storage capability can respond to short-term fluctuations in power generation that might occur if more solar PV generation is brought on line. Grid upgrades may be necessary for fast charging stations or if several charging stations are concentrated in a small area, to avoid overloaded transformers, voltage drop, or other distribution grid problems.

Technology and Market Description. There are two basic types of plug-in EVs:

- **All-Electric Vehicles (AEVs),** powered solely by electricity with a range of 60 to over 100 miles for vehicles under $40,000. AEVs manufactured by Tesla (purchase price of $70,000) can travel up to 270 miles without a charge. AEVs accounted for 25 percent of registered EVs in Vermont in 2015 and through the third quarter of 2016.
- **Plug-in Hybrid Vehicles (PHEVs**) offer 10 to 75 miles of electric range on a battery, and then the vehicles switch without interruption to gasoline for extended-range operation.

PHEVs accounted for 75 percent of the registered EVs in Vermont in 2015 and through the third quarter of 2016.

Most EVs in Vermont are passenger vehicles and travel about 3 miles per kWh of energy. Given the census of EVs in Vermont, this means an annual consumption of about 2 MWh for the average Vermont vehicle.

Reference scenario. The *Vermont Zero Emission Vehicle Action Plan* contains detailed information on activities under way in Vermont to support automakers in complying with zero-emission vehicle (ZEV) program requirements. **Figure 15** illustrates the anticipated continued growth in the market. This is particularly the case for 2017 and beyond, after the expiration of the existing travel provision, which allows manufacturers to meet their requirements by selling EVs only in California. The ZEV program requirements have credits for different vehicle technologies, so actual experience of sales could differ from the scenario presented below. A relatively conservative estimate under existing policies would be approximately 10,000 EVs in Vermont by 2023, or nearing about 2 percent of the fleet of registered vehicles.

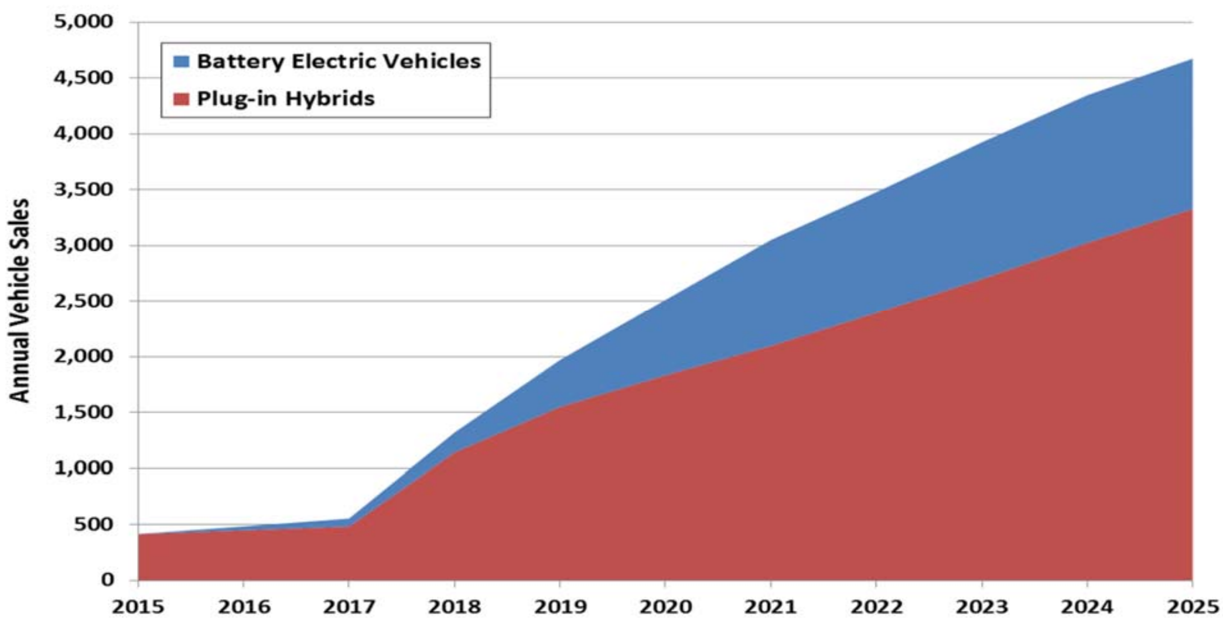


Figure 15. *Vermont ZEV Action Plan* compliance scenario.[35]

90 x 2050 and SDP scenario. The Vermont *Comprehensive Energy Plan* includes goals for 25 percent of vehicles to be powered by renewable energy in 2030 and 90 percent by 2050. These values translate to approximately 143,000 EVs in 2030 and 515,000 EVs by 2050. Achieving this rate of growth will depend on vehicle availability at competitive pricing, and sustained programs to transform the new and used vehicle markets.

---

[35] "Vermont Zero Emission Vehicle Action Plan" (State of Vermont: Agency of Natural Resources, September 2014), http://anr.vermont.gov/about_us/special-topics/climate-change/initiatives/zev.

Technical advances. Advancements in EV technology and battery capacity are beginning to make possible longer ranges for driving at the same or even a lower purchase cost than older EV models. While most cost-competitive all-electric vehicles currently have a range of around 100 miles, rapid technological advances are underway. The Chevy Bolt, an all-electric vehicle with a range of 238 miles and priced just under $30,000 (once the federal tax credit is factored in) is now available for purchase.[36] The lines separating energy generation, storage, and use are also beginning to blur. Shareholders from Tesla and SolarCity, a panel manufacturer, recently approved a merger for the two companies.[37] The new company plans to combine solar generation, battery storage, and transportation.

Figure 16 shows the projected change in fuel supplying light-duty vehicles in the model. Change starts slowly, but electricity powers more than half the demand by 2040 and almost all of it by 2050.

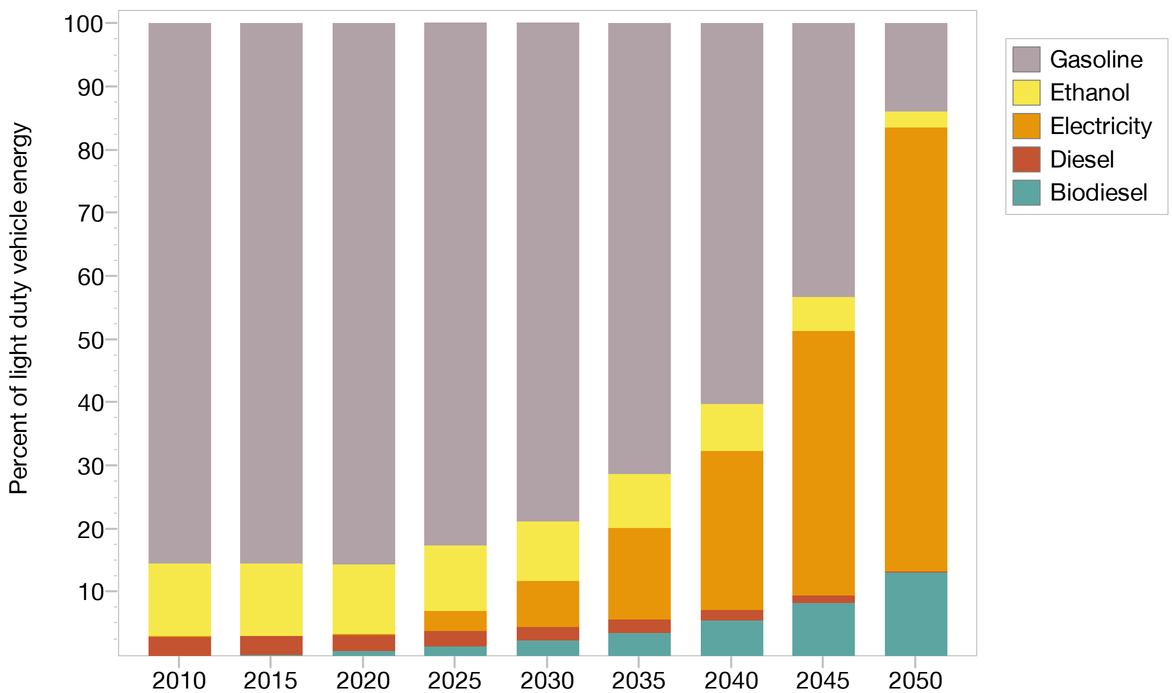


Figure 16. Share of light-duty vehicle energy provided by fuel, with electricity growing later in the period.

[36] Eric Tinwall, "Chevrolet Bolt EV," *Car and Driver*, October 2016, http://www.caranddriver.com/chevrolet/bolt-ev.
[37] Michael J. De La Merced, "Tesla and SolarCity Shareholders Approve Merger," The New York Times, November 17, 2016, http://www.nytimes.com/2016/11/18/business/dealbook/tesla-and-solarcity-shareholders-approve-merger.html.

Renewable Generation in the Decarbonized Grid

The shift to greater electrification heating systems and transportation provides a benefit if the electricity supply is clean. Vermont already has the lowest carbon intensity electricity generation in the country,[38] but a major change is still required to meet our 2025 and 2050 goals, especially after Vermont Yankee's low-carbon nuclear generation was partially replaced in 2014 with electricity from natural gas power plants.

Figure 17 shows the transition of Vermont's grid in the model. The data are based on utilities contracted supply through 2030. The Vermont Department of Public Service provided the data from selected Integrated Resource Plans filed by Vermont distribution utilities for the "Committed Resources" graph on page E.7 of *Utility Facts 2013*.[39] All in-state renewables are expected to continue beyond the contract periods. In-state nuclear generation is replaced by nuclear elsewhere in New England, and then disappears. By that time, solar and new wind have grown to provide more annual generation than Vermont Yankee had in the past.

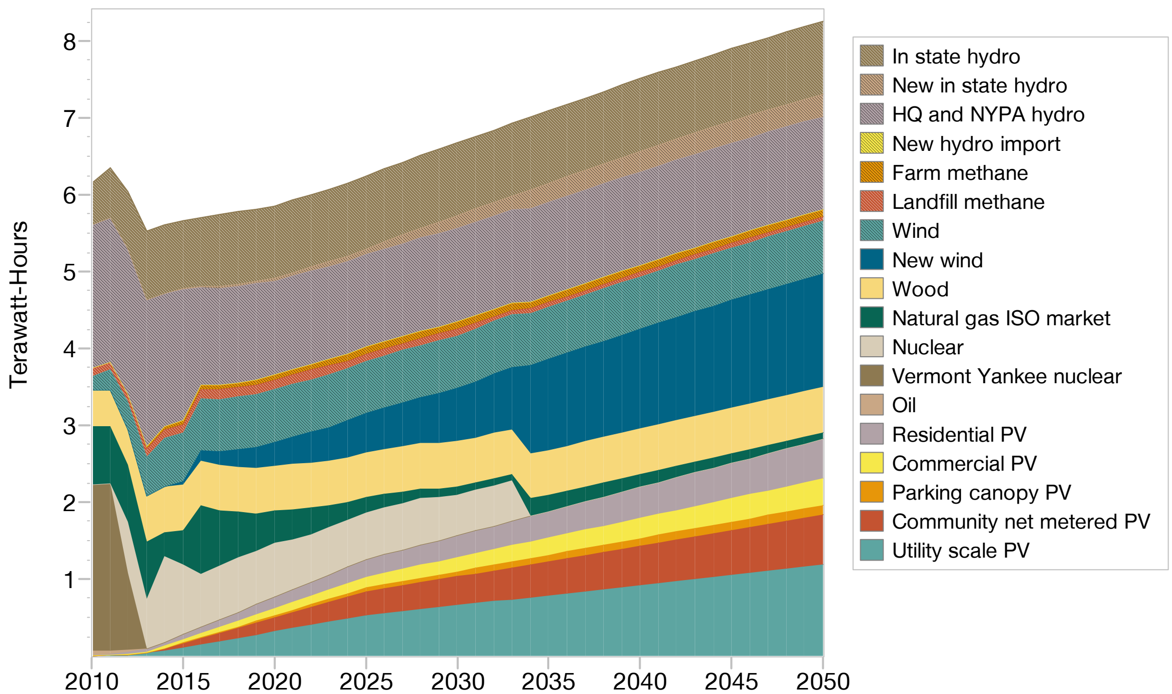


Figure 17. Electricity generation by year and source in the SDP.

Figure 18 compares electricity supply in the SDP scenario compared to the Reference scenario. Solar ramps up more quickly, but by 2050 wind and solar make roughly the same contribution to electricity demand. A small amount of new in-state hydropower adds to this to offset a large

[38] "State-Level Energy-Related Carbon Dioxide Emissions, 2000-2012," U.S. Energy Information Administration, October 26, 2015, http://www.eia.gov/environment/emissions/state/analysis/.
[39] "Utility Facts 2013."

amount of natural gas-fired electricity from the New England grid. The new hydropower capacity is from upgrades to existing facilities or adding generation equipment to existing dams; no new dams are assumed. In September of 2016, Green Mountain Power purchased fourteen hydropower facilities in New England with a combined capacity of 17 MW.[40] The Team updated the energy model to reflect this new capacity, adjusting for the Vermont dams that were already included.

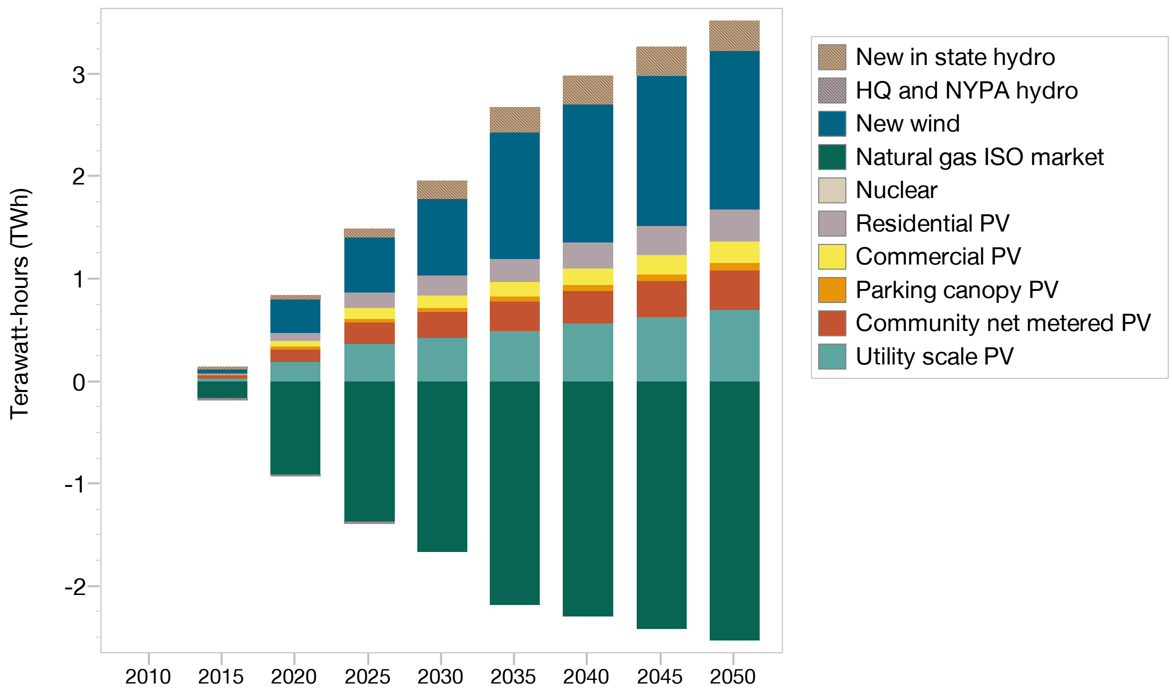


Figure 18. Difference in annual generation between the SDP and the Reference scenarios, showing a diverse mix of renewables displace natural gas-fired power from the New England grid.

3.2 Grid Impacts

The California "duck curve"[41] brought the issues of low daytime net load and high evening ramp rates to the attention of the solar industry, utilities, and regulators. Shawn Enterline, Director of Regulatory Affairs at GMP, and an active stakeholder on this project, used hourly forecasts and simulations to create the Vermont "Champ Curve" shown in **Figure 19**. "Champ" is a mythical creature residing in Lake Champlain, the state's major body of water. The creature is rumored to have the body of an Elasmosaurus.[42] Champ's belly goes below zero between 2025 and 2030, as the installed capacity increases beyond 1 GW.

[40] Polhamus, Mike. "Green Mountain Power To Buy 14 More Hydroelectric Dams." https://vtdigger.org/2016/08/17/green-mountain-power-agrees-buy-14-hydroelectric-dams/.
[41] Paul Denholm et al., "Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart" (National Renewable Energy Laboratory, November 2015), http://www.nrel.gov/docs/fy16osti/65023.pdf.
[42] Robert E. Bartholomew, *Untold Story of Champ, The: A Social History of America's Loch Ness Monster* (SUNY Press, 2012).

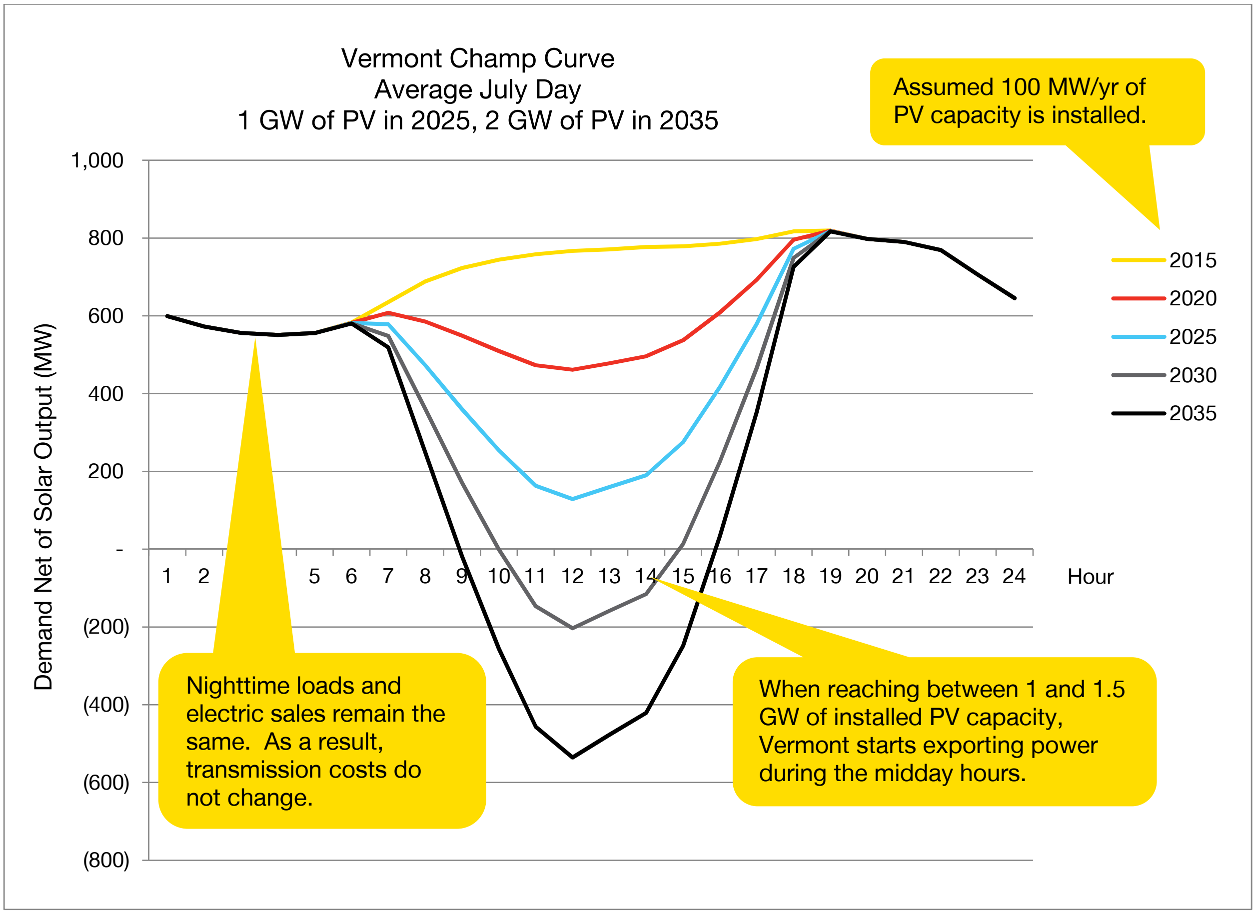


Figure 19. Vermont Champ Curve, showing the net load on an average July day.[43]

The potential for over-generation is a challenge. **Figure 19** considers only solar generation, so other generation would also need to be shutdown or curtailed during hours of negative load. Curtailment requires controls and other infrastructure and has economic impacts on projects, so is not a preferred strategy.

See **Figure 27** for a comparison of demand with all generation on three sample days in 2025. Ramping down hydropower generation has ecological impacts from rising water in the reservoirs. Curtailing wind or solar has economic impacts. Must-take contracts would need to be re-negotiated before this situation, or else utilities would have to pay for power they do not use. Demand response / load shifting and storage might mitigate this likely problem. These data raise many issues that can be addressed with several possible strategies, discussed in **Section 4.1 Bulk Power System Integration.**

3.3 Economic Outcomes

The team has conducted economic analyses for three advanced solar scenarios. These are the SDP, Delayed Deployment and Low Net Metering (NM) scenarios. These can be compared to

[43] Enterline, Shawn. "Vermont Champ Curve." Green Mountain Power, 2015.

the Reference scenario and to the 90 x 2050_{VEIC} scenario. The Reference scenario does not meet the statewide target of meeting 90 percent of total energy needs with renewables by 2050. The 90 x 2050_{VEIC}, SDP, Delayed Deployment and Low NM scenario all meet the 90 x 2050 target. The SDP and Low NM scenario also meet the advanced solar economy target of supplying 20 percent of total electric generation from solar by 2025.

In 2015, Vermont's solar industry employed 1,367 workers.[44] This project envisions four times more solar installed in 2025 than in 2015. However, the annual addition of solar capacity across that decade is not expected to change drastically from the rate of added solar occurring now. Employment in the industry is more closely tied to the installation rate than to the total installed capacity, so the Team forecasts moderate growth in Vermont's solar industry across that period.

Vermonters spent $3.3 billion for energy in 2014.[45] By annually investing less than 1 percent of that amount in efficiency, fuel switching, and renewable energy, these high renewable scenarios can be achieved. Compared to the Reference scenario, all three SDP scenarios have higher net present value costs, ranging from $91 million to $209 million for the 2010-2025 period, as shown in **Table 7**. That is the timeframe for the 20 percent solar goal; if the period is extended, the three scenarios all show net positive economic results by the 2030s.

Table 7. Cumulative costs and benefits: 2010 – 2025, relative to the Reference scenario (discounted at 3.0% to 2015, in millions of 2015 U.S. dollars)

	90 x 2050_{VEIC}	SDP	Delayed Deploy	Low NM
Demand	**$851**	**$851**	**$851**	**$851**
Residential	$416	$416	$416	$416
Commercial	$261	$261	$261	$261
Industrial	$58	$58	$58	$58
Transportation	$115	$115	$115	$115
Transformation	**$306**	**$498**	**$319**	**$488**
Transmission and distribution	-$3	$13	$13	$13
Electricity generation	$308	$485	$306	$475
Resources	**$-1,079**	**$-1,139**	**-$1,078**	**$-1,148**
Production	$82	$82	$82	$82
Imports	$-1,162	$-1,222	-$1,160	$-1,230

[44] "Vermont Solar Jobs Census 2015," *The Solar Foundation*, 2015, http://www.thesolarfoundation.org/solar-jobs-census/vt-2015/.
[45] "Total Energy Consumption, Price, and Expenditure Estimates, 2014," *U.S. Energy Information Administration*, accessed September 22, 2016, http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_te.html&sid=US&sid=VT.

	90 x 2050VEIC	SDP	Delayed Deploy	Low NM
Exports	-	-		-
Unmet requirements	-	-		-
Environmental externalities	-	-		-
Non-energy sector costs	-	-		-
Net present value	**$77**	**$209**	**$91**	**$190**
GHG savings (million tonnes CO_{2e})	7.1	7.1	7.1	7.1
Cost of avoiding GHGs ($ / tonne CO_{2e})	$10.7	$29.3	$12.8	$26.7

Over time, the benefits from investments in efficiency and solar far outweigh the costs, producing significant economic value for the state. The model projects close to $8 billion in cumulative net positive benefits by 2050, as shown in **Figure 20**. Overall, the economic analysis results indicate that a slight net investment (<1 percent of annual energy expenditures) in developing the advanced solar economy through 2025 creates very large positive net benefits across time. Vermont policy makers and consumers are increasingly recognizing the benefits of this value proposition, driving the levels of investment and savings emerging in the market.

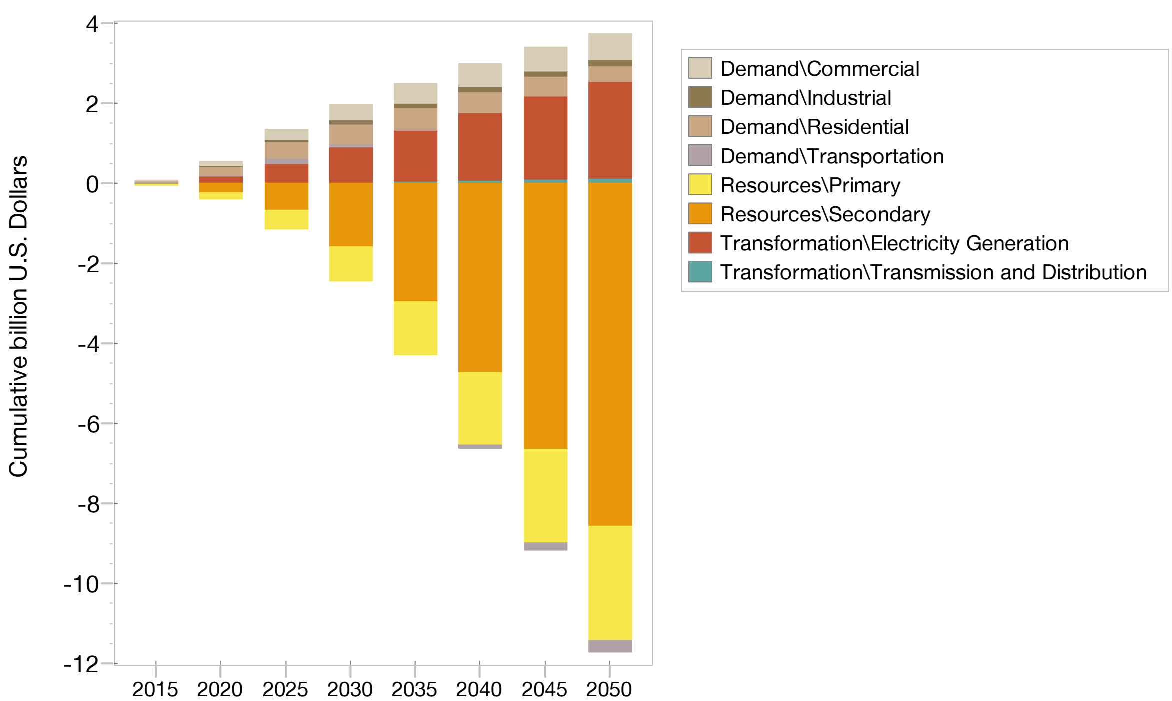


Figure 20. A comparison of cumulative discounted costs for electricity generation, between the SDP and References scenarios.

Figure 21 illustrates a comparison of the annual costs for electric generation between the SDP scenario and the Reference scenario. The SDP scenario has higher costs for solar, new wind, and new in-state hydropower. The increased costs for these resources are partially offset by a reduction in costs for natural gas-fired electricity imported from the regional power markets.

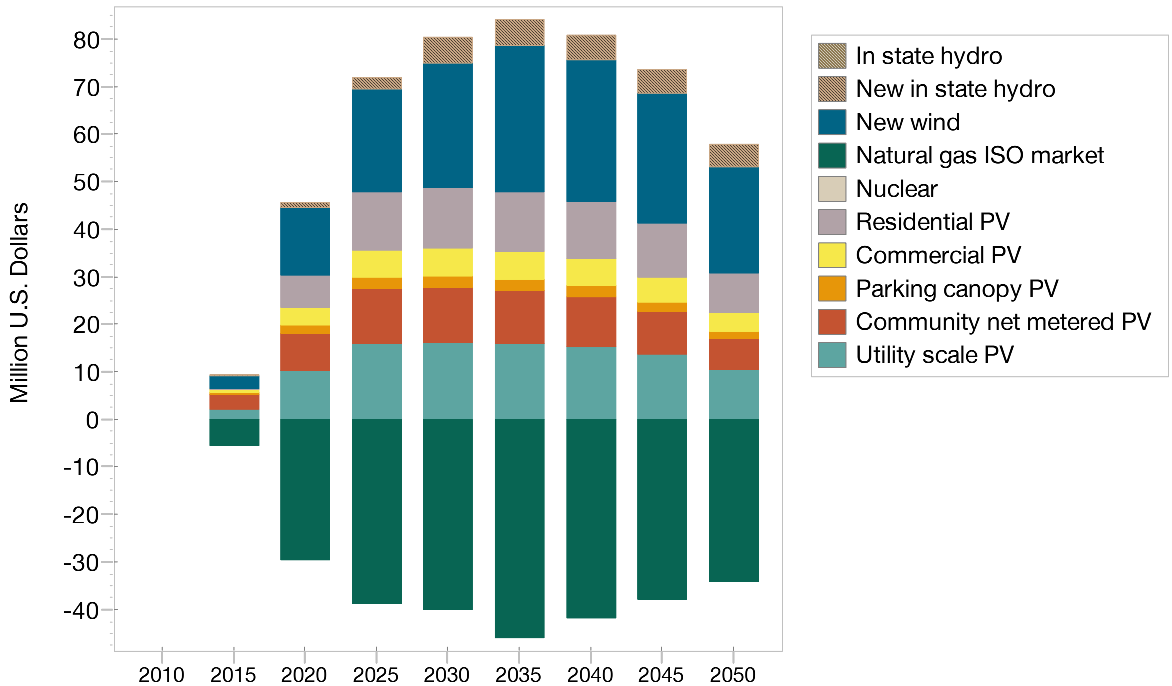


Figure 21. Annual discounted costs for electricity generation in the SDP scenario, compared to the Reference scenario.

3.4 Environmental Outcomes

The SDP scenario reduces greenhouse gas emissions by roughly 20 percent by 2025, and by more than 80 percent by 2050. **Figure 22** illustrates these effects.

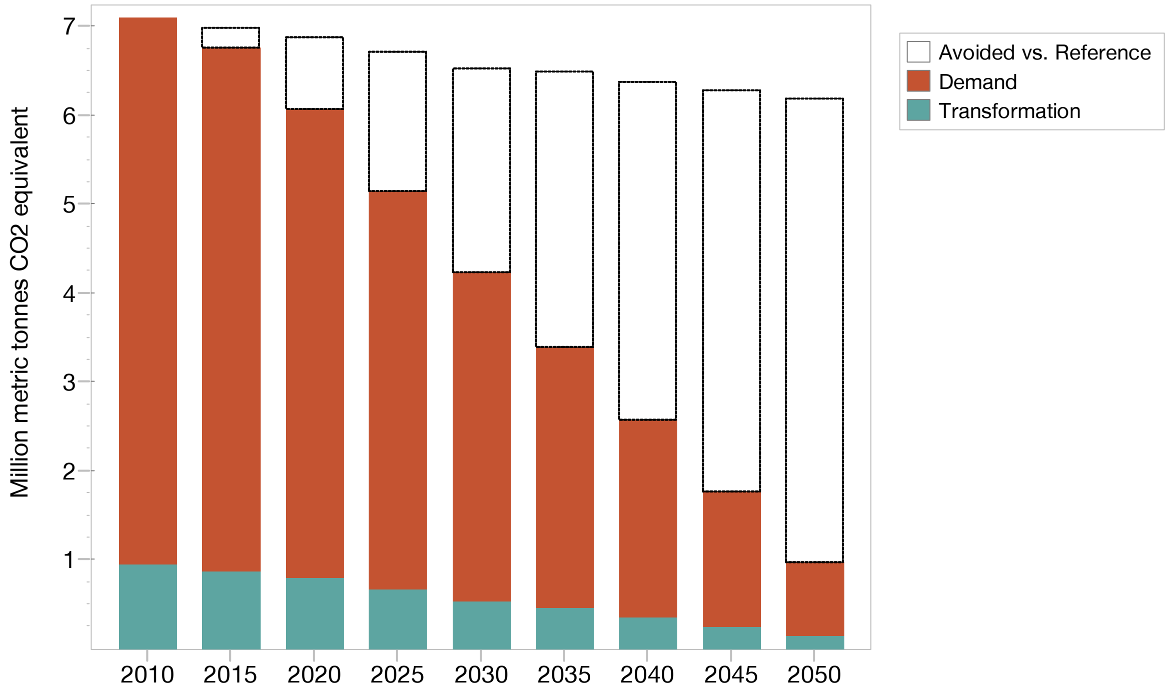


Figure 22. Emissions of the SDP scenario compared to the Reference scenario.

By 2050, Vermonter's emissions per person fall below 2 metric tonnes per person, a limit suggested for mitigating climate change. Vermonters will see much more of the energy system as in-state renewable projects replace imported energy. Careful siting and project design can limit the impact.

4. Strategies for Becoming an Advanced Solar Economy

4.1 How the Results Can Be Attained

Siting and System Integration

The Team identified the target of 20 percent of total electric needs met by solar power by 2025 as an ambitious but achievable solar energy goal. To achieve 20 percent of annual electricity supplied by solar in Vermont requires approximately 1 GW of solar, which is equal to Vermont's peak electric demand—before the electrification of transportation and heat.

To determine how to reach that target, the Team evaluated the impact of 1 GW of solar within the state's bulk power mix, and how that much solar would affect the distribution circuits where it would be connected.

This approach, identifying a goal and illustrating and exploring multiple ways of reaching it, allowed the Team to test several different scenarios. No predictive analysis will be 100 percent accurate, particularly one with a time span as long as 35 years. The end-oriented approach has provided a structure through which to test hypotheses and to elicit stakeholder feedback on likely issues. Other analyses screen for cost effectiveness or use economic optimizations. However, people do not always make consistent, rational economic decisions, nor do they immediately switch when a new, more cost-effective product or service becomes available.

This project describes a future that people want, even though they are not certain that it is achievable. The team built support for the 20 percent goal and then worked through issues to build confidence in the feasibility. **Volume 3, Barriers and Integration Brief** documented several possible problems from a future that offers high solar penetration. This section identifies potential solutions to each.

Space Requirement

Some observers cite the space requirements of solar as a reason for it not to play a major energy supply role. Although sunshine is one of the least dense forms of energy, and siting space might be a limiting factor in cities attempting to become energy self-sufficient, Vermont has more than enough space for solar. For an approximation of the space required for the SDP scenario, the Team examined land requirements based on the 2050 solar capacity, shown in **Table 8**.

At that point, solar produces close to one-third of annual generation, and the space requirements are just 2/10 of 1 percent. This finding helps to inform the public discussion of land requirements for solar, indicating that solar resource and land are not limiting factors.

Table 8. Land requirements for achieving the targeted 2050 solar capacity

	2050 MW	Percent on open land	MW on open land	Acres required[46]	Percent of state
Residential	360	25%	90	720	0.01%
Commercial	240	50%	120	960	0.02%
Parking canopy	90	0%	0	0	0.00%
Community	510	100%	510	4,080	0.07%
Utility	800	100%	800	6,400	0.10%
Total	**2,000**		**1,520**	**12,160**	**0.20%**

Even though the overall land requirements are modest, the proper siting of solar is an important topic, both for land use and grid integration. Recent Vermont Legislation requires RPCs to develop maps identifying the most and least acceptable areas for development for different types of renewable energy resources. Vermont's new net-metering law provides preferred pricing to net-metered generation located on disturbed sites, sites identified by municipalities as preferred sites for renewable development, or adjacent to the demand for the energy.

The Bennington County Regional Commission (BCRC) produced a map of "prime solar" land near existing power lines and away from floodways, wilderness areas, rare and irreplaceable natural areas, wetlands, agricultural soils, and other constraints. **Figure 23** shows a small section of the map and legend. The yellow prime solar land is near existing development and is not found in the forested mountains, which are shown by dotted elevation lines on the left side of the map.

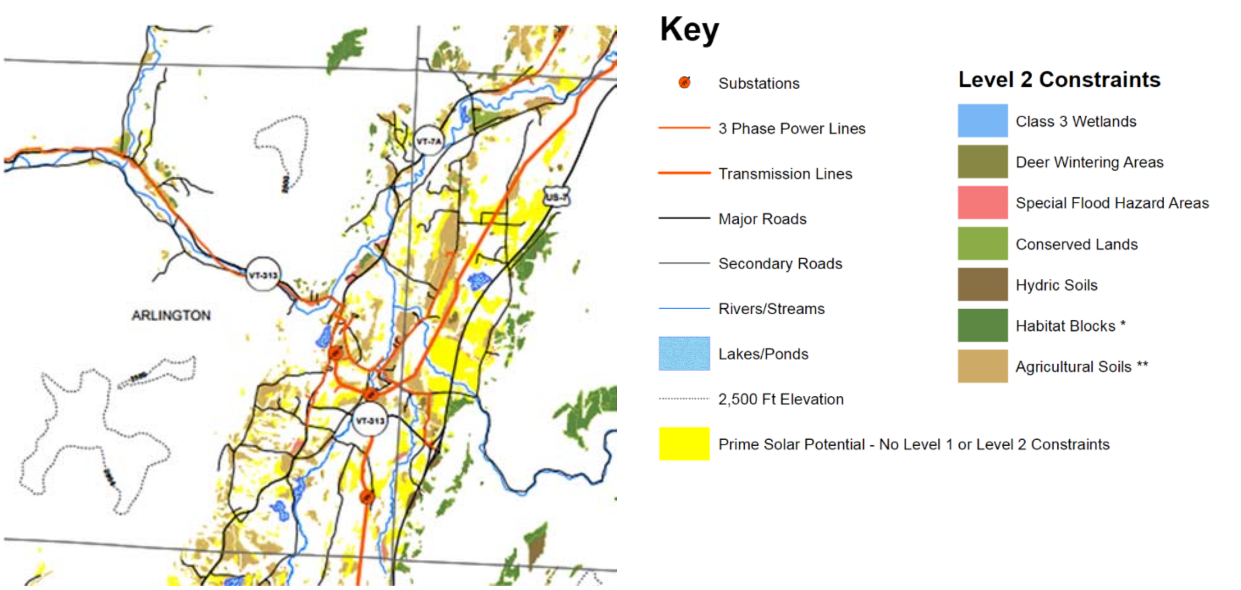


Figure 23. A section of a map showing "prime solar" land.

BCRC also analyzed the geography to summarize the availability of prime solar land in their region. **Figure 24** is an image they produced to help people visualize the vast amount of land,

46 Sean Ong et al., "Land-Use Requirements for Solar Power Plants in the United States" (National Renewable Energy Laboratory, June 2013), http://www.nrel.gov/docs/fy13osti/56290.pdf.

and of prime solar land available, compared to the amount required for their contribution to the statewide target.

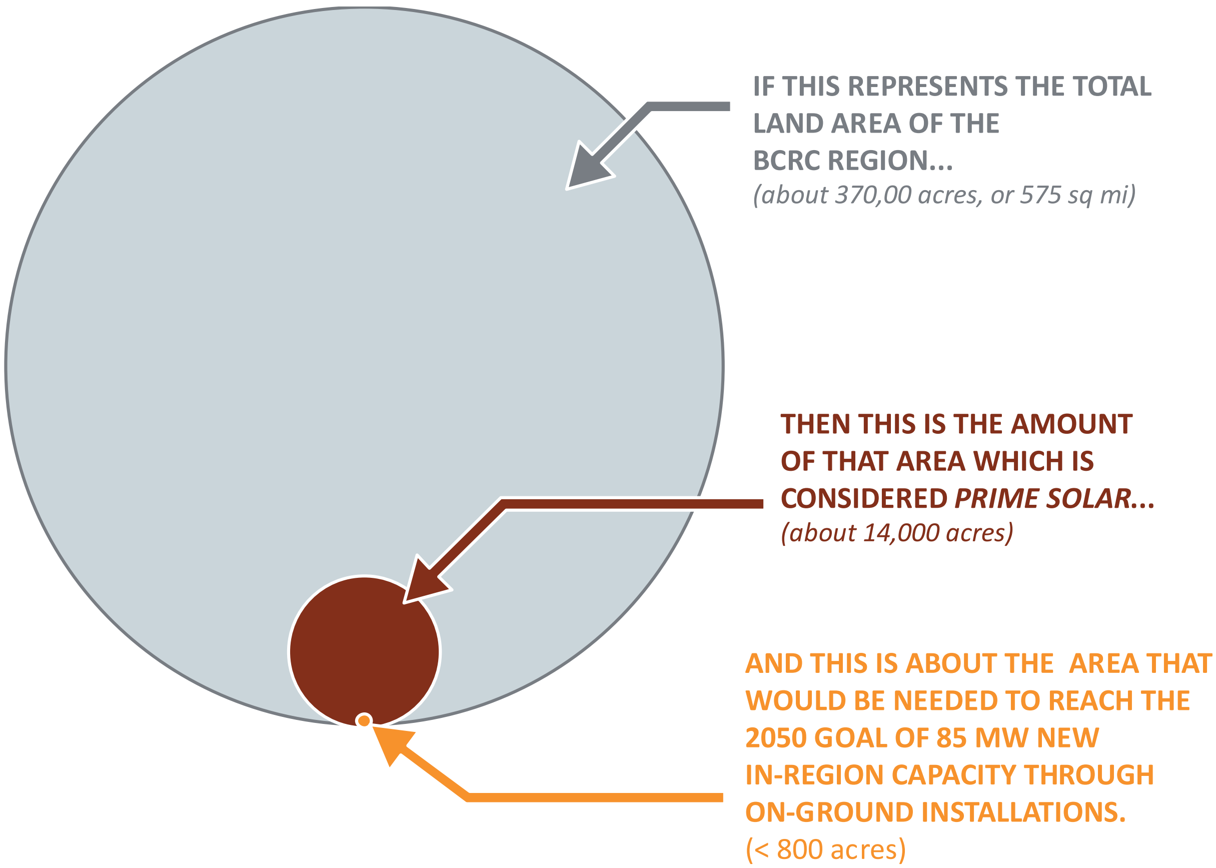


Figure 24. A Bennington County Regional Commission graphic showing more than enough prime solar land to site the targeted capacity of solar.

There are several ways solar can be added with minimal impact to the site. Rooftop systems are widely seen as low impact, and arrays over parking lots have the additional benefit of keeping the cars under them cooler. Ground mounted systems can be integrated into farms by locating them along existing fence lines or separations, in land with poor soil, or in the case of an apple orchard, in the low spots in the land where trees would be vulnerable to late spring frosts. Within large solar arrays, there are alternatives to mowed turf grass. Animals can graze, though some require taller or stronger solar racks to avoid damage. Wildflower and native grasses can be established to keep growth low and provide foraging habitat for bees and birds while those pollinators benefit nearby agriculture. Pollinator-friendly vegetation also has deeper roots than turf grass, helping retain soil and nutrients and controlling stormwater. Pollinator-friendly vegetation standards have been established in Minnesota and the approach is common in the UK.[47]

[47] Davis, Rob, "Can Solar Sites Help Save The Bees?" Bee Culture, July 25, 2016, http://www.beeculture.com/can-solar-sites-help-save-bees/.

Distribution System

A high percentage of solar and other renewables can cause problems on the distribution grid and in bulk power supply. Although this study did not conduct detailed distribution engineering analyses, the Team reviewed related work in other jurisdictions and is following the progress of the Vermont utilities' work with Sandia National Laboratory, funded through DOE's Grid Modernization Initiative.

Relevant outcomes of secondary research are summarized below. Well-designed and executed distribution study analyses provide the following results for substations and individual feeders. These findings are detailed on page 5-14 of Electric Power Research Institute's (EPRI) benefit-cost analysis of an integrated grid framework:[48]

- **Feeder-specific hosting capacity.** Individual feeders, and locations along an individual feeder, vary in their ability to host DERs without violating voltage and protection scheme thresholds. Generally, locations that are closer to the substation on a radial feeder will have a higher hosting capacity than locations at the end of the feeder line. The presence of DERs does not always result in negative impacts. For example, if the end of a radial feeder line is challenged to maintain adequate voltage, the development of DERs with appropriate controls may be able to alleviate the situation.
- **Substation-level hosting capacity.** The hosting capacity at a substation serving several feeders may or may not be the sum of the feeders' capacities. Determining substation hosting capacity helps to inform analysis of the bulk power system and analysis of overall supply adequacy and system reliability.
- **Energy consumption and loss impacts.** The levels of DER on a feeder affect the loading of the feeder which influences distribution system losses. For example, the high end of voltage operating windows results in higher line losses. If distributed generation causes higher current flowing back to the substation than the original load, line losses will increase in that condition. The operations of equipment along a feeder, such as the frequency of changes in voltage tap regulators, can also be affected by additional DER. Sometimes relatively simple solutions are available, whereas in other cases more expensive changes in the system are required.
- **Asset deferral.** The development of well-integrated DER can help to alleviate the need for distribution and substation capacity upgrades.

This type of analysis is already taking place at many leading utilities. An example of asset deferral is Consolidated Edison's Neighborhood program, which aims to defer the need for a $1.2 billion substation upgrade with investments in demand response and distributed resources.[49]

---

[48] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework" (Electric Power Research Institute, February 2015), http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004878.
[49] G. Bade, "ConEd Awards 22 MW of Demand Response Contracts in Brooklyn-Queens Project," *Utility Dive,* August 8, 2016, http://www.utilitydive.com/news/coned-awards-22-mw-of-demand-response-contracts-in-brooklyn-queens-project/424034/.

Data from Pepco distribution analysis shown in **Figure 25** echoes the EPRI study results:

- The ability of distribution feeders to accommodate solar varies widely and the average may not be meaningful.
- Some feeders have a high capacity to interconnect solar without any upgrade cost

Ideally, solar installations would be focused on feeders in the lower right corner of the graph, but without investing in studying each feeder's electric and loading characteristics, we do not know where feeders would appear on the chart. A utility stakeholder suggested patterns might emerge in this data if more information on the circuits were available. He expects that higher voltage feeders have higher hosting capacity.

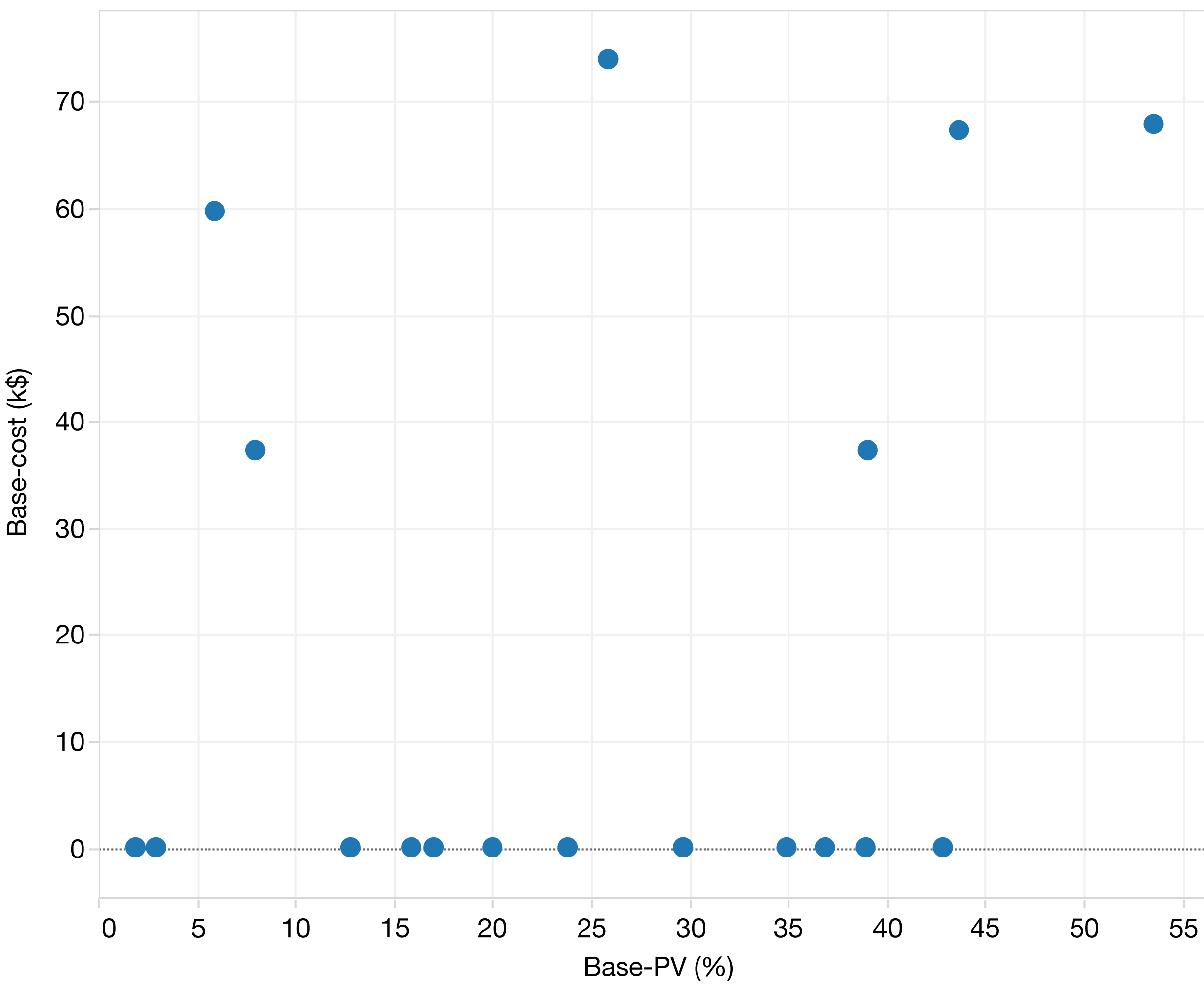


Figure 25. Solar capacity as a percentage of feeder rated capacity versus distribution system upgrade cost, the base case before optimizing for PV. Data from Pepco analysis is presented as part of "Preparing for a Distributed Energy Future: What Can Be Done Today to Integrate DERs Cost Effectively."[50]

[50] Walter Rojowsky, Steve J. Steffel, and Steve Propper, *Preparing for a Distributed Energy Future: What Can Be Done Today to Integrate DERs Cost Effectively* (Greentech Media, 2016),

Navigant performed similar analysis for the Virginia Solar Market Pathways project.[51] This analysis had similar results and showed that many feeders can host relatively high solar penetration without any upgrades. Very high solar penetration that generates power beyond the local needs and pushes power back onto the transmission or sub-transmission grid is likely to require utility upgrades.

Both of the Pepco and Navigant analyses also show that some feeders can host zero or small amounts of solar before requiring upgrades.[52] This highlights the needs for strategic siting. Vermont has many opportunities to apply these analyses in its siting practices.

In the typical process, a homeowner, business, or solar developer designs a solar system, applies for a permit (in Vermont it is a Certificate of Public Good) and applies for interconnection with the utility. If the project requires the utility to upgrade their equipment, the project is charged for the cost of that upgrade.

Stakeholders discussed two problems with this approach: First, it is inefficient and wastes system design time when cost-effective interconnection is not possible. Second, it may fully burden one project with upgrade costs that were partially caused by the systems that came before it, and systems that come later may get free use of the newly added hosting capacity.

Green Mountain Power provides potential developers with a Solar Map,[53] a section of which is shown in **Figure 26** that gives an initial indication of where projects are more or less likely to have high interconnection costs. This initial hosting capacity analysis has been helpful to guide development away from areas already constrained, but it is fairly simplistic. In 2017, GMP will implement circuit-level modeling to create a proactive distribution plan for every GMP circuit.

---

https://www.greentechmedia.com/events/webinar/preparing-for-a-distributed-energy-future-what-can-be-done-today-to-integra.

[51] Navigant Consulting, "Virginia Solar Pathways Project, Study 1: Distributed Solar Generation Integration and Best Practices Review," April 30, 2016. http://solarmarketpathways.org/wp-content/uploads/2016/09/DVP_DG-Transmission-and-Distribution-Grid-Integration-Study.pdf.

[52] Vermont's long and lightly loaded rural feeders may be different from those studied. Results from the Grid Modernization study by Sandia will help the Team and stakeholders understand more about Vermont's feeders.

[53] "Solar Map," Green Mountain Power, accessed September 21, 2016, http://www.greenmountainpower.com/innovative/solar/solar-map/.

Figure 26. GMP's Solar Map shows areas of the grid that have capacity, are approaching the limit, or have little to no capacity available.

In new net-metering rules for 2017, Vermont added a siting incentive to encourage solar installations on buildings and disturbed land. A similar incentive could encourage siting based on the needs and capabilities of the distribution system. Publically available information about the needs of the grid could also encourage strategic siting. If a grid siting incentive were used, it should be fair, predictable, and should not unduly influence land values.

In addition to analysis and upgrades, the utilities can do to estimate and increase solar hosting capacity, technology on the project side of the meter increases capacity by reducing the project's impact. Advanced, or smart, inverters will become an important tool in reducing the impact of so much solar on the grid. The standard for their operation was not yet available in 2016, but by 2025 these inverters could alter their voltage in support of the grid and remain steady during short-term frequency fluctuations, thus helping avoid what one stakeholder described as "the largest power plant in the state cycling on and off as clouds pass." Additional improvement is available through load management and storage.

Bulk Power System Integration

Looking at Vermont as a whole, high levels of solar generation can cause different issues. Solar generation varies in predictable and less predictable ways according to the position of the sun and the weather. While solar generation prediction software is rapidly improving, the bulk power system must provide adequate, complementary generation. This report summarizes potential issues on the bulk power system and explores how Vermont's system might be affected.

As detailed in a recent EPRI report, bulk power system impacts can include the following: [54]

[54] K. Forsten, "The Integrated Grid: A Benefit-Cost Framework."

- **Resource adequacy.** Are the existing and planned generating capacity levels sufficient to meet demand? For renewable resources, the daily and seasonal variability in output and the matching of generation to demand load shapes need to be considered. The National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS) system provides a national-level visualization of scenario modeling illustrating the mapping of generation loads and transmission in a high renewable energy future.[55]
- **Flexibility assessment.** The intermittent nature of solar and wind resources increases the need for resources on the system that are sufficiently flexible to adapt to increased ramping up and down.
- **Operational scheduling and balancing.** Operational processes and market structures to allow for adequate balancing of supply and demand, given the reliability, safety, and power quality standards and requirements.
- **Transmission system performance, deliverability, and planning.** Analysis and planning that considers constraints and congestion on the delivery of power on the transmission system. Increased renewable generation might result in generation that is both closer to load (in the case of DERs) and more distant from it (for example, large wind resources).

As levels of DERs increase and electrification of heating and transportation services changes the timing of demand, impacts from the distribution and sub-transmission levels affect the transmission system. Therefore, iterative analyses and planning processes are often required for a comprehensive assessment.

The Team simulated Vermont's electricity demand and supply in 2025 to look for these issues and determine the amount of flexible demand, storage, or additional supply needed. Using hourly data described in **Table 2** of **Volume 4,** the Team compared the sum of renewable and contracted supply to the forecast demand. The demand shape is from 2013, but is increased to reflect expected electrification.[56] **Figure 27** shows three sample days from the SDP scenario in 2025. When presented with similar graphs, **the utility stakeholders were not especially concerned with the mismatch between demand and supply;** they manage similar daily mismatches today using the regional spot market for wholesale electricity. The January day shows especially low generation, with both wind and solar at low levels. Large-scale storage such as pumped hydropower or additional winter supply might be necessary to manage extended periods of low renewable output.

One stakeholder noted that in times of low load and high solar, such as the example April day, the market price for power is likely to be low because the rest of the region, especially Massachusetts, would be experiencing the same situation. The excess power could sent the wholesale price of electricity below zero. Thus, selling the excess energy to other parts of New England might not be a good strategy. The supply mix is able to meet demand on the July

---

[55] Mai, T. et al., "Renewable Electricity Futures Study: Executive Summary" (Golden, CO: National Renewable Energy Laboratory, 2012), http://www.nrel.gov/analysis/re_futures/.

[56] This increase in loadshape reflects the early stages of electrification. Further analysis should include additional electrification, and have increases reflect the loadshapes of heat pumps and electric vehicles as data becomes available.

summer peak, but solar output decreases much more quickly than demand. In the figure, the dispatchable wood+biogas plants turn off during the short midday period that would otherwise have over-generation. Given the deficit all afternoon, the wood+biogas could continue running midday to pre-cool homes and buildings and charge batteries in preparation for the afternoon.

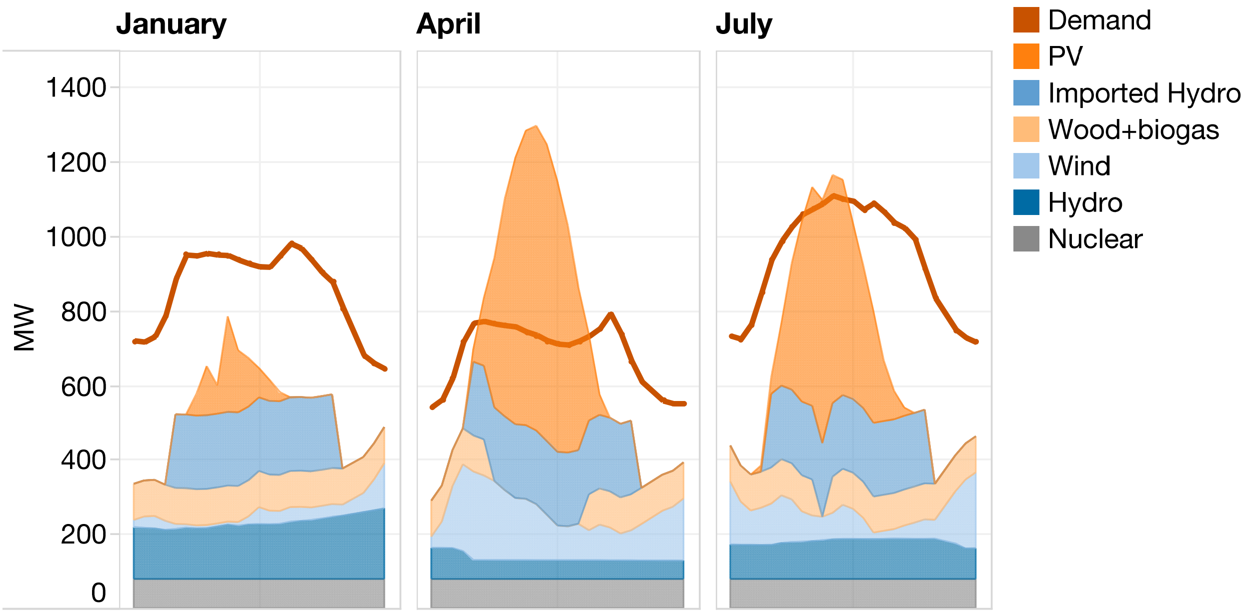


Figure 27. Projected supply and demand in 2025 show sample days with under-supply and over-generation. The January day suffers from a lack of wind and solar generation. The April day has lower load, some wind, and a lot of solar, creating 600 MW of excess capacity. The situation would be even worse if hydro was at a typical spring high. On the July day, supply matches demand in the afternoon.

Using the year of hourly data, the Team calculated the "imbalance" between demand and supply, defined as the sum of contracted supply and renewable output minus gross demand. In **Figure 27**, deficit imbalance is the white space below the demand line and above the stacked supply, and surplus imbalance is the area of supply above the demand line.

Optimal strategies for dealing with imbalance depend on the magnitude (MW), duration (hours), and the product of those, the energy imbalance in megawatt-hours. The choice of strategy also depends on proximity to an opposite balance, e.g. oversupply is easy to use effectively if it happens just before a period of shortage since the excess could be used for pre-cooling or pre-heating buildings and charging batteries. **Figure 28** shows the imbalance for each of the days in **Figure 27** and for the two days before and two days after. Unfortunately, this shows that the difficult conditions on the January and April days are the predominant conditions for several days. This limits the effective balancing strategies to additional generation or purchase, curtailment, or long-term storage. The days surrounding the sample July day offer a better balance of surplus and deficit conditions that offer more strategies.

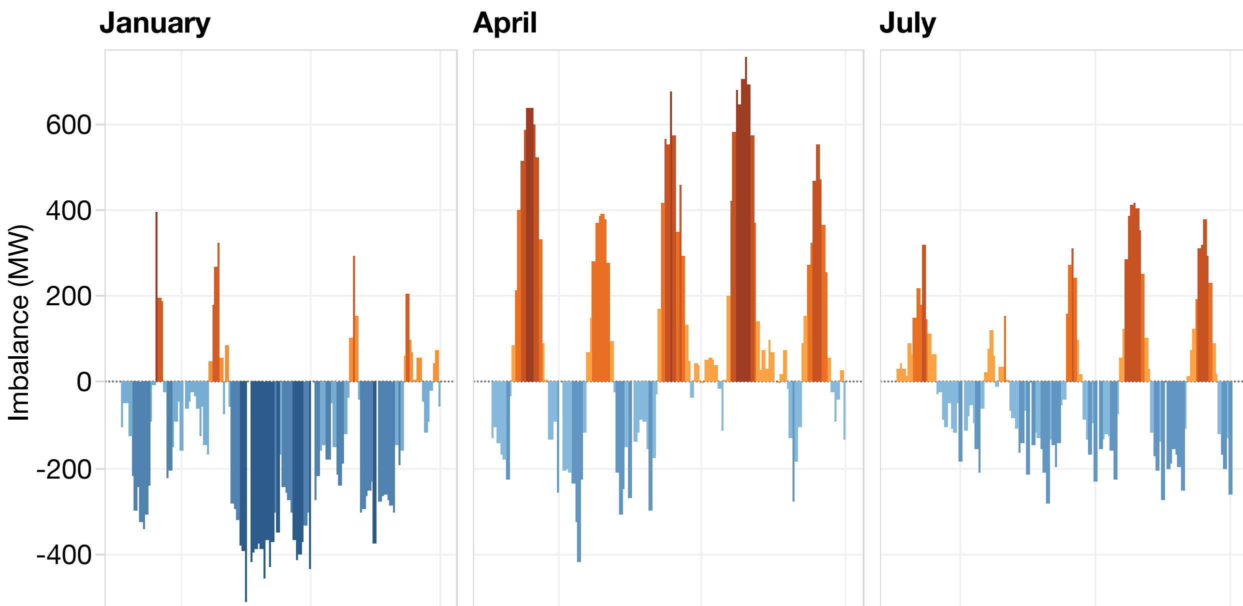


Figure 28. The demand/supply imbalance for each of the sample days above and two days before and after, show that the daily imbalance can be the prevailing condition for several days during the most challenging times of year.

To help determine whether investments in long-term storage or new generation are warranted, and if curtailment should be included in renewable energy financial planning, planners need to estimate how often each of these imbalance conditions occurs. The sample days were chosen because of the difficulty they presented, not because they characterize average days. The examples could be thought of similar to today's peak conditions—important but infrequent. **Figure 29** presents the year's imbalance in the shape of a load duration curve, one for daylight hours, and one for dark hours. Predictably, there is much more surplus during daylight.

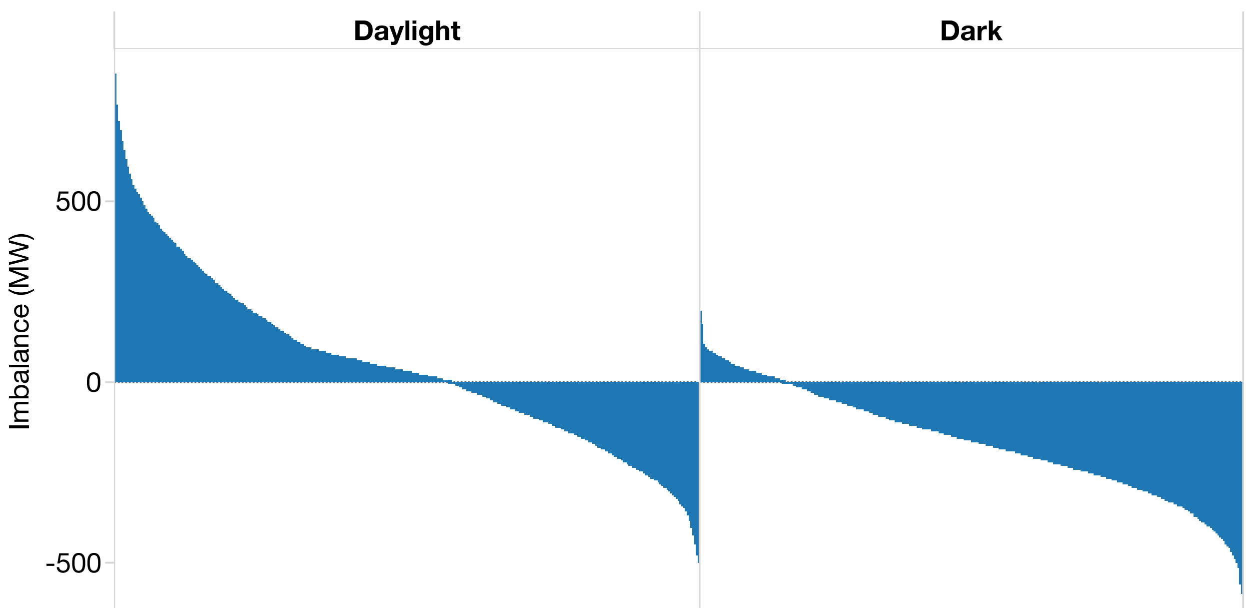


Figure 29. Imbalance Duration Curve by Daylight and Dark.

Figure 30 categorizes the imbalances in ways that inform the solutions: **Figure 30 A** shows that in the sample year, nearly all imbalances last for less than 25 hours, though a deficit can last for more than 80 hours and a surplus can last for more than 40 hours. Battery storage and demand management could likely address the most common, shorter duration imbalances. **Figure 30 B** provides a histogram of the magnitude of the imbalances. Most surplus imbalances are not more than 80 MW, and deficits commonly range up to 400 MW. The dual peak is because of the 97 MW of wood+biogas that is dispatchable in this model. **Figure 30 C** is the histogram for the energy of each imbalance period. Most surpluses and deficits are less than 500 MWh; deficits have a larger range of MWh than surpluses.

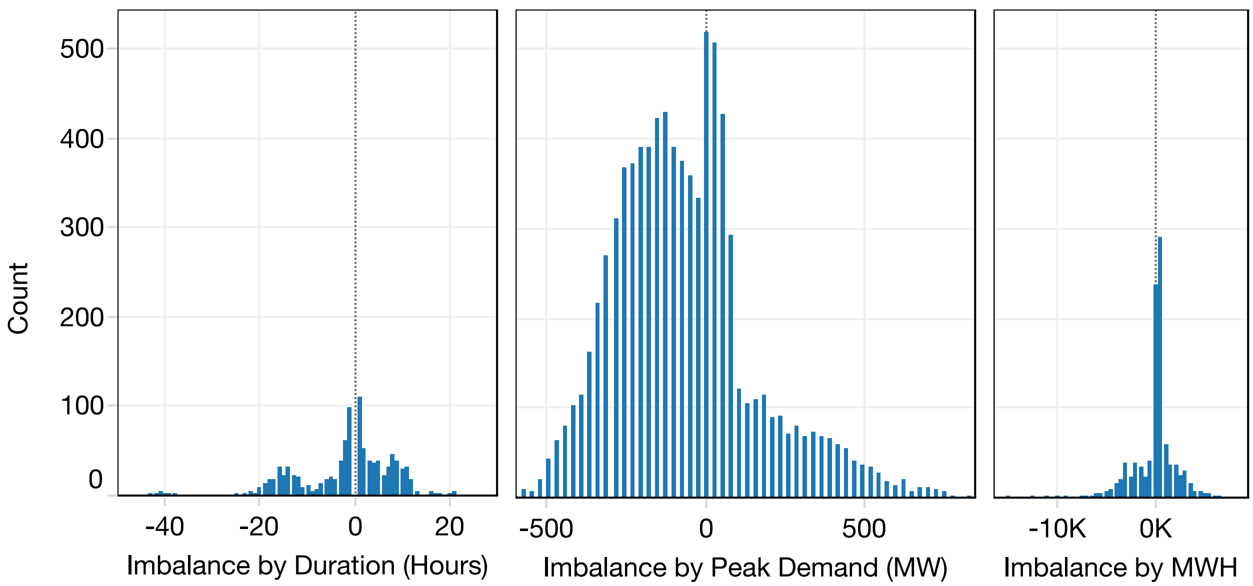


Figure 30. A. Imbalance by Duration (hours). B. Imbalance by Peak Demand (MW). C. Imbalance by MWH.

Smart Grid, Demand Management, and Storage

The smart grid offers opportunities to integrate improved forecasting (of weather, load, and generation) with grid system operations and management. The Vermont Weather Analytics Center, a collaboration between VELCO, IBM, GMP and others, is providing this type of cutting edge information today. Demand management through distributed customer-level equipment and devices can work with batteries and other forms of storage to enhance the capacity of the grid to support higher saturations of intermittent solar PV generation. The following are attributes of and future considerations for smart grid, demand management, and energy storage:

- The smart grid allows standards-based, real-time communication with inverters and generation meters. It also allows communication with responsive loads and storage (for example, electric vehicles, pre-heating and cooling, peak demand management). This communication and coordination helps manage the localized and system wide variability of PV system supply.
- As battery prices drop, “grid-scale” storage and distributed storage will be part of the smart grid capability to coordinate and optimize site and system energy.
- The location of controllable loads and storage, relative to sources of generation, will begin to matter at a certain level of solar penetration. It is important to note that location

will not be a primary concern for grid balancing, at first. However, the value of storage and demand response will vary by location, even in the relatively early stages. It is likely the variation in locational value will increase as saturations increase, overall.

- Providing sufficient system status, control, and forecast networks to distributed generation, controllable load, and storage will be challenging and must address concerns with cybersecurity and privacy protection.
- New rates models and interconnection rules and processes will likely be needed to fully realize the public and private cost savings potential of smart grid and energy storage. New utility regulatory paradigms which incentivize on-peak renewable generation and investments in non-traditional resources needed to decarbonize the grid may further bolster cost savings. Ensuing that utilities can recover the related investments in IT is also important.
- Smart grid, demand management, and storage can collectively provide insight into costs by location and time of use, to reflect the true cost and value of solar generation.

Business Models

The following two sections present several options for how business models and regulatory oversight can evolve in ways that are consistent with and supportive of an advanced solar economy. These are examples and are not meant to be prescriptive, or as predictions of the business and regulatory models that will necessarily emerge. The business models and regulatory structures associated with the actual development of Vermont's advanced solar economy will by necessity be informed and influenced by new market conditions and the process of public and stakeholder engagement, negotiation, and review.

Solar business models. The scenario analyses indicate that a mix of business approaches to solar projects will be required to accomplish the Solar Development Pathways target**.**

Individually and third-party-owned rooftop and ground-mounted systems will provide consumers with the opportunity to host or own solar generation on their properties. In the SDPα scenario, the share of solar expected to be located on site, in ground, and / or as rooftop systems is roughly 300 MW, by 2025.

Vermont's virtual net metering regulations enable **community solar,** one of the more rapidly evolving markets. Community solar allows a single system to provide credits for solar generation to virtually net-metered groups of customers who reside in the same utility service territory. Innovation, research, and market testing for community solar business models, including those offered by third parties and those offered directly by utilities, are under way in Vermont. This is also true of other parts of the country. Several of the other national Solar Market Pathways projects have community solar as integral components to their awards (the Solar Market Pathways projects addressing community solar are the Solar Electric Power Association, Cook County, the Center for Sustainable Energy, and Extensible Energy). Further, a community solar affinity group has been established to share information.[57] The U.S. Department of Energy has also launched a national community solar partnership with a specific emphasis on serving moderate- and low-income households. The White House announced this initiative on July 7, 2015.[58] In the SDPα scenario, the share of solar expected to be allocated to community solar is roughly 300 MW by 2025, with the majority of this being ground mounted.

The rooftop and community solar installations are based on principles of both direct and virtual net metering, and therefore offset consumption at retail electric rates. **Projects that have direct power purchase agreements with utilities** are also expected to play an important role in the growing market. Under Vermont's Standard Offer Program, projects of up to 2.2 MW are eligible for long-term contracts. Once online, these projects are made publicly available on the Vermont Standard Offer website.[59] Another option for larger projects is to apply for long-term contracts under Rule 4.100, Vermont's Small Power Production and Cogeneration structure for implementing the federal Public Utility Regulatory Policies Act (PURPA). Recently, the Vermont Public Service Board and VELCO received applications for several projects that are much larger (20 MW each) than what has currently been built in Vermont.[60] The process for review and interconnection of projects at this scale is not yet clear, but it indicates how evolving market strategies and business models will likely influence the technical and regulatory issues, and vice versa.

Complementary DER business models. Several distributed energy resources will enable, help to drive, and be driven by increasing solar saturation. The primary resources are storage (customer on-site, and storage located on the utility distribution system); electric vehicles with smart charging and vehicle-to-grid enabled capacities; controllable customer loads such as heat pumps, hot water heaters; and high-performance zero energy buildings, including high-performance modular housing. This project explicitly recognizes the importance of these markets and technologies through its Focus Area working groups. The project scenarios are examining the potential scale of development and potential barriers to progress in each.

Research conducted in Europe for the Power Perspective 2030 study illustrates the importance of integrating other DERs as part of the advanced solar scenarios.[61] These findings indicate that a shift of 10 percent of aggregate demand in a day results in a 20 percent reduction of investment required in the supply side infrastructure over a 15- to 20-year horizon.[62]

---

[57] "Solar Market Pathways," *Department of Energy: Office of Energy Efficiency & Renewable Energy*, accessed September 22, 2016, http://energy.gov/eere/sunshot/solar-market-pathways.
[58] "National Community Solar Partnership," *Department of Energy*, accessed September 22, 2016, http://energy.gov/eere/solarpoweringamerica/national-community-solar-partnership.
[59] Vermont Electric Power Producers, Inc., "SPEED Solar Online Projects - Comparison DC/AC" (Vermont Standard Offer, April 24, 2015), http://static1.1.sqspcdn.com/static/f/424754/26167074/1429817055967/SOLAR+AC-DC+ON+LINE+PROJECTS+4-24-15.pdf?token=1Yt%2FAygme2kIyXP2dW2SjliFs2M%3D.
[60] Erin Mansfield, "State Concerned about Proposal for Giant Solar Project," *VTDigger*, September 8, 2015, http://vtdigger.org/2015/09/08/state-concerned-about-proposal-for-giant-solar-project/.
[61] Christian Hewicker, Michael Hogan, and Arne Mogren, "Power Perspectives 2030: On the Road to a Decarbonised Power Sector," accessed September 22, 2016, http://www.roadmap2050.eu/reports.
[62] Ibid.

The distributed and networked attributes of the technologies contributing to an advanced solar economy increase the need and opportunities for aggregation of energy services. Community solar is one example. Another is aggregation of electric vehicles for coordinating charging or vehicle-to-grid services. The scale of service and value from an individual vehicle or other DER, such as an electric water heater, is not large enough to justify individuals' participating in a market. However, through aggregation, the coordination and value from a larger number of devices can be captured. Innovative approaches to aggregation can be combined. For example, through the coordination and aggregation of electric water heaters, a community solar power project in West Virginia was able to generate revenues sufficient to fund the investment required for installation of a community solar array on roof of the local church.[63]

Addressing Low-Income People: A Societal Imperative

A 2014 analysis by the Vermont Law School has sharpened statewide awareness of high-energy burdens on low-income households in Vermont.[64] The study found that those who spend more than 10 percent of their monthly income on energy services are considered "fuel poor." Further:

- One in five Vermonters lives in fuel poverty.
- People who lack sufficient energy to keep warm in winter face a higher-than-average risk of stroke, heart attack, influenza, pneumonia, asthma, arthritis, depression, anxiety, and accidents in the home.
- Between 1999 and 2011, Vermont averaged 172 excess winter mortalities per year.
- Annual excess winter deaths caused largely by fuel poverty account for more Vermont deaths than do car crashes.

It is a tenet of energy efficiency and renewable energy advocates that reducing the energy burden for people at risk strengthens economies. This message has relevance for the Vermont Solar Market Pathways stakeholders.

Of particular importance will be explicit goals for reducing the energy burden (the total costs for energy services as a percent of household incomes) for low- and moderate-income households.

---

[63] "Shepherdstown Presbyterian Church," *Solar Holler, Inc.*, accessed September 22, 2016, http://www.solarholler.com/shepherdstown-presbyterian-church/.

[64] Teller-Elsberg, Jonathan et al., "Energy Costs and Burdens in Vermont: Burdensome for Whom? A Report for the Vermont Low Income Trust for Electricity, Inc." (South Royalton, VT: Institute for Energy and the Environment at Vermont Law School, December 2014), http://www-assets.vermontlaw.edu/Assets/iee/VLS%20IEE%20Energy%20Burden%20Report.pdf.

Building practices and systems, such as the high-performance modular home (see sidebar on the model for affordable living) will help shift the retail energy market from one that is concerned about annual energy operating costs to one concerned about investment opportunities in new construction and retrofits. **Figure 31** illustrates how the efficient construction practices and energy systems reduce consumption and result in lower total costs.

A Model for Affordable Living

Highly efficient housing and end use services will be prevalent in Vermont's advanced solar economy. So will be an attention to the nexus of energy security for low- income and at-risk populations and community-level economic security.

High performance modular housing in Vermont offers the highest levels of indoor air quality, building durability, energy system integration and monitoring. A continuous energy recovery ventilation (CERV) system and other high-performance systems, design, and construction give these units an average annual energy intensity of less than 27 kBtu / sq. ft. (regional average = 55 kBtu). www.vermodhomes.com.

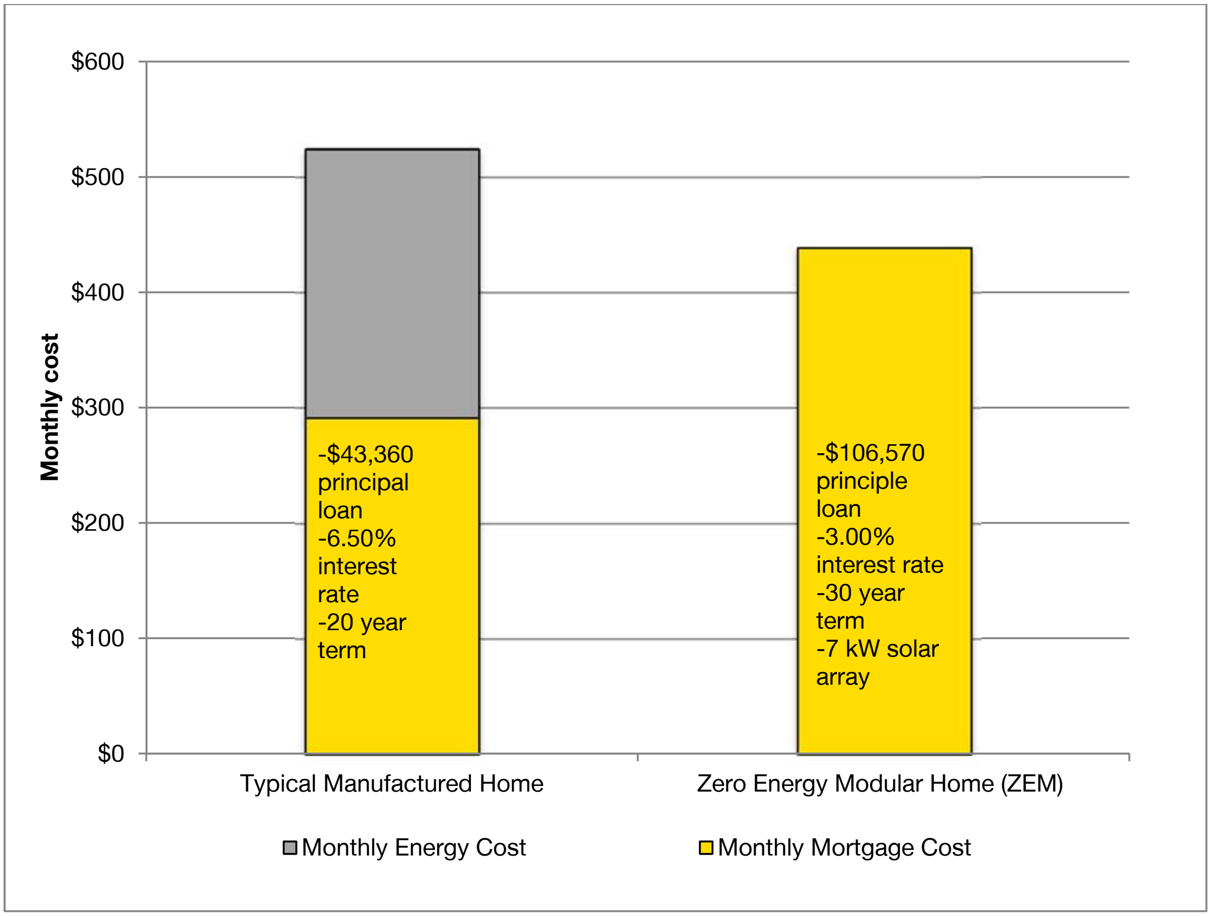


Figure 31. Comparison of total carrying costs for a typical manufactured home and a zero energy modular home.

Utility Business Model

The advanced solar economy opens the door to a wider range of customer service offerings for utilities, and can expand the portfolio of investments on the supply side of the customer's meter—and the demand side.

Current proceedings in California and New York, requiring the distribution utilities to develop and submit distributed energy resource plans, are an example of regulatory expansion of the scope of resources conventionally considered in distribution planning. In other cases, including examples from Vermont, utilities are offering incentives, financing, and leasing for equipment such as on-site storage, heat pumps, and solar generating equipment. These technologies have the potential for coordinated control and operations.

The distribution utilities may also have business opportunities related to the investments required to

What do "innovative grid services" look like?

Advanced, detailed meteorological forecasting—paired with operation and control of DER assets—are an example of the innovative, value-adding service that grid operators could provide. This can happen if they collaborate with partners, or if they invest in creating this kind of asset, in house.

support higher levels of saturation on the distribution system, whether these entail upgrades to distribution operation, communication, and control schemes—or direct investment in solar generation that is strategically sited on the distribution network.

The procurement of solar and other DERs and their inclusion in a utility's portfolio will affect the requirements for the balance of the portfolio. For example, they might require other power supply contracts to provide a higher level of flexibility.

Integrating and controlling a large number of DERs and solar will require greater visibility, communications, and control of resources. The required services might be provided by third parties, or directly by distribution and transmission system operators. A study conducted for the California grid operator, CAISO, estimated that the benefits from enhanced visibility and control of DERs far exceed the costs associated with the required costs for the communications and other required infrastructure.[65] Though dated and for a different market, this study might provide a first estimate of what Vermont may see with higher renewable saturation.

4.2 Regulatory Considerations

In some ways, Vermont's advanced solar economy will have a retail market structure that is similar to what we know today. Consumers will still receive basic electric service from a regulated utility under tariffs reviewed and approved by regulators. The tariffs will cover the costs of providing reliable grid service and commodity electricity. The service provided to the retail consumer will progressively reflect economic and environmental policy objectives by increasing the share of renewable resources in the electricity mix.

The mix of ownership of DER assets will vary across time and will be likely to vary from territory to territory, since the assets are tied to local conditions, priorities, and entrepreneurial assets. This progression from more to less regulated DER ownership is seen in **Figure 32**.

[65] KEMA, Inc., National Renewable Energy Laboratory, and Energy Exemplar, LLC, "Final Report for Assessment of Visibility and Control Options for Distributed Energy Resources" (California Independent Systems Operator Corporation, June 21, 2012), https://www.caiso.com/Documents/FinalReport-Assessment-Visibility-ControlOptions-DistributedEnergyResources.pdf.

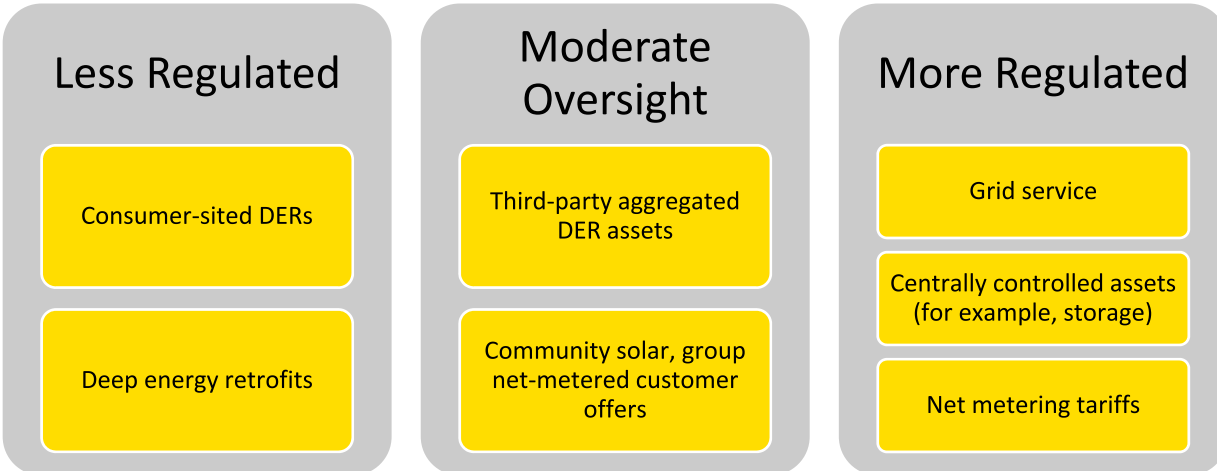


Figure 32. The array of options for consumer support services, under different regulatory levels, in a total service system.

Consumers will also benefit from, and have access to, services provided by a regulated public-benefit DER entity whose mission is to provide consumer support and market facilitation for distributed energy resources—primarily energy efficiency, renewable on-site generation, demand response, load shaping, and storage. We refer to this as a *consumer support entity.* The regulatory and policy oversight for both the grid services and consumer support entities will involve performance indicators and regulator-set metrics addressing the environmental and social economic impacts of energy consumption. The interaction of this type of entity is shown in **Figure 33**.

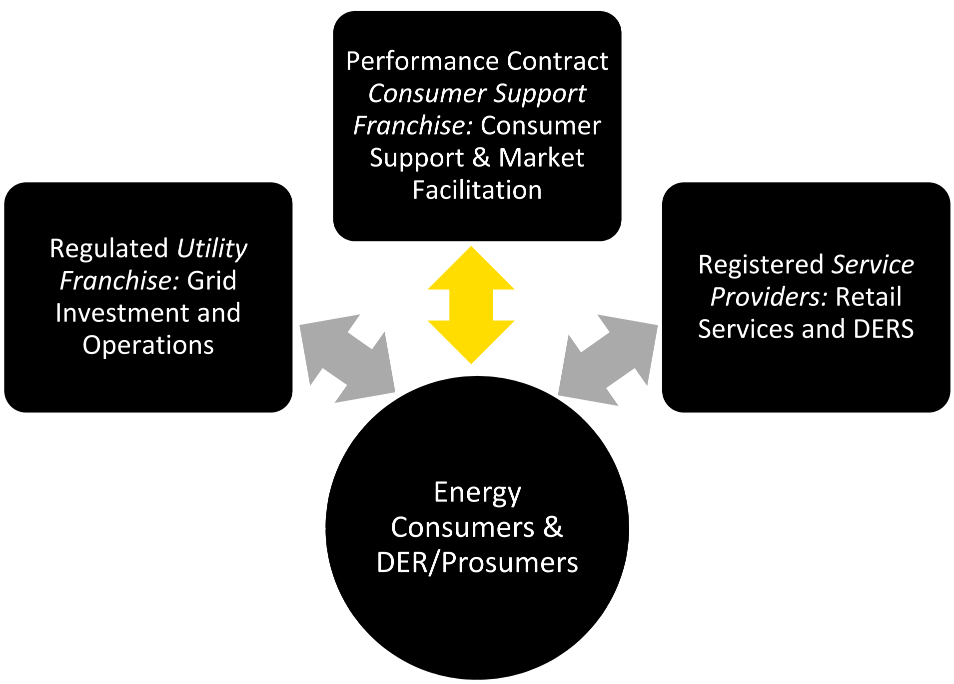


Figure 33. The relationship of various services and service providers in a new utility framework.

One reason to employ a "looking backward from the end" approach is that utility business models can change rapidly, greatly influencing the mechanisms for reaching solar goals. Currently, utilities provide electric power, maintain electric delivery infrastructure, and receive compensation from the rate of return on infrastructure upgrades. This system motivates utilities to sell more power and encourage infrastructure investments. A new utility model, in which utilities are compensated for creating and maintaining a clean, safe, reliable, and efficient grid is possible and will be invaluable in supporting an advanced solar economy.[66] Vermont utilities are already each creating innovative paths while adding new renewable energy. For example, GMP is piloting projects to install utility-operated batteries in homes that stabilize the grid while also benefiting homeowners by providing backup.[67]

[66] Scudder Parker and Jim Lazar, "The Old Order Changeth: Rewarding Utilities for Performance, Not Capital Investment," 2016 ACEEE Summer Study on Energy Efficiency in Buildings, http://aceee.org/files/proceedings/2016/data/papers/6_474.pdf

[67] "TESLA Powerwall," *Green Mountain Power*, accessed December 30, 2016, http://products.greenmountainpower.com/product/tesla-powerwall/.

Looking Forward

The most important conclusion of this study is that solar can provide 20 percent of Vermont's electricity by 2025, and can do so with costs that are less than 1 percent of total annual energy expenditures. Over the longer term, through 2050, the study analyses suggest net economic benefits from investing in Vermont's advanced solar economy are in the billions of dollars.

The Team and stakeholders have considered the most commonly cited limitations of solar—primarily cost, space requirements, and intermittency. They concluded it is possible and profitable to overcome those limits and move toward a future in which more of Vermont's energy comes from its own renewable sources, owned by Vermonters. In addition to cleaner air and billions of dollars a year stopped from leaving the state, there are co-benefits from enhanced affordability, occupant health, and building durability and resilience.

The study also highlights that more than one way to reach the end state exists and that further political, regulatory, and business planning work are all necessary. In places throughout this Summary Report, we have offered possible visions of business models and / or regulatory structures to help catalyze and advance the conversation.

Some elements are not in place, and some that are in place will evolve or disappear.

There will be changes not included in any of the analyses that will have important implications.

Nevertheless, there is a strong likelihood of economic and environmental benefits from a consumer-oriented, modernized system that reaches or surpasses the elements of Vermont's becoming an advanced solar economy.

Although there are many possible paths to a sustainable energy future, a continued reliance on imported fossil fuels supports destructive climate change, social inequality, and a continuous drain on the Vermont economy. Vermont has the opportunity to continue its longstanding environmental leadership and to demonstrate success in high-penetration solar and a transition to renewable total energy. The state can do this, while strengthening its economy.

The foundation is set; the work and the opportunity are just beginning.

Abbreviations and Acronyms

Abbreviation or acronym	Description
AMI	Advanced Meter Infrastructure
ARRA	American Recovery and Reinvestment Act of 2009
AWD	All Wheel Drive
BAU	Business-as-usual
BCRC	Bennington County Regional Commission
BED	Burlington Electric Department, the utility that serves the state's largest city
CAFE	Corporate Average Fuel Economy
CAISO	California Independent System Operator
CCF	hundreds of cubic feet
CEDF	Vermont Clean Energy Development Fund
CEO	Chief Executive Officer
CEP	Comprehensive Energy Plan
CESA	Clean Energy States Alliance
CNG	Compressed Natural Gas
COP	Coefficient of Performance
DER	Distributed energy resource
DHW	Domestic Hot Water
DOE	Department of Energy
DPS	Department of Public Service
DRP	Demand Resources Plan
DSM	Demand-Side Management
EEU	Energy Efficiency Utility
EIA	U.S. Energy Information Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EVSE	Electric Vehicle Supply Equipment
FACETS	Framework for Analysis of Climate-Energy-Technology Systems
FIT	Feed-in Tariff
GHG	Greenhouse Gas
GMP	Green Mountain Power, the state's largest utility and its only investor-owned utility
GW	Gigawatt, a unit of power demand; 1 GW is about equal to Vermont's peak demand
GWh	Gigawatt-hour, a unit of energy demand equal to one gigawatt of power for one hour
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
HOV	High Occupancy Vehicle
HPH	High-Performance Home

Abbreviation or acronym	Description
HPMH	High-Performance Modular Home
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
ICE	Internal Combustion Engine
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-owned utility
ISO-NE	Independent System Operator, New England
ITC	Investment Tax Credit
LDV	Light Duty Vehicle
LEAP	Long-Range Energy Alternatives Planning System
LIHEAP	Low-Income Home Energy Assistance Program
LLC	Limited Liability Corporation
LPG	Liquefied Petroleum Gas (Propane)
MACRS	Modified Accelerated Cost-Recovery System
MMBTU	Million British Thermal Units
MW	Megawatt, a unit of power demand; in Vermont, 1 MW is equal to the energy demand of approximately 500 homes
MWh	Megawatt-hour, a unit of energy demand equal to one megawatt of power for one hour
NARUC	National Association of Regulatory Utility Commissioners
NREL	National Renewable Energy Laboratory
NYPA	New York Power Authority
PHEV	Plug-in Hybrid Electric Vehicle
PPA	Power purchase agreement
PSB	Public Service Board
PURPA	Public Utility Regulatory Policies Act
RAP	Regulatory Assistance Project
RBES	Residential Building Energy Standards
REC	Renewable Energy Credit
RECS	Residential energy consumption survey
RESET	Renewable Energy Standard and Energy Transformation, Vermont RPS
RFS	Renewable Fuel Standard
ROI	Return on investment
RPC	Regional Planning Commission
RPS	Renewable portfolio standard
SDP	Solar Development Pathways, advanced solar scenario
SEP	Smart Energy Profile
SEPA	Smart Electric Power Alliance

Abbreviation or acronym	Description
SPEED	Sustainably Priced Energy Enterprise Development
SPEED	Sustainably Priced Energy Enterprise Development
SRECs	Solar Renewable Energy Credits
SSREIP	Small Scale Renewable Energy Incentive Program
TBD	To Be Determined
TES	Total Energy Study
TOU	Time-of-Use
TREES	Total Renewable Energy and Efficiency Standard
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
VAR	Volt-Ampere Reactive
VEC	Vermont Electric Cooperative, the state's 3rd-largest utility
VEIC	Vermont Energy Investment Company
VELCO	Vermont Electric Power Company
VMT	Vehicle Miles Traveled
VSPC	Vermont System Planning Committee
WEC	Washington Electric Cooperative, the state's 4th-largest utility
ZEM	Zero energy modular home
ZEV	Zero Emission Vehicle

Stakeholders

Name	Organization
Alex DiPillis	Agency of Agriculture
Allison Rogers Furbish	Solarize Upper Valley/Vital Communities
Amy Hollander	NREL
Andi Colnes	EAN
Andrea Cohen	VEC
Andrew Perchlik	CEDF
Andrew Savage	AllEarth
Asa Hopkins	PSD
Austin Thomas	UVM
Ben Gordesky	DC Energy Innovations
Ben Walsh	VPIRG
Betsy Ide	GMP
Bill Kallock	Integral Analytics
Bill Miller	Green Lantern Group
Bill Powell	WEC
Billy Coster	ANR
Bob Barton	Catalyst Financial Group
Bridgette Remington	Legal Counselors and Advocates, PLC
Charlie Smith	Move the Peak
Chris French	Clean Power Research
Chris Wetherby	Stiebel Eltron
Christine Hallquist	VEC
Christine Salembier	RAP
Dan Belarmino	GMP
Dan Kinney	Catamount
Darren Springer	PSD
David Blittersdorf	AllEarth
Deb Markowitz	ANR
Debra Perry	ISC
Deena Frankel	VELCO
Diane Bothfield	Agency of Agriculture
Dorothy Wolfe	Wolfe Energy
Dotty Schnure	GMP
Doug Smith	GMP
James Moore	SunCommon
Dylan Zwicky	KSE
Edward Son	
Elaine O'Grady	NESCAUM
Ernie Pomerleau	Pomerleau Real Estate
Evan Forward	Smart Resource Lab
Gabriella Stebbins	Energy Futures Group
Gaye Symington	High Meadows Fund
Gina Campoli	Vtrans

Name	Organization
Hannah Huber	VNRC
James Gibbons	BED
James Tong	Advanced Grid Consulting
Jared Alvord	Conergy
Jeff Forward	REV
Jeff Wolfe	groSolar
Jeff Wright	VEC
Johanna Miller	VNRC
John Woodward	PSD
Katie Michels	High Meadows Fund
Ken Nolan	BED
Kevin Jones	Vermont Law School
Kevin McCollister	Catamount
Kim Jones	GMP
Kirk Herander	Vermont Solar Engineering
Kirk Shields	GMP
Lauren Hierl	VCV
Leigh Seddon	LW Seddon LLC
Linda McGinnis	EAN
Lisa Morris	VEC
Luke Shullenberger	Green Lantern Group
Mads Almassalkhi	UVM
Mary Powell	GMP
Matt Fraijo	Positive Energy NY LLC
Meghan Dewald	AllEarth
Melissa Bailey	VPPSA
Mike Trahan	SolarConnecticut/NESEMC
Nate Freeman	GridMarketplace
Nate Hausman	Clean Energy Group/Clean Energy States Alliance
Nicole Denering	ISC
Olivia Campbell Andersen	REV
Pam Allen	GMP
Patricia Kenyon	NRG
Patty Richards	WEC
Paul Hines	UVM
Rep. Mary Sullivan	Legislature
Rep. Rebecca Ellis	Legislature
Rep. Tony Klein	Legislature
Richard Watts	UVM
Robert Dostis	GMP
Ryan Garvey	VPIRG
Sarah McKearnan	ANR
Sarah Simonds	Solarize Upper Valley/Vital Communities
Sarah Wolfe	VPIRG
Scott Pellegrini	Faraday
Sen. Chris Bray	Legislature
Sen. Virginia Lyons	Legislature

Name	Organization
Senowa Mize-Fox	
Shawn Enterline	GMP
Stephanie Smith	Agency of Agriculture
Steve LeTendre	Green Mountain College
Stu Fram	High Meadows Fund
Theo Fetter	
Kerrick Johnson	VELCO
TJ Poor	VPPSA
Tom Buckley	BED
Tom Lyle	BED
Will King	AEDG
Will Smith	REV