Portfolio Analysis of Renewable Energy Opportunities

Preprint

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Presented at the SCTE/ISBE Cable-Tec Expo
Philadelphia, Pennsylvania
September 26–29, 2016

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Conference Paper
NREL/CP-7A40-67281
November 2016

Contract No. DE-AC36-08GO28308

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Portfolio Analysis of Renewable Energy Opportunities

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Abstract

Time Warner Cable (TWC), now Charter Communications (CC), partnered with the National Renewable Energy Laboratory (NREL) to assess the technical and economic potential for solar photovoltaic (PV), wind, and ground-source heat-pump systems at 696 TWC facilities. NREL identified 306 sites where adding a renewable energy system would provide cost savings over the project life-cycle. In general, the top sites have some combination of high electricity rates ($0.16–$0.29/kWh), significant state incentives, and favorable net-metering policies. Most of the viable projects identified are PV systems. There are only a few viable wind and ground-source heat-pump systems, due in part to limited land availability and lack of heating loads at many TWC/CC sites. If all projects were implemented via third-party power purchase agreements, TWC/CC would save $37 million over 25 years and meet 10.5% of their energy consumption with renewable energy.

This paper describes the portfolio screening methodology used to identify and prioritize renewable energy opportunities across the TWC sites, as well as a summary of the potential cost savings that may be realized by implementing these projects. This may provide a template for other companies interested in identifying and prioritizing renewable energy opportunities across a large number of geographically dispersed sites. Following this initial portfolio analysis, NREL will be conducting in-depth analysis of project development opportunities at ten sites and evaluating off-grid solutions that may enable carbon emission reduction and grid independence at select facilities.

Background

Energy 2020 is a multi-year campaign through the Society of Cable Telecommunications Engineers (SCTE) Energy Management Program. Energy 2020 aims to envision and enable what energy will look like in cable in 2020, targeting maximum customer uptime and enabling capacity growth via successful organizational, customer, and environmental energy solutions.[i] The goals of the program are to:

- Reduce energy intensity by 15% year on year
- Reduce energy costs by 25% on a unit basis
- Reduce grid dependency by 10%
- Optimize technical facilities and datacenters footprint by 20%
- Reduce fleet cost by 25% on a unit basis
- Reduce fleet consumption by 20% on a unit basis.

In addition to the objectives of the Energy 2020 program, TWC/CC also set a goal of reducing their carbon intensity by 30% by the end of 2016. With a portfolio of thousands of sites across the United States, it is challenging for TWC/CC to select and prioritize projects to meet their targets. TWC/CC partnered with NREL to utilize their renewable energy and project development expertise to assist TWC/CC with meeting their goals as cost-effectively as possible.

We (NREL and TWC/CC) divided the assessment into three phases. The first phase consists of a high-level enterprise screening for renewable energy opportunities across hundreds of sites and facilities in the TWC/CC portfolio. The second phase is a more detailed techno-economic feasibility study on the ten most-promising sites identified during the first phase. The third phase considers a microgrid analysis that includes four of the sites in the second phase. The three phases are illustrated in Figure 1. The focus of this paper is on the methodology and results of the first phase of the project.

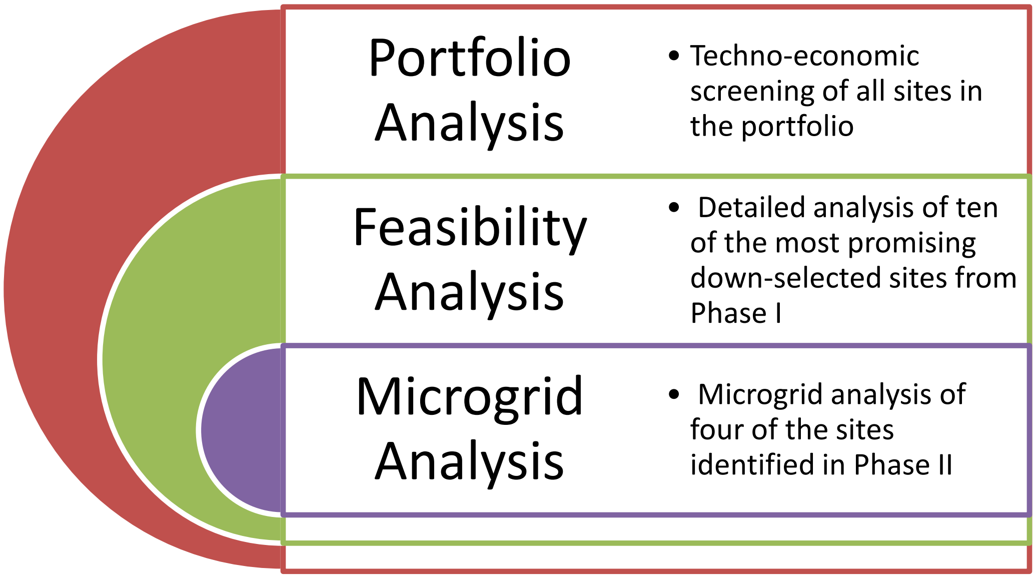

Figure 1 – The three phases of the collaborative project

Methodology

The objective of the enterprise screening phase of the project was to identify ten sites from the portfolio that showed the most promise for technically and economically viable renewable energy projects. This section describes the portfolio screening methodology and the software modeling.

1. The REopt Model

We used NREL's REopt software modeling platform for energy system integration and optimization to programmatically perform the portfolio screening of renewable energy opportunities across the collection of 696 sites.[ii] The REopt software is based on a mixed-integer linear program that seeks to minimize the life-cycle cost of energy at a site over the analysis period subject to a variety of constraints. The life-cycle cost of energy generally includes all of the costs associated with providing energy to the site, including the cost of purchasing energy from the utility grid, the capital cost of building new technologies, operating and maintenance (O&M) costs, and any tax benefits from incentives or depreciation. The model performs an energy balance where both the electrical and thermal loads must be met by some combination of renewable and conventional generation, purchased energy from the utility grid, discharges from energy storage, or dispatchable load at every time step. This energy balance is typically solved for the first year, and then assumed to repeat for each of the ensuing years in the analysis period.

The output of the REopt model is a set of cost-optimal sizes for each technology in the candidate pool and the net present value (NPV) that would be achieved if the technologies in the solution were to be implemented. The optimal dispatch strategy for each technology that is required to achieve the NPV is also provided.

2. Modeling Rationale

The portfolio analysis is used to efficiently rank sites from most promising to least promising according to techno-economic potential. This ranking is used to identify the most viable project opportunities, so companies can selectively allocate additional resources for more detailed analysis to projects with the highest potential for success.

It is often challenging to determine the level of resolution at which to conduct a renewable energy screening analysis. On one hand, it is desirable to use highly detailed techno-economic models that accurately predict the cost savings of the renewable energy technologies to determine the optimal system size of technology and the economic benefits that it can be expected to produce. On the other, it is often difficult, or at least costly in terms of the effort required, to collect and collate time-series data for large numbers of sites. It may also be computationally cumbersome to run entire portfolios through detailed techno-economic models.

The NREL renewable energy screening methodology is designed to balance these competing issues by attempting to find the sweet spot between accuracy and effort required. The methodology is unique in that it prioritizes projects across a large portfolio of sites using the limited set of data typically available across a large number of sites: the geospatial location, an estimate of the land and roof area available for renewable energy projects, the building type and size, and the cost and consumption for both electricity and natural gas at each site. For renewable energy screenings, we typically use only the annual cost and consumption for both electrical and thermal energy consumed. The annual cost of electricity for a site therefore combines both demand and usage charges into a single blended rate. This can simplify the data collection burden because only two figures—an annual cost in dollars and an annual consumption in kilowatt-hours—are required and there is no need to research and understand the intricacies of a complex utility rate tariff.

We then attempt to match the reliability of the model to the data available. Because we only have the avoided cost in terms of a simple blended rate—and therefore, no data regarding demand charges—we use a quasi-time-series analysis in the techno-economic optimization model. This means that instead of modeling the production and consumption of renewable energy at every hour throughout the year, we model a typical day for each month. This has the effect of reducing our computational complexity by over an order of magnitude—from 8,760 time steps to 288 (24 × 12)—while still providing what we believe are acceptably accurate results during the screening phase of the analysis.

There are, of course, caveats to this approach. Because we are using a blended-rate analysis, we are inherently assuming that usage and demand charges will be reduced in the same ratio in which they are represented in the utility bill. For technologies such as PV, this is unlikely to be true, and as a result, such an approach is likely to overstate the benefits of PV in terms of utility-bill reduction. We believe that it is better to err on the side of optimism during the screening stage, however, rather than to inadvertently exclude a potential technology or site from consideration later in the process.

3. Candidate Technologies

NREL's renewable energy screening process typically considers a broad range of renewable energy technologies including those based on solar, wind, biomass, and municipal solid-waste resources. For this analysis, however, we decided to restrict the candidate pool of technologies to solar PV, wind, and ground-source heat-pump systems given their ability to serve small, distributed electrical and cooling loads that dominate the sites in TWC/CC's portfolio. Battery storage may be economically viable at these sites—or even required technically for the potential microgrids to be considered in the third phase. But we excluded them for now because, in our experience, batteries are most often cost-effective at sites that feature some combination of demand charges and time-of-use usage rates—both of which are obscured through the use of blended rates that we have chosen to use in this phase of the project. Instead, we expect to consider battery storage at the ten down-selected sites in the second phase of the project, as well as in the four microgrid sites during the third phase.

4. Model Inputs

4.1. Site Data

TWC/CC collected and collated four primary pieces of data for each of the 696 sites to be screened during the portfolio analysis. These included the geospatial location, an estimate of the land and roof area available for renewable energy projects, the building type and size, and the cost and consumption for both electricity and natural gas at each site (see Figures 2 and 3). Visibility into electricity and natural gas consumption and cost are critical for this process. With over 130,000 utility accounts and over 1,000 utility providers, this was not an easy task for TWC/CC. A TWC/CC initiative to create a centralized resource for energy data was a key success factor in providing data for the 696 sites.

For the ten sites where electrical cost and consumption data were unavailable, we assumed the electrical consumption to be equal to that of the portfolio average and assumed the prevailing cost of electricity for the region. Sites for which natural gas data were unavailable were assumed to use electricity for heating.

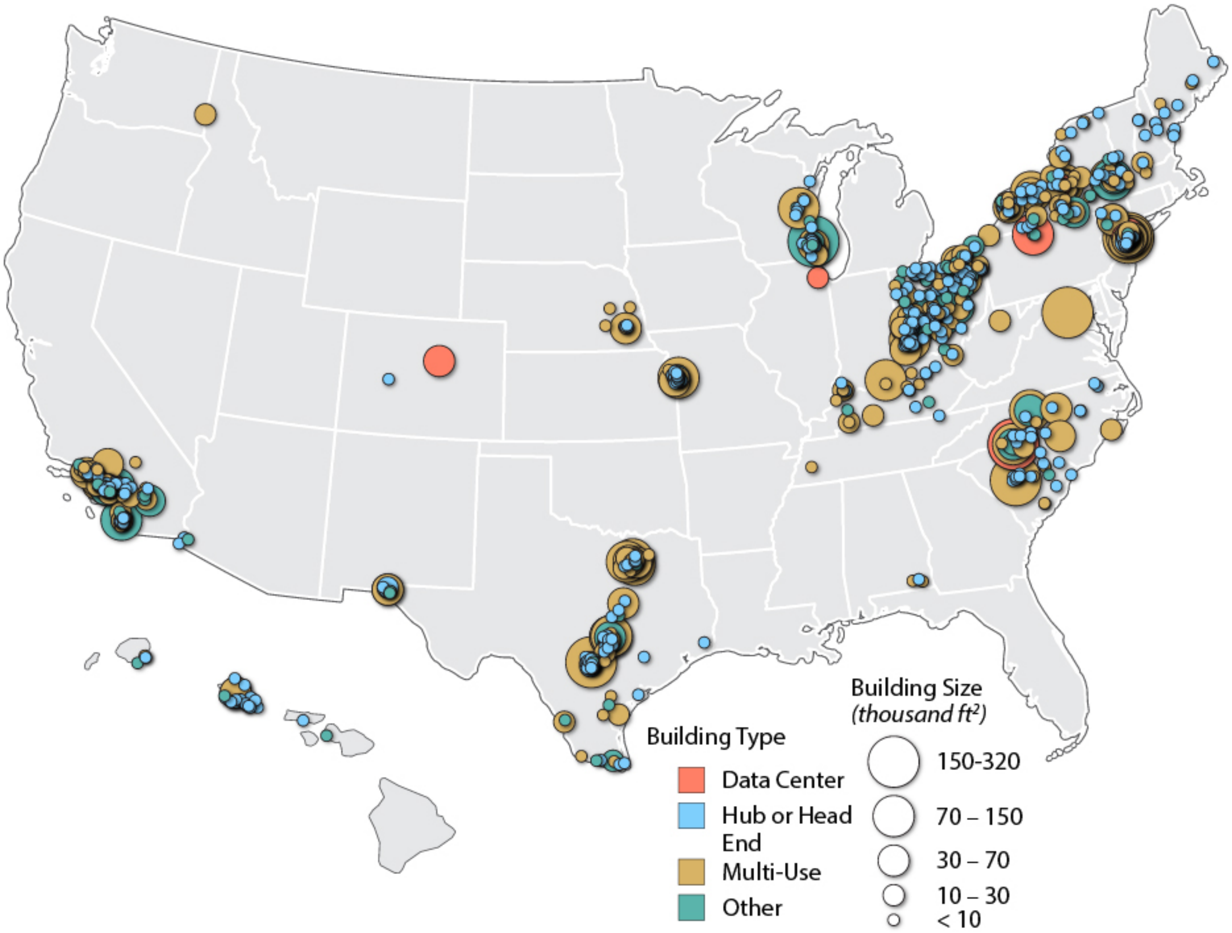

Figure 2 – Building types and sizes for each of the 696 sites in the portfolio analysis

Credit: Billy Roberts, NREL

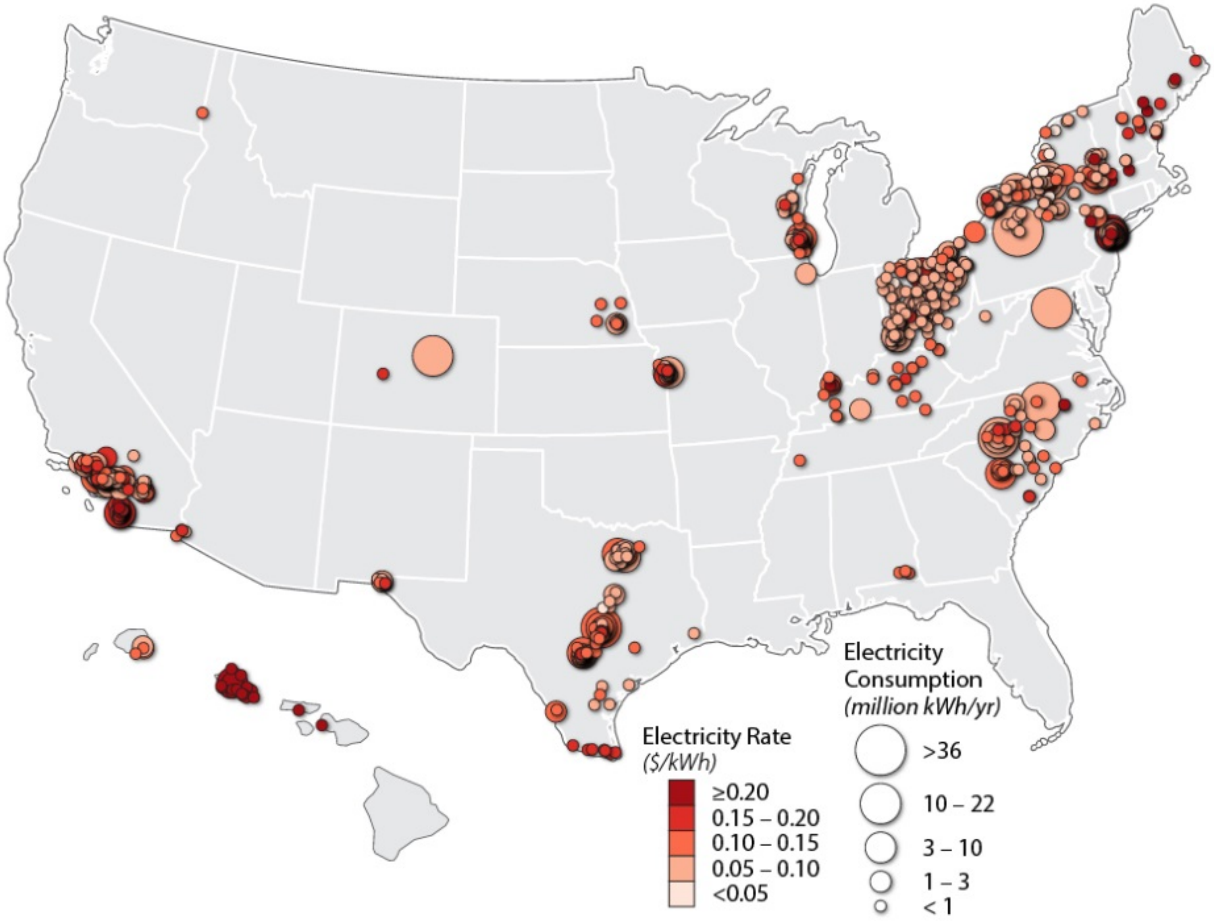

Figure 3 – Electricity consumption and blended electricity rate for each of the 696 sites in the portfolio analysis
Credit: Billy Roberts, NREL

NREL then used the geospatial coordinates of the site to obtain the solar, wind, and geothermal resource availability for each. The location was also used to identify any available federal and state tax incentives, as well as the applicable electric utility net-metering and interconnection limits for each site.

Typically, a time-series electrical load profile would be required for an analysis such as this. But because we chose to use a reduced-complexity model for the screening analysis, we only needed the yearly cost and consumption as described in Section 2. We then synthesized an electrical load profile shape for each site by scaling the load profile obtained from the Department of Energy (DOE) Commercial Reference Buildings dataset, which is indexed by building type and climate zone.[iii] This resulted in an estimated time-series electrical load profile for each site. The heating and cooling load profile were also based on those obtained from the DOE Commercial Reference Buildings dataset. We believe this a reasonable approximation during the screening phase of a project because even though the shape of the profile may differ, the integral of the profile matches the annual consumption of the site.

The land area available for renewable energy project development, in combination with the roof area available, was used to constrain the size of renewable energy projects that the model could specify. For all sites, we assumed that roof area available was equal to 60% of the total building size. This is equivalent to assuming that each of the buildings are single-story and that 60% of the roof is unobstructed. Hub sites that lacked land availability information were assumed to have 1.0 acres available for renewable energy projects, whereas all other sites were assumed to have the portfolio average of 1.25 acres available.

4.2. Renewable Energy Technology Assumptions

The NREL REopt software used hourly capacity factors to model the production of each renewable energy technology during every hour of the year. In the case of PV, the hourly capacity factors were obtained from PVWatts for the specific location, assuming typical PV panel orientation and efficiency.[iv] In the case of wind, the hourly capacity factors were obtained using custom curve-fit equations that relate the wind speed at a given site to the expected energy produced, assuming a common wind turbine. Finally, the hourly capacity factors for the ground-source heat-pump model were calculated using a TRNSYS[v] sub-model that considers the available heating and cooling loads, ground temperature, and characteristics of a typical system.

In all cases, the hourly capacity factors were translated into quasi-hourly capacity factors by creating a composite day for each month to align with the reduced-complexity optimization model.

Capital, operating, and maintenance costs for each of the technologies were estimated based on published market research and input from subject-matter experts within NREL.

4.3. Economic Assumptions

We assumed that any renewable energy technologies selected by the optimization model would be built immediately and would continue to produce energy for the duration of the analysis period, which was assumed to be 25 years. We further assumed that the energy produced (or saved) by these technologies would remain constant in each year, but that the cost of purchasing energy from the utility grid (and any O&M associated with technologies) would escalate each year at an assumed escalation rate.[vi] The revenue from these avoided costs in the out-years was then discounted to the present.

For the purposes of this portfolio screening analysis, we assumed that any renewable energy projects specified by the optimization model would be developed and financed by a third party, rather than TWC/CC itself. Also, we assumed that the third-party developer and TWC/CC would have different required rates of return. Specifically, we assumed a discount rate for TWC/CC and the developer of 7% and 10%, respectively.

We assumed that any renewable energy project selected by the model would be developed and financed by a third party who would have sufficient earned income such that any and all available incentives could be fully monetized and passed along to TWC/CC. These tax benefits include the investment tax credit (ITC) for PV, the production tax credit (PTC) for wind, applicable state incentives, and depreciation under the modified accelerated cost-recovery system (MACRS) for all technologies.[vii]

5. Running the Model

After we compiled the site data, technology assumptions, and economic assumptions, we ran the REopt model to determine the mix of technologies that would minimize the life-cycle cost of energy at each site.

The solution set for each site consisted of the optimum system size for each technology in the candidate pool, which included the utility grid, PV, wind, and ground-source heat-pump systems. An optimal size of null for a technology indicated that it was not economically viable at that particular site.

Because all technologies were considered simultaneously by the model, it was possible for the model to select multiple technologies at the same site. This would indicate that the optimal solution consisted of multiple technologies operating concurrently. Although this was theoretically possible, most sites had one or fewer economically viable renewable energy technologies.

The NPV associated with implementing the solution set of renewable energy technologies was then used to prioritize and down-select the ten sites for further analysis in the second phase of the project. A larger NPV was assumed to indicate that the projects were more economically viable.

6. Assumptions

Key assumptions for the portfolio analysis are listed in Table 1. More detail on these assumptions is provided in the appendix.

Table 1 – Model Key Inputs

	Assumptions
Technologies	PV, wind, ground-source heat pumps
Objective	Minimize life-cycle cost of energy for each site
Analysis period	25 years
Ownership model	Third-party owned
Discount rate for TWC	7%
Developer discount rate	10%
Corporate tax rate	35%
General inflation rate	0.1% per National Institute of Standards and Technology (NIST)
Utility cost escalation rates	NIST utility cost escalation rates defined by four census regions, from 0.1%–1.5%
Incentives	Federal: 30% ITC for PV, 10% ITC for ground-source heat pump, $0.023/kWh PTC for wind for 10 years, MACRS depreciation. State and utility incentives as reported in the Database of State Incentives for Renewables and Efficiency (DSIRE)
Net-metering limit	Per state as reported in DSIRE
Value of electricity exported to grid	Utility wholesale rate
Interconnection limit	None
Technology capital costs	See appendix
Technology resource	NREL Typical Meteorological Year (TMY) solar data and AWS Truepower wind data. See appendix.
Land area	If not provided, assume 1 acre for hub sites, 1.25 acres for other sites
Roof area	If not provided, assume equal to 60% of the building square footage
Load profile	See appendix
Heating efficiency of existing system	Assume default efficiency of 0.9
Cooling efficiency of existing system	Assumed default coefficient of performance of 2.5

Results of the Portfolio Analysis

7. Summary

Of the 696 sites in the portfolio analysis, the model found 306 where the deployment of one or more renewable energy systems would result in cost savings as compared to continuing to purchase energy from the utility grid. If all projects identified were to be implemented, TWC/CC would save a projected $37 million over the 25-year analysis period. They would also generate 10.5% of their energy from renewable technologies.

Table 2 provides a summary of the project opportunities identified in the portfolio screening. Figures 4–6 show the cost-effective PV, wind, and ground-source heat-pump projects identified by NPV, with the largest circles representing the opportunities with highest NPV.

Table 2 – Summary of Results for the Portfolio Screening

Sites	Sites with Cost-Effective Projects	PV (MW)	Wind (MW)	Ground-Source Heat Pump (tons)	NPV (millions of U. S. Dollars [USD])	Annual Electric Generation (GWh)	Renewable Electricity Penetration (%)
696	306	38.79	7.23	396	37	64.7	10.5

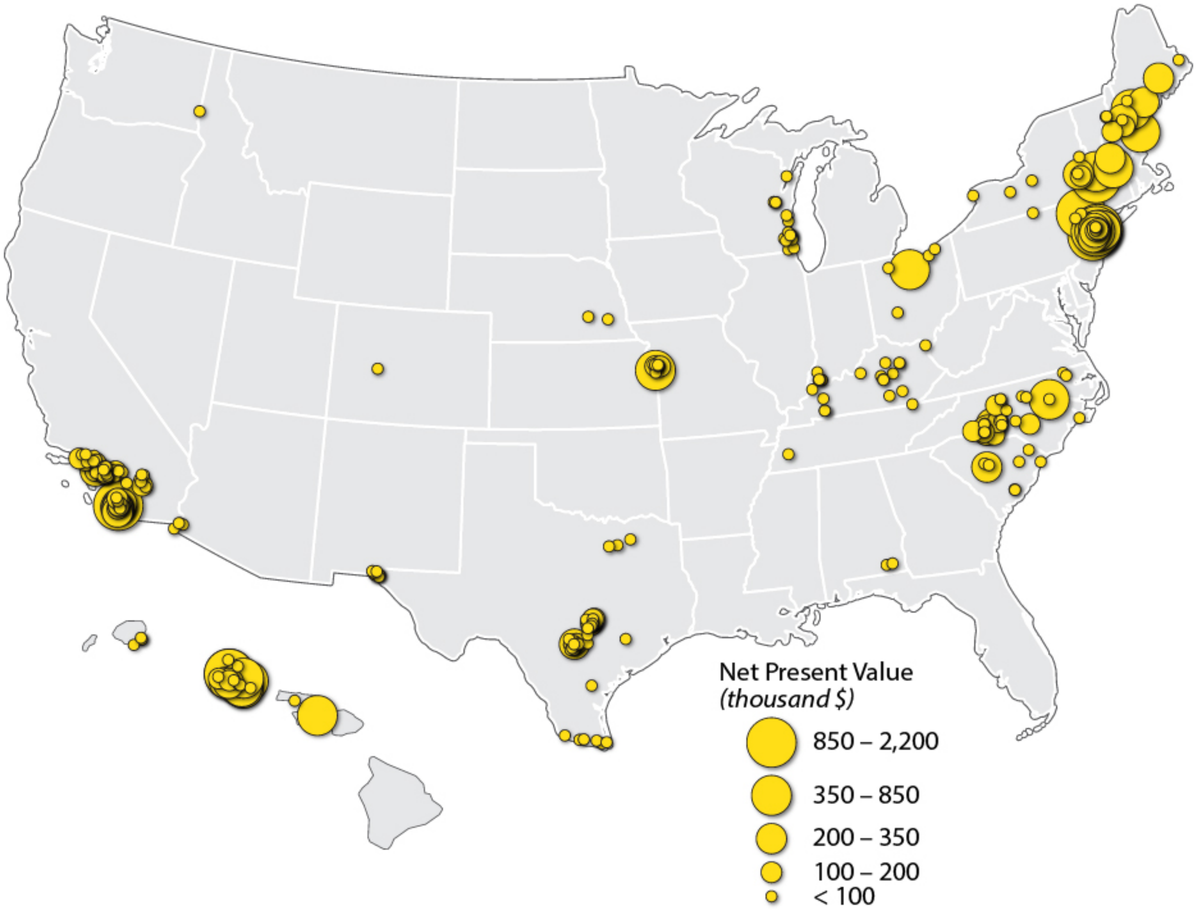

Figure 4 – Cost-effective PV projects identified
Credit: Billy Roberts, NREL

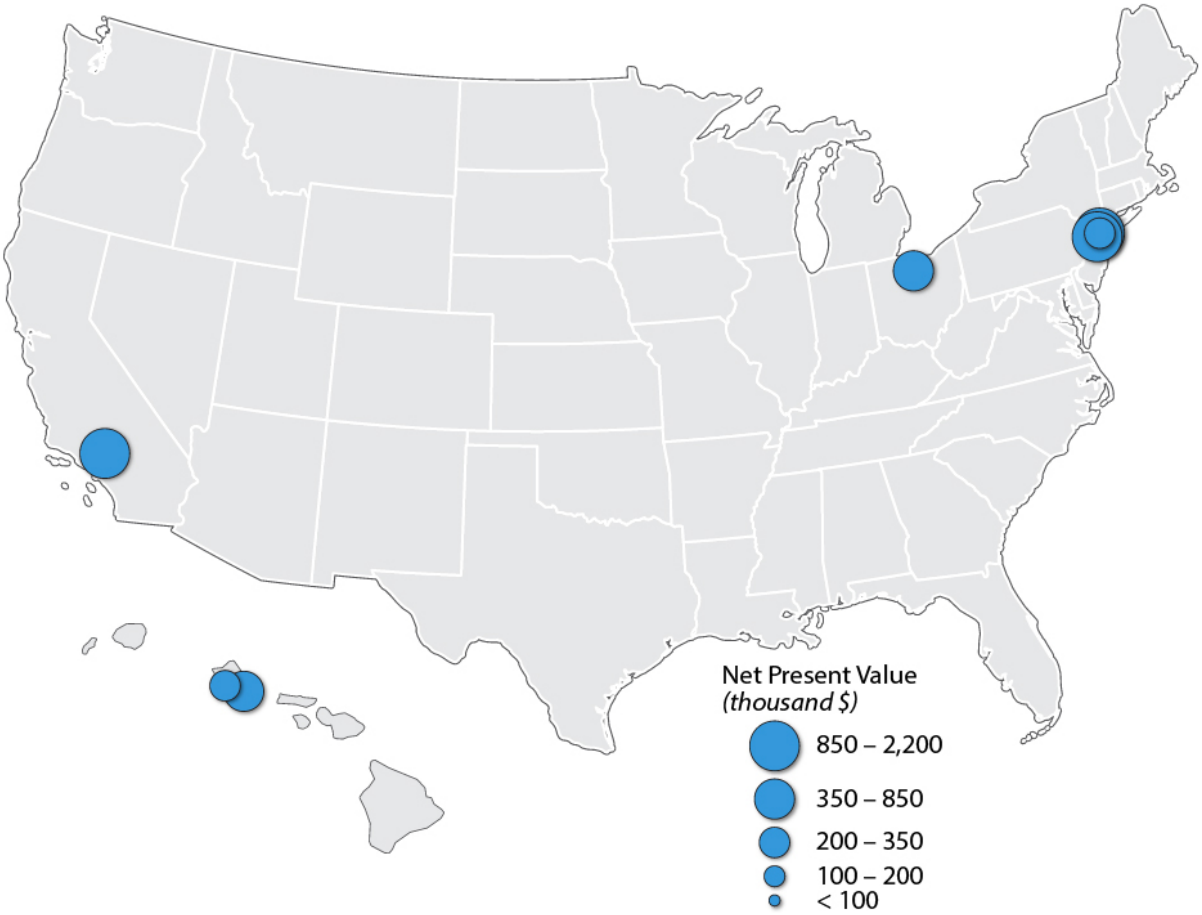

Figure 5 – Cost-effective wind projects identified

Credit: Billy Roberts, NREL

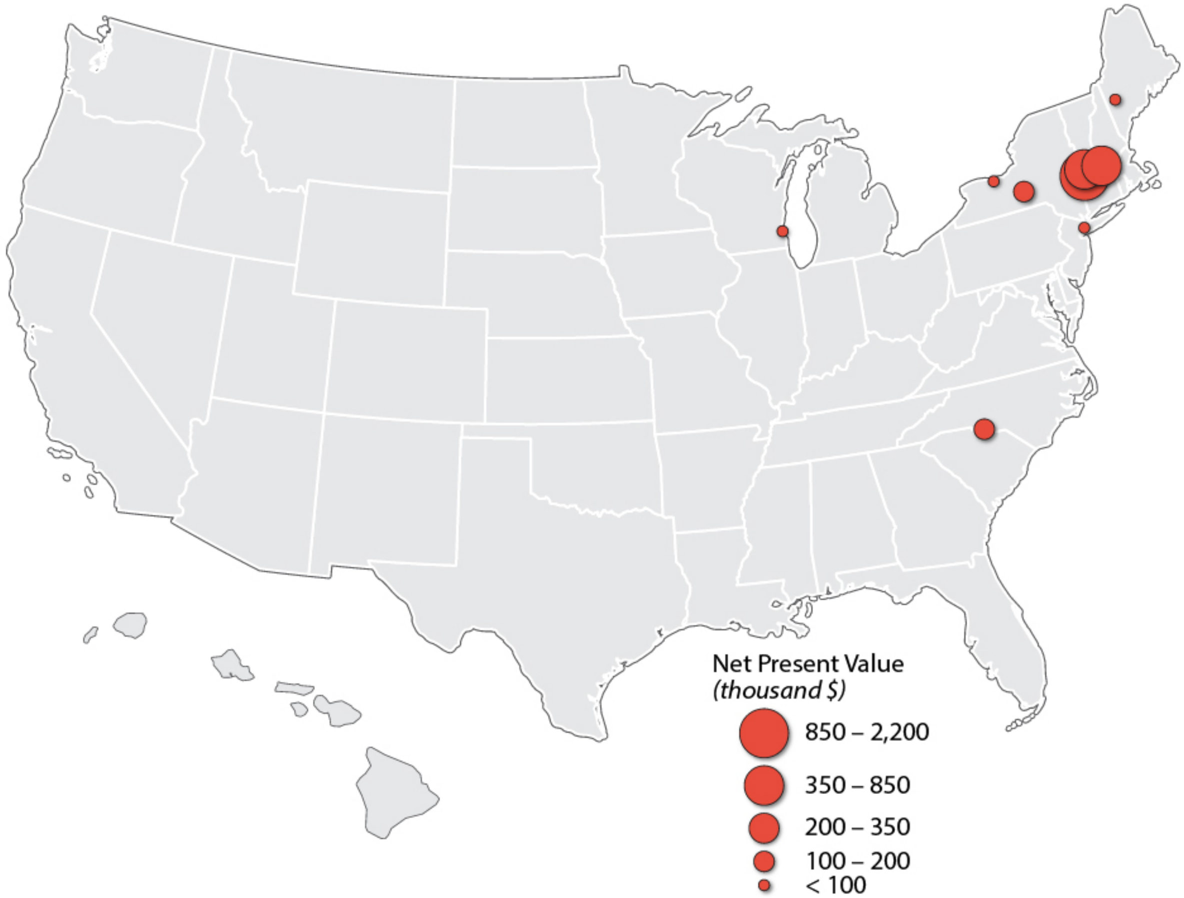

Figure 6 – Cost-effective ground-source heat-pump projects identified
Credit: Billy Roberts, NREL

Over half of the projects identified were under 100 kW of installed capacity, and most of the remaining projects were under 500 kW (see Figure 7). There are only 14 projects larger than 500 kW. This is largely driven by the size of the load at the sites, as well as the area available for renewable energy projects.

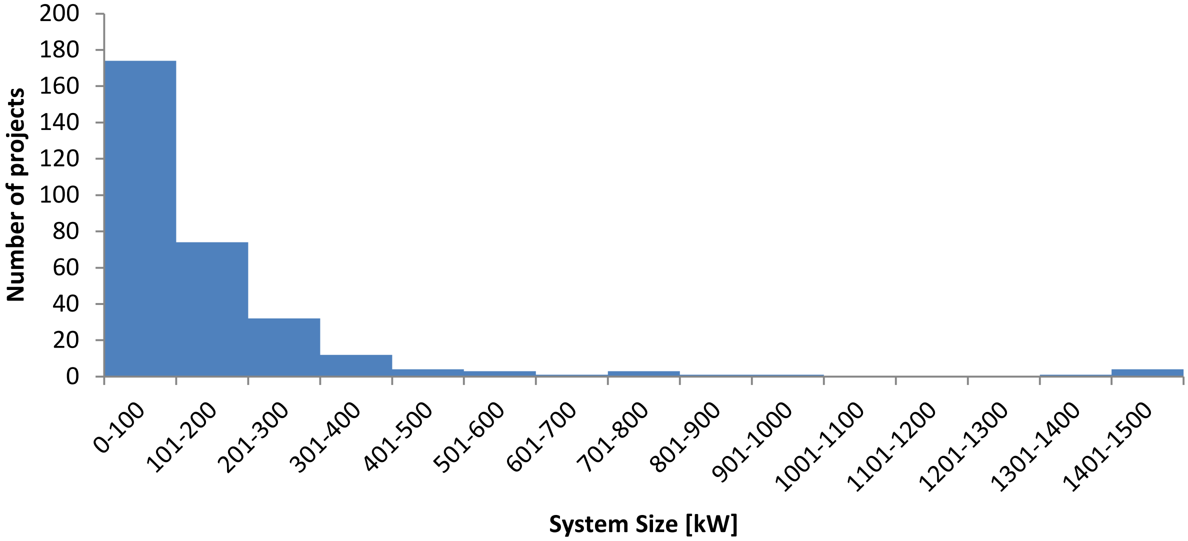

Figure 7 – System size distribution

NPV is generally positively correlated to project size, as shown in Figure 8, with larger projects having higher NPVs. There may be some small projects with higher NPV and some large projects with less NPV per installed capacity; however, in general, larger systems can and do attain a higher NPV.

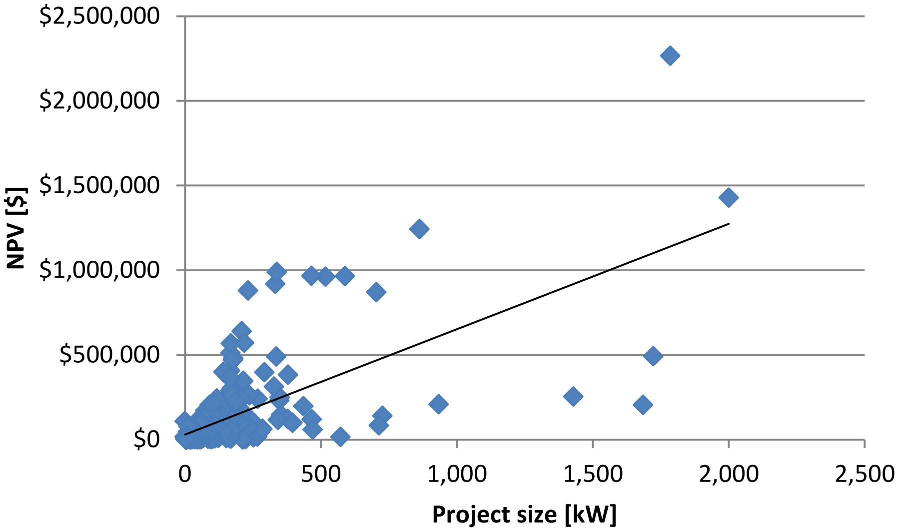

Figure 8 – Correlation of NPV to project size

At most sites, the recommended renewable energy systems offset less than 100% of the electric load, and the site continues to purchase all remaining electricity required from the grid. Renewable energy systems at 70 sites meet 100% of on-site electric consumption. These sites have high electric rates and some combination of production-based incentives, state rebates, and favorable policies for net energy metering. Note that ground-source heat pumps are not included in the calculation of renewable energy penetration.

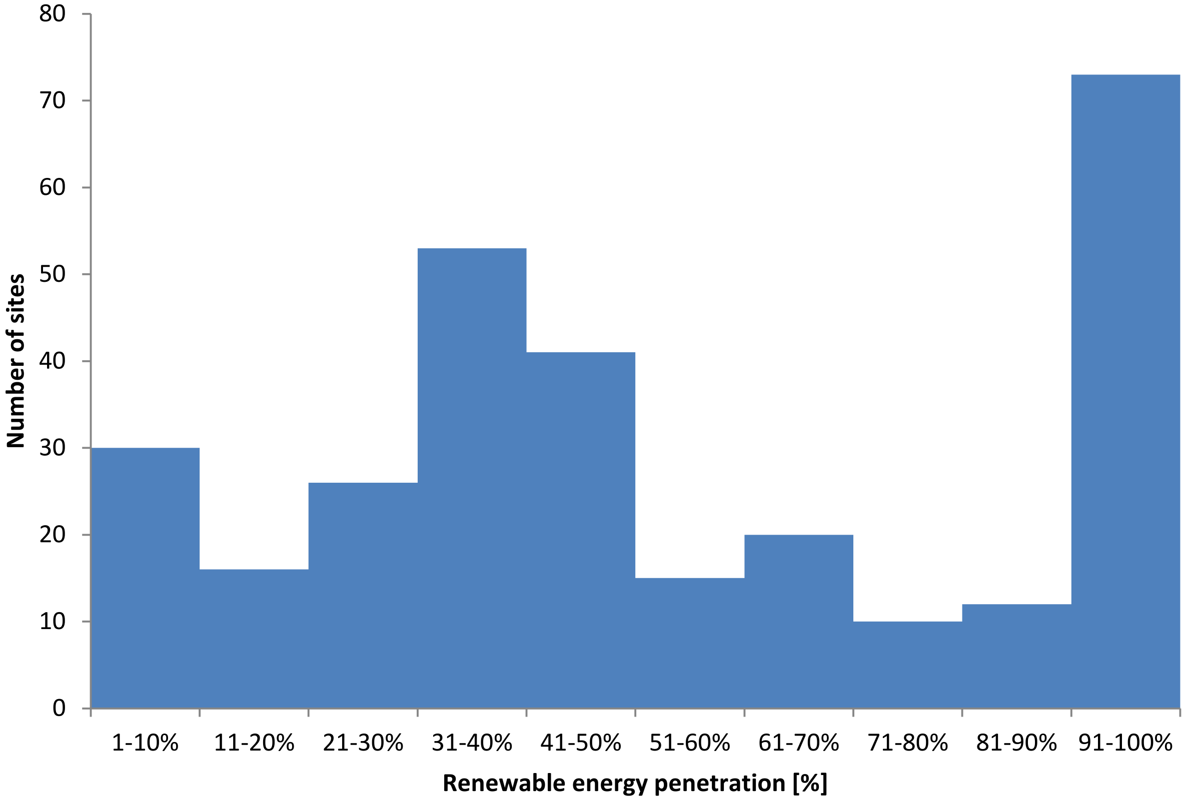

Figure 9 – Renewable energy penetration

The projects identified in the portfolio analysis were ranked by NPV. The ten sites with the highest NPV projects are shown below in Table 3. These sites were selected for a more detailed analysis in Phase 2 of the project.

Table 3 – Top 10 Sites Identified in the Portfolio Screening

Site	Site Location	PV Size (kW)	Wind Size (kW)	Ground-Source Heat-Pump Size (tons)	Capital Cost ($)	Electricity Generation (kWh)	Renewable Energy Penetration (%)	NPV ($)
1	NY	286	1,499	0	2,857,737	1,888,079	69	2,267,000
2	NY	632	1,368	0	3,033,438	2,137,949	77	1,427,000
3	CA	0	863	0	1,020,960	1,590,078	100	1,243,000
4	HI	338	0	0	253,778	513,883	47	988,000
5	NY	466	0	0	518,274	580,463	34	967,000
6	NY	589	0	0	641,127	754,449	77	965,000
7	CA	517	0	0	569,213	809,895	24	961,000
8	HI	332	0	0	249,882	505,010	9	919,000
9	MA	232	0	138	675,336	690,710	68	878,000
10	NY	704	0	0	755,990	901,512	29	871,000

8. Discussion

Although the results presented here are specific to TWC/CC sites, we can draw some general conclusions that may be applicable to other multiple system operators (MSOs).

Several assumptions play a key role in determining whether a renewable energy system will be cost-effective at a site. As other MSOs evaluate their own renewable energy opportunities, it is important to collect and refine utility electric rates, electric consumption, and area available for renewable energy projects. It is also important to gather recent data on renewable energy incentives.

8.1. Technologies

The number of recommended system types by technology is shown in Table 10. Most of the projects identified are PV systems, with only a few economically viable wind and ground-source heat-pump projects.

Table 4 – Projects by Technology

Technology	Number of Systems	Total Size	Average Project Size
PV	303	38.8 MW	0.128 MW
Wind	7	7.2 MW	1.03 MW
Ground-Source Heat Pump	9	396 tons	44 tons

PV is the most common renewable energy opportunity for several reasons. Almost all TWC/CC sites are constrained by available area for renewable energy deployment. PV is a very scalable technology, and it can easily be adapted to fit smaller areas. Additionally, PV costs have dropped significantly in recent years.

Wind opportunities are limited by the small amount of available land area at TWC/CC sites. At most TWC/CC sites, land constraints limit wind opportunities to only a single turbine, and this does not allow wind to reach the economies of scale typically required to be cost-effective.

Ground-source heat-pump opportunities are limited for several reasons. First, ground-source heat pumps are most cost-effective when they can offset both heating and cooling loads. Many TWC/CC sites have only cooling loads, and although ground-source heat pumps are technically viable, they are not as economically attractive at sites with only cooling loads. Second, the economics of ground-source heat pumps are highly dependent on the efficiency of the existing heating and cooling systems that they are offsetting. If the existing systems are highly efficient, then economic gains from ground-source heat-pump installation may be less. The cost effectiveness of the system also depends on the cost of the natural gas that is being offset, as compared to the electricity costs for powering the ground-source heat pump. The NPV associated with economically viable ground-source heat-pump projects tended to be relatively small compared to other technologies evaluated in this analysis.

8.2. Electric Rates

One of the most important factors in determining the economic viability of renewable energy projects is the utility electric rate that the renewable energy will offset. In general, the best opportunities for cost-effective renewable energy systems are at sites with high electricity rates. Table 5 shows that the percentage of sites with renewable energy projects identified goes up considerably as the electric rate increases. Cost-effective projects were identified at only 2% of sites with rates under $0.07/kWh, but at 100% of sites with rates over $0.115/kWh. Projected utility escalation rates also have a large impact on the analysis, with higher escalation rates resulting in more cost-effective renewable energy projects.

Table 5 – Projects by Electric Rate

Electric Rate ($/kWh)	Number of Sites Evaluated	Projects Identified	
		Number of Sites	Percent of Sites (%)
≤0.075	269	5	2
0.075–0.85	36	10	28
0.085–0.95	66	12	18
0.095–0.105	57	26	46
0.105–0.115	65	50	77
≥0.115	203	203	100

8.3. Electric Consumption

The electric consumption of the site impacts the size of cost-effective projects identified. In general, a site with higher consumption can support a larger size project. Sites with higher consumption tend to be larger and have more roof area available for renewable energy. Most of the renewable energy generation can be consumed on site (offsetting retail-rate purchases), rather than sold back to the utility at a potentially lower rate.

Table 6 – Projects by Site Electric Consumption

Site Electric Consumption (MWh)	Number of Sites Evaluated	Number of Sites with Projects Identified	Average Project Size (kW)
<100	112	75	26
100–300	180	79	95
300–500	162	61	133
500–1000	118	38	148
≥1000	124	53	400

8.4. Additional Factors

Information on land availability was not available for most of the sites evaluated, so we used an assumption of 1–1.25 acres at most sites. Because there is little variability in land size across the dataset, we cannot draw conclusions about the impact of land availability. In general, however, land and roof area available for renewable energy project development can constrain the size of potential systems. Area available limited project size in about 37% of the projects. Some 112 of the 303 PV projects identified were limited by area, and 3 of the 7 wind projects were limited by area available. Lack of land area available could also be preventing projects at sites where no technologies are recommended.

Building type impacts the shape of the load profile, which can influence the alignment of demand and generation for certain technologies. Building size influences both total consumption and available roof area, which impacts the total system size that a site can effectively install.

Incentives also play a large role in determining system viability. Various renewable energy incentives are present on the federal, state, and local level depending on the location and technology considered. The federal ITC and MACRS accelerated depreciation are available nationwide, and some states or utilities also offer tax credits, capital cost incentives, or production incentives. The most profitable renewable energy installations are often in locations with favorable incentives.

Conclusion

The primary takeaways from the analysis are the following:

- In general, the top sites have high electricity rates and favorable state incentives.
- Buildings with higher energy consumption and more space available can accommodate larger renewable energy systems, which typically offer larger life-cycle savings.

- PV is the top renewable energy opportunity at the sites evaluated due to its scalability and competitive cost even at smaller capacities.

- Data are critical in performing a portfolio assessment. Key data inputs include technologies being considered; MSO objective for investing in renewable energy; ownership model; incentives; portfolio details on land and roof availability for renewable energy electricity generation; and electricity and natural gas consumption and cost.

The project deliverables will provide strategic guidance to Charter Communications in our pursuit of renewable energy projects to offset energy costs and carbon emissions. Projects will be prioritized for further assessment and project development based on potential NPV.

Abbreviations

COP	coefficient of performance
DOE	Department of Energy
DSIRE	Database of State Incentives for Renewables and Efficiency
GIS	geographical information systems
GWh	gigawatt-hour
ITC	investment tax credit
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
MACRS	modified accelerated cost-recovery system
MSO	multiple system operator
MW	megawatt
MWh	megawatt-hour
NIST	National Institute of Standards and Technology
NPV	net present value
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PPA	power purchase agreement
PTC	production tax credit
PV	photovoltaics
RE	renewable energy
REC	renewable energy credit
SCTE	Society of Cable Telecommunications Engineers
TMY	Typical Meteorological Year
TWC	Time Warner Cable
USD	United States dollar
TRNSYS[viii]	TRaNsient SYstems Simulation Program
GSHP	Ground-source heat pump
AWS Truepower	Renewable Energy Consulting Firm
REopt	NREL's renewable energy planning platform
IEC	International Electrotechnical Commission

Acknowledgements

The authors would like to thank Joe Jankosky, Ed Martin, and the Real Estate and Critical Infrastructure Managers of TWC/CC for their assistance in providing data and review during the portfolio screening. We would also like to thank Dylan Cutler and Dan Olis of NREL for their role in developing and validating the REopt model, including the ground-source heat-pump model, and reviewing the paper. We would like to thank Billy Roberts of NREL for developing the GIS maps. We would also like to thank the SCTE Energy 2020 Alternative Energy working group Chair and Co-Chair Simpson Cumba and Dave Mendo and SCTE's Derek DiGiacomo for industry insights. Lastly, this project was possible due to the vision and sponsorship of Dan Cooper, VP Critical Infrastructure, TWC/CC.

Appendix

1. Technology Assumptions

Key assumptions for each technology are outlined in Table 7.

Table 7 – Technology Assumptions

<table>
<tr><th>Technology</th><th>Assumptions</th></tr>
<tr><td>Photovoltaics</td><td>

Fixed-axis PV systems are modeled with due south orientation and with tilt set to the site's latitude.
PV is constrained by land and rooftop space available. We assume PV requires 6 acres/MW.
We assume overall system losses of 14% for soiling, electrical wiring losses, availability, etc.
We assume an inverter efficiency of 96%.
We assume an annual performance degradation of 0.5% per year.[ix]

</td></tr>
<tr><td>Wind Power</td><td>

Five representative wind turbines are modeled based on size and wind resource: small, medium, large class 1, large class 2, and large class 3.

<table>
<tr><th>Size</th><th>Small</th><th>Medium</th><th colspan="3">Large</th></tr>
<tr><td>Nameplate</td><td>10 kW</td><td>100 kW</td><td>3,000 kW</td><td>2,000 kW</td><td>1,800 kW</td></tr>
<tr><td>IEC Class (average wind velocity)</td><td>N/A</td><td>N/A</td><td>Class 1 (> 9m/s)</td><td>Class 2 (7.5-9m/s)</td><td>Class 3 (< 7.5m/s)</td></tr>
<tr><td>Power Control Method</td><td>Stall</td><td>Stall</td><td>Pitch</td><td>Pitch</td><td>Pitch</td></tr>
<tr><td>Nacelle height assumed</td><td>30 m/98 ft</td><td>50 m/164 ft</td><td>80 m/262 ft</td><td>80 m/262 ft</td><td>80 m/262 ft</td></tr>
</table>

We assume 15% losses for wake effects, electrical losses, availability, etc.
Wind projects are constrained by land available. For wind projects larger than 1.5 MW, we assume a land requirement of 30 acres/MW. A single turbine of 1.5 MW or less is not constrained by land available, although it will require some land (less than an acre).
The model uses a database of wind resource that is representative of the regional wind resource in the vicinity of the site. However, wind resource is highly sensitive to site-specific features and it should be verified before any investment decisions are made as part of the project development's due diligence. We access the wind resource database using the site's latitude and longitude and a search radius. The default search radius is 1 mile.

</td></tr>
<tr><td>Ground-Source Heat Pump</td><td>

Ground-source heat-pump systems are not limited by land available in the model.
We assume the following coefficients of performance (COP):

<table>
<tr><th>Conventional cooling COP</th><th>2.5</th></tr>
<tr><td>Conventional heating COP</td><td>Varied, depending on conventional heating method
2.5 for electric heat pumps
1 for electric resistance heating
0.9 for natural gas or heating oil</td></tr>
<tr><td>Ground-source heat- pump cooling COP</td><td>5.77</td></tr>
<tr><td>Ground-source heat-pump heating COP</td><td>3.78</td></tr>
</table>
</td></tr>
</table>

2. Cost Data

REopt uses a cost dataset that is based on research, market data, and recently constructed renewable energy projects. The costs below reflect U.S. national averages and include assumed contracting costs for design, supervision, and contingency. Grid improvement costs are not included. REopt uses a segmented system cost curve to account for the economies of scale realized when constructing larger systems. The marginal cost represents the cost to add the last, or incremental, unit of nameplate capacity to the system in each of the segments.

Table 8 – Technology Cost Assumptions

Technology	Cost Assumption	
PV, Fixed Axis [x], [xi]	Marginal capital cost	$2.54/W-dc for systems sized 0–199 kW
		$2.01/W-dc for systems sized 200 kW–5 MW
		$1.79/W-dc for systems sized >5 MW
	O&M cost	$0.02/W-year
Wind Power [xi], [xii]	Marginal capital cost	$8.00/W for systems sized 0–50 kW
		$2.38/W for systems sized 50–850 kW
		$1.75/W for systems sized >850 kW
	O&M cost	$0.035/W-year
Ground-Source Heat Pump	Marginal capital cost	$25/linear foot for drilling $3515/ton for capital expenditure
	O&M cost	$42.50/ton-year

3. Resource Data Sources

Renewable energy resource information is provided by NREL's GIS department.[xiii] This information is used in the renewable energy technology equations to represent the magnitude of a renewable energy resource in the area. Datasets used in the analysis are described below.

Table 9 – Resource Data Assumptions

Resource	Assumptions
Solar	• Hourly solar radiation. TMY 3 (NREL 2008). Represents 1,020 locations in the U.S. Derived from 1991–2005 National Solar Radiation Data Base.
Wind	• Hourly TMY wind resource data for the United States from AWS Truepower. • Wind speed, wind direction, temperature, and air density are provided at 30, 50, 80, and 110 meters above ground level. • Dataset resolution is 20 km × 20 km.

4. Load Profile Assumptions

TWC provided a description of each building screened, which were mapped to the DOE Commercial Reference Buildings dataset to obtain an estimate of the load profile at each hour throughout the year. The TWC buildings were mapped as shown below.

Table 10 – Load Profile Modeling Assumptions

Building Type	Load Profile Assumption
Data Center Head End Hub Hub Site Other	100% flat load
Call Center	50% medium office, 50% flat load
Communications Site Optical Transport Network Production Studio Tech Center	100% small office
Office	100% small office or medium office depending on building size
Customer Service	100% retail storefront
Multi-use	25% small office, 25% warehouse, 25% flat load, 25% retail storefront
Land Parking	None

The mapping was determined based on input from TWC/CC. In general, the load of office buildings, warehouses, and retail storefronts increases as the workday starts, levels off in the middle of the day, and then decreases as the workday ends. The figures below illustrate an example day for the non-flat profiles used.

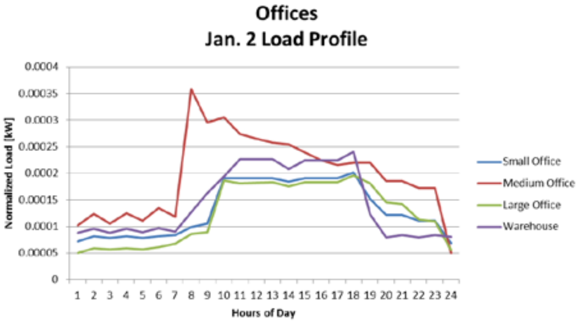

Figure 10 – Reference profile for office-type buildings

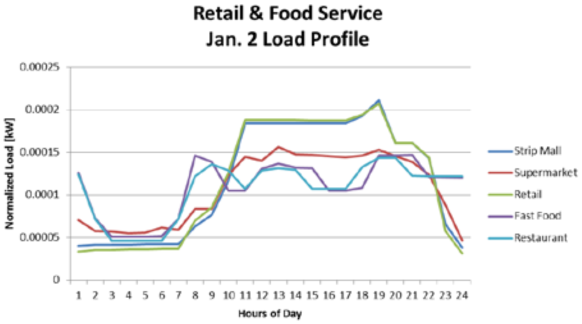

Figure 11 – Reference profile for retail-type buildings

5. Economic Assumptions

Federal tax incentives including the ITC and MACRS are available to taxable entities. A 35% corporate tax rate is assumed to calculate the value of the ITC and MACRS. The capital cost used as the basis for MACRS is decreased by 50% of the value of the ITC. Currently, the federal ITC for solar energy is 30%. Because the ITC and MACRS are not available upfront, but rather are captured in future years, their values are discounted at the 10% discount rate. Table 11 describes the ITC and MACRS assumptions.

Table 11 – ITC and MACRS Assumptions

Technology	30% ITC	10% ITC	PTC $0.023/kWh for 10 Years	5-Year MACRS	7-Year MACRS
PV	●			●	
Wind			●	●	
Ground-Source Heat Pump		●		●	

The NIST nominal fuel escalation rates for 2015 were used in this study, shown below in Table 12.

Table 12 – 2015 NIST Fuel Escalation Rates

Census Region	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
Electricity	1.52	0.71	0.61	0.10	0.66
Natural Gas	2.67	1.39	1.32	1.65	1.74
#1, #2 Distillate Fuel Oil	2.03	2.10	2.11	2.17	2.09
#4, #5, #6 Residual Fuel Oil	2.49	3.02	2.78	3.35	2.53
Coal	0.64	0.88	0.79	1.06	0.86

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