The Business Case for Eco-Sustainable Facilities based on Renewable Resource Availability

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ABSTRACT

The worldwide focus on reducing energy consumption and ecological impacts is adding another dimension to the business cases for implementation of energy-efficient or alternative power solutions in facilities. With costs moving higher for grid power and lower for sustainable energy options, and with technological progress, government incentives, and increased consumer demand for eco-friendly products and services, the case for change within the building industry is becoming more compelling.

While numerous alternative energy sources are available, determining the most viable option for a facility - if indeed any are viable - remains complicated. In order to compare hybrid on-site renewable energy solutions and their associated business cases for commercial buildings, the Alternative Power Analyzer tool was developed. Publically available renewable energy data were coupled with solar, wind, battery, and diesel generation models. Case studies representing a mixture of telecommunications building locations were chosen to characterize different renewable energy scenarios across the United States based on financial incentives, grid electricity costs and renewable energy availability. The business case result helps decision makers compare the levelized cost of energy for various technologies over a facility's lifetime and prioritize decisions based on capital costs, operational costs or greenhouse gas emissions. From the analysis, not all locations with a high availability of renewable resources are the best to implement renewable technology. The business case for using renewable energy options is strongly impacted by the availability of incentives. Furthermore, the paper concludes by suggesting policies that communities may consider when discussing sustainability improvements in their city.

Introduction

Federal, state, and local governments, businesses large and small, and individuals are increasingly aware of the advantages of reducing power consumption, and the associated greenhouse gas (GHG) emissions and dependence on natural resources. The telecommunications industry, like any business, has constraints that limit investment in areas that do not help the bottom line, no matter how worthy the cause. As a result, Bell Labs, the research division of Alcatel-Lucent, has been working with Carnegie Mellon University's Green Design Institute to develop tools that the industry can use to identify cost-effective solutions for reducing power consumption and implementing renewable energy options in their networks.

Most of the energy consumption in a telecommunications network is at the network "edge", which includes base stations in wireless networks and central offices in wireline networks. The edges of networks consist of many relatively small facilities that support customers in a region. Facilities in the core of the network exist for connectivity and higher-level processing of the traffic and tend to be larger, but there are fewer of these core facilities.

Cumulatively, the power consumed in the edge represents 60% to 80% of the power consumed in the entire telecommunications network. As a result, our prior research has focused on improving the energy and environmental performance of these edge facilities; however the tools developed can be applied to other parts of the network as well. Combining these performance based tools with other tools and assessments targeted to reduce energy consumption and the associated impact of emissions and expenses can lead to large benefits.

Telecommunications base stations provide the radio interface between mobile phones and the telecommunications network, allowing the ubiquitous, untethered voice and data services that are prevalent today. Base station power requirements range from 500 W for a small implementation to as high as 5 kW for a high-traffic site. The daily power needs of these facilities are generally in the same range as many residential and small commercial buildings, so energy-saving initiatives and renewable energy options are often comparable.

Central office power requirements vary from 20 kW into the MW range. It is thus conceivable that for facilities in the lower end of this range both solar and wind systems could provide much of the energy requirement. Trying to address larger energy requirements with renewables usually requires significant additional real estate for large solar array farms or very large wind turbines [DOE 2005].

Finally, the financial viability of renewable energy is tied to policy and incentives. Renewable energy is closing the gap on cost versus grid power, but in almost all cases, federal, state, and/or local incentives, coupled with power company incentives are still necessary to make a positive business case.

Scope of Project

Owners must consider the financial viability of any energy solution whether it is traditional grid or renewable energy. The financial viability of on-site renewable energy is largely determined by site conditions. There are many factors beyond weather that affect these components, including shading, topography, obstructions, etc. While these factors must be analyzed with on-site data, initial scoping estimates of viability can be gleaned from historical weather databases.

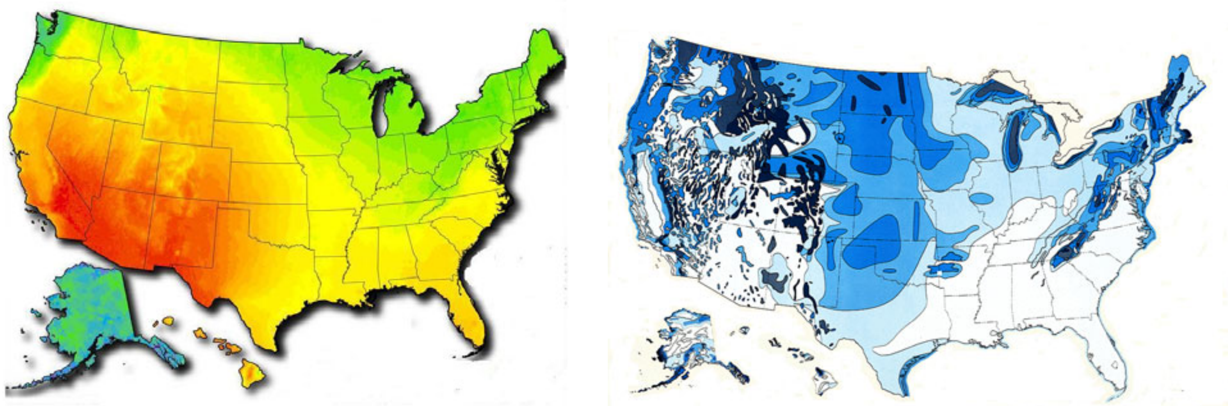
Another factor that has a considerable impact on the viability of a renewable energy solution is the total power required for a facility. Because this baseline power requirement is such an important factor, energy-reducing measures should always be implemented prior to undertaking a renewable energy analysis. Major components of energy consumption include equipment power needs, heating, ventilation, and air conditioning (HVAC). Often equipment upgrades implementing higher-efficiency components or software features that reduce power consumption under light loads, as well as migration to high-efficiency HVAC or "free-air cooling" solutions can reduce the power consumption at a site to a level that renewable energy solutions become viable. The analysis presented herein assumes these energy-saving considerations have been implemented prior to designing the renewable energy solutions.

To provide examples of what can be done to improve sustainability in telecommunications network facilities, this paper provides analyses performed at the network edge, specifically for wireless base stations. We then suggest approaches for extending sustainability efforts throughout commercial and government buildings by replacing conventional electricity carbon intensive fuel sources with renewable energy for producing electricity. Three different US case studies are examined representing a range of renewable energy availability, GHG emissions factors and incentives. Lastly, we suggest possible policies or recommendations that communities may want to adopt to encourage sustainability improvements by businesses and governments in their locale.

Renewable Energy Availability

Comparing potential solar and wind availability with facility location provides a first-order insight into facilities that may benefit most from renewable resources. Records of average solar intensities and wind speeds are good indicators of how efficient an array of solar cells or a wind turbine would be at generating renewable energy. Solar availability is typically measured in kWh/m^2-day. Wind availability is usually reported within increasing power classes from 1-7 which correlate to wind speed. A visual distribution of these averages across the United States can be seen in Figure 1 [NREL 2009].

Figure 1. Solar and Wind Availability in the US, Darker Colors Indicate Higher Availabilities



In order to conduct an analysis on the data behind the renewable availability resource maps in Figure 1, geographic information system software was used. Postal codes and latitude and longitude coordinates were matched to the nearest weather station. The analysis was conducted by connecting the center of the postal code area to the location of the nearest weather station. The corresponding distances from postal codes to weather stations range from zero to 600 miles. The total number of US weather stations used in this analysis was approximately 700. Facilities were subsequently matched to solar intensity values and wind speeds by their geographical location information.

Renewable Energy Data Sources

The National Renewable Energy Laboratory (NREL) and National Air and Space Administration (NASA) are the two agencies that publish renewable resource availability data for the U.S. While these two data sets are similar, the resource availability maps differ due to data collection. NREL publishes the National Wind Resource and National Solar Photovoltaics datasets. For data collection, NREL primarily uses ground weather stations and past research models [NREL 2009]. NASA has numerous wind and solar datasets under the category of

Surface Meteorology and Solar Energy. NASA uses satellites and in-house models to gather weather information and compares the collected data to the same ground stations as NREL [NASA 2009].

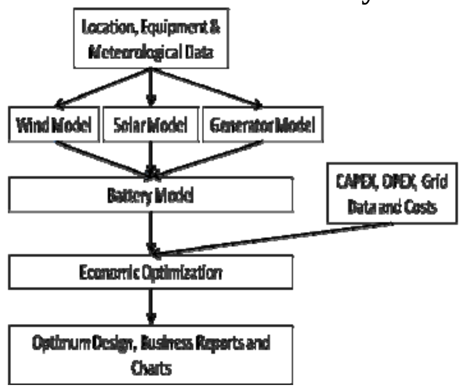
Since the data is collected differently, the data granularity varies between NREL and NASA datasets. NREL is more granular with wind and solar map resolution of approximately 0.2km x 0.2km and 40km x 40km respectively for the United States. The NASA data is coarser with grid sizes of 1° latitude x 1° longitude covering the world. The analysis presented in this paper is based on NASA solar and wind data because of its global application and because it has more recorded parameters.

The Alternative Power Analyzer Tool

The Alternative Power Analyzer (APA) is a tool developed by Bell Labs that determines the optimum power solution for telecommunications base stations and central offices. It optimizes off-grid or grid-connected sites for the most economically attractive mix of power sources. The APA highlights the investment required and cost savings for various energy scenarios, clearly showing the advantage of renewable energy options in locations that have the right mix of favorable weather conditions and incentives. Even though the APA's user interface and business case outputs are optimized for telecommunications, the analysis performed is generic and could be applied to any facility.

Figure 2 presents a functional view of the APA architecture. A graphical user interface allows input of the geographic location, power requirements, and solar panel, wind turbine, battery, and diesel generator parameters. A power analysis is then performed using the built-in wind, solar, generator, and battery models. This step provides the incremental power data available from each source option for each month of the year, based on the weather data at the chosen location. Default values for various financial parameters such as grid power costs, diesel costs, incentives, capital (CAPEX) costs, operations and maintenance (OPEX) costs, etc., are provided for analysis, but a user can override these values with more specific local data. The incremental power data and baseline financial parameters are the inputs to the economic optimization function. The economic optimization identifies the most financially attractive solution for up to six scenarios—various combinations of grid, wind, and solar power. Data for the six optimized scenarios are reported and graphed to present the viability and financial impact of each scenario. Results incorporate projected diesel consumption, estimated OPEX and CAPEX, applicable energy credits due to the reduction of fuel consumption, and renewable power generation, and are applied to both present and future modes of operation.

Figure 2. Alternative Power Analyzer Structure



As seen in Figure 2, four primary models were developed as the foundation for the APA tool, corresponding to wind, solar, battery and diesel generators. The solar panel and wind turbine models use the technical parameters from the manufacturer specifications as mentioned in the model descriptions below. These parameters are manufacturer tested values and based on component design. Using these parameters, energy output of both the wind turbine and solar panels is estimated. Based on the estimates from the model, the actual energy output from the manufacturer data was compared and found to be within a reasonable range.

Wind Turbine Model

The wind turbine model probabilistically estimates output power from either a horizontal or vertical axis wind turbine. The inputs for the wind turbine model include: monthly average wind speed at 10m above ground level; turbine specifications (e.g. rated power, rotor diameter, hub height, cut-in speed, and cut-out speed);Weibull Probability Distribution Function (PDF) shape parameter; site altitude; soiling losses; and array losses (when more than one wind turbine is in operation).

The average wind speed for a location is scaled to the hub height of the wind turbine that is inclusive of the tower and the mast height using the power law coefficient estimate. The power law coefficient is estimated from the surface roughness value of the location based on the terrain.

The power output at the hub is calculated using the estimated wind speed, wind turbine swept area, latitude air density and power coefficient of the wind turbine. The swept area of the wind turbine is an estimate of the rotor diameter and blade length for a horizontal and vertical axis wind turbine, respectively. The air density is estimated using the average temperature and the altitude of the location. The power coefficient is derived from the angular velocity and the optimum lift-to-drag force ratio for a typical two or three bladed wind turbine.

Turbine power is calculated from the hub power and conversion efficiency estimate for each value of wind speed. This results in predicted output power values for each value of wind speed within the cut-in and cut-out speed, from which a power curve can be plotted. The power curve is plotted using the Weibull PDF, which is estimated from the shape and scale factor values within the specified time speed and operating wind speed range of the wind turbine from the monthly average wind speed value for the location. The monthly average energy output is then estimated using the turbine power output considering the effects of soiling and the array losses. The monthly average energy output values are then summed up to estimate the annual energy estimate for the wind turbine.

Solar Photovoltaic Model

The solar photovoltaic (PV) model is based on relationships between the rated power output of the PV array, its operating temperature and the ambient temperature. The inputs for the solar PV model include: monthly average horizontal radiation incident on a surface, maximum rated power of a single PV panel, normal operating cell temperature, ambient temperature, temperature coefficient, and solar panel area.

The monthly average global solar radiation incident on a horizontal surface is used to estimate the incident solar radiation at any tilt of the array on a typical day of the month. The tilted solar array radiation can be estimated using the latitude, azimuth angle, declination angle, sunrise and sunset angle. The tilted angle solar radiation value is then used to estimate the average number of hours of sunshine on a typical day of the month. The number of hours of sunshine can then be used to estimate the average hourly incident solar radiation on a typical day.

The average hourly solar radiation is used to estimate the hourly power output from the solar panel considering the effect of ambient temperature. The ambient temperature panel output and the solar cell temperature are estimated using the ambient and manufacturer specified panel test conditions of temperature and pressure. Using the estimate of solar cell temperature, rated power of the panel and hourly average solar radiation estimate, the hourly solar panel power output can be estimated. The hourly solar panel power output is used to estimate the monthly average and annual solar energy output from the panel.

Battery Model

The battery model builds on the Renewable Energy Research Laboratory's Kinetic Battery Model and is a quasi-steady time series simulation, combining phenomenological and physical effects. A simplified approach is taken based on the charge and discharge behavior of the battery in the voltage model. The inputs for the battery model include: minimum battery state-of-charge, battery autonomy required (i.e. hours for the battery to supply the load without any other energy input), voltage of each battery cell, rated capacity of the battery, and number of cycles to failure.

The number of batteries required is determined based on the minimum state of charge, number of days of autonomy, rated battery capacity, and battery cell voltage. A traffic load model accounts for hourly load variations. Thus, the hourly battery capacity, solar and wind availability and diesel generator usage are managed continually for a varying hourly load.

Starting with the initial battery charge (full capacity for all batteries), the amount of energy available from the battery during charging or discharging each hour over the simulation period is estimated, taking into account the inverter efficiency, self discharge factor of the battery and the resource power availability. From the hourly estimate of battery capacity, the battery state-of-charge, alternative power resource contribution to the load, generator set contribution to the load, fuel consumption, and battery energy available are estimated.

Generator Model

The battery model is inclusive of a controller that triggers and deactivates the operation of a generator set when the minimum and maximum state of charge is reached to avoid battery performance degradation. From the hourly values, a simulation is performed to estimate the battery replacement time and generator run time based on the battery usage, alternative power resource availability and generator set trigger period.

The generator model is primarily based on Hunter and Elliot's linear interpolation model. Based on the model manufacturer's available fuel curve, a detailed fuel curve is estimated for a specified minimum load point for an hourly fuel consumption estimate. The input parameters include rated power output, generator lifetime, site voltage and the output type. The generator model does not size a generator for the required load. Instead, it provides a levelized cost of energy analysis based on the relationship between the power requirements of the facility and the rated power capacity output of the diesel generator set. Depending on the amount of unmet load after renewable energy production, the generator set gets initiated by a controller which determines the fuel requirement and usage. Once demand decreases so renewable can satisfy the load, the generator set is turned off. The generator model analyzes hourly fuel consumption values based on a load profile and estimates the annual fuel consumption, life expectancy, total cost, and fuel cost inclusive of maintenance, supply and transport.

Case Study Analysis and Results

Case Study Locations

Since renewable energy availability varies by geography, locations with high availability may be initial targets for renewable technology installations. In addition, implementing renewable technology should also consider total carbon footprint reduction targets and financial constraints. A carbon footprint refers to the total amount of GHGs emitted. Carbon intensive energy sources (i.e., coal and petroleum) have higher GHG emission factors and are more harmful to the environment. To achieve carbon footprint reduction targets, carbon intensive fuels are often replaced with renewable energy sources because they have lower emission factors. Electricity providers use a mix of these energy sources at various times which translates to varying GHG emission factors. It is important to understand the mixture of energy sources used for grid electricity in each region. For example, a facility in Idaho may want to reduce its carbon footprint by investing in renewable energy instead of using grid electricity. According to the US EPA's state level Emissions & Generation Resource Integrated Database (eGRID), Idaho gets 84% of its electricity from renewable sources [EPA 2010]. Therefore to reduce a facility's carbon footprint in Idaho, investment in renewable electricity may only have marginal benefits.

In choosing the three case study locations in Table 1, consideration was given to renewable energy availability, GHG emission factors and available financial incentives. First, Deming, New Mexico was chosen to represent an area with good sun availability and relatively high incentives. Second, Whitlash, Montana has the highest wind availability. Lastly, Montauk, New York has relatively high availability of wind and solar, and represented a location in the eastern U.S. All three of these locations have relatively high GHG emission factors for grid electricity. Electricity grids are interconnected and do not follow state boundaries. Based on fluctuations in electricity grid mix, a GHG range is more appropriate than a single point value [Weber, Jaramillo &Marriot 2010].

Table 1. Case Study Specifications

Case Study Location	Zip Code	Latitude and Longitude	Average Wind Power Class	Average Solar Incidence (kWh/m^2-day)	Electricity GHG Emissions (kg CO_2e/kWh)
Deming, NM	88031	32.25, -107.76	2	6.5	0.54-1
Whitlash, MT	59545	48.84, -111.1	7	4.8	0.45-0.91
Montauk, NY	11954	41.04, -71.95	6	4.6	0.43-0.72

Baseline Assumptions

A large wireless base station in use today can typically require 4000 Watts. For each case study location, analysis is performed for two different load conditions, i.e. full assumed load (4kW) and 25% load. Included within the load profile are base station communications equipment, backhaul communications equipment, site facility loads (e.g., security systems, lights, tools etc.), and cooling loads. The number of transmitter-receiver units (TRX) and the corresponding antenna configuration comprises 70% of the load profile, as detailed in Table 2. The power equipment selected for each case study is shown in Table 3.

Table 2. Typical Telecom Facility Site Load Profile

Typical Baseline Site Loads	Max (W)
Equipment (3x4 TRX)	2850
Transport (Backhaul)	150
Facility (lights etc.)	350
Cooling (AC or Fan)	650
Total	**4000**

Table 3. Case Study Power Equipment

Type	Name	Output
Wind Turbine	Urban Green Energy	4 kW
Solar Panel	Photalia	170 W
Battery Bank	Hoppecke	600 Amp-hours
Diesel Generator Set	Lister Petter	16 kVA

Based on the selected power equipment, the APA tool analyzes the power requirement of the facility. From the baseline inputs, the APA tool optimizes the number and configuration of solar panels and wind turbines based on four different scenarios: hybrid, generator set, renewable only (no generator set) and grid-assist. The hybrid scenario implies an off-grid location comprised of renewable energy sources with a battery bank as well as a diesel generator set. The generator set scenario implies an existing dual diesel generator set in operation. The renewable only scenario is a purely off-grid renewable based scenario with battery storage. The grid-assisted scenario relies on power based systems with renewable energy connected to the electricity grid.

To compare the renewable technology to the financial business case, a Discounted Cumulative Cost Estimate (DCCE) analysis was performed for a ten year period for the baseline assumptions defined above. As mentioned earlier, federal, state and local incentives exist for renewable energy generation. In order to highlight the value of incentives, we have conducted our analysis both with and without them.

Non-Incentive Based Results

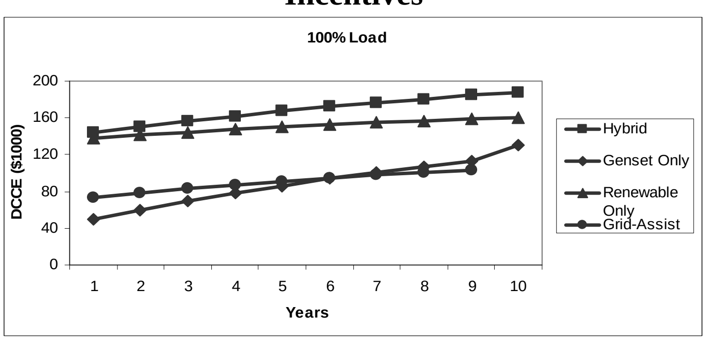
Table 4 shows results for the three case study locations and four different scenarios without modeling the effect of incentives.

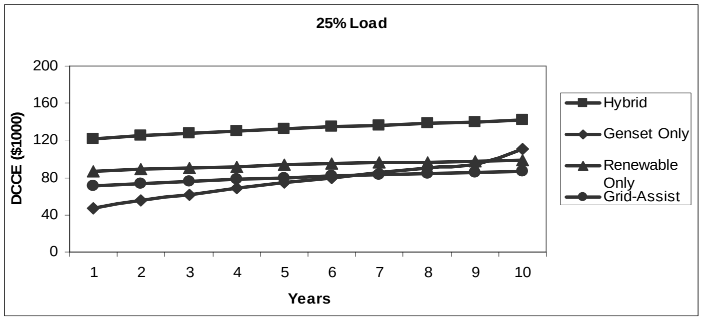
For each case study, the payback period for the various technologies analyzed is more than 10 years for all three off-grid scenarios when compared to the generator-only scenario. The grid-assist scenario has a better payback period, in the range of 1 to 6 years. The results of 100% and 25% load profile can be seen in Figure 6. Since the results for each case study are similar, only the plots for Deming, New Mexico are shown in this paper. The DCCE plots are understood by noting when one scenario intersects the grid-assist scenario and the number of years corresponds to the payback period of the system. In short, hybrid systems would be most expensive, followed by renewables. Grid-assist and genset options would be comparable.

Table 4. Case Study Scenario Summary

Location	Scenario	No. of Genset	No. of Solar Panels	No. of Wind Turbines	No. of Battery Banks	CO_2 Emissions kgCO_2 /yr	Genset Runtime (hrs/day)
Deming, New Mexico	Genset	2	0	0	0	24,000	24
	Hybrid	1	20	1	8	8,600	8.7
	Grid-assist	0	20	1	5	0	0
	Renewable	0	80	1	9	0	0
Whitlash, Montana	Genset	2	0	0	0	24,000	24
	Hybrid	1	15	1	9	7,000	7.1
	Grid-assist	0	15	1	4	0	0
	Renewable	0	60	1	7	0	0
Montauk, New York	Genset	2	0	0	0	24,000	24
	Hybrid	1	10	1	9	7,000	7.1
	Grid-assist	0	10	1	6	0	0
	Renewable	0	70	1	10	0	0

Figure 6. 100% and 25% Load Profile for Deming, New Mexico for each Scenario-No Incentives





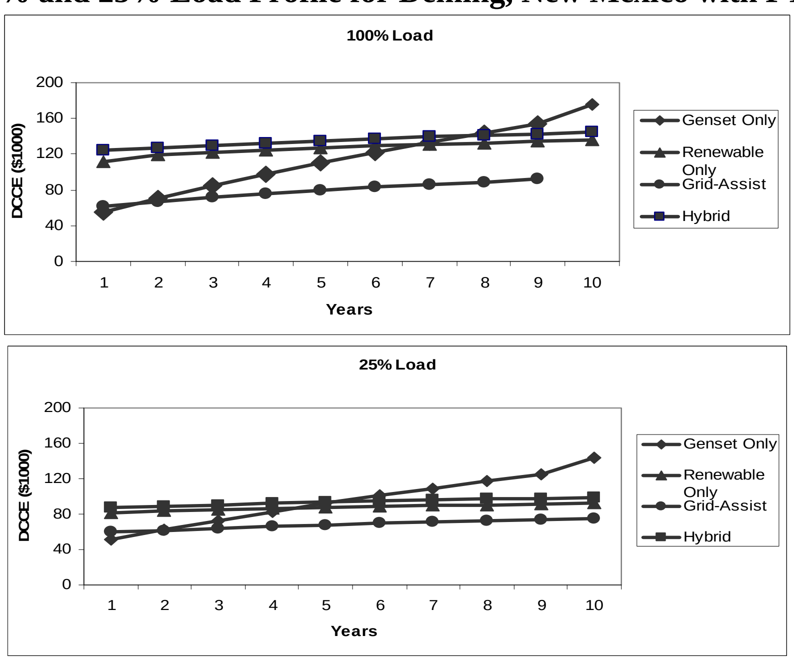
Incentive Based Results

We analyzed two different incentives for reducing renewable energy capital expenses (CAPEX), namely production tax credits (PTCs) and grants. The DOE and other organizations sponsor the Database of State Incentives for Renewables and Efficiency (DSIRE) that summarizes current federal and state incentives for renewable energy and energy efficiency [DSIRE 2009]. The following incentives are applicable to the case study locations:

1. Federal PTC of $0.021/kWh for wind, $0.011/kWh for solar in Montana and New York.
2. Federal PTC of $0.021/kwh for wind, $0.011/kWh for solar and the local performance based customer solar PV program of $0.13/kWh in New Mexico.

The analysis above was redone to include these incentives. Figure 7 shows that in Deming, New Mexico, the current PTCs have limited effect on the system DCCE. Furthermore, the effect of using 100% and 25% of renewable load profiles on powering the facility was minimal.

Figure 7. 100% and 25% Load Profile for Deming, New Mexico with PTC Incentives



In a second analysis, a grant for 35% of the initial CAPEX of the renewable technology is added to the PTC. The results of the capital cost grant coupled with the PTC incentive can be seen in Figures 8 & 9 for Deming, New Mexico. Now, we can infer that the CAPEX incentives improve the payback period of the system. The payback period as evident from Figure 8 comes down to 6.5 years. This analysis demonstrates that availability of better capital grants and tax credits can help achieve greater system cost deductions and a more feasible payback period.

Figure 8. **100% Load Profile for Deming, New Mexico for each Scenario with Capital Cost Grant Incentives and Production Tax Credits**

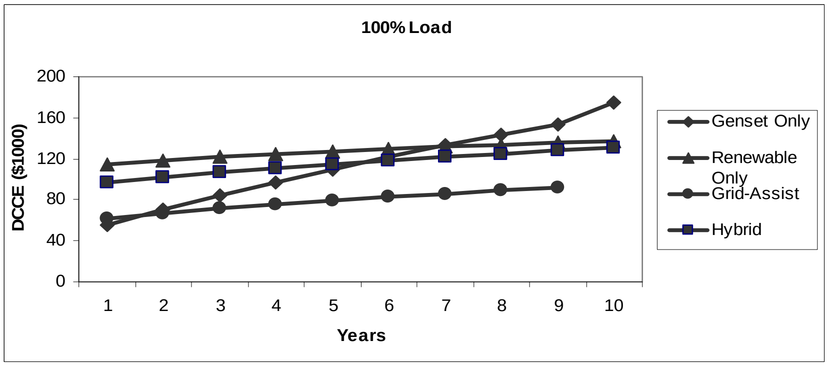
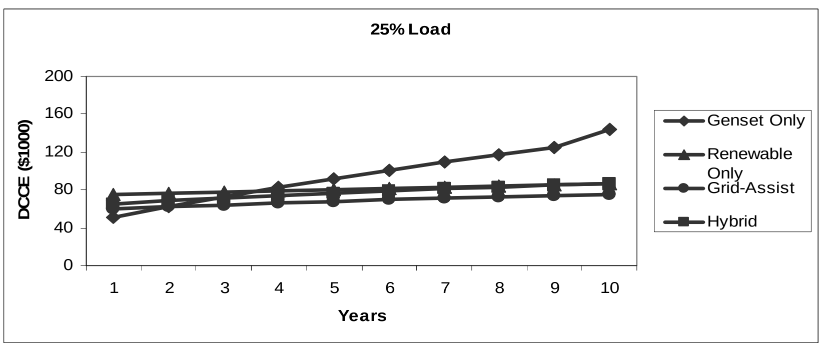


Figure 9. **25% Load Profile for Deming, New Mexico for each Scenario with Capital Cost Grant Incentives and Production Tax Credits**



Policy Implications

Models such as the APA tool presented above are valuable in helping to screen the potential for facilities to cost-effectively pursue renewable sources to provide all or a portion of their energy requirements. Such results can be combined with or compared to the incorporation of energy-efficient practices or technologies. As discussed, renewable resource availability varies widely, as do the underlying grid energy costs and the availability of state, local, and federal subsidies or incentives that promote these technologies and reduce the (comparative) levelized cost of energy.

The case studies above demonstrate the range of resources that could be used to support eco-efficient facilities and their resulting costs as a function of grid energy performance. Unfortunately, the base case cost-effectiveness results are underwhelming, partly due to low grid electricity costs. A key factor in improving the cost-effectiveness (levelized cost of energy) would be the promotion of state, federal, or local-level policies or incentives. In the domain of efficiency, policies such as building codes, industry standards, and equipment-level specifications can affect the energy use of a facility. Buildings overall contribute 40% of the US 2008 primary energy consumption and therefore provide a substantial opportunity for conservation and retrofits [NRC 2009].

The key policy analysis result is to consider the necessary breakeven investment in efficiency subsidies or incentives that can lower the levelized cost of energy of the alternative technologies to the grid energy cost. However such an analysis considers only the private costs of electricity (i.e., those costs paid by the customer) rather than any of the broader social costs of electricity. This analysis did not try to internally "value" the cost of carbon emissions for full-cost accounting, and also does not consider the potential for emerging increases in costs as a result of carbon regulation such as cap and trade.

Conclusions

The APA tool was designed for evaluating renewable energy options for telecommunications base station and central office facilities. APA incorporates location specific metrological data and building loads into models representing wind, solar, battery and generator technology. The analysis examines various energy solutions and the associated levelized cost of energy for comparison and can be practically extended to other commercial and residential buildings to investigate the economic and environmental feasibility of renewable energy solutions for buildings. Understanding the interplay of renewable resource availability and tax incentives for specific locations makes the APA a good screening tool when considering where to invest in renewable energy solutions. It can assist building owners and managers in prioritizing improvements based on cost and carbon footprint reduction targets and in identifying which sites to consider for more detailed feasibility assessments.

Currently, not all areas with high renewable resource availability are the best locations to invest in renewable energy technology. The business case for using renewable energy options is strongly impacted by the availability of incentives. Additional considerations need to be given to grid electricity prices, state and federal incentives and grid GHG emission factors. Optimal incentive policies would further encourage the adoption of renewable energy technologies in geographic areas where viable solar or wind resources are available.

References

[DSIRE 2009] Database of State Incentives for Renewables and Efficiency. 2009. http://www.dsireusa.org/

[DOE 2005] US Department of Energy. 2005. '**Keeping the High-Tech Industry Plugged-In with Onsite Energy**' http://www.eere.energy.gov/de/pdfs/cs_verizon.pdf

[EPA 2010] US Environmental Protection Agency. Accessed March 2, 2010. "**Emissions & Generation Resource Integrated Database (eGRID)**" http://cfpub.epa.gov/egridweb/

[NASA 2009] National Aeronautics and Space Administration-Earth Science Enterprise Program. Accessed June 2009. '**Surface Meteorology and Solar Energy**' http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?+s01#s01

[NRC 2009] National Research Council. 2009. "**Realistic Prospects for Energy Efficiency in the United States**. " Washington, D.C.: National Academies Press

[NREL 2009] National Renewable Energy Laboratory. 2009. '**Dynamic Maps, GIS Data & Analysis Tools**' http://www.nrel.gov/gis/data_analysis.html

[Weber, Jaramillo &Marriot 2010] Weber, C., Jaramillo, P., Marriot, J., Samaras, C., "**Life Cycle Assessment and Grid Electricity: What do we know and what can we know?**" In Press ES&T 2010