FOUR CORNERS MONUMENT

A preliminary analysis was performed on the feasibility of a stand-alone power system for the Four Corners Monument. The Four Corners Monument is part of the Navajo Nation and managed by the Navajo Parks and Recreation. The Navajo Tribal Utility Authority is currently considering extending their grid to provide service to several small buildings that are planned for the site. It is our understanding that there is currently no electric service at the site.

This analysis is only a preliminary analysis. There are several important pieces of data that are required before a definitive determination can be made about the cost-effectiveness of a stand-alone power system at this site. The most important data that needs improving is a description of the loads, including how they vary over the day and through the seasons. We also need better data about a service plan for the system and about the wind resource at the site. Nevertheless, the initial analysis is promising enough that further effort can be justified to collect the additional data to perform a more detailed analysis.

Loads

We derived load profiles for the site from the Electrical Power and Lighting Plans, obtained from the Navajo Tribal Utility Authority. These plans show several buildings but do not show how close those buildings are to each other. We assumed that they were very close together, such that they could be served by the same system. We also did not consider any costs for the distribution system that would connect them. That distribution system would be required for electric service regardless of whether that service was provided by a conventional grid extension or by a stand- alone system. In the case where the buildings were not very close together a set of stand-alone systems could provide service to the buildings individually. This would have a further advantage of reducing these distribution costs.

The electrical plans showed conventional rooftop chillers and electric resistance heaters. We assumed that these would be replaced with evaporative coolers and propane heaters. The climate of the Four Corners region is ideal for evaporative coolers. Evaporative coolers are much more energy efficient and provide for greater comfort and ventilation in dry climates.

We assumed a nighttime load of 4 x 150 watts for metal halide security lighting. We identified the following daytime loads. There are plans for 73 “PL” style light fixtures with 2 x 26 watts apiece. This amounts to about 3800 watts of connected load. To this we added 1200 watts of miscellaneous load and 2 kW of fan load for the evaporative coolers, which only operated from May through October. These daytime loads operate from 8 AM to 5 PM.

Component Costs

The costs of components are detailed in the Input Summary. Each component has capital, replacement, and O&M costs that are specified on a per unit basis. We did not include any overall system costs that are not associated with a specific component.

Resources

Because of the remoteness of the site we assumed that the non-renewable resource would be propane. The results for diesel or natural gas would be very similar.

The solar resource data was obtained from NREL's website through HOMER's automated solar data retrieval process for a latitude of 37 North and 109 West.

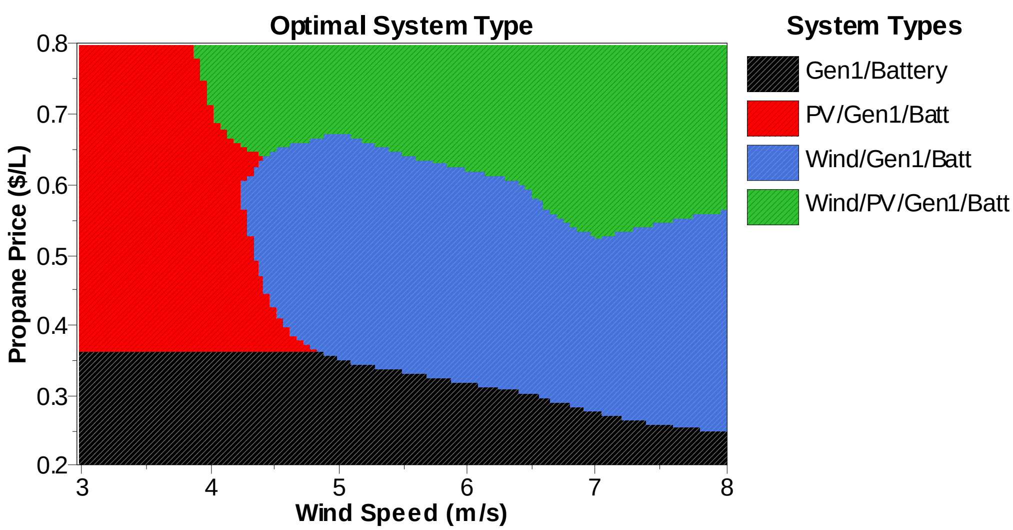
Wind data is more problematic, so a sensitivity analysis was performed on this data. In the absence of hourly data for an entire year, HOMER can use monthly data along with four statistical parameters, Weibull "k", autocorrelation factor, diurnal pattern strength and hour of peak wind. HOMER's help system and resource database contains monthly averages for Alamosa, Grand Junction, Winslow, Albuquerque, and Cedar City. It also contains the four statistical parameters for all of those cities, except Winslow. We used an average of this data. We assumed an altitude of 1400 meters above sea level. The data for the five cities that were used came from NREL's TMY2 (Typical Meteorological Year) Database. This database consistently underestimates the average windspeed, but can be useful for identifying seasonal patterns and the other statistical parameters. The Four Corners is also at a high elevation. Even after HOMER's correction for reduced air density we expect the wind resource at the Four Corners to be significantly stronger than the averages in this database. For this reason, we provide results for annual average windspeeds of 3, 4, 5, 6, 7, and 8 meters per second. We can be very confident that the actual annual average windspeed is within that broad range, but some on-site anemometry is necessary to more precise estimate the wind resource.

Possible Configurations

There are many possible system configurations that are possible alternatives to a grid extension. The simplest would be a single gen-set that ran all the time. The gen-set can be supplemented with a battery and inverter so that that the gen-set only operates when the load is relatively large and the battery and inverter covers the off-peak loads. There are also renewable power components that can be part of the system. Photovoltaic systems are very modular and can come in almost any size. There are a variety of small wind turbines that are commercially available. For this analysis we looked at 13 different sized PV arrays between 1 and 13 kW. We considered one or two units of either a 3 kW wind turbine or an 8 kW turbine. We considered a 10 kW gen-set that could cover the peak load and any surge currents. We considered both a small 1 kW inverter that could just handle the night-time off-peak loads and a 10 kW inverter that could handle all of the loads. We considered battery banks consisting of large deep-cycle batteries. Each Surrette 6CS25P battery has a capacity of about 7 kWh. We considered 7 different sized battery banks of up to 24 batteries or 168 kWh. Altogether HOMER simulated the operation of 3360 different configurations.

Results

The results of the analysis are quite sensitive to assumptions about the uncertain parameters of wind speed and fuel price. The windspeed is uncertain because there has been no on-site anemometry. The fuel price is uncertain because it depends on volatile market conditions. HOMER has an automated capability to perform sensitivity analyses on these uncertainties. The following graph show how the results depend on these 2 parameters.



At low fuel prices below $0.25 - $0.35 per liter the optimal system is a gen-set with 4 batteries and a 1 kW inverter for off-peak periods. The HOMER optimization results for the sensitivity case where the windspeed was 4 meters per second and the fuel price was $0.30 per liter is shown below. The categorized results are listed in the order of increasing Net Present Cost (NPC), so the least cost system is at the top. The simple diesel system is the fifth system down in the list. The optimal system involves an extra capital expenditure of $7,000 for the battery and inverter, but the fuel consumption dropped from 24,737 liters per year to 14,890 liters per year. Additional savings in gen-set O&M and replacements costs were achieved because the gen-set only ran for 4015 hours instead of 8760 hours per year. These savings more than compensated for the O&M and replacement costs of the battery and inverter. Taking all of the capital, fuel, O&M and replacement costs into consideration the optimal system with the battery and inverter has a net present cost that is about 40% less than the simple gen-set.

Sensitivity variables

Wind Speed (m/s) 4 Propane Price ($/L) 0.3

Double click on a system below for simulation results. Categorized

PV (kW)	XLR	W175	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Propane (L)	Gen1 (hrs)
			10	4	1	$ 13,000	$ 104,187	0.364	0.00	14,890	4,015
1			10	4	1	$ 20,000	$ 105,405	0.368	0.08	13,623	3,793
		1	10	4	1	$ 28,000	$ 109,102	0.381	0.18	12,064	3,341
1		1	10	4	1	$ 35,000	$ 114,031	0.398	0.26	11,361	3,317
			10			$ 6,000	$ 169,860	0.593	0.00	24,737	8,760
1			10		1	$ 14,000	$ 176,562	0.616	0.06	24,066	8,758
		1	10		1	$ 22,000	$ 182,039	0.635	0.12	22,947	8,246
1		1	10		1	$ 29,000	$ 187,623	0.655	0.17	22,432	8,214
20	1			24	10	$ 216,000	$ 266,510	0.931	1.00		

Above about $0.35 per liter it becomes cost-effective to add a small amount of photovoltaics to the system if there is a poor wind resource. If the wind resource is greater than about 4.5 meters per second it is cost effective to add a wind turbine to the system unless the fuel price is very low. At high fuel prices it becomes cost-effective for the system to be primarily renewable with gen-set running for less than 1000 hours per year. The following table shows the results for a windspeed of 6 meters per second and a fuel price of $0.70 per liter.

Sensitivity variables

Wind Speed (m/s) 6 Propane Price ($/L) 0.7

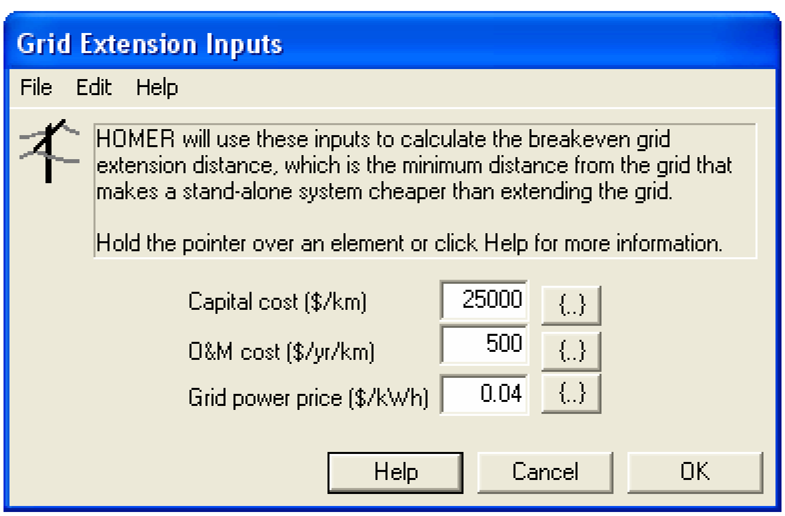
Double click on a system below for simulation results. ⦿ Categorized

PV (kW)	XLR	W175	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Propane (L)	Gen1 (hrs)
9		1	10	8	10	$ 106,000	$ 154,679	0.540	0.90	2,175	832
		1	10	2	1	$ 25,000	$ 167,009	0.583	0.32	11,880	3,637
1			10	8	1	$ 26,000	$ 172,166	0.601	0.08	12,803	3,302
			10	8	1	$ 19,000	$ 187,865	0.656	0.00	14,808	3,984
12	1			24	10	$ 160,000	$ 203,932	0.712	1.00		
		2	10		1	$ 37,000	$ 261,121	0.911	0.41	17,982	6,343
1		2	10		1	$ 44,000	$ 265,888	0.928	0.44	17,679	6,302
			10			$ 6,000	$ 296,347	1.034	0.00	24,737	8,760
1			10		1	$ 14,000	$ 299,620	1.046	0.06	24,066	8,758

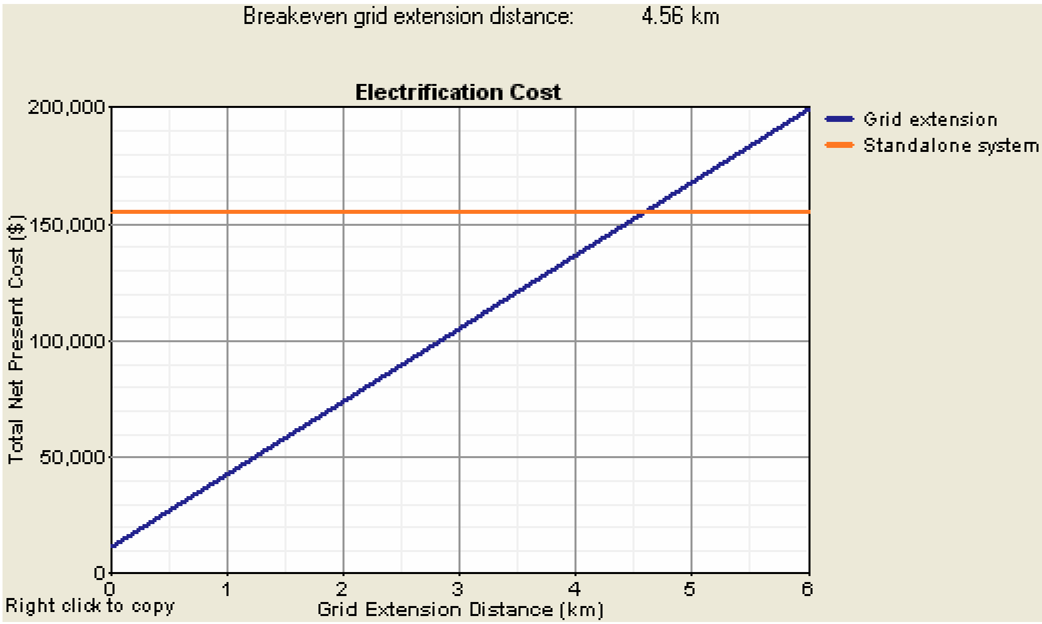
In this case the optimal system contains 9 kW of PV and a 3 kW wind turbine. Fuel consumption has been reduced to only 2,175 liters per year. The gen-set run-time is only 832 hours. Capital costs are much higher at $106,000, but the Net Present Cost of this system is 18% less than the system with a gen-set, battery and inverter and 48% less than the systems with just a gen-set.

Appendix B contains a detailed HOMER Output report for this particular system. Because not all of the 3360 possible systems were feasible under each of the 42 sensitivity cases, there are only 47,922 feasible systems that have simulated results, but a detailed output report is available from HOMER for each of these system simulations. HOMER also has graphical and tabular data illustrating the hourly operation of each of these systems.

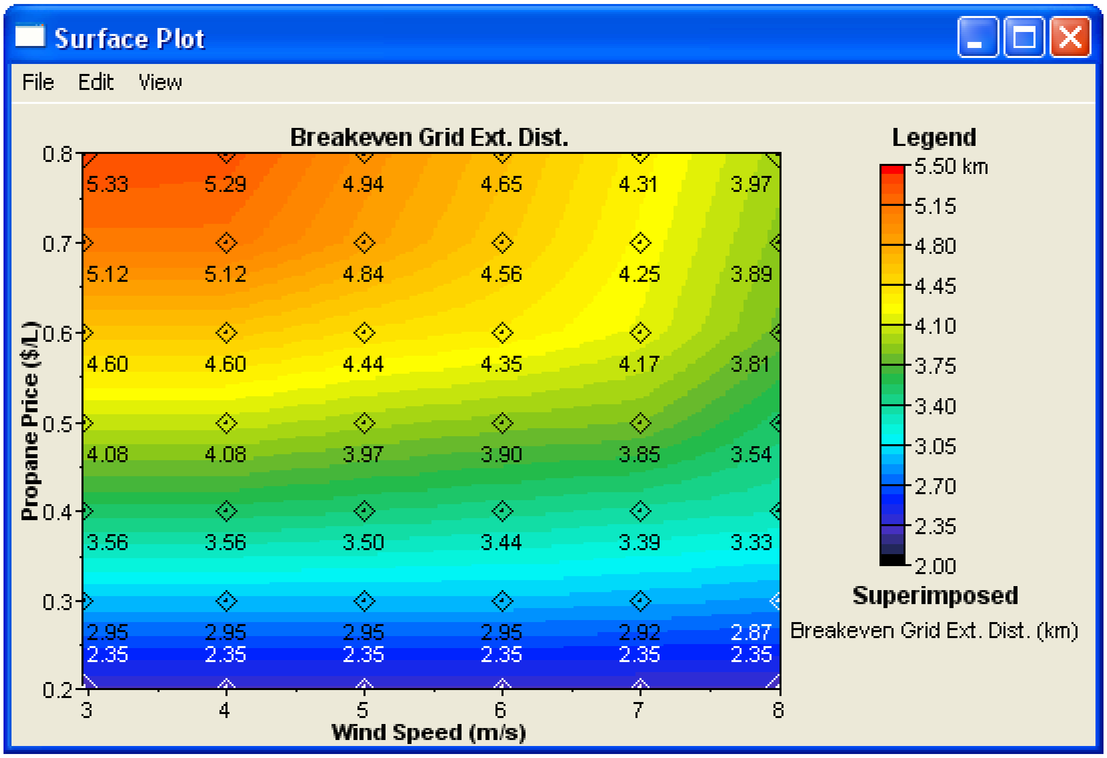
One of HOMER's most useful outputs for applications such as this is its ability to compare the stand-alone system to a grid extension. For this analysis we assumed the following costs of a grid extension:



We do not know how far the site is from an existing distribution line, but we can determine the Breakeven Grid Extensions Distance. The is the distance beyond which the stand-alone system has a lower Net Present Cost than the grid extension. If the site is less than this distance from the existing distribution system it is more cost-effective to extend the grid, but if it is more than this distance from the grid than the stand-alone system is economically preferable. This is illustrated by the following graph:



The breakeven grid extension is different for each system in each sensitivity case. The following graph shows the breakeven grid extension distance for the least cost system for each sensitivity case. It varies from 2.35 km to 5.33 km depending on the fuel price and windspeed.



Although the results are undoubtedly very sensitive to the load we did not perform any sensitivity analyses on the load. We recommend that careful attention be given to the loads, particularly the choice of heating and cooling technologies. It was beyond the scope of this analysis to compare different HVAC systems, but that is a logical next step that could have dramatic effects on the system design and costs. We also recommend that some effort be put into obtaining a better sense of the wind resource at the site.

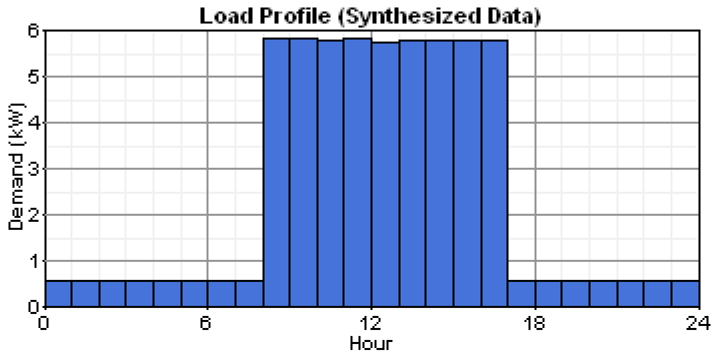
Appendix A

HOMER Input Summary

File name: 4 corners.hmr
File version:
Author:

AC Load: Combined Load

Data source:	Synthetic
Daily noise:	5%
Hourly noise:	5%
Scaled annual average:	61.4 kWh/d
Scaled peak load:	8.68 kW
Load factor:	0.295



PV

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
1.000	7,000	6,000	0

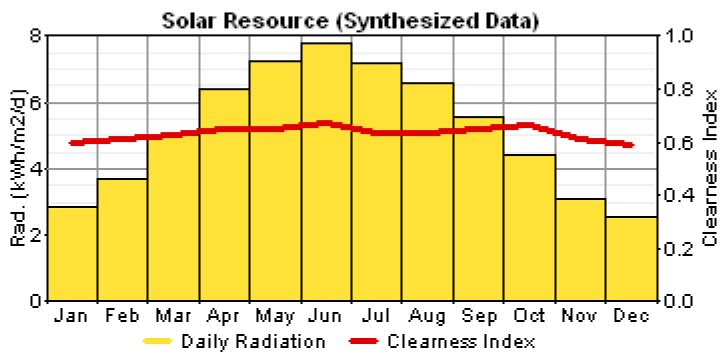
Sizes to consider: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20 kW
Lifetime: 20 yr
Derating factor: 90%
Tracking system: No Tracking
Slope: 37 deg
Azimuth: 0 deg
Ground reflectance: 20%

Solar Resource

Latitude: 37 degrees 0 minutes North
Longitude: 109 degrees 0 minutes West
Time zone: GMT -7:00
Data source: Synthetic

Month	Clearness Index	Average Radiation
		(kWh/m^2/day)
Jan	0.596	2.830
Feb	0.609	3.720
Mar	0.631	5.040
Apr	0.650	6.390
May	0.653	7.230
Jun	0.674	7.800
Jul	0.637	7.200
Aug	0.639	6.560
Sep	0.650	5.590
Oct	0.665	4.420
Nov	0.615	3.100
Dec	0.589	2.550

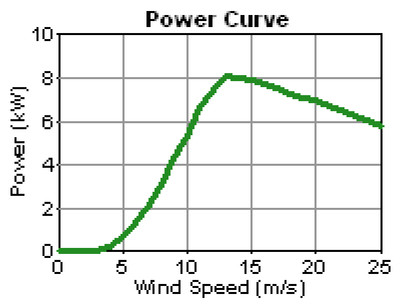
Scaled annual average: 5.21 kWh/m2/d



DC Wind Turbine: BWC Excel-R

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	30,000	25,000	200

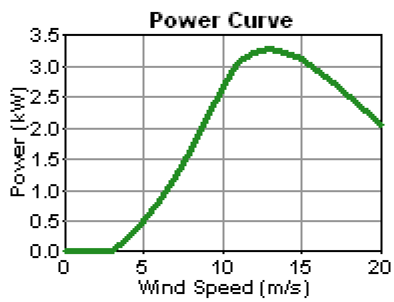
Quantities to consider: 0, 1, 2
Lifetime: 15 yr
Hub height: 25 m



DC Wind Turbine: SW Whisper 175

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	15,000	12,500	200

Quantities to consider: 0, 1, 2
Lifetime: 15 yr
Hub height: 25 m

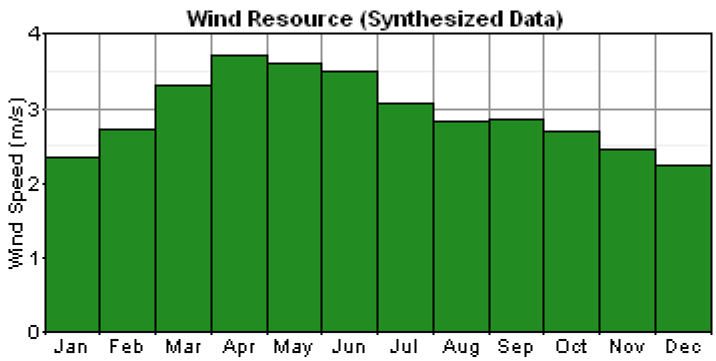


Wind Resource

Data source: Synthetic

Month	Wind Speed

	(m/s)
Jan	2.36
Feb	2.74
Mar	3.31
Apr	3.73
May	3.62
Jun	3.50
Jul	3.07
Aug	2.84
Sep	2.86
Oct	2.69
Nov	2.47
Dec	2.25



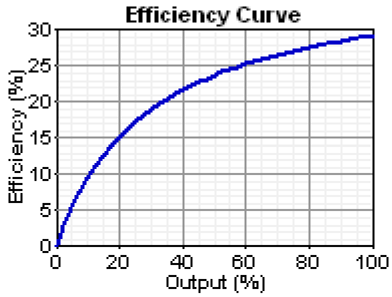
Weibull k: 1.547
Autocorrelation factor: 0.843
Diurnal pattern strength: 0.279
Hour of peak wind speed: 16
Scaled annual average: 2.95, 4.00, 5.00, 6.00, 7.00, 8.00 m/s
Anemometer height: 10 m
Altitude: 0 m
Wind shear profile: Logarithmic
Surface roughness length: 0.01 m

AC Generator: Generator 1

Size (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
10.000	6,000	5,000	0.300

Sizes to consider: 0, 10 kW
Lifetime: 15,000 hrs
Min. load ratio: 30%
Heat recovery ratio: 0%
Fuel used: Propane

Fuel curve intercept: 0.12 L/hr/kW
Fuel curve slope: 0.4 L/hr/kW



Fuel: Propane

Price: $ 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8/L
Lower heating value: 46.4 MJ/kg
Density: 510 kg/m3
Carbon content: 82.0%
Sulfur content: 0.330%

Battery: Surrette 6CS25P

Quantity	Capital ($)	Replacement ($)	O&M ($/yr)
1	1,500	1,200	10.00

Quantities to consider: 0, 2, 4, 8, 12, 16, 20, 24
Voltage: 6 V
Nominal capacity: 1,156 Ah
Lifetime throughput: 9,645 kWh

Converter

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
10.000	10,000	10,000	100

Sizes to consider: 0, 1, 10 kW
Lifetime: 15 yr
Inverter efficiency: 90%
Inverter can parallel with AC generator: Yes
Rectifier relative capacity: 100%
Rectifier efficiency: 85%

Grid Extension

Capital cost: $ 25,000/km
O&M cost: $ 5,000/yr/km
Power price: $ 0.04/kWh

Economics

Annual real interest rate: 6%
Project lifetime: 25 yr
Capacity shortage penalty: $ 0/kWh
System fixed capital cost: $ 0
System fixed O&M cost: $ 0/yr

Generator control

Check load following: No
Check cycle charging: Yes
Setpoint state of charge: 80%
Allow systems with multiple generators: Yes
Allow multiple generators to operate simultaneously: Yes
Allow systems with generator capacity less than peak load: Yes

Emissions

Carbon dioxide penalty: $ 0/t
Carbon monoxide penalty: $ 0/t
Unburned hydrocarbons penalty: $ 0/t
Particulate matter penalty: $ 0/t
Sulfur dioxide penalty: $ 0/t
Nitrogen oxides penalty: $ 0/t

Constraints

Maximum annual capacity shortage: 0%
Minimum renewable fraction: 0%
Operating reserve as percentage of hourly load: 10%
Operating reserve as percentage of peak load: 0%
Operating reserve as percentage of solar power output: 25%
Operating reserve as percentage of wind power output: 50%

Appendix B

System Report - 4 corners.hmr

Sensitivity case

Wind Data Scaled Average: 6 m/s
Propane Price: 0.7 $/L

System architecture

PV Array:	9	kW
Wind turbine:	1	SW Whisper 175
Gen-set:	10	kW
Battery:	8	Surrette 6CS25P
Inverter:	10	kW
Rectifier:	10	kW

Dispatch strategy: Cycle Charging

Cost summary

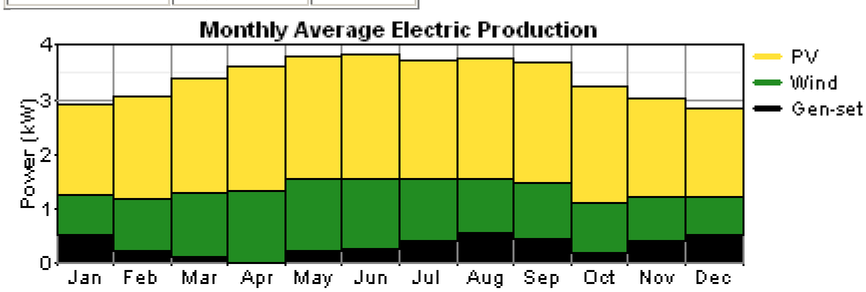
Total net present cost: 154,679 $
Levelized cost of energy: 0.540 $/kWh

Cost breakdown

Component	Initial Capital	Annualized Capital	Annualized Replacement	Annual O&M	Annual Fuel	Total Annualized
	($)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV Array	63,000	4,928	579	0	0	5,507
SW Whisper 175	15,000	1,173	332	200	0	1,705
Gen-set	6,000	469	81	250	1,523	2,322
Battery	12,000	939	398	80	0	1,417
Converter	10,000	782	266	100	0	1,148
Totals	106,000	8,292	1,656	630	1,523	12,100

Annual electric energy production

Component	Production	Fraction
	(kWh/yr)	
PV array	17,979	60%
Wind turbine	8,988	30%
Gen-set	2,942	10%
Total	29,909	100%



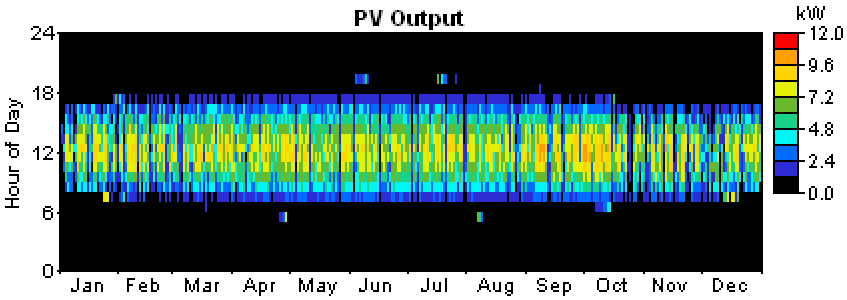
Annual electric energy consumption

Load	Consumption (kWh/yr)	Fraction
AC primary load	22,411	100%
Total	22,411	100%

Variable	Value	Units
Renewable fraction:	0.902	
Excess electricity:	4,173	kWh/yr
Unmet load:	0	kWh/yr
Capacity shortage:	0	kWh/yr

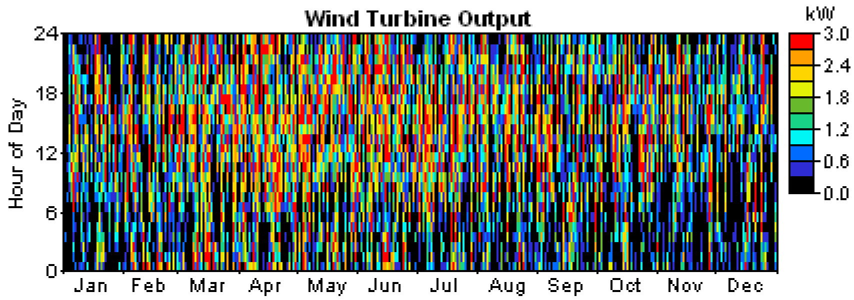
PV

Variable	Value	Units
Average output:	49.3	kWh/d
Minimum output:	0.0001333	kW
Maximum output:	10.35	kW
Solar penetration:	80.2	%
Capacity factor:	22.8	%
Hours of operation:	4,701	hr/yr



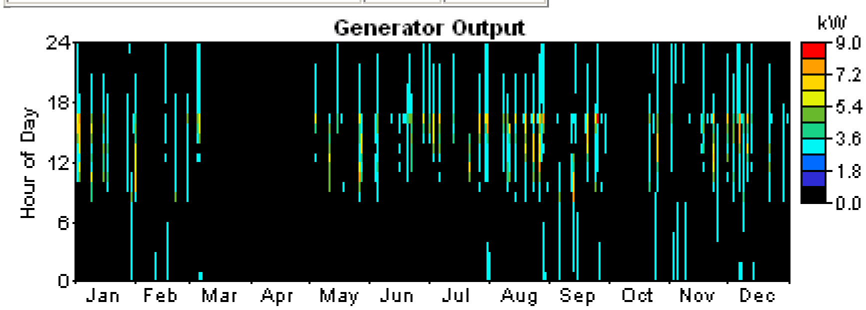
DC Wind Turbine: SW Whisper 175

Variable	Value	Units
Total capacity:	3.28	kW
Average output:	1.026	kW
Minimum output:	0.000	kW
Maximum output:	2.86	kW
Wind penetration:	40.1	%
Capacity factor:	31.3	%
Hours of operation:	6,953	hr/yr



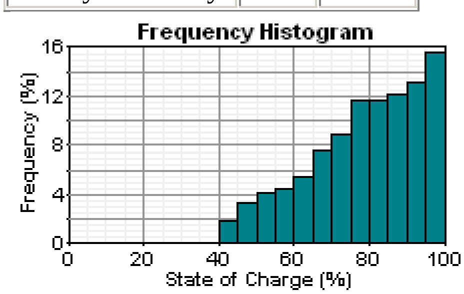
Gen-set

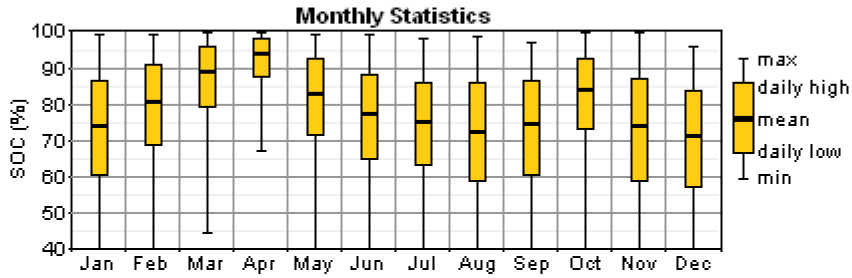
Variable	Value	Units
Hours of operation:	832	hr/yr
Number of starts:	114	starts/yr
Operational life:	18.03	yr
Average electrical output:	3.54	kW
Minimum electrical output:	3.00	kW
Maximum electrical output:	8.91	kW
Annual fuel usage:	2,175	L/yr
Specific fuel usage:	0.739	L/kWh
Average electrical efficiency:	20.6	%

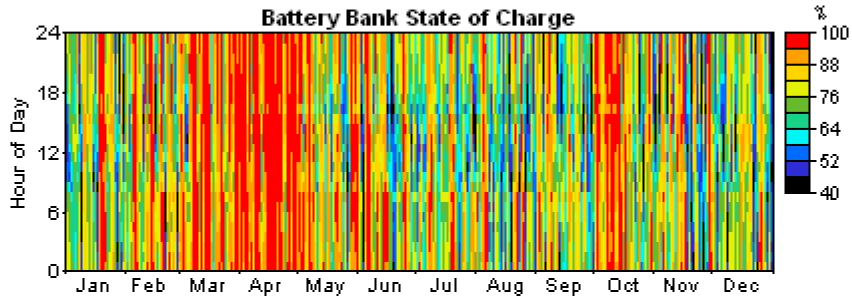


Battery

Variable	Value	Units
Battery throughput	4,470	kWh/yr
Battery life	12.00	yr
Battery autonomy	13.01	hours

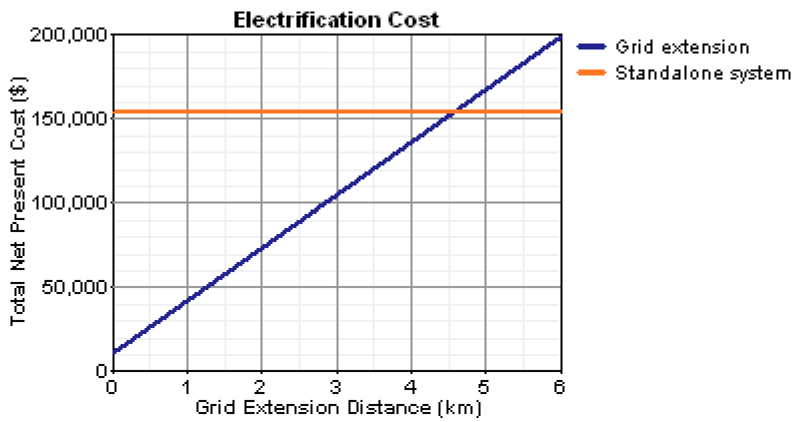






Grid Extension

Breakeven grid extension distance: 4.56 km



Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	3,308
Carbon monoxide	14.14
Unburned hydrocarbons	1.566
Particulate matter	1.066
Sulfur dioxide	7.15
Nitrogen oxides	126.2