Wendy Jennings was an intern at the National Renewable Energy Laboratory through the Department of Energy's Pre-Service Teacher program in the summer of 2000. She is a mathematics education student at Colorado State University in Fort Collins, Colorado. She plans to teach high school mathematics in California next year. She also holds a bachelor's degree in Anthropology from California State University. Ms. Jennings would like to help her future students discover and maintain a link between the mathematics she will be teaching them and their future lives as productive adults. Her research experience has given her the insight to guide future students through the process of understanding the world around them.

Jim Green works on wind turbine applications at the National Wind Technology Center, part of the National Renewable Energy Lab (NREL) in Golden, CO. He started at NREL in 1978 and has been working in wind energy since 1992. He manages development subcontracts with wind turbine manufacturers for the design and test of new models of small wind turbines. He has also conducted research on small wind turbine applications including modeling and testing of the performance of off-grid hybrid power systems. Mr. Green also participates in the IEEE P1547 Working Group, which is writing a standard for grid interconnection of distributed resources. He received a BS in General Engineering from the University of Illinois in 1975 and he is a registered Professional Engineer in the state of Colorado.

OPTIMIZATION OF ELECTRIC POWER SYSTEMS FOR OFF-GRID DOMESTIC APPLICATIONS: AN ARGUMENT FOR WIND/PHOTOVOLTAIC HYBRIDS

WENDY JENNINGS AND JIM GREEN

ABSTRACT

The purpose of this research was to determine the optimal configuration of home power systems relevant to different regions in the United States. The hypothesis was that, regardless of region, the optimal system would be a hybrid incorporating wind technology, versus a photovoltaic hybrid system without the use of wind technology. The method used in this research was HOMER, the Hybrid Optimization Model for Electric Renewables. HOMER is a computer program that optimizes electrical configurations under user-defined circumstances. According to HOMER, the optimal system for the four regions studied (Kansas, Massachusetts, Oregon, and Arizona) was a hybrid incorporating wind technology. The cost differences between these regions, however, were dependent upon regional renewable resources. Future studies will be necessary, as it is difficult to estimate meteorological impacts for other regions.

INTRODUCTION

According to Richard Perez, editor of *Home Power* magazine, approximately 180,000 homes in the United States are not connected to a public power source or utility grid (e-mail to author; August 2, 2000). These homes are either without an electric power supply or provide their own power through the use of fossil-fueled generators, photovoltaics, or wind turbines. Batteries and inverters are additional components that are likely to be used with these power sources. Any power system that incorporates two or more of the following is referred to as a *hybrid* power system: photovoltaic (PV) panels; wind turbines; or diesel, propane, or gasoline generators (Figure 1). Hybrid power allows stand-alone power systems to operate at maximum effectiveness because the various power components complement one another.

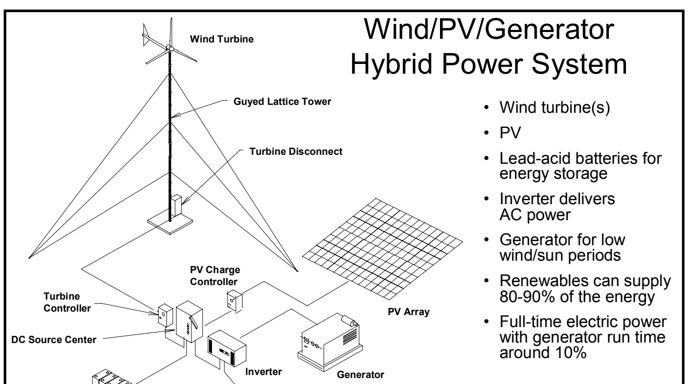


Figure 1. Diagram of Wind/PV/Generator Hybrid Power System

Remote homeowners are often left with many decisions and little knowledge regarding the most cost-effective system for providing power to their homes. Most remote homeowners use fossil-fueled generators or a hybrid of PV panels with a generator (Figure 2). According to a survey of new subscribers to *Home Power* magazine, 80.6% use PV systems and half of those also incorporate a generator. Only 19.4% of this population use wind technology to power their homes (E-mail to author; August 2, 2000) (Figures 3 and 4). Consumers have limited access to information regarding the best configuration of power components for their regional meteorological conditions. Optimal cost scenarios are also wanting.

The goal of this study was to determine the optimal configuration of residential power sources relevant to different regions in the United States, including systems with any or all of the previously discussed components of a potential hybrid system. The hypothesis formulated for this study was as follows: remote homeowners who currently own power systems without a wind turbine are not operating the most cost-effective systems, regardless of their geographical region. This hypothesis was tested using the computer simulation model HOMER, the Hybrid Opti-

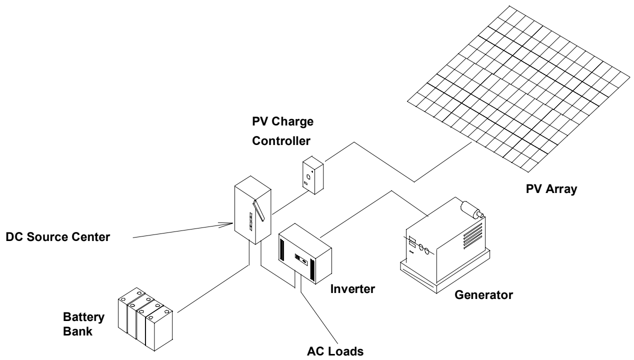


Figure 2. Diagram of PV/Generator Hybrid Power System

mization Model for Electric Renewables. Although HOMER was initially developed to provide optimization models for developing countries, it is also an appropriate reference tool for this regional study of remote homes in the United States.

MATERIALS AND METHODS

The primary tool used in this research was the HOMER optimization model. The National Renewable Energy Laboratory (NREL), under the guidance of Peter Lilienthal and Tom Lambert, developed HOMER, a computer model for optimizing electrical resources. HOMER "simulates and optimizes hybrid power systems, which are standalone power plants that employ some combination of wind turbines, photovoltaic panels, or diesel generators to produce electricity" (Lambert 2000). HOMER is capable of simulating more than 1000 different hybrid systems per minute. HOMER has two types of data windows: Inputs and Outputs. The Inputs provide the definition of the search space; the Outputs provide the results. The Inputs consist of the following: loads, resources, components, and optimizations.

Specific simulations were prepared, which defined the span of the search space, and certain sensitivities were defined, each resulting in an optimum being chosen from the search space. A simulation with the household energy usage of 7.52 kWh/d was selected. This load size was determined using seasonal approximations for remote homes. Local data regarding solar radiation monthly averages (in kWh/m^2/day) and hourly wind speed (in m/s) were input. The regions chosen for this study were Kansas, Massachusetts, Oregon, and Arizona. The solar data was from Dodge City, Kansas; Worcester, Massachusetts; Pendleton, Oregon; and Prescott, Arizona. The wind data was from Russell, Kansas; Holyoke, Massachusetts; Pendleton, Oregon; and Kingman, Arizona. Although the solar and wind data were from different locations, they had comparable latitudes and climates. The exception was Arizona for which the two cities are at somewhat different elevations. The permissible components of a power system were the following: PV panels, wind turbines, generators, batteries, and inverters. For each of these components, information regarding typical market prices and power generation statistics were input. These were the primary inputs, which provide the base data for the optimization process.

Several input parameters were allowed to vary within a range. Each unique combination of all the inputs was a simulation. These simulations provided the scope of the search space and are needed to encompass all feasible combinations. The ranges chosen were under the categories of PV Array, Turbine 2 (a one kW wind turbine), Diesel (generator), Battery, and Inverter. For example, the PV array ranged from zero kW to 4 kW, as indicated by the load size and necessary search space. This range was then divided into eight sub-divisions, in order to determine the optimal size of the PV array. HOMER would not search for a system that was not defined in this space. Therefore, if the optimal system consisted of 2 kW of PV, but HOMER was only given 1 kW and 3 kW under the optimizations window, then the optimal system would be passed over in lieu of the next best choice that had a defined PV component. Wind turbines were categorized in HOMER by the number of turbines (from 0 to 2) necessary to optimize the power output. The Diesel (generator) and Inverter variables consisted of a variety of sizes (in kW). Batteries were varied using typical "market" size ranges (in kWh).

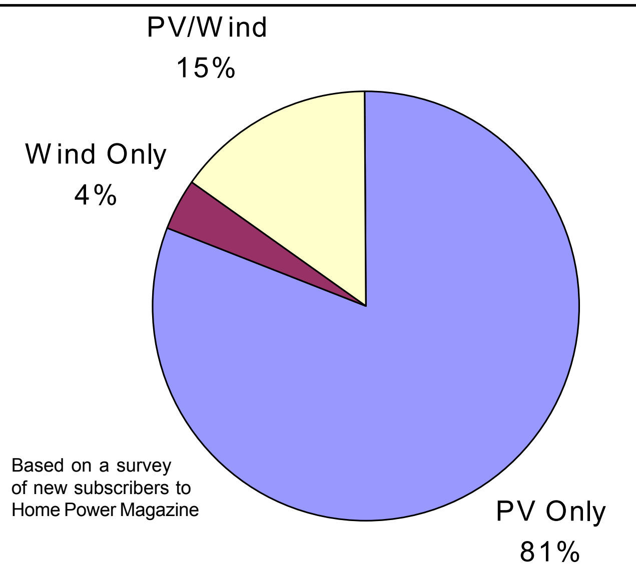


Figure 3. Wind and PV Use in Off-Grid Homes

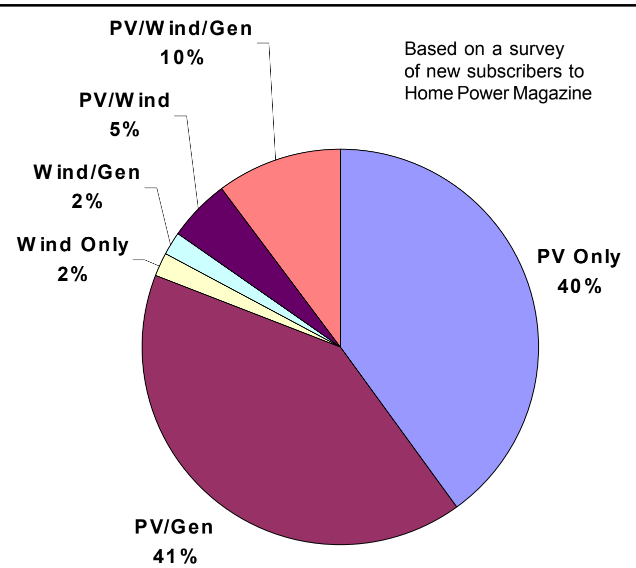


Figure 4. Wind, PV, and Generator Use in Off-Grid Homes

These simulations used 0.5 $/liter for a fixed fuel price and negligible (0.3%) unserved energy. The "unserved energy" percentage referred to the percentage of the year during which no energy was being provided. The value chosen allowed for up to 2 hours a month as the maximum unserved energy for the home.

Once the initial characteristics of each HOMER run were standardized (meaning the important variables were chosen), the solar radiation and wind data for the four different regions of the United States were input to determine regional variations in the optimal power system. A new HOMER run was executed for each region. HOMER then ranked each of the simulations according to "Net Present Cost" (NPC), which is the total cost over the lifetime of the system using current monetary values. The established lifetime of each system was 20 years. HOMER also provided data regarding the initial capital cost and the annualized cost. The objective of this research was to determine the optimal (least-cost) power system for each region and compare these results to the lowest-cost system that did not include a wind turbine.

RESULTS

Kansas

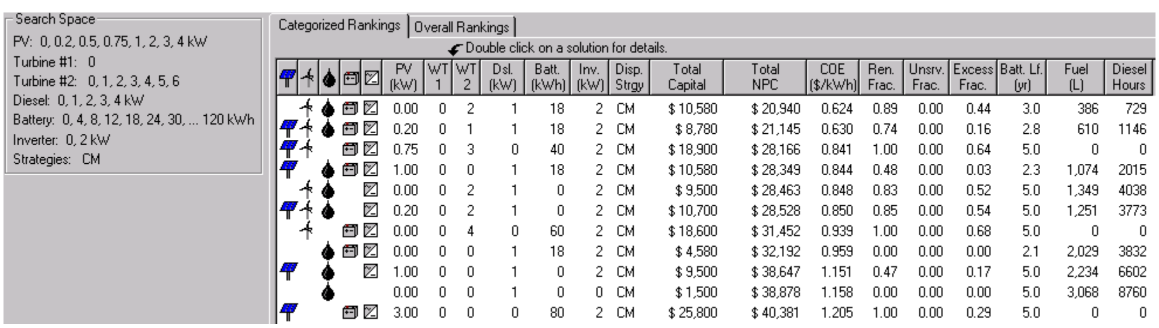
Based on 1977 data provided by NREL for Dodge City and Russell, Kansas, the annual average global solar insolation was 4.9 kWh/m^2/day and the annual average wind speed was 5.7 m/s. According to HOMER, using the control variables specified, the "optimal" system (meaning the least-cost) for this load size and location was a hybrid with a wind turbine, diesel generator, battery, and inverter system (Figure 5). HOMER recommended that two 1.0-kW wind turbines, a 1.0-kW generator, an 18.0-kWh battery bank (meaning approximately 2 days of energy storage), and a 2.0-kW inverter be purchased as the optimal system, for a capital cost of $10,580. Over the lifetime of the system, the NPC, which was a sum of the capital cost and the total cost to maintain this system, would be $20,940. Typically, 89% of the total energy production would be the result of renewable resources and the generator would run approximately 729 hours per year. The annual fuel usage would be 386 liters.

The first system that did not involve a wind turbine incorporated 1.0 kW of PV along with a 1.0-kW generator, an 18.0-kWh battery bank, and a 2.0-kW inverter, for an initial cost of $10,580. The NPC over the lifetime of the system was $28,349, which was 35% more expensive than the optimal system. This system generated 48% of its energy from renewable resources and used 2015 annual hours of generator energy. This increase in generator run time caused the system to use 688 more liters of diesel (178%) than the optimal wind/generator hybrid power system (Table 1).

Massachusetts

The data provided for Worcester and Holyoke, Massachusetts, in 1979 had an annual global solar radiation average of 3.8 kWh/m^2/day and a 3.3 m/s annual average wind speed. According to HOMER, the ideal system in this region of Massachusetts was a hybrid including a PV array, a wind turbine, generator, battery, and inverter (Figure 6). The components necessary to fulfill this primary load of 2744 kWh/yr were 0.8 kW of PV, one 1.0-kW wind turbine, a 1.0-kW generator, an 18.0-kWh battery bank, and a 2.0-kW inverter. The capital cost of this configuration was $12,080. The lowest NPC is $29,090. This system produced 49.6% of its energy production from renewable sources. The generator would typically be running 1,930 hours per year and use 1,018 liters of fuel.

The least-cost system, absent a wind turbine, consisted of 1.0 kW of PV, a 1.0-kW generator, a 18.0-kWh battery bank, and a 2.0-kW inverter, for an initial capital cost of $10,580. This capital



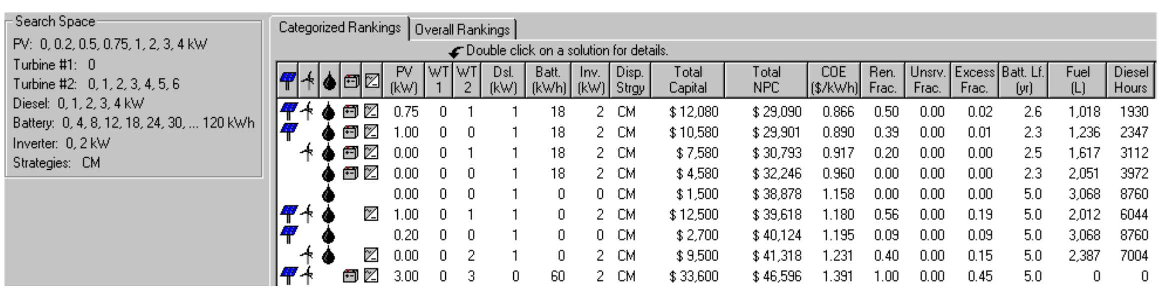
Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.00	0	2	1	18	2	CM	$ 10,580	$ 20,940	0.624	0.89	0.00	0.44	3.0	386	729
0.20	0	1	1	18	2	CM	$ 8,780	$ 21,145	0.630	0.74	0.00	0.16	2.8	610	1146
0.75	0	3	0	40	2	CM	$ 18,900	$ 28,166	0.841	1.00	0.00	0.64	5.0	0	0
1.00	0	0	1	18	2	CM	$ 10,580	$ 28,349	0.844	0.48	0.00	0.03	2.3	1,074	2015
0.00	0	2	1	0	2	CM	$ 9,500	$ 28,463	0.848	0.83	0.00	0.52	5.0	1,349	4038
0.20	0	2	1	0	2	CM	$ 10,700	$ 28,528	0.850	0.85	0.00	0.54	5.0	1,251	3773
0.00	0	4	0	60	2	CM	$ 18,600	$ 31,452	0.939	1.00	0.00	0.68	5.0	0	0
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,192	0.959	0.00	0.00	0.00	2.1	2,029	3832
1.00	0	0	1	0	2	CM	$ 9,500	$ 38,647	1.151	0.47	0.00	0.17	5.0	2,234	6602
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
3.00	0	0	0	80	2	CM	$ 25,800	$ 40,381	1.205	1.00	0.00	0.29	5.0	0	0

Figure 5. HOMER Results for Kansas



Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.75	0	1	1	18	2	CM	$ 12,080	$ 29,090	0.866	0.50	0.00	0.02	2.6	1,018	1930
1.00	0	0	1	18	2	CM	$ 10,580	$ 29,901	0.890	0.39	0.00	0.01	2.3	1,236	2347
0.00	0	1	1	18	2	CM	$ 7,580	$ 30,793	0.917	0.20	0.00	0.00	2.5	1,617	3112
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,246	0.960	0.00	0.00	0.00	2.3	2,051	3972
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
1.00	0	1	1	0	2	CM	$ 12,500	$ 39,618	1.180	0.56	0.00	0.19	5.0	2,012	6044
0.20	0	0	1	0	0	CM	$ 2,700	$ 40,124	1.195	0.09	0.00	0.09	5.0	3,068	8760
0.00	0	2	1	0	2	CM	$ 9,500	$ 41,318	1.231	0.40	0.00	0.15	5.0	2,387	7004
3.00	0	3	0	60	2	CM	$ 33,600	$ 46,596	1.391	1.00	0.00	0.45	5.0	0	0

Figure 6. HOMER Results for Massachusetts

Table 1. Results for Kansas

	Optimal System	Least-Cost PV-only System	Difference: PV only compared to Optimal
PV, kW	0.0	1.0	
Wind, kW	2.0	0.0	
Diesel, kW	1.0	1.0	
Battery, kWh	18.0	18.0	
Inverter, kW	2.0	2.0	
Renewable %	89.0%	47.7%	
Generator Run Time, h/y	729.0	2015.0	176.5%
Diesel Fuel Usage, liters/y	386.0	1074.0	177.8%
Capital Cost, US$	$10,580	$10,580	0.0%
Total NPC, US$	$20,940	$28,349	35.4%

Table 2. Results for Massachusetts

	Optimal	Least-Cost PV-only System	Difference: PV only compared to Optimal
PV, kW	0.8	1.0	
Wind, kW	1.0	0.0	
Diesel, kW	1.0	1.0	
Battery, kWh	18.0	18.0	
Inverter, kW	2.0	2.0	
Renewable %	49.6%	39.4%	
Generator Run Time, h/y	1930.0	2347.0	21.6%
Diesel Fuel Usage, liters/y	1018.0	1236.0	21.4%
Capital Cost, US$	$12,080	$10,580	-12.4%
Total NPC, US$	$29,090	$29,901	2.8%

cost was less than the capital cost for the optimal system. However, the NPC of this system was $29,901, which was 3% more expensive than the optimal. Of the total production, 39% was from renewable resources. This system ran the generator 2,347 hours a year (417 hours more than the wind system) and used 1,236 liters of fuel (21% more than the optimum) (Table 2).

Oregon

Oregon was the only region for which the data for solar and wind resources were from the same city, Pendleton, Oregon, in 1992. The average global solar radiation index was 5.4 kWh/m^2/day, and the average annual wind speed was 3.5 m/s. The optimization generated was as follows: 0.8 kW of PV, one 1.0-kW wind turbine, a 1.0-kW generator, an 18.0-kWh battery bank, and a 2.0-kW inverter (Figure 7). The capital cost for this system was $12,080, and the NPC was $26,525. This system would produce 67% of its energy from renewable resources. The generator would run 1,393 hours per year, using 731 liters of fuel annually.

The least-cost system without a wind turbine was composed of 1.0 kW of PV, a 1.0-kW generator, an 18.0-kWh battery bank, and a 2.0-kW inverter. The initial capital cost was $10,580, and the NPC was $27,526. The capital cost for this system was less than that for the optimal, but the NPC was 4% more expensive. This configuration would produce 55% of its energy from renewable energy sources. The generator would typically run 1,827 hours annually, using 963 liters of fuel per year. A hybrid that does not use wind technology would use 232 more liters of non-renewable fossil fuel (32%) than the optimal system (Table 3).

Arizona

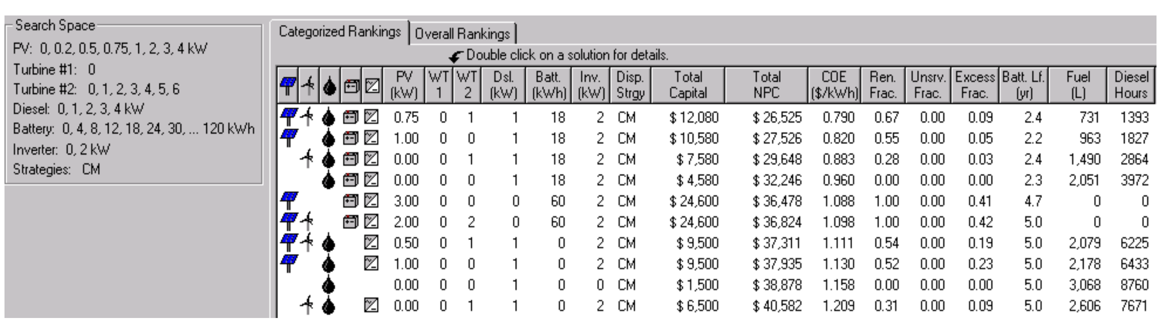
The data available for Arizona were from Prescott (solar) and Kingman (wind), in 1985. The annual average global solar radiation was 4.2 kWh/m^2/day, and the annual average wind speed was 4.5 m/s. HOMER calculated the optimal system as a hybrid configuration including a PV array, a wind turbine, generator, and inverter (Figure 8). The optimal components were 0.5 kW of PV, one 1.0-kW wind turbine, a 1.0-kW generator, an 18.0-kWh battery bank, and a 2.0-kW inverter. The initial capital cost of this hybrid was $10,580, and the NPC was $27,157. Typically, 54% of the energy produced would be from renewable resources. The generator would typically run 1,871 hours annually, using 980 liters of fuel.

The least-cost system without a wind component had 1.0 kW of PV, a 1.0-kW diesel generator, an 18.0-kWh battery, and a 2.0-kW inverter, for a total capital cost of $10,580. The net present cost came to $30,176. It would produce 38% of its energy from renewable sources. The generator would run 2,420 hours annually and use 1,270 liters of fuel, exceeding the optimal system by 290 liters (29.6%)(Table 4).

DISCUSSION

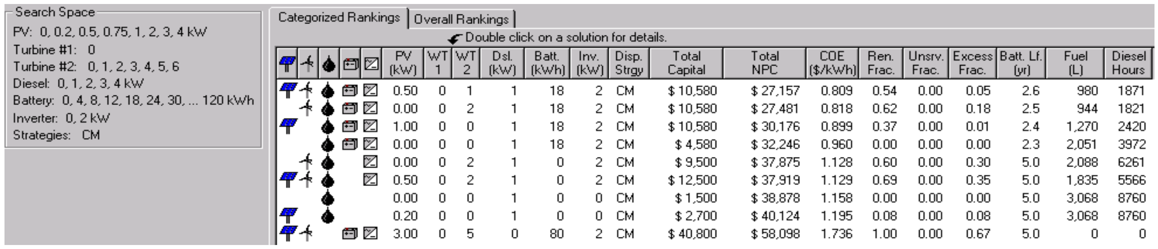
Kansas

Of the four regions studied, Kansas had the most favorable meteorological conditions for wind energy usage. Homeowners in Kansas not using wind technology, but using PV/generator systems, were spending an average of $8000 (36%) more over the 20-year lifetime of their system than they would had they added a wind turbine to their initial system. These homeowners were also running their diesel generators 2.8 times longer than they would using wind energy and using 2.8 times more diesel fuel. Both economically and ecologically, the use of a wind turbine hybrid system is the more appropriate system than the PV/generator configuration.



PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.75	0	1	1	18	2	CM	$ 12,080	$ 26,525	0.790	0.67	0.00	0.09	2.4	731	1393
1.00	0	0	1	18	2	CM	$ 10,580	$ 27,526	0.820	0.55	0.00	0.05	2.2	963	1827
0.00	0	1	1	18	2	CM	$ 7,580	$ 29,648	0.883	0.28	0.00	0.03	2.4	1,490	2864
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,246	0.960	0.00	0.00	0.00	2.3	2,051	3972
3.00	0	0	0	60	2	CM	$ 24,600	$ 36,478	1.088	1.00	0.00	0.41	4.7	0	0
2.00	0	2	0	60	2	CM	$ 24,600	$ 36,824	1.098	1.00	0.00	0.42	5.0	0	0
0.50	0	1	1	0	2	CM	$ 9,500	$ 37,311	1.111	0.54	0.00	0.19	5.0	2,079	6225
1.00	0	0	1	0	2	CM	$ 9,500	$ 37,935	1.130	0.52	0.00	0.23	5.0	2,178	6433
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
0.00	0	1	1	0	2	CM	$ 6,500	$ 40,582	1.209	0.31	0.00	0.09	5.0	2,606	7671

Figure 7. HOMER Results for Oregon



Search Space
PV: 0, 0.2, 0.5, 0.75, 1, 2, 3, 4 kW
Turbine #1: 0
Turbine #2: 0, 1, 2, 3, 4, 5, 6
Diesel: 0, 1, 2, 3, 4 kW
Battery: 0, 4, 8, 12, 18, 24, 30, ... 120 kWh
Inverter: 0, 2 kW
Strategies: CM

Categorized Rankings | Overall Rankings

Double click on a solution for details.

PV (kW)	WT 1	WT 2	Dsl. (kW)	Batt. (kWh)	Inv. (kW)	Disp. Strgy	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Unsrv. Frac.	Excess Frac.	Batt. Lf. (yr)	Fuel (L)	Diesel Hours
0.50	0	1	1	18	2	CM	$ 10,580	$ 27,157	0.809	0.54	0.00	0.05	2.6	980	1871
0.00	0	2	1	18	2	CM	$ 10,580	$ 27,481	0.818	0.62	0.00	0.18	2.5	944	1821
1.00	0	0	1	18	2	CM	$ 10,580	$ 30,176	0.899	0.37	0.00	0.01	2.4	1,270	2420
0.00	0	0	1	18	2	CM	$ 4,580	$ 32,246	0.960	0.00	0.00	0.00	2.3	2,051	3972
0.00	0	2	1	0	2	CM	$ 9,500	$ 37,875	1.128	0.60	0.00	0.30	5.0	2,088	6261
0.50	0	2	1	0	2	CM	$ 12,500	$ 37,919	1.129	0.69	0.00	0.35	5.0	1,835	5566
0.00	0	0	1	0	0	CM	$ 1,500	$ 38,878	1.158	0.00	0.00	0.00	5.0	3,068	8760
0.20	0	0	1	0	0	CM	$ 2,700	$ 40,124	1.195	0.08	0.00	0.08	5.0	3,068	8760
3.00	0	5	0	80	2	CM	$ 40,800	$ 58,098	1.736	1.00	0.00	0.67	5.0	0	0

Figure 8. HOMER Results for Arizona

MASSACHUSETTS

The Massachusetts analysis provided the least dramatic conclusions of the four regions. However, the optimal system in Massachusetts was still a hybrid incorporating wind technology. The PV without wind system used 20% more diesel fuel than the optimal system and ran this generator 20% more frequently. Conservation of fossil fuels and reduction of emissions were the benefits of incorporating a wind turbine. Regardless of the system, Massachusetts seldom had an option with a renewable percentage larger than 50%. The capital cost of a system with a wind turbine was 12% more than the cost without a turbine. After the 20-year lifetime, the consumer had only saved about 3% over a PV only system. Using wind technology would be only slightly less expensive.

OREGON

Oregon's optimal electrical system was comparable to that of Massachusetts. The optimal was a hybrid incorporating wind technology, but the system without wind was only about $1000 more in NPC. The capital cost of the system without a wind turbine was less expensive than the hybrid incorporating wind. The PV/generator system used the generator 30% longer than the system with a wind turbine and used 30% more fossil fuel. Oregon also tended to rank low on the percentage of renewables used: the optimal system was 67% while the PV only was 55%. Using wind technology did reduce the NPC of the system but only by a small margin.

ARIZONA

Next to Kansas, Arizona had the largest savings when using wind technology. The optimal system was, again, a hybrid using wind technology. By investing in a wind turbine (over a PV-only system), Arizona homeowners may save more than 10% over the 20-year lifetime of the system. The capital costs were identical regardless of the addition of wind or not. Without a turbine, Arizona homeowners typically ran their generators 30% longer while increasing their fuel usage by the same amount. The argument for a wind turbine in Arizona was not only the savings in fuel usage but also the $3,000 saved over the system lifetime.

This study showed that, in these four regions, a hybrid electrical system incorporating wind technology was generally the optimum in terms of NPC. This was consistent with the hypothesis of the study. However, the cost difference between the system incorporating wind technology and the first PV-only solution varied and depended upon regional and meteorological conditions. Kansas had the strongest argument in favor of a wind system since the optimum system was without PV. Arizona had the second-strongest argument, although with a very low renewable fraction. Both Oregon and Massachusetts, although having optimal systems incorporating wind, had weaker arguments for a wind hybrid system, taking into account the minimal cost differences between the optimal hybrid wind system solution and the PV-only solution. In any case, two conclusions were made from this preliminary research: wind hybrid systems had similar or lower costs than PV-only systems, and regional differences affected electrical production and system feasibility.

Further studies are being proposed using HOMER. In particular, the results from Arizona should be confirmed with meteorological data from the same location or locations more similar in elevation.

Table 3. Results for Oregon

	Optimal	Least-Cost PV-only System	Difference: PV only compared to Optimal
PV, kW	0.8	1.0	
Wind, kW	1.0	0.0	
Diesel, kW	1.0	1.0	
Battery, kWh	18.0	18.0	
Inverter, kW	2.0	2.0	
Renewable %	66.7%	55.0%	
Generator Run Time, h/y	1393.0	1827.0	31.2%
Diesel Fuel Usage, liters/y	731.0	963.0	31.7%
Capital Cost, US$	$12,080	$10,580	-12.4%
Total NPC, US$	$26,525	$27,526	3.8%

Table 4. Results for Arizona

	Optimal	Least-Cost PV-only System	Difference: PV only compared to Optimal
PV, kW	0.5	1.0	
Wind, kW	1.0	0.0	
Diesel, kW	1.0	1.0	
Battery, kWh	18.0	18.0	
Inverter, kW	2.0	2.0	
Renewable %	53.6%	37.5%	
Generator Run Time, h/y	1871.0	2420.0	29.3%
Diesel Fuel Usage, liters/y	980.0	1270.0	29.6%
Capital Cost, US$	$10,580	$10,580	0.0%
Total NPC, US$	$27,157	$30,176	11.1%

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