Optimization of Hybrid Distributed Generation Systems For Rural Communities in Alaska

Lindsay Willman
Moncef Krarti, PhD, PE, LEED®AP

ABSTRACT

This article summarizes the results from a feasibility study to design optimal distributed generation (DG) plants for three remote communities in Alaska. All three of these towns have isolated electrical grids and currently rely on diesel fuel for 100% of their electricity and heating requirements. This assessment included an analysis of each community's electrical and thermal load, a wind and solar resource evaluation, modeling and optimization of various DG systems using HOMER software, and an economic analysis of these systems. For all three of the communities, hybrid wind-diesel systems have the potential to provide reductions in the cost of energy. However, the economic feasibility of these systems is extremely site-specific. In addition to providing possible decreases in the cost of energy, these hybrid systems can also provide significant environmental benefits, such as reductions in diesel fuel use and CO_2 emissions. Future research should evaluate hybrid solar/wind generators with combined-heat-and- power (CHP) diesel engines.

Keywords: hybrid distributed generation, remote communities, levelized cost of energy, HOMER, wind-diesel hybrid systems

INTRODUCTION

In the state of Alaska, large transmission systems exist in the most populated areas such as the Railbelt region, which runs from Fairbanks through Anchorage to the Kenai Peninsula. Transmission systems are also present in some areas in Southeast Alaska; however, over 150 rural Alaskan communities have their own isolated electrical grids. About 70% of the electricity requirements for the Railbelt region are met with natural gas generators whereas in the majority of the remote areas, most of the electricity and heating requirements are met with diesel generators [1]. In 2010, residents in these rural areas had electricity rates between 40 and 60 cents per kilowatt hour (kWh), with some paying over $1.00 per kWh [2]. Conversely, communities in the Railbelt region that get electricity from hydroelectric facilities or natural gas generators have electricity rates between 10 and 15 cents per kWh [3].

Due to rising electricity rates and diesel prices, many rural Alaskan communities are considering the addition of renewable energy sources and other distributed generation (DG) technologies to form hybrid DG systems. Alaska's significant wind resource has led many coastal communities to invest in wind energy projects [1]. As of spring 2009, ten hybrid wind-diesel systems were operating in rural communities, with six more systems in development [4]. Preliminary results are promising; hybrid DG systems have the potential to lower the cost of electricity, improve the reliability of electricity and heating systems, and lower the emissions from diesel generators.

Numerous studies have analyzed hybrid DG systems involving diesel for remote communities. Shaahid and El-Amin [5] performed a techno-economic evaluation of a hybrid PV-diesel-battery system for a rural area in Saudi Arabia. Due to the excellent solar resource for the community, a PV hybrid system would be a good option that would maximize diesel generator efficiency, minimize generator maintenance, and reduce carbon emissions. Saheb-Koussa, Haddadi, and Belhamel [6] performed a similar study of a hybrid wind-PV-diesel-battery system for remote areas in Algeria, noting that the cost of energy and the characteristics of the system are extremely site-specific.

In addition to studies from other areas around the world, rural hybrid diesel systems are also an active area of research in the state of Alaska. Clark and Isherwood [7] believe that DG systems can compete with conventional fossil fuel generation for communities with high electricity costs, available renewable resources, and no interconnection with a large grid. For the location of their study, the results indicated that a wind-diesel hybrid system could result in diesel fuel savings of over 50% and cost savings of over 30% compared to the base case (diesel only). Overall, Clark and Isherwood believe that the results of their study "should be realizable at numerous sites throughout Alaska."

This article summarizes the results of a feasibility study of hybrid DG systems for three rural communities in Alaska: Mountain Village, Deering, and Ambler. This study included an analysis of each community's electrical and thermal load, a wind and solar resource evaluation, modeling and optimization of hybrid DG systems, an economic analysis of these systems, and an evaluation of the environmental benefits that they can provide. In the following sections, each component of the study is discussed.

ELECTRICAL AND THERMAL LOADS

All three communities have a stand-alone electrical grid and currently rely on diesel fuel for all of their electricity and heating requirements. The annual electricity generation, diesel fuel use for electricity generation, and CO_2 emissions from electricity generation for each town are shown in Table 1.

Table 1: Electricity Generation, Diesel Fuel Use, and CO_2 Emissions [2]

Community	Electricity Generation (kWh/yr)	Diesel Fuel Use (gal/yr)	CO_2 Emissions (t/yr)
Mountain Village	2,799,595	189,184	1,920
Deering	711,319	55,145	560
Ambler	1,249,161	89,892	912

The total generating capacity for the community of Mountain Village is 2,212 kW [8]. However, the type and capacity of the diesel generators are unknown. As a result, Mountain Village was modeled as having four 455 kW Caterpillar generators and a 410 kW Cummins generator for a total capacity of 2,230 kW. Deering has four generators with a total capacity of 578 kW. These units include 100 kW and 138 kW John Deere generators and two 170 kW Cummins generators [9]. Ambler has three generators with a total capacity of 982 kW [8] but the type and capacity of the generators are unknown. As a result, Ambler was modeled as having three Cummins generators with the following capacities: 270 kW, 315 kW, and 410 kW for a total generating capacity of 995 kW.

Since hourly electricity and heating demand data were not available for any of the communities, the software program eQUEST (QUick Energy Simulation Tool) was used to model the hourly electrical and thermal load for each village. The results of the simulation including the peak and average electric and thermal loads are shown in Table 2.

Table 2: Average and Peak Electric and Thermal Loads

Community	Average Electric Load (kW)	Average Thermal Load (kW)	Peak Electric Load (kW)	Peak Thermal Load (kW)
Mountain Village	303	2,277	512	7,846
Deering	74	775	132	2,232
Ambler	139	1,212	285	4,439

RESOURCE ASSESSMENT

The Alaska Energy Authority (AEA) has performed an extensive study [1] regarding renewable energy resources in Alaska. Due to the state's significant wind resource, a wind resource assessment was performed for each of the villages. Although Alaska's solar resource is minimal during the winter, a solar resource assessment was also completed. Hourly wind and solar resource data were obtained from the AEA and the National Solar Radiation Database. The annual average wind speed, wind power density, and solar radiation values for each community are shown in Table 3.

Table 3: Annual Average Wind Speed, Wind Power Density, and Solar Radiation Values

Community	Annual Avg. Wind Speed (m/s)	Annual Avg. Wind Power Density (W/m^2)	Annual Avg. Solar Insolation ($kWh/m^2/d$)
Mountain Village	7.28	523	2.80
Deering	5.22	322	2.61
Ambler	3.60	88	2.58

ELECTRICITY AND DIESEL FUEL PRICES

Power Cost Equalization (PCE) program statistics for fiscal year 2010 [2] were obtained for each community. This program provides subsidies for residential customers in rural areas in order to decrease the cost of electricity for the first 500 kWh used by a customer each month. Community facilities are also eligible for a subsidized rate, but state and federal customers and commercial facilities are not. PCE subsidies are based on both non-fuel and fuel costs [10]. The PCE program statistics provide electricity price information for the electricity that is eligible for a subsidy and that which is not eligible. Diesel fuel prices are also provided. Current diesel fuel costs for each community are shown in Table 4 and PCE statistics are shown in Table 5.

The results from a study performed by the Institute of Social and Economic Research (ISER) at the University of Alaska Anchorage indicate that electricity rates and PCE subsidies decrease as wind penetration increases [11]. As wind power supplies more electricity to a community,

Table 4: Diesel Fuel Prices [2]

Community	Diesel Fuel Price ($/gal)
Mountain Village	$3.16
Deering	$4.69
Ambler	$3.75

Table 5: PCE Program Statistics [2]

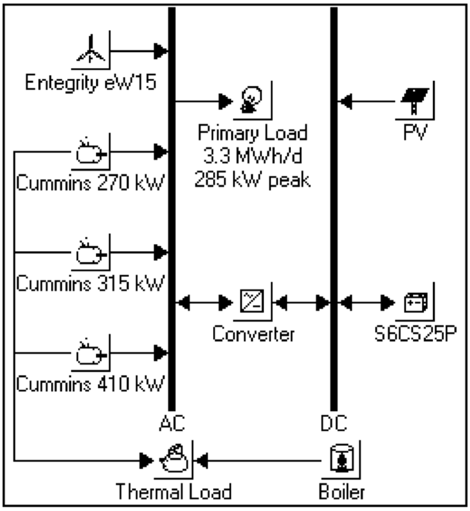
Community	Mountain Village	Deering	Ambler
Total Electricity Sales (kWh)	2,650,142	647,749	1,216,727
PCE Eligible Sales (kWh)	1,094,841	Unknown	540,632
Non-PCE Eligible Sales (kWh)	1,555,301	Unknown	676,095
Electricity Rate (¢/kWh)	50.62	77.37	53.80
PCE Subsidy (¢/kWh)	29.20	30.74	32.22
PCE Electricity Rate (¢/kWh)	21.42	46.63	21.58

diesel fuel use decreases, which lowers the electricity rate. However, a reduction in the electricity rate also results in a lower subsidy from the PCE program. It should be noted that this has been viewed as a disincentive for communities to invest in wind-diesel systems. As diesel fuel prices increase, the PCE subsidy also increases. However, communities with wind-diesel systems are not protected by the PCE program to the same extent that those with diesel systems are. This effect has the most significant impact on communities whose wind-diesel systems operate at low wind penetration levels. For systems with high penetration levels, the effect is not as great, since an increase in wind penetration protects the community from high fuel prices. Despite the issues surrounding the PCE subsidy, wind systems continue to be an attractive option for remote communities with an abundant wind resource due to their potential to lower electricity rates, reduce CO_2 emissions, and protect these areas from diesel price fluctuations.

DISTRIBUTED GENERATION SYSTEM MODELING

Distributed generation systems were modeled and optimized using HOMER software [12]. Each town was modeled with its electrical and thermal load, a boiler, diesel generators with heat recovery, wind turbines, solar panels, batteries, and converters. An example of the structure of the system, as modeled in HOMER, is shown in Figure 1. For

Figure 1: Hybrid system structure



the sensitivity analyses, the diesel price was varied from $1/L to $3/L (about $3.80/gal to $11.40/gal). These values are consistent with the fuel price projections from ISER. Based on other wind-diesel system studies, a project lifetime of 25 years and a discount rate of 3% were chosen for the analysis.

The capital cost and operation and maintenance (O&M) costs that were used for the simulations are shown in Table 6. The capital cost for the solar panels was obtained through the examination of grant applications for the Alaska Renewable Energy Fund. Battery system costs were reported by Susitna Energy and Sandia National Laboratories and converter costs were obtained from ABS Alaskan. Based on the types of wind turbines currently installed in Alaska, the Entegrity 50 kW turbine was considered for each hybrid system.

Table 6: Economic Parameters for HOMER Simulations [9], [11], [13]

System Component	Capital Cost ($/kW)	O&M ($/kWh)
Diesel generator	0	0.02 [9]
Wind turbine	4,000-15,000 [11]	0.04 [11]
Solar panels	11,000	110 ($/yr) [13]
Battery (Surrette 6CS25P)	$1,375 (total cost)	15 ($/yr)
Converter	1,100	50 ($/yr)

ANALYSIS OF RESULTS

Mountain Village

The simulation results for the community's current diesel fuel cost of $3.16/gal are shown in Table 7. This table displays the capital cost, the net present cost (NPC), and the cost of energy (COE) for the optimal system for each level of wind turbine capital costs. The first wind-diesel-battery (W-D-B) hybrid system listed in the table includes eight wind turbines, a 455 kW John Deere generator, a 410 kW Cummins generator, 100 batteries, and a 200 kW converter system.

The monthly average electric production profile for the hybrid system with eight wind turbines is shown in Figure 2. For this case, the annual electricity production from wind is 1,227,169 kWh and that from the

Table 7: Mountain Village Simulation Results

Optimal System	Turbine Capital Cost ($/kW)	Initial Capital ($)	Total NPC ($)	COE ($/kWh)
W-D-B	4,000	1,887,500	44,168,904	0.210
W-D-B	6,000	2,082,500	44,776,100	0.223
W-D-B	8,000	1,787,500	45,186,308	0.232
D-B	10,000-15,000	247,500	45,315,064	0.235

diesel generators is 1,748,822 kWh. Wind accounts for 41% of electricity production. The diesel generator electricity production, diesel fuel use for electricity generation, and CO_2 emissions from electricity generation for this hybrid system and the baseline system are shown in Table 8. The wind-diesel-battery hybrid system results in a reduction of 1,050,773 kWh of diesel generator electricity production. This equates to a reduction in diesel fuel use of about 71,020 gallons and a CO_2 emissions reduction of 721 metric tons per year.

The results from the sensitivity analysis are shown in Figure 3. The sensitivity variables are the diesel price and the capital cost of the wind turbines, denoted by eW15 Capital Multiplier. The capital cost ranges from $4,000 to $15,000 per kW of installed capacity. The levelized cost of energy (LCOE) for each system is also shown in the figure. A wind-diesel-battery hybrid system is the optimal system, except for low diesel prices and high capital cost values.

Figure 2: Electric production profile for the hybrid system

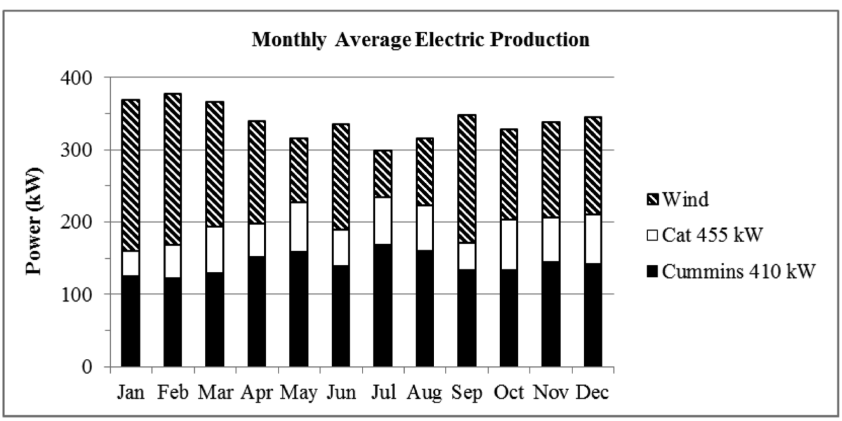


Table 8: Comparison Between Baseline System and the Hybrid DG System

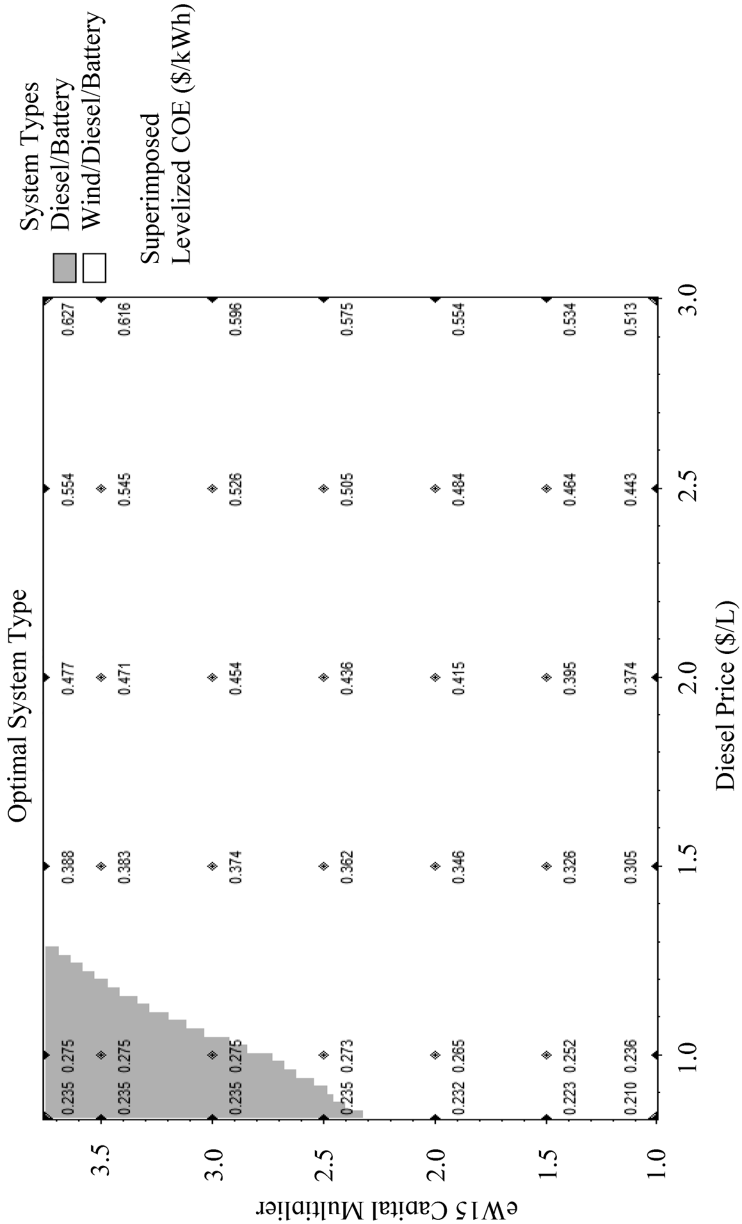


Figure 3: Mountain Village wind turbine sensitivity analysis. Numbers mapped are LCOE ($/kWh).

Even though PV is not included in the optimal system, it could still be economically feasible. According to the simulation results, the COE for solar hybrid systems at a diesel price of $3.16/gal ranges from $0.214/kWh to $0.265/kWh. Solar hybrid systems become part of the optimal system if *renewable energy fraction* (REF) constraints are imposed on the electric profile. The optimal system for REFs ranging from 0% to 50% and wind turbine capital costs ranging from $4,000 to $15,000 per kW are shown in Figure 4. The figure indicates the optimal systems for a fixed diesel price of $3.16/gal, the current cost of fuel. As shown in the figure, a wind-diesel-battery system is the predominant optimal system; however, wind-PV-diesel-battery systems are the optimal system for high REF constraints. For all of these systems, the COE falls below Mountain Village's standard electricity rate of $0.51/kWh.

The LCOE as a function of the percent reduction in CO_2 emissions from electricity generation is shown in Figure 5. As indicated in the chart, the optimal system in terms of the COE has a REF of 50%, a COE of $0.23/kWh, and a reduction in CO_2 emissions of 44.3%. These values are achieved with a wind-diesel-battery system with ten turbines at a capital cost of $4,000 per kW, two generators, 200 batteries, and a 300 kW converter system. With a capital cost of $10,000 per kW, the COE for this system increases to $0.292/kWh. The system with the highest COE includes ten turbines at a capital cost of $15,000 per kW, a 20 kW PV system, two generators, and a 400 kW converter system.

Deering

The simulation results for Deering's current fuel cost of $4.69/gal are shown in Table 9. This table displays the capital cost, the net present cost NPC, and the cost of energy COE for the optimal system for each level of wind turbine capital costs. The wind-diesel-battery hybrid systems include two turbines, both of the John Deere generators, one of the 170 kW Cummins generators, 50 batteries, and a 50 kW converter system.

The monthly average electric production profile for the wind-diesel hybrid system is shown in Figure 6. For this system, the annual electricity production from wind is 233,587 kWh and that from the diesel generators is 462,072 kWh. Wind accounts for 34% of electricity production. The diesel generator electricity production, diesel fuel use for electricity generation, and CO_2 emissions from electricity generation for the hybrid system and the baseline system are shown in Table 10. The

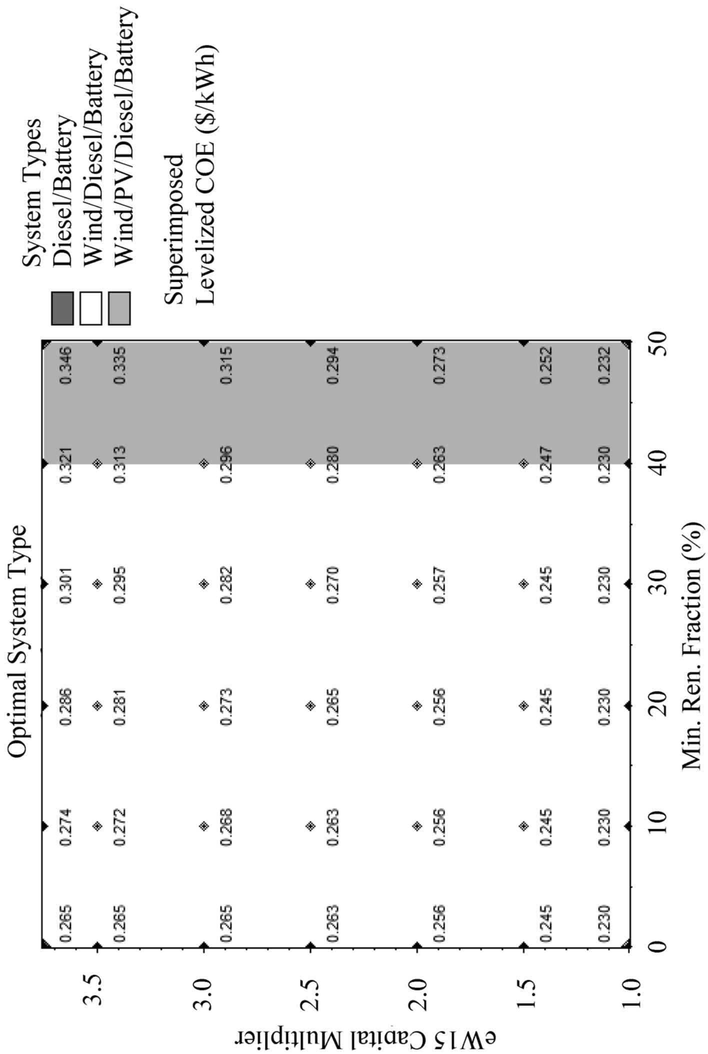


Figure 4: Mountain Village REF sensitivity analysis. Numbers mapped are LCOE ($/kWh).

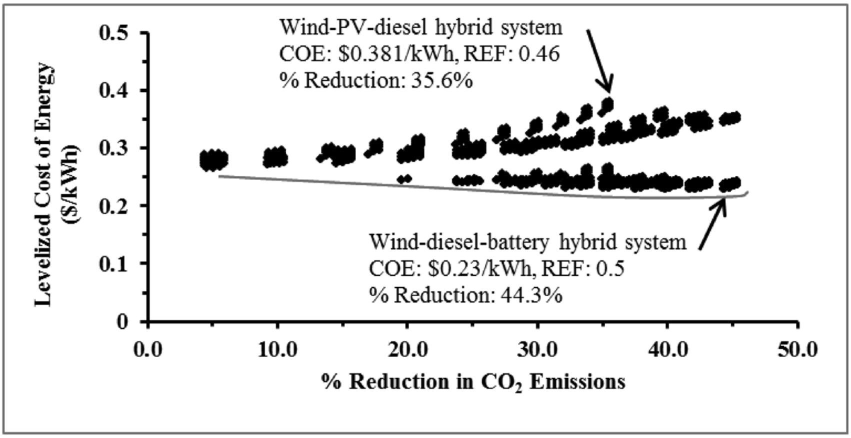


Figure 5: COE as a function of reduction in CO_2 emissions

Table 9: Deering Simulation Results

Optimal System	Turbine Capital Cost ($/kW)	Initial Capital ($)	Total NPC ($)	COE ($/kWh)
W-D-B	4,000	513,750	20,786,188	0.288
W-D-B	6,000	708,750	20,981,188	0.305
Diesel	8,000-15,000	0	20,992,308	0.306

wind-diesel-battery hybrid system results in a reduction of 249,247 kWh of diesel generator electricity production. This equates to a reduction in diesel fuel use for electricity generation of about 19,322 gallons and a CO_2 emissions reduction of 196 metric tons per year.

The results from the sensitivity analysis are shown in Figure 7. The sensitivity variables are the diesel price and the capital cost of the wind turbines, denoted by eW15 Capital Multiplier. The capital cost ranges from $4,000 to $15,000 per kW of installed capacity. When the diesel price is high (above about $2.3/L), a wind-diesel-battery hybrid system is the optimal system. When the diesel price is low, this hybrid system is only the optimal system for relatively low wind turbine capital costs.

Even though PV is not included in the optimal system, it could still be economically feasible. According to the simulation results, the COE for solar hybrid systems at a diesel price of $4.69/gal ranges from $0.292/kWh to $0.412/kWh. Solar hybrid systems become part of the

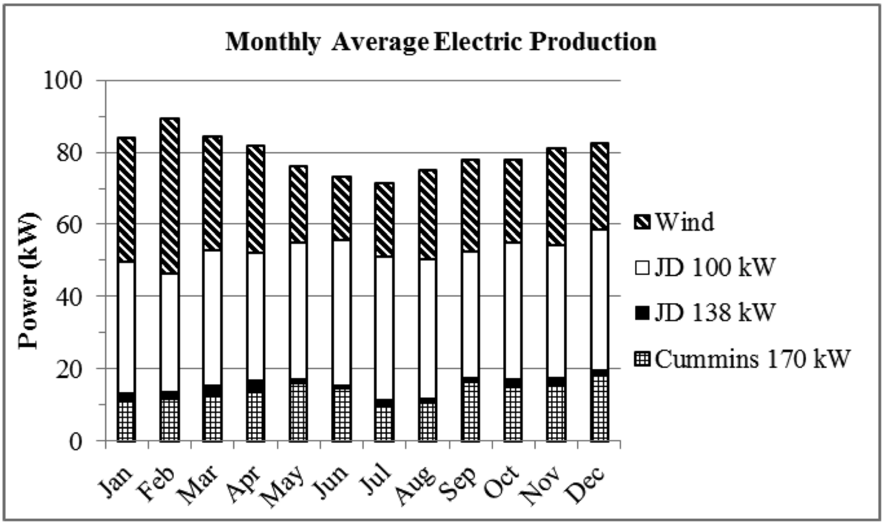


Figure 6: Electric production profile for the hybrid system

Table 10: Comparison Between Baseline System and the Hybrid DG System

System	Electricity Production from Diesel (kWh/yr)	Diesel Fuel Use (gal/yr)	CO_2 Emissions (t/yr)
Baseline	711,319	55,142	560
Hybrid	462,072	35,820	364

optimal system if REF constraints are imposed on the electric profile. The optimal system for REFs ranging from 0% to 40% and wind turbine capital costs ranging from $4,000 to $15,000 per kW are shown in Figure 8. The figure indicates the optimal systems for a fixed diesel price of $4.69/gal, the current cost of fuel. As shown in the figure, wind-PV-diesel-battery systems are the optimal system for high REF constraints and high wind turbine capital costs. Additionally, PV-diesel systems are the optimal system for low REF constraints and high wind turbine capital costs. For all of these hybrid systems, the COE falls below Deering's standard electricity rate of $0.77/kWh.

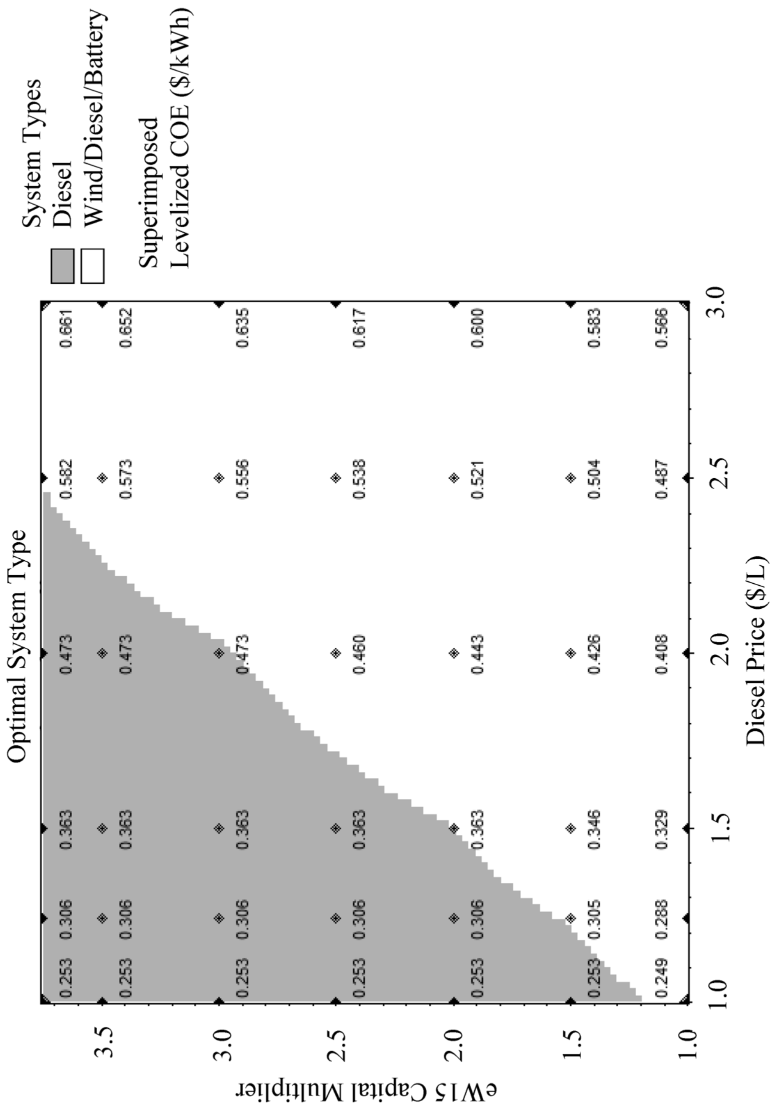


Figure 7: Deering wind turbine sensitivity analysis. Numbers mapped are LCOE ($/kWh)

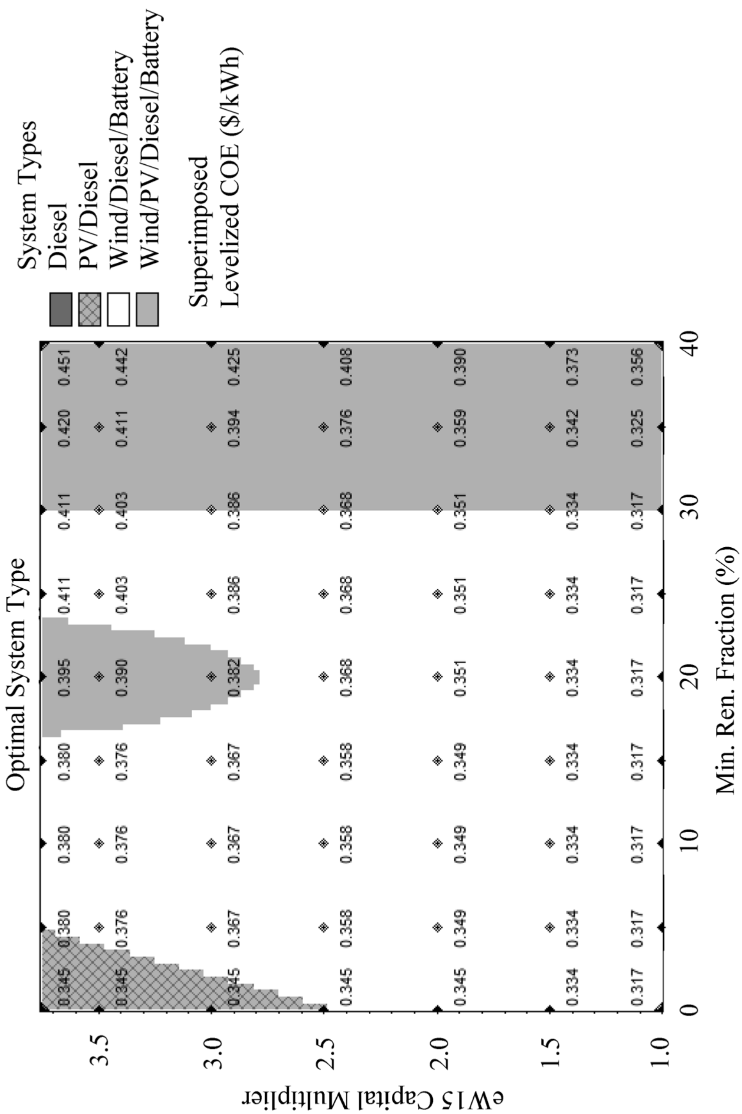


Figure 8: Deering REF sensitivity analysis. Numbers mapped are LCOE ($/kWh)

The LCOE as a function of the percent reduction in CO_2 emissions from electricity generation is shown in Figure 9. As indicated in the chart, the optimal system in terms of the COE has a REF of 34%, a COE of $0.317/kWh, and a reduction in CO_2 emissions of 35.4%. These values are achieved with a wind-diesel-battery system with two turbines at a capital cost of $4,000 per kW, three generators, 50 batteries, and a 75 kW converter system. With a capital cost of $10,000 per kW, the COE for this system increases to $0.369/kWh. The system with the highest COE has two turbines at a capital cost of $15,000 per kW, a 70 kW PV system, three generators, and a 100 kW converter system.

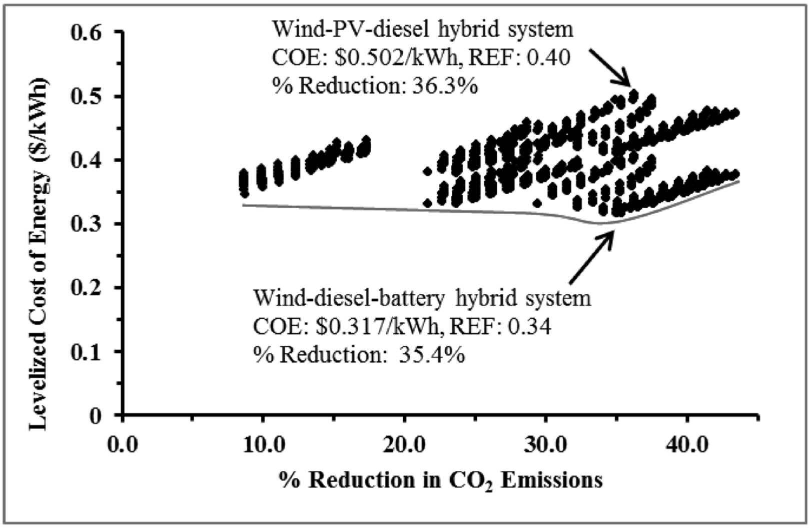


Figure 9: COE as a function of reduction in CO_2 emissions

Ambler

The simulation results for the community's current diesel fuel cost of $3.75/gal are shown in Table 11. This table displays the capital cost, the NPC, and the COE for the optimal system. In this case, the optimal system is the diesel system with heat recovery for each level of wind turbine capital costs. With current diesel fuel prices, hybrid DG systems are not the optimal system for this community. It should be noted that although wind-diesel systems are not the optimal system, as they are for the other two communities, they could still provide reductions in the electricity rate. According to the simulation results, the COE for these systems ranges from $0.311/kWh to $0.876/kWh, depending on the diesel price and the capital cost of the turbines. As a result, the COE for several of these systems falls below Ambler's current electricity price of $0.54/kWh.

Table 11: Ambler Simulation Results

Optimal System	Initial Capital ($)	Total NPC ($)	COE ($/kWh)
Diesel with heat recovery	0	28,494,520	0.302

The results from the sensitivity analysis are shown in Figure 10. The sensitivity variables are the diesel price and the capital cost of the wind turbines, denoted by eW15 Capital Multiplier. The capital cost ranges from $4,000 to $15,000 per kW of installed capacity. For this community, a wind-diesel-battery hybrid system is the optimal system only when the price of diesel is high and the capital cost of the turbines is low. This is a result of the poor wind resource in Ambler compared to the other two communities.

Although hybrid systems with photovoltaics are not included in any of the optimal systems, they could still provide reductions in the electricity rate for Ambler. According to the simulation results, the COE for solar hybrid systems ranges from $0.311/kWh to $0.883/kWh. Like the wind-diesel systems, the COE for some of these systems also falls below the current electricity rate for Ambler.

Solar hybrid systems become part of the optimal system if REF constraints are imposed on the electric profile. The optimal system for REFs ranging from 0% to 20% and wind turbine capital costs ranging from $4,000 to $15,000 per kW of installed capacity are shown in Figure 11. The figure indicates the optimal systems for a fixed diesel price of $3.75/gal, the current cost of fuel for Ambler. As shown in the figure, wind-PV-diesel-battery systems and PV-diesel systems are the optimal system for high REF constraints and high wind turbine capital costs. It should be noted that solar hybrid systems make a larger contribution in this community than in the other two. Again, this is a result of the poor wind resource in Ambler compared to Mountain Village and Deering. As a result, solar systems may be more economically feasible than wind systems for Ambler, especially when the cost of the wind turbines is high.

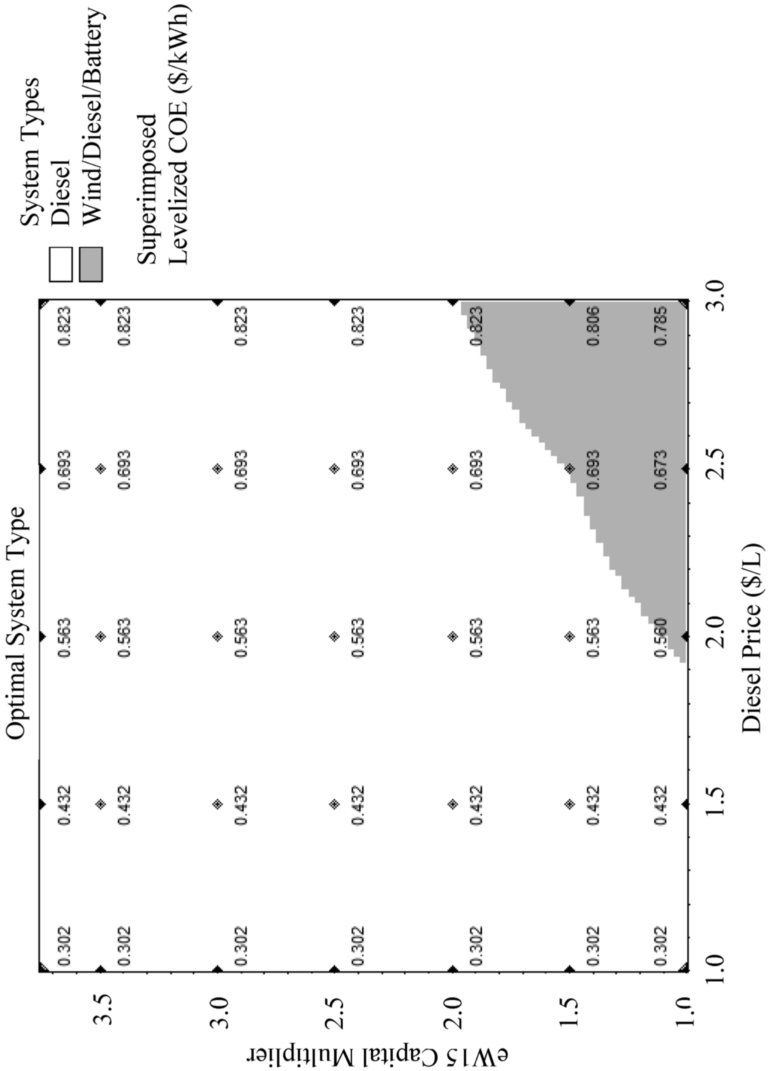


Figure 10: Ambler wind turbine sensitivity analysis. Numbers mapped are LCOE ($/kWh)

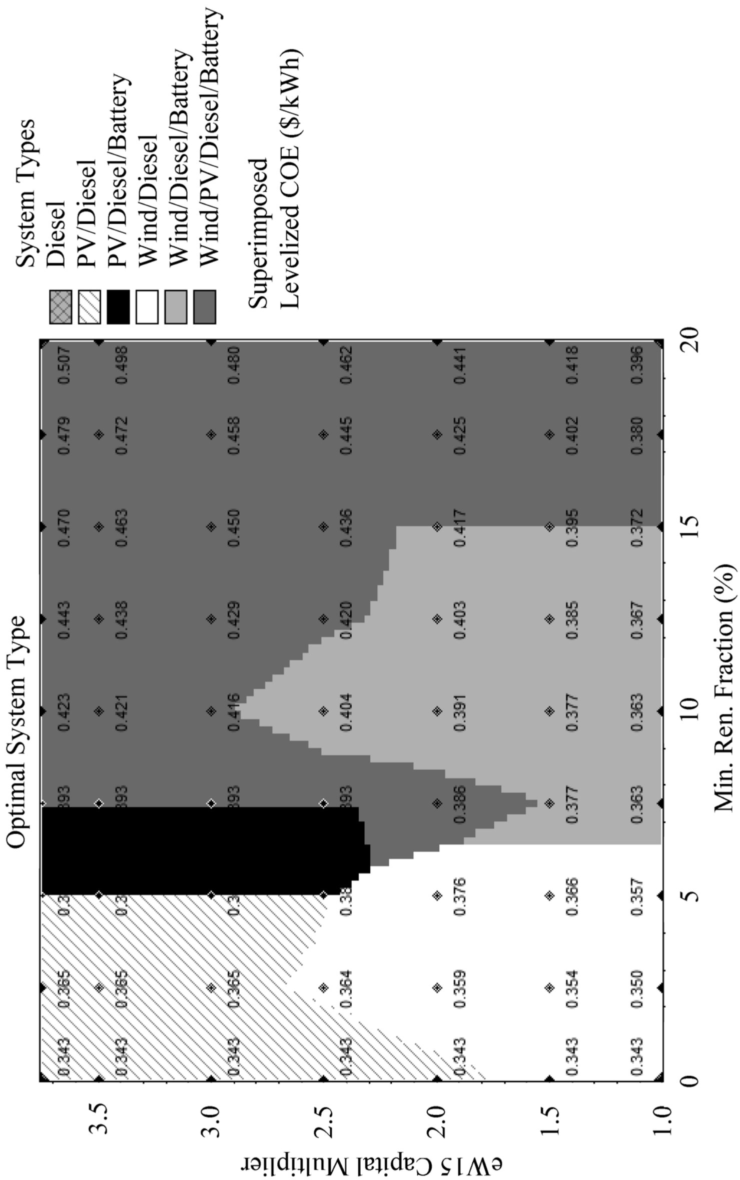


Figure 11: Ambler REF sensitivity analysis. Numbers mapped are LCOE ($/kWh)

The LCOE as a function of the percent reduction in CO_2 emissions from electricity generation is shown in Figure 12. Unlike the other two communities, the COE increases with the percent reduction in CO_2 emissions for all systems. The optimal system in terms of the COE is a system with a REF of zero and therefore no reduction in CO_2 emissions.

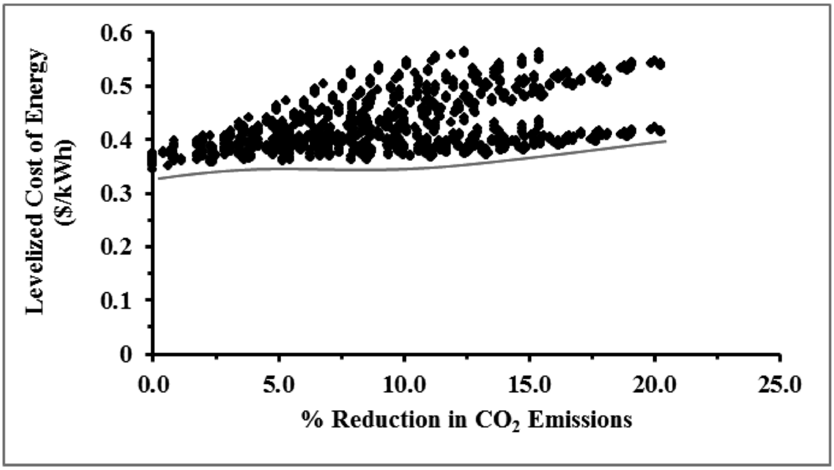


Figure 12: COE as a function of reduction in CO_2 emissions

SUMMARY AND CONCLUSIONS

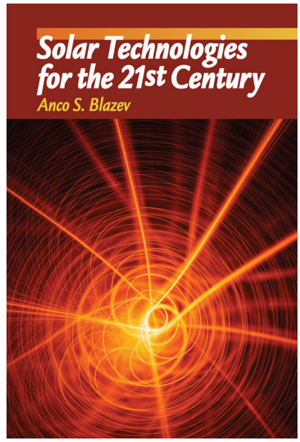
In order to evaluate the feasibility of distributed generation systems for Mountain Village, Deering, and Ambler, HOMER software was used to model these systems. For Mountain Village and Deering, wind-diesel-battery systems are the optimal system for current diesel fuel prices, depending on the capital cost of the wind turbines. The levelized cost of electricity for these hybrid systems ranges from \$0.210/kWh to \$0.232/kWh for Mountain Village and from \$0.288/kWh to \$0.305/kWh for Deering. These ranges are well below the standard electricity prices for each of these communities.

The sensitivity analysis results indicate that the optimal system for Mountain Village is a wind-diesel-battery system for almost the entire range of diesel fuel prices and wind turbine capital costs that were considered. For Deering, when the diesel price is high (above about \$2.3/L), a wind-diesel-battery system is the optimal system. When the diesel

10% Online Discount
Use Code JR10

Solar Technologies for the 21st Century

Anco Blazev



A detailed and insightful examination of both current and emerging solar technologies, this book evaluates both the practical and technological potential of each. The reader gets a clearer understanding of the logistics of deploying solar energy as a viable and sustainable way to solve urgent energy, environmental, and socioeconomic problems. Discussed in detail are solar power generation, solar thermal, silicon PV, thin PV, 3D solar cells, nano PV, organic solar cells and more. Among the many topics examined are solar successes and failures, solar markets, and solar energy's environmental impact. The book serves as both a guidebook for beginners as well as an outline for the debates on solar power technologies.

ISBN: 0-88173-697-X

8 ½ x 11, hardcover, illus, pp. 728
Hardcover, Order Code: 0676

ORDER CODE: 0661

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Solar Technologies for the 21st Century	**0676**	**$150.00**	

② Indicate shipping address: CODE: Journal 2013

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

Applicable Discount

Georgia Residents add 6% Sales Tax

Shipping $10 first book $4 each additional book

TOTAL

MEMBER DISCOUNTS—A 15% discount is allowed to AEE members (discounts cannot be combined).

☐ **AEE Member (Member No.________________)**

③ Select method of payment:

☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

CARD NO.

Expiration date *Signature*

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org/books
(use discount code)

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

price is low, this hybrid system is only the optimal system for relatively low wind turbine capital costs. Solar systems could also be economically feasible for both Mountain Village and Deering, but they are not part of the optimal system unless a REF constraint is imposed on the electric profile. Unlike Mountain Village and Deering, a wind-diesel-battery system is not the optimal system for Ambler. For this community, a diesel system with heat recovery is the optimal system for almost the entire range of diesel fuel prices and wind turbine capital costs that were considered in the sensitivity analysis. However, it should be noted that although a wind-diesel system is not the optimal system for Ambler, this type of system could still be economically feasible for this community. This is also true for systems with photovoltaics.

The range of COE results supports the findings from previous studies that have shown that the economic feasibility of wind-diesel systems is extremely site-specific. The hybrid systems for Mountain Village have a lower COE than those for Deering. It is the wind resource that has the largest effect on this result, since Mountain Village has a significantly better wind resource than Deering. The wind resource also has an effect on the optimal system for Ambler. This community has the worst wind resource; as a result, a wind-diesel system is not the optimal system. Additionally, solar hybrid systems may be more economically feasible than wind systems for Ambler, especially when the cost of the wind turbines is high.

Overall, the results from this assessment indicate that hybrid wind-diesel systems may be an economically beneficial option for rural Alaskan communities with an abundant wind resource. However, it should be noted that these results are based on simulated electricity and heating demand data since real hourly demand data were not available for any of the communities. The electricity and heating demand have a significant impact on the optimization, and any changes in the demand may alter the HOMER results for the optimal system type and the levelized cost of energy for each system. As a result, a more detailed analysis with real hourly electricity and heating demand data should be completed in order to more accurately evaluate the economic feasibility of these hybrid systems. Additionally, more research is needed to determine the impact that the PCE program may have on communities that develop these systems. Despite the issues surrounding the PCE subsidy, wind systems continue to be an attractive option for remote communities due to their potential to lower electricity rates and provide significant environmental benefits, such as reductions in diesel fuel use and CO_2 emissions. In some cases, these benefits may be achieved without an increase in the cost of energy.

For further investigation: An enhanced DG approach for this Alaskan communities could result from the evaluation of hybrid systems (wind or PV generators) in conjunction with cogeneration or combined heat and power (CHP) diesel generators, where in addition to power generation from diesel, engine and exhaust waste heat is recovered for water and housing heating.

References

(1) Alaska Energy Authority, "Renewable Energy Atlas of Alaska," *Alaska Energy Authority*, Aug. 2011, 30 pp.

(2) Alaska Energy Authority, "Statistical Report of the Power Cost Equalization Program," *Alaska Energy Authority*, Mar. 2011, 22 pp.

(3) G. Fay, A.V. Meléndez, and A. Converse, "Alaska Energy Statistics 1960-2010, Preliminary Data," prepared for Alaska Energy Authority, *Institute of Social and Economic Research, University of Alaska Anchorage*, Sep. 2011, 31 pp.

(4) I. Baring-Gould and M. Dabo, "Technology, Performance, and Market Report of Wind-Diesel Applications for Remote and Island Communities," *National Renewable Energy Laboratory*, Preprint for the European Wind Energy Conference, Marseille, France, Feb. 2009.

(5) S.M. Shaahid and I. El-Amin, "Techno-economic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia—A way forward for sustainable development," *Renewable and Sustainable Energy Reviews*, vol. 13, pp. 625-633, Apr. 2009.

(6) D. Saheb-Koussa, M. Haddadi, and M. Belhamel, "Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria," *Applied Energy*, vol. 86, pp. 1024-1030, Jul. 2009.

(7) W. Clark and W. Isherwood, "Distributed generation: remote power systems with advanced storage technologies," *Energy Policy*, vol. 32, pp. 1573-1589, Sep. 2004.

(8) Alaska Village Electric Cooperative, "AVEC Facilities," *AVEC Communities Served*, 2011, http://www.avec.org/communities/.

(9) D. Vaught, "Deering Wind-Diesel Hybrid Feasibility Study Report," *V3 Energy, LLC*, Aug. 26, 2011, 38 pp.

(10) Alaska Energy Authority, "Power Cost Equalization Program Guide," *Alaska Energy Authority*, Aug. 2007, 34 pp.

(11) G. Fay, K. Keith, and T. Schwörer, "Alaska Isolated Wind-Diesel Systems: Performance and Economic Analysis," prepared for Alaska Energy Authority and Denali Commission, *Institute of Social and Economic Research, University of Alaska Anchorage*, Jun. 2010, 101 pp.

(12) HOMER Energy: http://homerenergy.com/.

(13) D. Arvizu, P. Balaya, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V. Meleshko, W. Stein, Y. Tamaura, H. Xu, and R. Zilles, "IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation—Direct Solar Energy," Aug. 2011, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

ABOUT THE AUTHORS:

Lindsay Willman is a graduate student in the Atmosphere/Energy Program in the Civil and Environmental Engineering Department at Stanford University. She has worked on several projects related to renewable energy technologies and hybrid energy systems for rural communities. She has also investigated the impacts that energy systems have on air pollution and climate. Contact:

Lindsay Willman
Civil and Environmental Engineering,
Stanford University,
473 Via Ortega, MC 4020, Stanford, CA, 94305, USA

Moncef Krarti, Professor, Building Systems Program, Civil, Environmental, and Architectural Engineering Department at the University of Colorado, has vast experience in designing, testing, and assessing innovative energy efficiency and renewable energy technologies applied to buildings. He also directed several projects in energy management of buildings. He has published textbooks on energy audits of building systems that are widely used to teach energy audit techniques. Moreover, Prof. Krarti has published over 200 technical journals and handbook chapters in various fields related to energy efficiency, combined heat and power, and renewable energy technologies. Contact:

Moncef Krarti, PhD, PE, LEED®AP
Civil, Environmental, and Architectural Engineering,
University of Colorado at Boulder,
428 UCB, Boulder, CO, 80309-0428, USA