

PV-WIND HYBRID SYSTEMS FOR SWEDISH LOCATIONS

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Abstract

PV-Wind-Hybrid systems for stand-alone applications have the potential to be more cost efficient compared to PV-alone systems. The two energy sources can, to some extent, compensate each others minima. The combination of solar and wind should be especially favorable for locations at high latitudes such as Sweden with a very uneven distribution of solar radiation during the year.

In this article PV-Wind-Hybrid systems have been studied for 11 locations in Sweden. These systems supply the household electricity for single family houses. The aim was to evaluate the system costs, the cost of energy generated by the PV-Wind-Hybrid systems, the effect of the load size and to what extent the combination of these two energy sources can reduce the costs compared to a PV-alone system. The study has been performed with the simulation tool HOMER developed by the National Renewable Energy Laboratory (NREL) for techno-economical feasibility studies of hybrid systems.

The results from HOMER show that the net present costs (NPC) for a hybrid system designed for an annual load of 6000 kWh with a capacity shortage of 10% will vary between \$48,000 and \$87,000. Sizing the system for a load of 1800 kWh/year will give a NPC of \$17,000 for the best and \$33,000 for the worst location. PV-Wind-Hybrid systems are for all locations more cost effective compared to PV-alone systems. Using a Hybrid system is reducing the NPC for Borlänge by 36% and for Lund by 64%. The cost per kWh electricity varies between \$1.4 for the worst location and \$0.9 for the best location if a PV-Wind-Hybrid system is used.

Introduction

In the Nordic countries stand-alone PV systems are mainly used to supply electricity to remote weather and telecommunication stations, traffic signals/lights and for other remote applications with a relatively low power demand. Due to the extensive developed electrical grid only a few remote residential buildings for all year round usage are supplied by stand-alone systems. An obstacle for the use of stand-alone PV systems is also the uneven distribution of the solar radiation causing high costs if the system needs to be sized for a constant load throughout the year. As the example for Gothenburg in Figure 1 shows has wind power the potential to compensate at least to some extent the low irradiation during the winter. The average wind power at the most locations in Sweden is higher during the seasons with low irradiation. Another reason why the combination of PV- and wind-alone systems can be economical interesting is that the costs for PV modules per Watt peak are still higher than the cost per Watt peak of wind turbines. If there will be a cost benefit depends of course also on other parameters, especially on the available local wind speed.

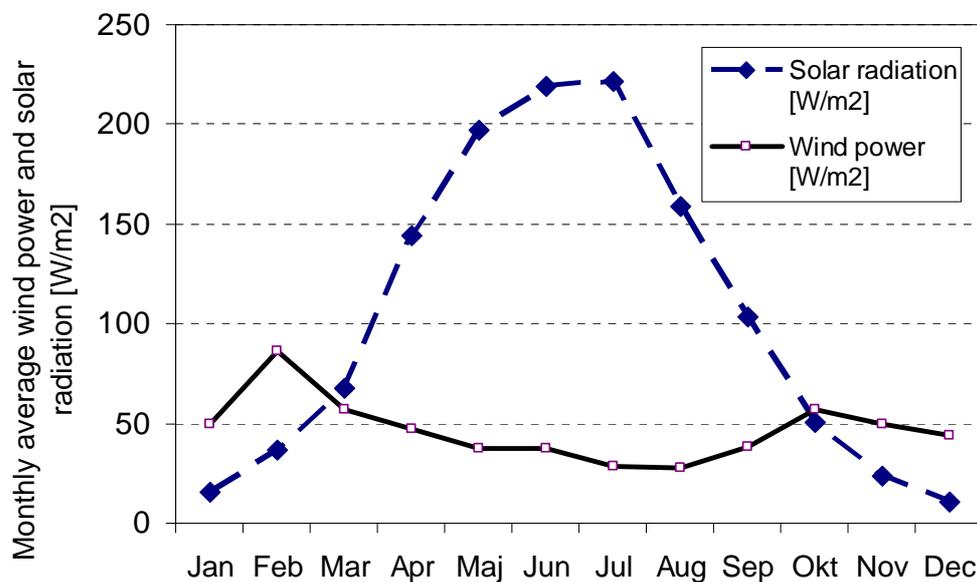


Figure 1. Monthly average wind power at 10 m height and monthly average horizontal solar radiation for Gothenburg (TMY weather data).

Studies have performed for several other locations worldwide showing often that PV-Wind-Hybrid systems can be more cost effective than PV-alone or wind-alone systems (Borowy and Salameh 1994; Celik 2002; Koutroulis et al. 2006; McGowan et al. 1996; Protoogeropoulos et al. 1997).

The results presented in this paper are based on two Master theses reports of students of the European Solar Engineering School in Borlänge/Sweden (Berruezo and Maison 2006; Pazmino 2007).

Aims

In this paper PV-Wind-Hybrid systems have been studied for 11 locations in Sweden. The aim was to evaluate the system costs, the cost of energy generated by the PV-Wind-Hybrid systems, the effect of the load size and to what extent the combination of these two energy systems can reduce the costs compared to a PV-alone system.

Method and boundary conditions

The study has been performed with the simulation software HOMER developed by the National Renewable Energy Laboratory (NREL). HOMER can be used for the sizing of hybrid systems based on the Net Present Costs (NPC). The modeled systems supply the household electricity for single family houses. The load profile for the electrical consumption has been derived from usage patterns and the average yearly electricity consumption for single family houses in Sweden (about 6000 kWh). Two additional load profiles with 3300 kWh and 1800 kWh have been generated, assuming the application of power efficient appliances and other energy saving measures to reduce the annual electricity consumption. The system size has been limited to 6 kW PV power which corresponds approximately to the available area of the south roof of a single family house, 3.6 kW wind turbine power and a battery bank size of 120 kWh. For the simulation a Bergey XL.1 wind turbine with a hub height of 20 m was used (max. 3 turbines each 1.2 kW). Another variable has been the capacity shortage which defines the percentage of load that is accepted to be uncovered. The applied prices and other economic parameters have been identified for Swedish conditions

In total 11 locations have been studied from the very South to the very North of Sweden (Table 1) using the local annual solar and wind resources (Figure 2).

Table 1. Studied Swedish locations latitudes, longitudes, and altitudes

City	Latitude	Longitude	Altitude (m)
Kiruna	67.83°N	20.43°E	408
Luleå	65.55°N	22.13°E	17
Umeå	63.82°N	20.25°E	10
Östersund	63.20°N	14.50°E	376
Borlänge	60.48°N	15.43°E	140
Karlstad	59.37°N	13.47°E	46
Stockholm	59.35°N	18.07°E	30
Norrköping	58.58°N	16.15°E	43
Gothenburg	57.70°N	12.00°E	5
Visby	57.67°N	18.35°E	51
Lund	55.72°N	13.22°E	73

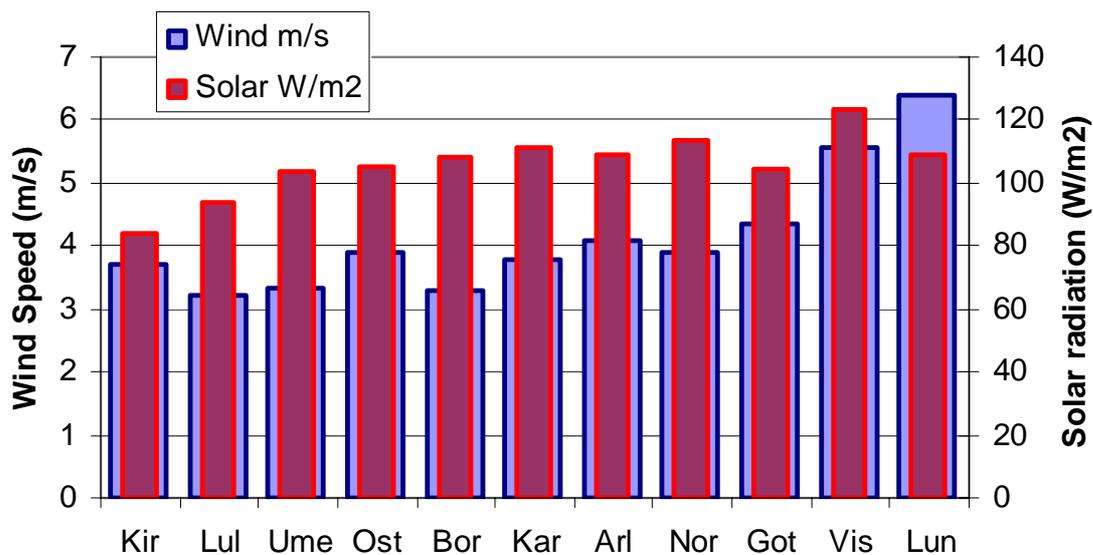


Figure 2. Average annual wind speed and annual global solar radiation for all 11 locations.

Results and discussion

The results from HOMER show that for a load of 6000 kWh with a capacity shortage allowance of 10% and a hub height of 20 m not for all locations a feasible system is

possible (Figure 3). For the load of 6000 kWh no feasible systems were found for the locations with the two highest latitudes. For loads of 3300 kWh and 1800kWh for all locations feasible systems were found. The NPC varies between \$48,000 and \$87,000 for the highest load and \$17,000 and \$33,000 for the lowest load. It is obvious that energy saving measures would a cost effective alternative instead of enlarging the system size.

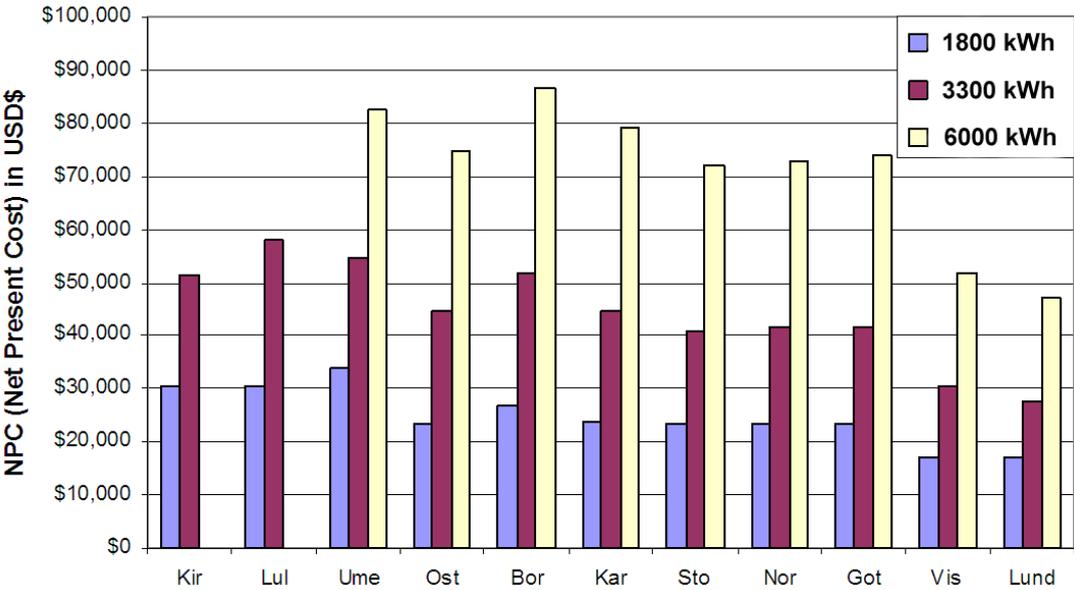


Figure 3. NPC for PV-Wind hybrid systems at each location for 3 different loads, hub height 20 m, 10% capacity shortage allowance.

In Figure 4 the Net Present Costs are compared for capacity shortages of 0, 5 and 10 percent. It can be seen that the costs are highest for locations in the North of Sweden with low winter radiation and low wind speeds. For these locations also the difference between the no capacity shortage and 5% capacity shortage allowance are most significant. If no capacity shortage would be allowed the NPC would amount between \$23,000 and \$49,000. In this case, for the most locations, the use of a small diesel backup generator would probably be more cost effective to provide the uncovered load than an increased systems size.

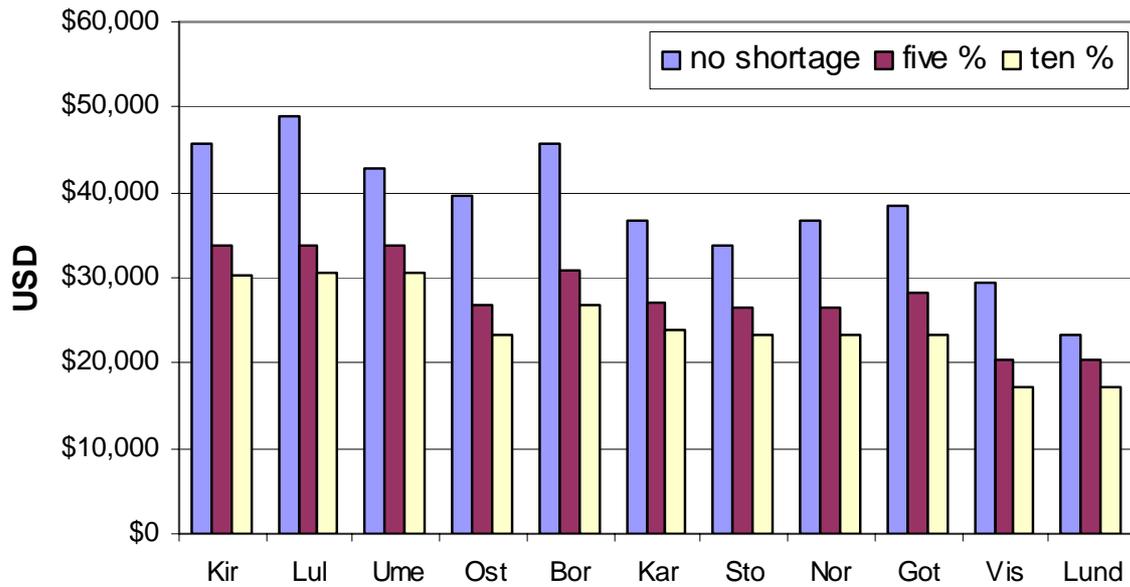


Figure 4. Comparison of NPC for 5% 10% and 15% capacity shortage allowance, 20 m hub height, 1800 kWh load.

Simulations with the 1800 kWh load profile have been done to compare PV-Wind Hybrid systems with PV-alone systems. The results in Figure 5 show the hybrid systems to be consistently less expensive than the PV-alone system. Logically at locations with higher wind speed such as Lund and Gothenburg the difference is greater than for locations with lower wind speed such as Borlänge. Using a Hybrid system is reducing the NPC by 36% (for Borlänge) and 64% (for Lund).

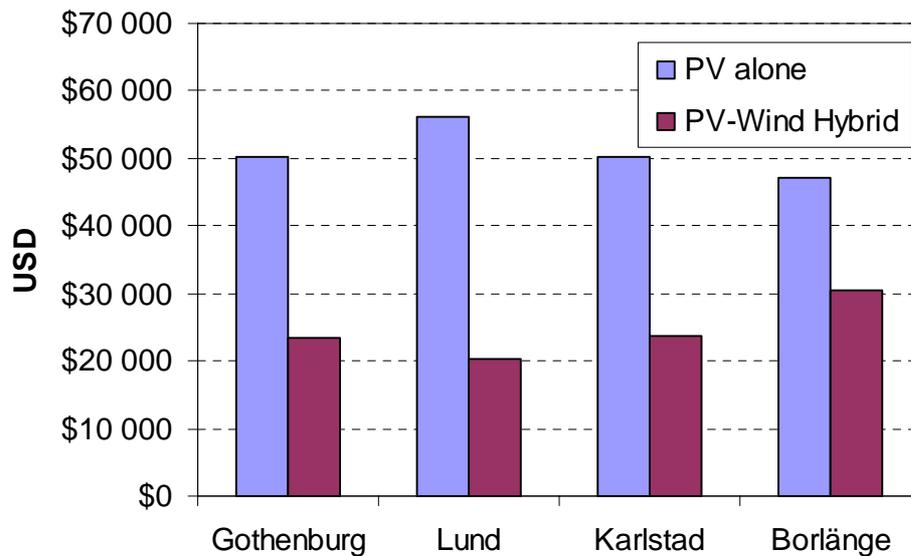


Figure 5. NPC comparison of PV alone and PV-Wind Hybrid systems for Gothenburg, Lund, Karlstad and Borlänge, hub height of 20 m, load 1800 kWh.

Summary and conclusions

PV-Wind-Hybrid systems are for all locations more cost effective compared to PV-alone systems. Adding a wind turbine halves the net present costs (NPC) for the coastal locations in the south of Sweden and cuts the NPC by one third for a location as Borlänge with low wind speeds. The load that has to be supplied has of course a large impact on the system size and costs. The results from the simulations show that the NPC for a hybrid system designed for an annual load of 6000 kWh will vary between \$48,000 and \$ 87,000. Sizing the system for a load of 1800 kWh/year will give a NPC of \$17,000 for the best and \$33,000 for the worst location.

However, these values are calculated for a capacity shortage allowance of 10%. The question is of course if such a shortage is acceptable in a single family house and if not what means could be applied to supply the remaining 10% and what would this cost. These questions have not been studied but as Figure 4 shows for most location it would increase the cost significantly if the last 10% should be supplied with the PV-Wind system. The cost per kWh electricity produced by a PV-Wind-Hybrid system varies between 1.4\$ for the worst location and 0.9\$ for the best location.

References

- Berruezo, I., and Maison, V. (2006). "Electricity Supply with PV-Wind Systems for Houses Without Grid Connection," Master thesis, Högskolan Dalarna, Borlänge.
- Borowy, B. S., and Salameh, Z. M. (1994). "Optimum photovoltaic array size for a hybrid wind/PV system." *Energy Conversion, IEEE Transaction on*, 9(3), 482-488.
- Celik, A. N. (2002). "Optimisation and techno-economic analysis of autonomous photovoltaic-wind hybrid energy systems in comparison to single photovoltaic and wind systems." *Energy Conversion and Management*, 43(18), 2453-2468.
- Koutroulis, E., Kolokotsa, D., Potirakis, A., and Kalaitzakis, K. (2006). "Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms." *Solar Energy*, 80(9), 1072-1088.
- McGowan, J. G., Manwell, J. F., Avelar, C., and Warner, C. L. (1996). "Hybrid wind/PV/diesel hybrid power systems modeling and South American applications." *Renewable Energy*, 9(1-4), 836-847.
- Pazmino, V. (2007). "PV-Wind Energy Hybrid Systems Techno-Economic Feasibility Analysis for Different Swedish Locations," Master thesis, Högskolan Dalarna, Borlänge.
- Protogeropoulos, C., Brinkworth, B. J., and Marshall, R. H. (1997). "Sizing and techno-economical optimization for hybrid solar photovoltaic/wind power systems with battery storage." *International Journal of Energy Research*, 21(6), 465-479.