LOCALLY MANUFACTURED SMALL WIND TURBINES – HOW DO THEY COMPARE TO COMMERCIAL MACHINES?

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ABSTRACT

This paper describes the modelling of a complete PV-wind hybrid domestic energy system in the micropower optimisation software, HOMER. The actual PV-wind hybrid energy system features a 3m diameter, 800W rated Locally Manufactured Small Wind Turbine (LMSWT) and the model is used to compare the consequences of replacing it with a commercial equivalent. It was found that in this local context, where there is access to the necessary maintenance services and environmental conditions are favourable, locally manufactured technology is the most cost effective option (20% lower net present cost). What is more, it offers the added benefit of spreading the costs more evenly over the lifespan of the energy system and therefore lowering the barrier of high upfront capital costs that often limits the uptake of renewable energy technologies.

NOMENCLATURE

AEP	Annual Energy Production
GBP	Great British Pound (£)
LCoE	Levelised Cost of Energy
LGC	Levelised Generating Cost
LMSWT	Locally Manufactured Small Wind Turbine
NPC	Net Present Cost
O&M	Operation & Maintenance
PV	Photovoltaic
RAEY	Rated Annual Energy Yield[1]
SWT	Small Wind Turbine
USD	United States Dollar ($)

INTRODUCTION

This paper follows on from work presented at the 8th PhD Seminar on Wind Energy in Europe [1], which introduced the first set of results from a long-term study designed to measure the performance of a series of small wind turbines designed, built and installed on the Scottish peninsula, Scoraig. Scoraig resident and world renowned small wind expert, Hugh Piggott, publishes a recipe book [2] that describes the manufacturing process for these Small Wind Turbines (SWTs) and as a result, thousands have now been constructed and are providing power to many other remote communities around the globe [3]. Depending on the value attributed to labour during the manufacturing process, the capital costs of a Locally Manufactured Small Wind Turbine (LMSWT) can be less than one quarter of an equivalent commercial SWT. However, the fact that locally manufactured technology is built with basic hand tools using cheap and readily available materials means that it is often perceived as being less reliable than its commercial counterpart[2], which will have been manufactured using precision machinery from state of the art materials in a hi-tech factory. Nevertheless, if the necessary maintenance services are available locally, repairs can be performed relatively cheaply and it is possible that when considering the lifecycle costs of the two options, locally manufactured technology may still be able to provide a lower cost alternative.

METHODOLOGY

In order to understand the technical and economic consequences of choosing either locally manufactured of commercial SWT technology, a household energy system from the Scoraig peninsula was modeled in the micro-power optimisation software, HOMER. The software simulates the supply and demand of energy throughout the year by dividing it up into hourly intervals and calculating the energy generated by each power source. This energy is fed into a battery bank, from which energy demand from the domestic loads is drawn. The modeling process allows visualisation of the energy flow throughout the system on an hourly basis and of the cash flow throughout the lifespan of the system. It also calculates various measures that can be used to compare between a number of technological options, such as the LGC (Levelised Generating Cost, i.e. the cost of producing each kWh from a particular generating technology regardless of whether the energy is used or not) and the LCoE (Levelised Cost of Energy, i.e. the cost of meeting each kWh of electricity demand).

The Davy household was selected for modeling, as their 3m diameter LMSWT has been in operation for over 5 years, providing a reasonable amount of data with which to estimate

[1] Energy produced during one year on a site with 5m/s mean wind speed and a standard (Rayleigh) wind distribution.

[2] Further research is needed to determine whether this is actually the case, however for the purposes of this study it has been assumed to be true.

Operation and Maintenance (O&M) costs. Fig. 1 shows the power generation and balance of system components installed in the Davy household. Interviews with both the Davy family and community technician (Hugh Piggott) were conducted to collect both quantitative and qualitative data with which to model the domestic energy system. Further quantitative data was obtained by reviewing relevant invoices issued by Piggott's company, Scoraig Wind Electric.

Fig. 1: The power generation and balance of system equipment installed at the Davy household.

INPUT PARAMETERS

The wind resource at the Davy household is high, with an annual mean wind speed of 5.53m/s. The wind data shown in Fig. 2 was extrapolated from 3 months of measured data at the Davy household using the seasonal profile measured by Piggott at his home on the Scoraig peninsula since 2009. It can be seen that the wind resource is significantly lower in the summer; however Fig. 2 shows that due to the Northern latitude, the solar resource peaks during this period. As a result, the Davy energy system consists of a PV-wind hybrid, with a 628W PV array[3] to complement the 800W rated LMSWT.

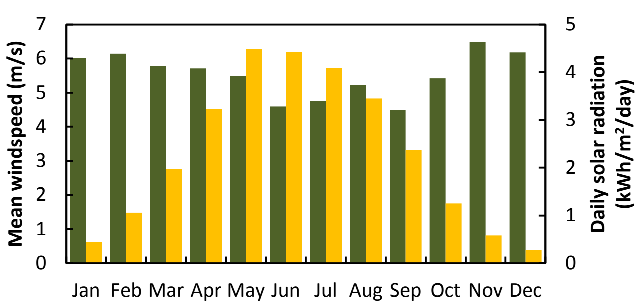


Fig. 2: Wind and solar resource availability at the Davy household.

Fig. 3 illustrates the power demand during a typical day in the Davy household, which at 3.391kWh/day (1,237kWh/yr), is modest by UK standards. The fridge draws a constant load throughout the day and demand peaks in the evening, when lights, computers and the sound system are often in use.

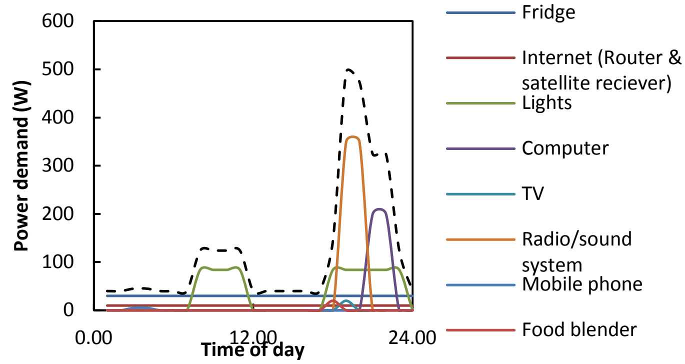


Fig. 3: Daily electricity demand at the Davy household.

Table 1 shows the input parameters used to represent each of the system components in HOMER. A discount rate of 10% [4] was used to model the opportunity cost of capital across the 15 year system lifespan. All costs are inclusive of the relevant sales taxes and the conversion rate of 1USD=0.63831GBP[4] was used throughout.

Wind turbine	Model	Piggott 3N
	Rated power	800W
	Hub height	10m
	Capital cost	$2,445[5]
PV	Model	2x 84W Kyocra + 2x 230W REC
	Nominal power (no MPPT)	628W
	Capital cost	$1,735
Batteries	Model	8x Rolls 4000 series S-530
	Nominal voltage	6V
	System voltage	24V
	Round trip efficiency	85%
	Rated capacity, per battery	400Ah
	Capital cost	$2,431
Converter	Model	PulseStar
	Rated output	800W
	Efficiency as inverter	90%
	Efficiency as battery charger	n/a
	Capital cost	$0[6]

Table 1: Input parameters for the various components of the Davy energy system.

In addition to its capital cost, each system component also has an associated O&M cost, which was modeled as a percentage of the capital cost. The Davy household is a particularly turbulent site and as a result, the LMSWT has experienced a major failure approximately once per year since it was installed in 2009. Fig. 4 shows the tower failure that occurred during high winds earlier this year, which resulted in a bill of $707 to build a new tower and repair the blade that hit the ground.

[3] Nominal power, no MPPT.

[4] Source: xe.com 12/6/13.

[5] Labour costs for LMSWT construction are modeled as $0 as the machine was built on a wind turbine construction course run by Piggott.

[6] On long term loan, so capital costs modeled as $0.

Fig. 4: "By the standards of our windmills, which usually helicopter off the tower and destroy themselves, this was nothing!" Debbie Davy

Fig. 5 shows the breakdown of these O&M costs, totaling an average of $345 per year, approximately 15% of the capital cost of the LMSWT. Despite the many failures, John Davy points out that "in terms of things that break down all the time, it's no more irritating than a car or a computer," and that by providing access to the required maintenance services "Hugh [Piggott]'s done a pretty good job of keeping us supplied with cheap power." In spite of the high number of failures, Piggott's ability to cobble together predominantly second hand parts and get machines that would otherwise be written off back into service all for a very reasonable fee (just $16 per hour) has allowed the Davys to live an unexpectedly high quality of life considering their low income and remote location.

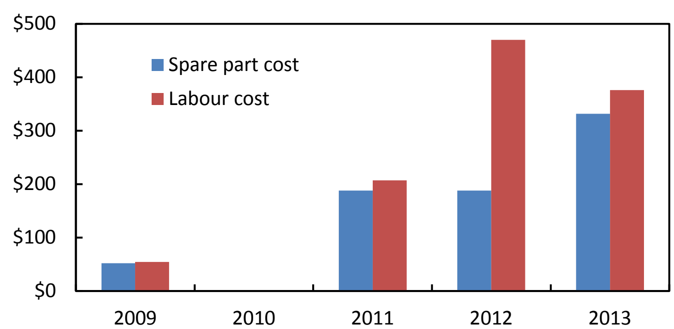


Fig. 5: Breakdown of the O&M costs incurred by the Davy household for their wind power system

Table 2 shows the estimated annual O&M costs and lifetimes for each system component, as entered into the HOMER model. These figures are based upon the experience of Hugh Piggott, who has been offering maintenance services for small scale renewable energy systems on the Scoraig peninsula and the surrounding area for over 30 years.

System component		*O&M Costs (% of capital costs)*	*Lifetime*
Power generation	LMSWT	15% per year	10 years
	Commercial SWT	5% per year	15 years
	PV array	0.5% per year	20 years
Energy storage	Batteries	5% per year	10 years max. (dependent on no. cycles)
Converter	Inverter	0.5% per year	10 years

Table 3: O&M costs and expected lifetime for each system component.

To be able to compare locally manufactured with commercial SWT technology, an alternative energy system was also modeled in HOMER, in which the Piggott 3N was replaced by a comparable commercial SWT, the Bergey XL.1. Table 4 compares the key variables in this comparison, whilst all other parameters used in both models were identical.

		Piggott 3N	*Bergey XL.1*
Capital costs	Wind turbine	$940	$4,595
	Tower	$368	$368
	PV	$1,644	$1,644
	Electrical system	$3,263	$3,263
Installation costs		$252	$252
Delivery costs		0% ($0)	10% ($460)
O&M costs (per year)		15% ($367)	5% ($321)
Lifespan		10 years	15 years
Rotor diameter		3m	2.5m
Rated power		800W	1,000W
RAEY (Rated Annual Energy Yield)		1,739 kWh/yr	1,935 kWh/yr

Table 4: Comparison of the Piggott 3N with the Bergey XL.1, as modeled in HOMER

Performance data for the Piggott 3N was measured during this study using the procedure described by Sumanik-Leary et al. [1], whilst data for the Bergey XL.1 is built into the HOMER software and originates from the manufacturer and is therefore likely to be more optimistic. Despite being of similar size (3m vs. 2.5m diameter) the performance of the two machines is very different. Fig. 6 shows how the bigger locally manufactured machine performs better at lower wind speeds, whilst the smaller commercial machine performs better at higher wind speeds. The Bergey XL.1 actually exceeds its rated power of 1kW, whilst the Piggott 3N never actually reaches its rated power of 800W[7]. Whilst this may be seen as disappointing for the Piggott turbine, in fact both wind turbines operate using a furling system (which limits the turbine output during high winds) and the Piggott 3N has been set at a more conservative value, turning the rotor out of the wind at 8m/s, as opposed to 12m/s. The benefit of doing so is that it increases reliability, as the faster the machine spins, the quicker its parts will wear out. Therefore, the Piggott turbine sacrifices peak power for reliable operation, something that is especially

[7] The power curve is based on 10 min averages, so both machines will actually produce instantaneous peaks much higher than the values shown on the power curve. During the test period, the Piggott 3N was observed to produce more than 800 watts, however as these readings came from an invalid measurement sector, they were not included in the final power curve. The difference is likely to be due to a leaning tower, which can cause significant asymmetry in the performance of a furling system.

important in remote, turbulent and windy sites, such as the Davy household.

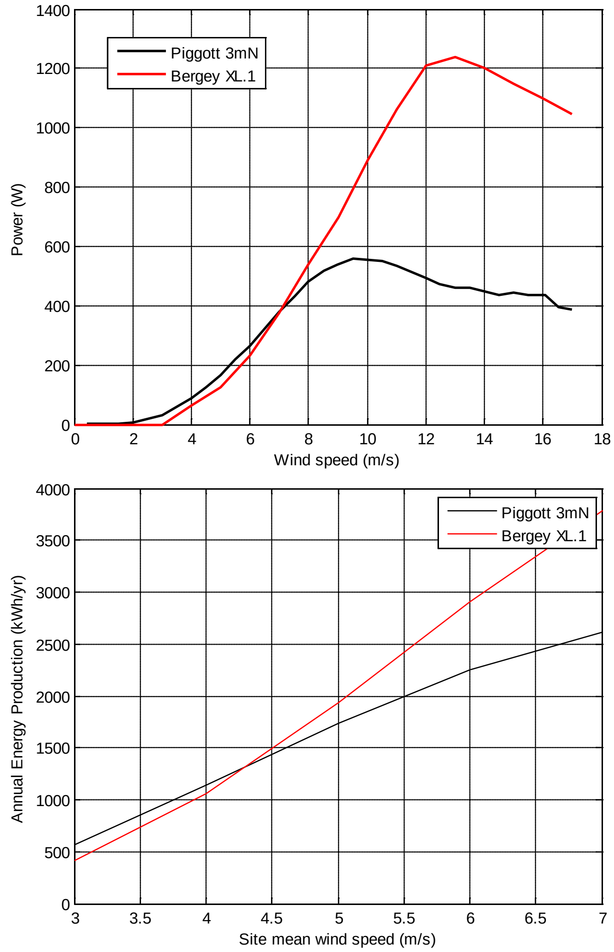


Fig. 6: a) Power curves and b) AEP for the locally manufactured Piggott 3N and commercial Bergey XL.1.

RESULTS

Fig. 7 shows the results of the HOMER simulation for the LMSWT-based energy system installed at the Davy household, displaying the flow of energy from conversion to electricity by the PV array and LMSWT, to filling the batteries and ultimately fulfilling the demand from the domestic loads. The complementarity of the wind and solar power generation is clear: on a seasonal basis, wind generates most in the winter, whilst solar produces most in the summer. On a daily basis, wind can produce throughout the night, whilst solar offers more predictability. Although power shortages can occur throughout the year, they are most likely in the summer months when the wind resource is lowest. This demonstrates that although the rated power of the wind and solar systems is similar (800W vs. 628W), the system is highly dependent on the wind power component due to the superior quality of the resource available in this location.

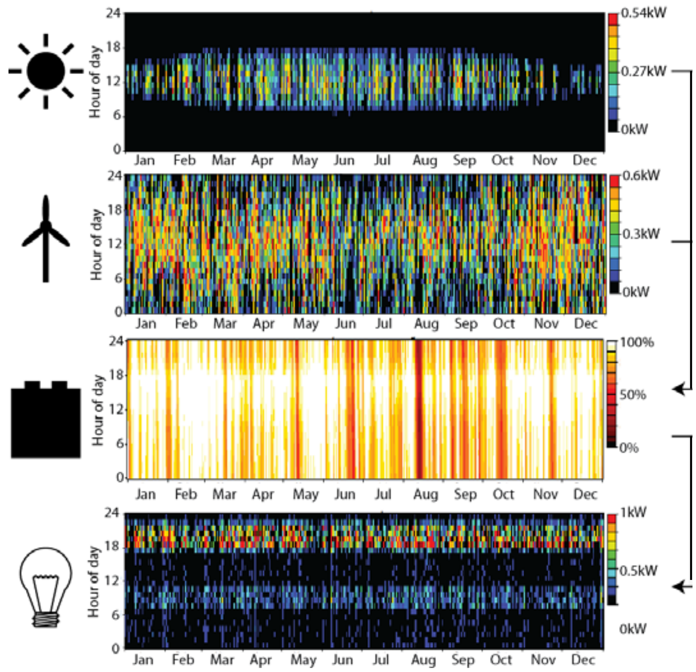
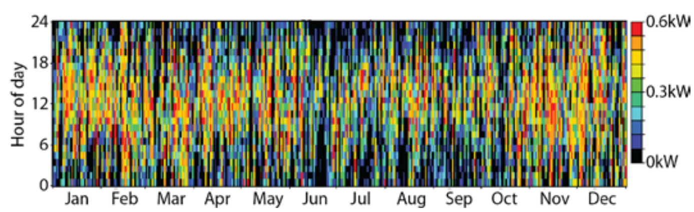


Fig. 7: Hourly energy flow through the Davys' household energy system throughout the day (y-axis) and across the seasons (x-axis).

When comparing between the locally manufactured and commercial SWTs, the simulation reveals that the increased energy yield generated by the Bergey XL.1 is largely wasted, as most of the extra power is generated when the batteries are already full. Although the Bergey XL.1 produces 386kWh (19%) more than the Piggott 3N, 943kWh are sent to the dump load when the batteries are full (as opposed to 553kWh for the Piggott 3N). Interestingly, due to its poor performance in low winds (when the batteries are likely to be empty) it is actually the Bergey which leaves a greater proportion of the load unmet (70kWh, as opposed to 60kWh with the Piggott turbine). So whilst Fig. 6 suggests that the Bergey XL.1 would perform better on a windy site such as the Davy household, Fig. 8 demonstrates that the output of the Piggott 3N is much more evenly spread throughout the day and across the seasons. In fact, Fig. 9 reveals that their ability to fill the batteries is almost identical and Fig. 10 shows that whilst the average power production by the Bergey XL.1 in the most windy month, November, is 43% greater than the Piggott 3N, in the least windy month, September, it is actually 2% lower.



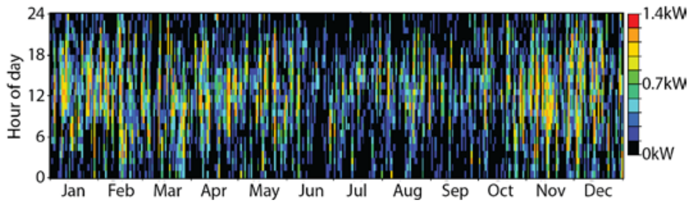


Fig. 8: Hourly average power output throughout the year for a) the Piggott 3N and b) Bergey XL.1.

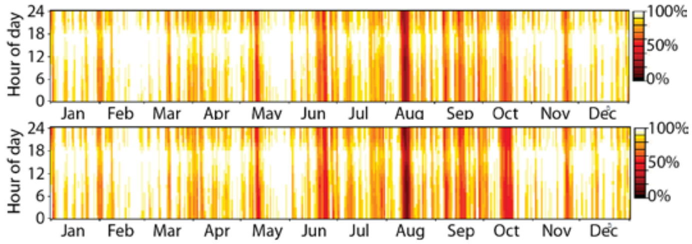


Fig. 9: Battery bank state of charge throughout the year for a) the Piggott 3N and b) the Bergey XL.1

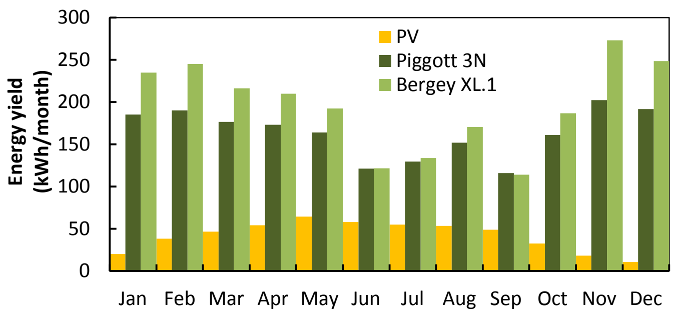


Fig. 10: Monthly average power output for a) the Piggott 3mN and b) the Bergey XL.1.

Fig. 11 compares the Net Present Cost (NPC) of the two systems, clearly showing that despite its higher O&M costs and shorter lifespan, the locally manufactured turbine represents better value over the 15 year expected lifetime of the energy system. What is more, this spreads this cost more evenly throughout the system lifetime, giving the Davys time to build up the necessary capital rather than having to pay almost all of it upfront.

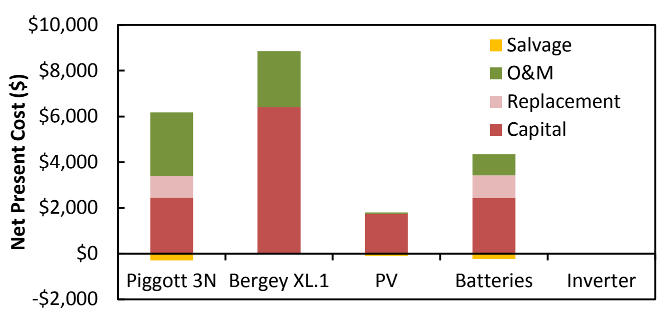


Fig. 11: Net present cost by system component.

When considering the cost of producing each kWh of electricity from the wind turbines alone, at 0.39$/kWh, the LGC of the Piggott turbine is significantly lower than that of the Bergey (0.49$/kWh), primarily due to its lower upfront cost. What is more, its more consistent power output makes it more compatible with demand in an off-grid system. Therefore when considering the cost of meeting end-user demand with this PV-wind hybrid system, the Piggott turbine is the outright winner, producing electricity with an LCoE of just 0.95$/kWh, as opposed to 1.23$kWh with the Bergey. However, this assumes that no value is attributed to the heat produced by the dump loads that contribute towards heating the Davys' water, as well as their living room. This excess heat is mainly produced during the cold winter months, when demand for it is greatest, suggesting that the Bergey may actually be more appropriate for this Northern context than previously thought.

CONCLUSION

	Piggott 3N	Bergey XL.1
SWT capital costs (installed)	$2,445	$6,418
SWT O&M costs (% of capital costs)	15%/yr	5%/yr
AEP at Davy household	1,989kWh/yr	2,375kWh/yr
Excess electricity	553kWh/yr	943kWh/yr
Unmet electric load	60kWh/yr	70kWh/yr
LGC (electricity produced by SWT)	0.39$/kWh	0.49$/kWh
LCoE (meeting demand with PV/wind hybrid)	1.31$/kWh	1.64$/kWh
NPC (PV/wind hybrid energy system)	$11,702	$14,755

Table 5: Comparison of key variables between the locally manufactured Piggott 3N and commercial Bergey XL.1.

Of the two energy systems modelled in HOMER, it was found that whilst their ability to meet demand was similar, the Piggott 3N was able to offer a lower cost solution than the Bergey XL.1. Providing that sufficient local technical knowledge and access to the relevant tools and spare parts are available, then locally manufactured technology can offer savings of 20% over the lifespan of the system. What is more, the majority of the costs of locally manufactured technology are distributed throughout the lifespan of the energy system, lowering the barrier of high upfront capital costs that often inhibits the uptake of renewable energy technologies.

ACKNOWLEDGEMENTS

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