Participatory Manufacture of Small Wind Turbines: A Case Study in Nicaragua

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II) Abstract

Small wind turbines can be manufactured locally in developing countries, creating local jobs, shortening the supply chain for spare parts, increasing local capacity and providing a low-cost solution for rural electrification initiatives. What is more, local manufacture presents the opportunity for community members to take part in the construction of the machine that will be installed in their community. This not only increases the sense of ownership of the technology, but also greatly improves knowledge transfer. Wind turbines are complex machines and are notoriously unreliable, therefore it is essential that somebody close to where the turbine is installed knows how to fix it. As the vast majority of unelectrified communities are located in remote regions, it is impractical for engineers to frequently travel long distances to maintain the technology. This study shows that participatory construction can reduce lifecycle costs by 43% (compared to an engineer driving a pickup to the community each time maintenance is required) as members of the community are capable of performing the vast majority of maintenance themselves. It is shown that where a suitable wind resource is available, the technology can be significantly cheaper than solar PV.

III) Keywords

wind, participatory manufacture, Nicaragua, small scale, renewable

IV) Introduction

> *"blueEnergy made the hard decision in 2011 to stop implementing small wind for our community energy projects on the Caribbean: the wind resource is not optimal, solar PV became very competitive and its hard to ensure the necessary quality at low volume" Mathias Craig, Director and Founder of blueEnergy*

For over 7 years, blueEnergy[1] installed small wind turbines along the Atlantic Coast of Nicaragua, however due to the combined effects of the remote nature of the communities, the increasing cost-competitiveness of solar, coupled with the extremely unfavourable environmental conditions (low-winds, lighting strikes, corrosion and hurricanes) and the lack of interest on behalf of the communities to maintain the systems, the vast majority fell into disrepair and all but 3 have now

[1] www.blueEnergygroup.org

been uninstalled. The following figure shows the operational status of four of blueEnergy's turbines during 2010 and 2011:

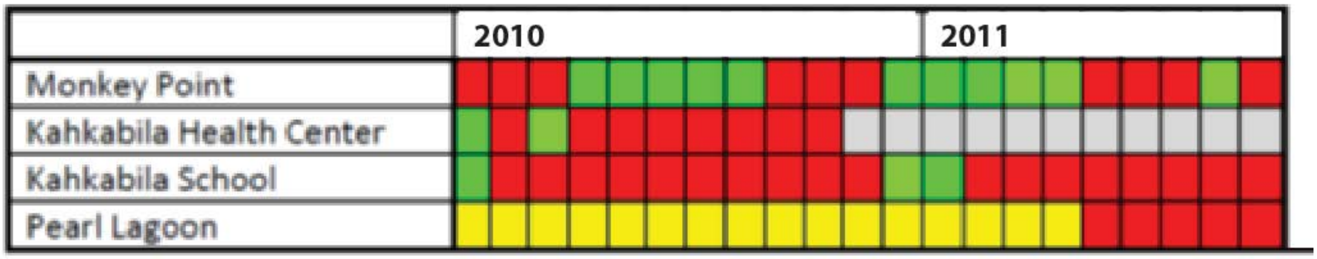

Figure 1: Operational status of four blueEnergy wind turbines (Red = offline, yellow = online, but awaiting repair, green = online, grey = uninstalled) Source: (Neves, Bennet, & Gleditsch, 2011)

Table 1 shows an excerpt from the maintenance logs kept by blueEnergy engineers visiting the turbine in Monkey Point to perform maintenance. It clearly shows the immense challenges facing small scale wind in this region of the country:

Problem – Activities	**Date**
Installation work. One phase of the stator doesn't work. Problem with the solar controller	Jun 2007
Replace stator, trimetric and solar charge controller (Phocos). Lilian connected to the system (2 weeks after installation).	Jun 2007
Stator burnt, brought back to Bf.	Aug 2007
Replace stator. Install battery charger. Hub a bit loose. Inverter doesn't work. Send to Managua. Remove solar controller.	Oct 2007
Rotors rubbed on stator. Fixed with resin. Problem come from the hub.	Nov 2007
Blade painting. Remove something making noise inside the alternator.	Nov 2007
Change the batteries, connect the new inverter. Bring back the Trimetric to Bf. Rise the tower.	Dec 2007
Stator burnt ???	
Put back the Trimetric	Mar 2008
Turbine free spinning, stator burnt since 2 months ? Install new body with a 50 turns #11 wire.	Mar 2008
Install a 12V battery charger in Bomboy house	Jun 2008
Remove battery charger. Install the new grounding.	Jun 2008
Install meters and breakers in Lilian's house. Remove inverter, damage by a lightening. Trimetric doesn't work, brought back to Bf. Install 12V inverter. Tail vane maintenance.	Aug 2008
2 batteries pretty dry (1.5 gallon to refill them !). Remove Trimetric. Change the vane.	Octo 2008
Batteries in bad shape. Replace one. Change the 12V inverter for the 24V original one. Reinstall the Trimetric. Repair school lights.	Jan 2009
Rotors rubbed on stator due to the shaft rear nut which got loose. Fixed up with Epoxymil.	End of march
Mother board of inverter burnt. La loma inverter lent to MP so that the system can still function.	Aug 2009
Mother board replaced and inverter installed	And counting

Table 1: Maintenance logs for blueEnergy's wind turbine in Monkey Point
Source: (Neves et al., 2011)

Despite blueEnergy's decision not to install any new wind turbines in its community electrification projects on the Atlantic Coast, a collaborative project with the Nicaraguan NGO[2] AsoFenix[3] was initiated in 2009 to establish whether the technology could be viable in a different local context: the central highlands. The community of Cuajinicuil is located in the municipality of San José de los Remates in the department of Boaco and was chosen for this pilot project because of its excellent wind resource (5.77m/s mean annual wind speed). In May 2010, a PV-Wind hybrid system was installed to charge batteries and supply 14 households interconnected via a micro-grid, whilst individual PV systems were installed at 4 more distant households. A 1kW bD4 wind turbine manufactured in Bluefields by blueEnergy was installed alongside a 540W PV array.

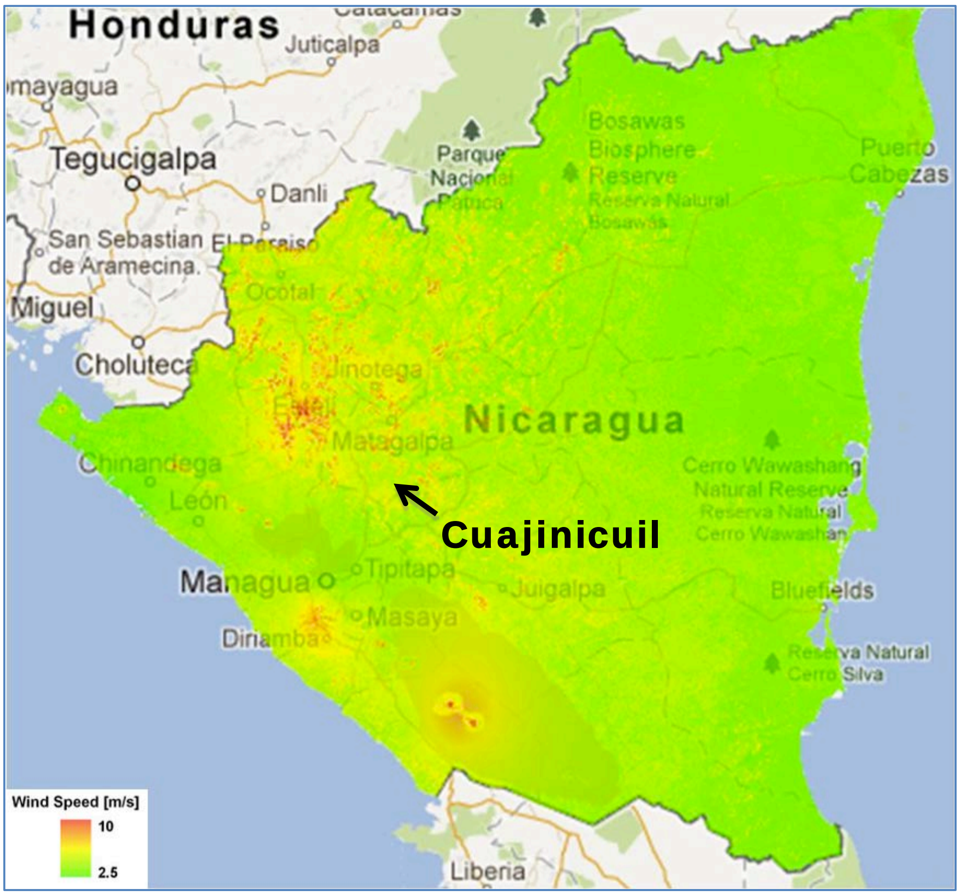

Figure 2: Location of Cuajinicuil in relation to the wind resource available in Nicaragua
Source: ENCO Central America (30m hub height)

A new method of technician training was also trialed during this project – participatory manufacture. The members of the community chosen to be responsible for operating and maintaining the system after installation were invited to travel to Bluefields and take part in the manufacture of the wind turbine that was to be installed in their community.

V) Technician training

[2] Non-Governmental Organization (non-profit)
[3] www.asofenix.org

The level of technician training given in wind-based rural electrification projects varies wildly from a quick chat after installation to multiple days of specialist training at a renewable energy demonstration centre (Leary et al., 2012). Whilst many organisations around the globe run educational courses based around the construction of a small wind turbine and many others promote their use in rural development projects, the authors are unaware of any that have previously linked the two together such that the end user becomes the student in the course.

Figure 3 shows the participants and organisers of this construction/training course that was held at blueEnergy's workshop in Bluefields. As will be demonstrated in this paper, this practical approach to knowledge transfer is much more likely to be effective than conventional theoretical methods when working with people who may have had little formal education, but already have excellent practical skills, such as farmers.

Figure 3: 1 kW Piggott turbine manufactured during a small scale wind power workshop led in 2010 by blueEnergy in Bluefields (RAAS, Nicaragua).

VI) Operation and maintenance (O&M)

For community electrification projects, operation and maintenance (O&M) is absolutely critical for ensuring project sustainability. Many people who live without access to electricity do so because they live in remote areas and the cost of extending the national grid is far too high compared with the amount that they are able to pay for the electricity. The electricity produced by decentralized generation is almost always more expensive than that supplied by the grid, often due to the efficiencies of scale that centralized generation is able to exploit. What is more, any failures in the generating equipment require either a lengthy journey by an engineer from a nearby population centre or an extensive program of training for community members. Even if maintenance can be performed by a community member, they will need access to the necessary tools and spare parts, both of which will be much harder to obtain due to the remote location of the community. These additional costs are not usually taken into account when calculating lifecycle costs for energy projects.

Maintenance operations can be divided into two categories:

1. Preventative maintenance – actions designed to reduce the frequency of failures

2. Corrective maintenance – performing repairs when failures occur

Preventative maintenance

It is widely acknowledged by utility scale power providers that preventative maintenance can:

> *"reduce maintenance costs and breakdown frequency, increase machine life and productivity, and reduce spare parts inventories"* *(US DoE, 2011)*

Interviews with the community technicians and administrator were conducted to determine the amount of time and money spent on preventative maintenance every year by the community[4] (Cuajinicuil Interviews #8 and #13). The results for each renewable technology are compared below in Figure 4.

Not only are more tasks required in order to maintain the wind turbine than the solar panels, but it is important to note that each task is more complicated. For example, the most complex task required to maintain the solar panels is climbing onto the roof to clean them at most once a month, something that one person can do alone in less than half an hour with virtually no training. In fact, the preventative maintenance required of the solar systems is so simple that the end-users of the domestic (55 W) solar systems are capable of doing it all themselves.

In contrast, the wind turbine requires a well-trained technician for over 100 hours/year, to perform daily checks to make sure it is operating properly (listen for strange noises, check that it is following the wind direction etc.) and to lower it every six months for a check-up (bearings greased, blades and metal parts repainted, nuts & bolts tightened, power cable untwisted etc.), as well as before any hurricanes or big storms. This also requires the assistance of the whole community to lower the tower and a full check-up takes at least 2 days. In fact, the community once spent 4 days without electricity after a check-up because there were not enough people around to raise the tower again (Cuajinicuil End-user Interview #12, 2012).

With regards to safety, just lowering the tower is already far more dangerous than any of the required operations for the solar systems:

> *"[the turbine] is incredibly dangerous. It's not easy to raise and lower this thing. It's very costly and very dangerous." Cuajinicuil PV-Wind End-user (Interview 12, 2012)*

However, this risk does have a hidden benefit:

> *"Solar is easier to use…but wind is more secure because nobody is going to be able to run away with it!" Cuajinicuil Technicians (Interview 13, 2012)*

[4] Full details of the exact tasks performed, consumables and tools required, along with their associated costs and time commitments are listed in the full report (Marandin, Craig, Casillas, & Sumanik-Leary, 2013).

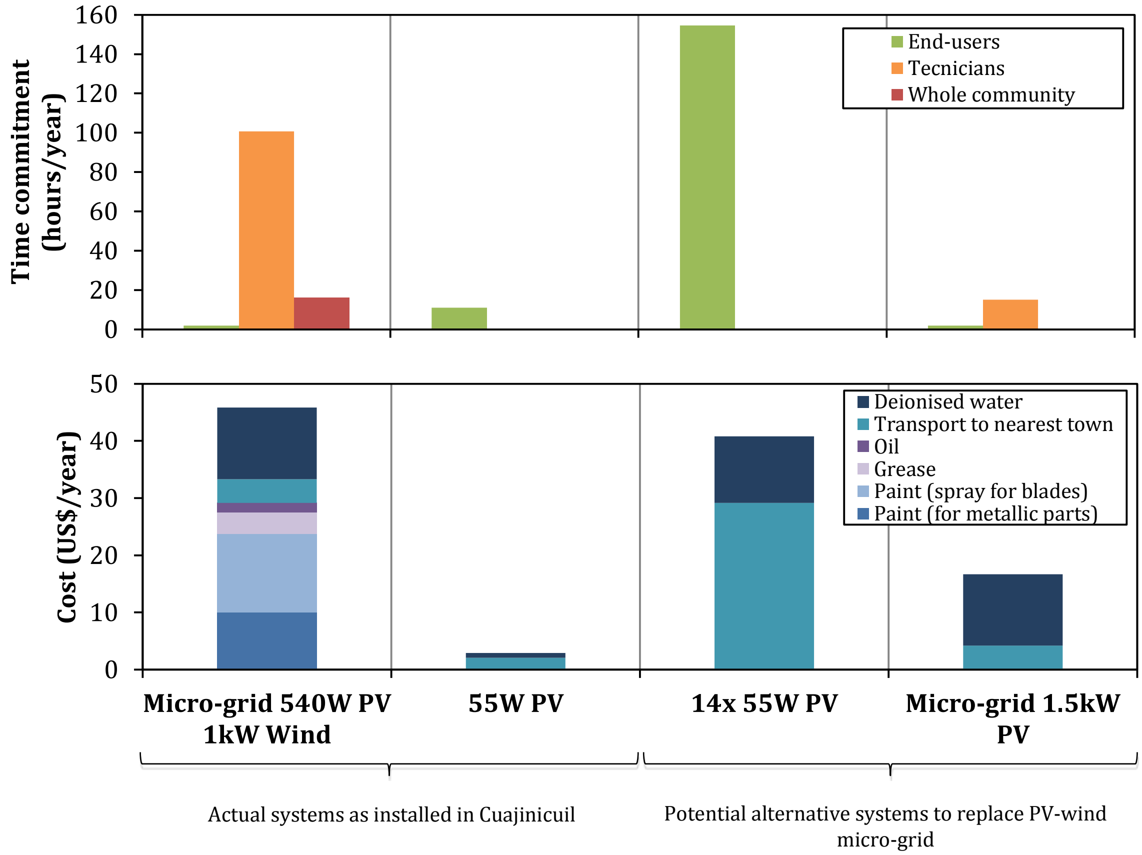

Figure 4: Comparison of a) the time commitment and b) the costs required to perform the necessary preventative maintenance for the actual renewable energy systems installed in Cuajinicuil with 2 potential PV only alternative systems for the micro-grid. Data obtained from Cuajinicuil Interviews #8 and #13.

Also shown in Figure 4 are two potential alternatives for the electrification of the 14 houses connected to the micro-grid: 14 individual household PV systems (55W each) and a PV only micro-grid (1.5kW). With regards to time, the first option would require over 150 hours/year from the end users, however this is split between the 14 households and equates to just 11 hours/year each. The second option would require just 15 hours/year of technician time, an 85% reduction on the installed PV-wind system. In terms of cost, both options require around US$12/year to keep the batteries hydrated and the only real difference between the two is the transport costs required to get all 14 users to the shop selling deionised water vs. just one technician, putting the costs of consumables 11% and 64% respectively below that of the existing PV-wind micro-grid.

Corrective maintenance

Wind turbines are mechanical devices that sit on top of tall towers and spin at high speed, deliberately exposed to the full force of wind and all that comes with it (rain, sun, lightning etc.). As a result, regardless of the quantity and quality of preventative maintenance performed, failures are inevitable:

> *"…wind turbines are surprisingly troublesome pieces of equipment…because of all the little things (and some big things) that go wrong."* (Piggott, 2009)

Figure 5 shows the amount of time that each energy system has spent out-of-operation, for maintenance. It is important to note that the hybrid nature of the PV-wind micro-grid gives it a much higher reliability than either system alone as it can continue to provide energy to the community until both sources (or the shared storage and distribution system) go offline.

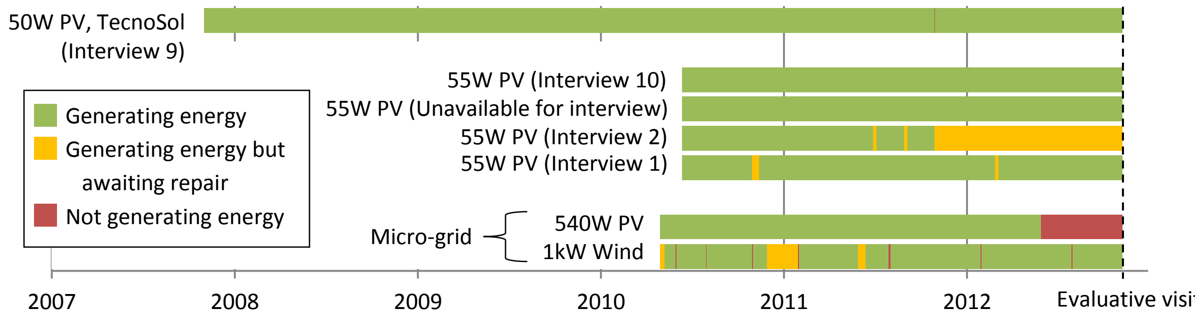

Figure 5: Diagram of the downtime experienced due to routine preventative maintenance or pending corrective maintenance for each renewable energy system in Cuajinicuil.

The data presented in Figure 5 is summarized in Figure 6 with the aid of three key metrics conveying reliability, resilience and a combination of the two.

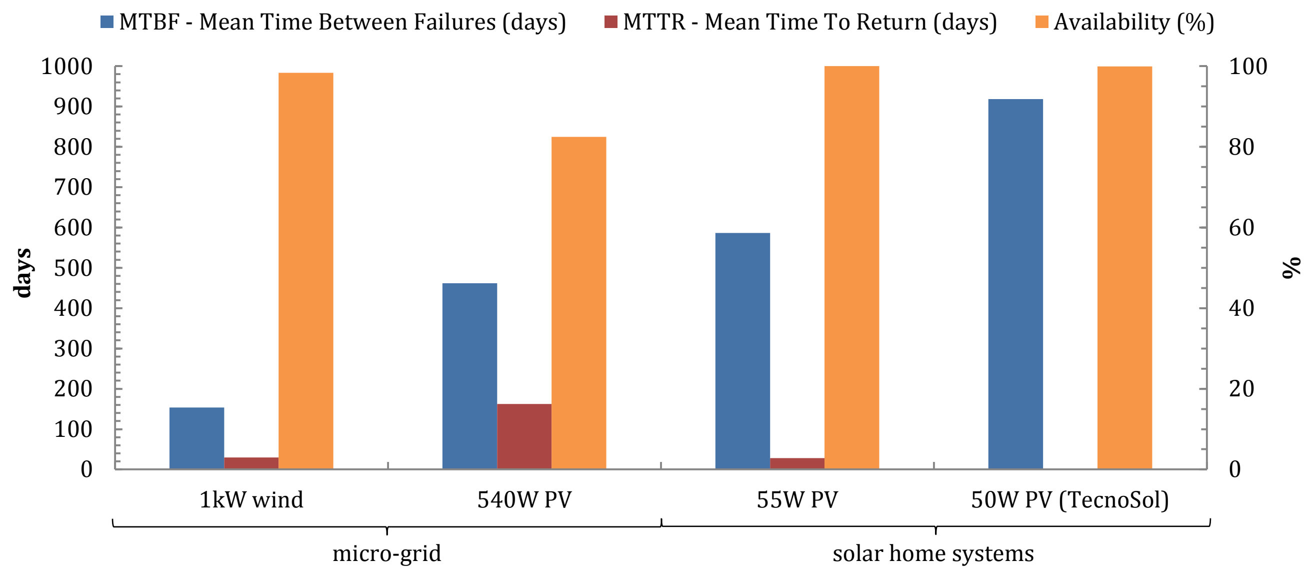

Figure 6: Comparison of the reliability and resilience of the various renewable energy systems in Cuajinicuil

The Mean Time Between Failures (MTBF) is a measure of reliability, taking into account the frequency with which faults occur:

$$\mathrm{MTBF} = \frac{\sum \text{no. days between failures}}{\text{total no. failures}}$$

At 154 days, the MTBF for the wind system is more than three times smaller than even the worst of the solar systems. What is worse is that if the metric had included times when the tower was lowered for preventative maintenance, it would have been just 70 days. This is not uncommon for locally manufactured small wind turbines, as a similar analysis conducted in Peru studying technology produced by two similar NGOs, WindAid (7 turbines) and Soluciones Prácticas (35 turbines) found MTBFs of 115 and 291 days respectively (Leary et al., 2012). Fortunately, it is expected that this number will increase over the lifetime of the installation:

"…I would expect a couple of problems in the first year and one per year thereafter" (Piggott, 2009)

In addition to the number and frequency of failures, the time taken to repair each is also important. The resilience of the system is measured by the Mean Time To Return (MTTR):

$$\text{MTTR} = \frac{\sum \text{no. days from when fault occurs until repair completed}}{\text{total no. failures}}$$

In spite of what may have been predicted, at 162 days it is actually the solar system that has the highest MTTR. However, this is not a fair reflection on the ability of the community to repair the solar system as replacing the charge controller is simple, however the community currently has no money to buy a replacement. What is more, the controller burnt out in June 2012 when ants invaded the control panel– something that could equally well have happened to any of the wind power system's electrical components.

Figure 7: Invasion of the fuse box by ants that led to the failure of the solar controller in June 2012
Photo courtesy of Bryan Ferry

In addition to this, one of the solar home systems has been awaiting a repair for over a year now; however it is the fuse that has blown in the inverter and as they no longer have a television, they are happy to continue using the DC light bulbs and no more (Cuajinicuil Interview #2). This has pushed the MTTR of the 55W PV systems up to 28 days, just below that of the wind system, which was expected to be much higher due to the longer supply chain for spare parts coming from the Bluefields, the increased complexity of the repairs and the need to lower the turbine. The short time in which each of the faults with the wind system were fixed is testament to the skill of the community operators, who due to the success of the technician training program, were able to fix all of the problems themselves apart from the replacement of the rotor and stator discs in the generator, which is one of the most complex repairs in the whole system.

In Peru, it was found that the wind power systems could be fixed even quicker (MTTR of just 3 days for Soluciones Prácticas) by having more spare parts available in the community (Leary et al., 2012). The replacement of the rotor & stator in Cuajinicuil took over 60 days as a new part had to be made from scratch, shipped across the country and installed by an engineer. In contrast, the Peruvian community were able to keep 3 entire spare systems in the community as they had installed many smaller turbines as opposed to a single larger one, as in Cuajinicuil. If more communities in the Cuajinicuil region were to install small wind turbines, then a service network could be established that would allow the system to get back into operation much faster.

The final metric is the availability, which is a combination of both reliability and resilience and indicates the percentage of time that the system is capable of producing energy:

$$\text{Availability} = \frac{\sum \text{no. days not able to produce energy}}{\text{total no. days since installation}}$$

Even though the wind system has been out of service for at least 4 days per year for preventative maintenance check-ups, has been taken down to replace the rotor and stator discs and both the dump load and rectifier have been replaced, the overall availability of the wind system (98%) is unexpectedly better than that of its solar counterpart in the mini-grid (82%). This is again due to the on-going lack of funds for a new solar controller, combined with the fact that the wind turbine was able to continue operating whilst the faults were occurring (e.g. a switch with a bad connection was simply left closed). In Peru, the wind systems were found to have availabilities of 83% (WindAid) and 97% (Soluciones Prácticas) (Leary et al., 2012).

However, as expected the 50 and 55W solar home systems performed even better than the wind system (100% availability) as the only interruption to energy production for these systems was the changing of the battery of the 50W TecnoSol system at the end of its life.

Whilst preventative maintenance has a negligible cost for the solar and minimal cost for the wind systems, Figure 9 shows that corrective maintenance makes up 46% and 30% of the net present cost of the solar and wind generation systems respectively. The costs associated with each of the incidents shown in Figure 5 are shown below in Figure 8, alongside the fund collected by community members from the tariff roughly equivalent to 30C$ ($1.25) per household per month that has been put aside to cover maintenance costs. Whilst the fund easily covers the consumables required for preventative maintenance, the costs of each failure are huge in comparison. Fortunately for the community, the first 4 failures were deemed to be design flaws and installation faults, and as a result were paid by the NGOs that implemented the projects. However, when the solar controller burned out in June 2012, there was nowhere near enough money to pay for a replacement, let alone cover the installation cost.

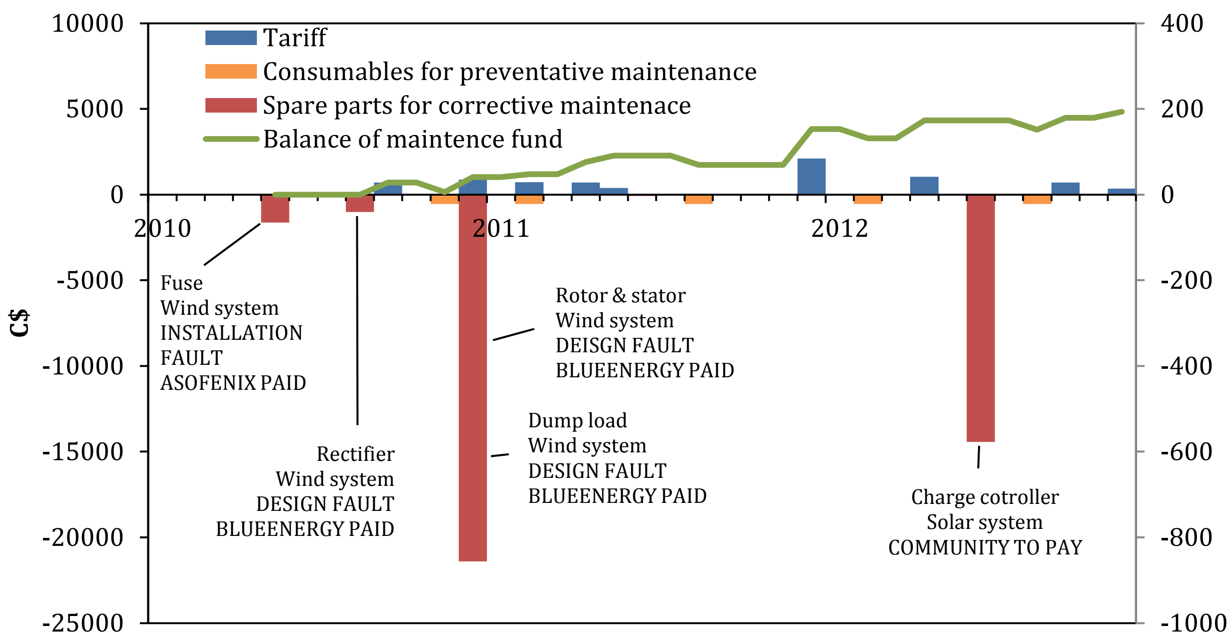

Figure 8: Comparison of the maintenance fund collected by the community and the maintenance costs incurred by the system since operation.

Note: the cost of spare parts in this illustration does not include installation costs.

Impact of lifecycle costs

The Cuajinicuil PV-wind micro-grid was modelled in the software Homer[5] to establish the influence of various parameters on the economic viability of the system. The results of the analysis are summarized below in Figure 9[6]. To reflect the true cost associated with the local manufacture of the wind turbine, overheads of 30% and 50% were added to all materials and labour costs respectively. As previously stated, a commercial scenario that does not rely on volunteer labour was assumed[7]. The system was modelled over a 25 year period, with replacement of the batteries (7 years), wind turbine (15 years) and inverter (15 years) scheduled to occur during this time period. A real interest rate of 8% and an exchange rate of C$24.01=US$1 was used to model the current financial climate in Nicaragua.

[5] www.homerenergy.com

[6] The complete breakdown of the costs used as inputs for the model can be found in the full report (Marandin et al., 2013)

[7] Please note that these economic models developed in this study assume a commercial scenario, such as that taken by the Nicaraguan suppliers of renewable energy equipment, TecnoSol, Ecami and SuniSolar. This is in contrast to the volunteer model adopted by the NGOs blueEnergy and AsoFenix, in which many of the labour costs are zero as they employ many international volunteers, who often even pay for their own overheads. While this is seen as a viable model for introducing new technologies, it is not sustainable in the long term as it does not continue to build local capacity and will not allow the organization to scale up the technology to reach all those that could benefit from it.

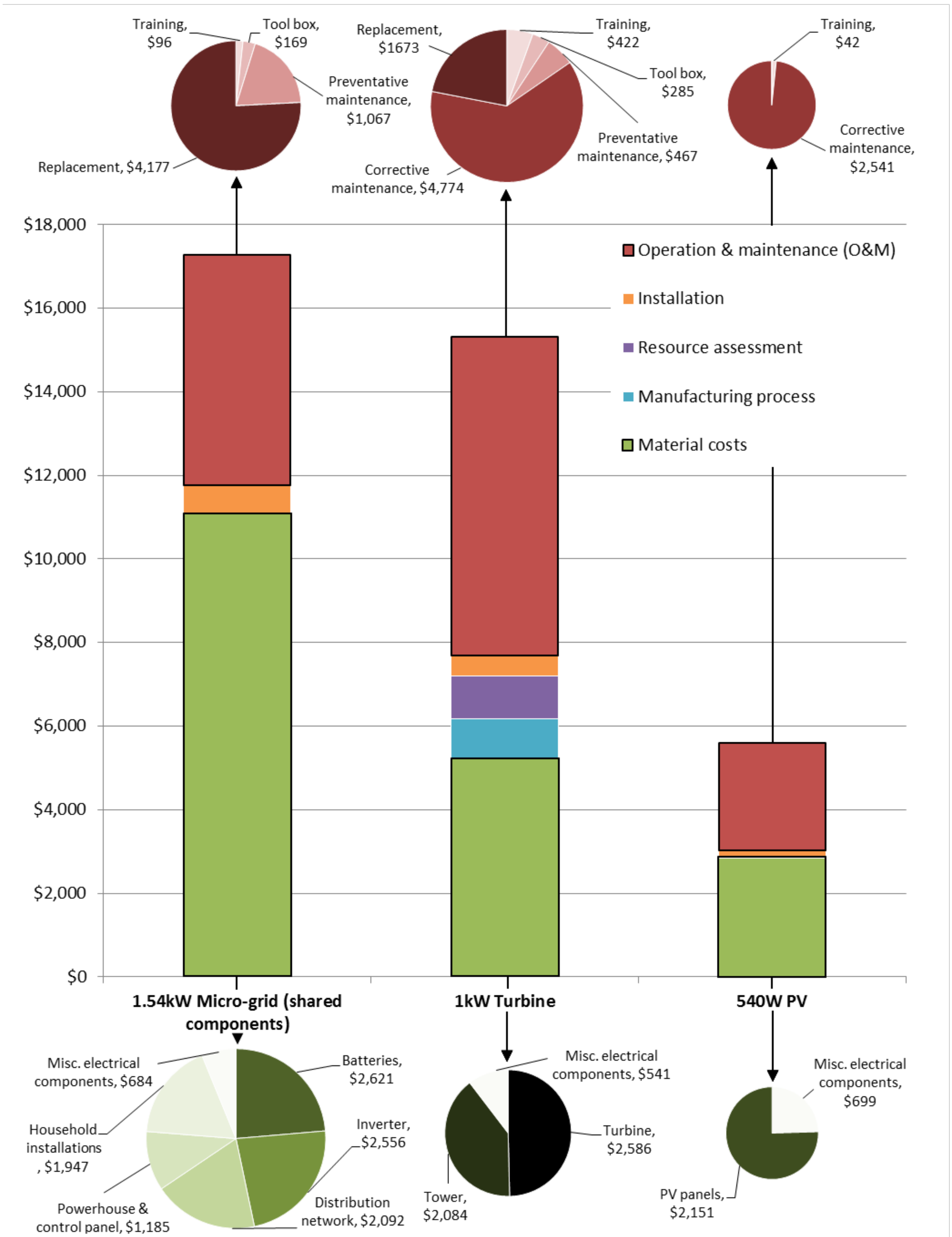

Figure 9: Breakdown of the net present costs of the major system components in the Cuajinicuil micro-grid (modelled in Homer with a real interest rate of 8% over a 25 year period)

In Figure 9, the costs are first categorized into those associated with the 1kW wind (e.g. tower, wind study), the 540W solar array (e.g. PV panels, installation of panels) and those that are shared between the two (e.g. inverter, training on principles of electricity). It is possible to see that the cost per watt of the wind turbine (US$5.21/W) works out at just below that of solar panels (US$5.27/W) when you include just the cost of the materials.

However, when you add in the resource assessment (wind: installing an anemometer on a mast at the site and logging data for a year – PV: zero), manufacturing (wind: labour costs for the construction of the wind turbine – PV: zero) and installation costs (wind: transport of tower and turbine to site, digging and concreting of anchor points, laying of underground cable to powerhouse – PV: transport of panels to site, fabrication of aluminium frames and installation on roof of powerhouse) to give the installed cost, the balance tips the other way to US$7.70/W and US$5.59/W respectively.

Despite the success of the technician training program, the increased maintenance requirements of the wind turbine push the gap even wider when including O&M costs ($15.32 and $10.38), showing that watt for watt, wind is a more expensive solution. However, this does not take into account the energy yield of the two renewable technologies.

Below, Figure 10 shows the variation in Levelized Cost of Energy (LCoE) between the most cost-effective system typologies, as modelled in Homer[8]. Wind is clearly the most cost effective system, due to the superior energy yields on this excellent wind site.

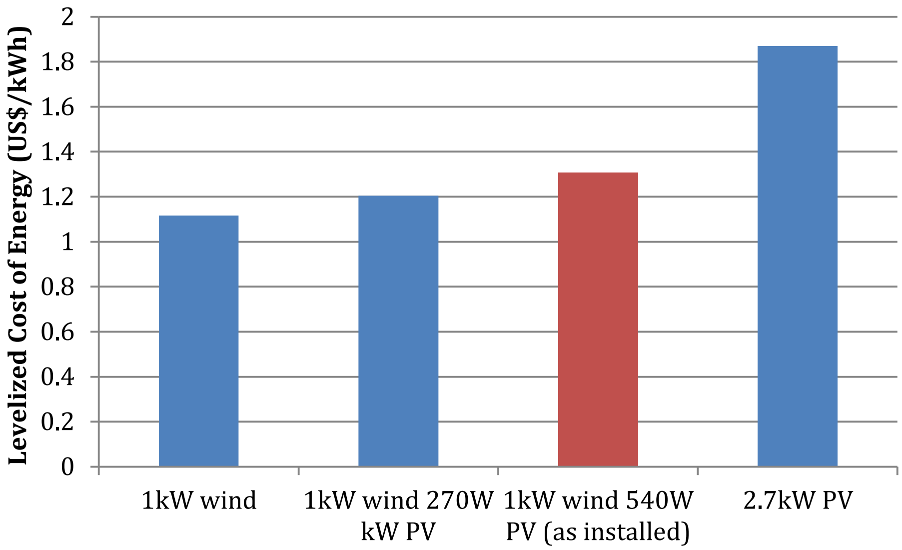

Figure 10: Comparison of Levelized Cost of Energy for the most economical wind, PV-wind hybrid and PV systems with the 1.54kW PV-wind hybrid installed in Cuajinicuil.

Despite making up a significant portion of the total costs, the operation and maintenance costs of the renewable energy system in Cuajinicuil are a lot lower than if there had not been any technician training. If there had been no training given, initial capital costs for the wind system would decrease by 5%, the PV system by 1%, and the rest of the project by less than 1%. As a result, instead of the community technicians being able to fix most of the problems (with assumed negligible cost), an engineer would have had to visit the community for repairs, leading to an

[8] Full details of the variables used in these calculations can be found in the full report (Marandin et al., 2013).

increase in operation and maintenance costs by 7% for the PV system, and 27% for the wind system (due to the higher number of failures). These cost increases assume that the engineer would take the bus to the community and back, for repairs that don't require large spare parts; this would be a trip of 3 hours followed by a 2 hour walk, each way. If, instead, they were to drive a pickup (2.5 hours followed by a 40 min walk), as is more realistic for a commercial installer, they would rise by 16% and 76% respectively. The result is an increase in the net present cost of the system from $37,420 to $39,013 and $41,810 respectively.

End-user opinions

The fact that the community technicians were involved in the manufacturing and installation of wind turbine and that significant time and effort was put into training them has meant that despite the quantity and complexity of maintenance required by the wind power system, they are capable of performing almost all of it:

> *"It's great that AsoFenix suggested that the guys learn about the installation and theory of the system….that they're prepared, so that they can respond to situations…no matter what happens to the turbine, because going to Managua would be very difficult…it would take a long time" (Cuajinicuil Interview #8)*

Not only is their level of knowledge impressive, but also their dedication as they are not paid for all the work they do on the system:

> *"They've worked hard to learn for the benefit of the community" (Cuajinicuil Interview #14)*

> *"I maintain the turbine because I love it!" (Cuajinicuil Interview #13)*

During the field survey, 75% of those who were asked about the turbine technicians' job performance rated it as good, 25% as average, and none deemed it bad (Cuajinicuil Interviews #3-#8, #11 and #12, 2012). In fact, since the installation of the renewable energy system in Cuajinicuil, one of the technicians has now worked with AsoFenix in the installation of over 20 PV systems and a micro hydro project in other communities. The engineers from AsoFenix have inspired him to study to become an engineer himself. He currently travels 3 hours each way to Managua every Saturday to take classes to prepare him for university entrance exams.

It is necessary to have somebody with this level of knowledge and enthusiasm for the technology that lives in the community because there are so many technical problems to solve with a wind system:

> *"They're really active…they're always checking over things, repairing the battery shed, cleaning the batteries, filling them with water…and when there's a problem with the turbine, perhaps a strange sound and maybe it needs to be greased…its really nice because if there's a problem, they know how to fix it" (Cuajinicuil Interview #8)*

In fact, during the evaluative visit, this is exactly what happened: the technicians heard a strange sound the night before lowering the tower to install an anemometer. Sure enough, when the tower was lowered the next day, the rotor and stator were touching in one tiny portion of the rotation. The technicians adjusted the spacing between the two discs and avoided what could have developed into a major problem (see Figure 11).


Figure 11: Inspection of the rotor and stator by the Cuajinicuil technicians to prevent potential future failures

One unfortunate downside to all this training is the potential for ‘brain drain’, i.e. despite the fact that the technicians now have so much more technical knowledge than the rest of the community, there are few other opportunities in the local area in which they can use their new skills. They may therefore choose to leave the community to seek a better paying job in the nearby towns and cities and abandon their maintenance responsibilities:

> *“We’re in the process of becoming sustainable…it would be good to train more people because…for example, one [technician] already left, he’s in Costa Rica…another suddenly has to go off and study in Managua or work far away and won’t be spending much time here” (Cuajinicuil Interview #8)*

Despite this, the technician training programme in Cuajinicuil has undoubtedly been a success, with a number of capable and motivated individuals now in charge of the renewable energy system and able to perform the vast majority of maintenance without an engineer ever having to leave their office. However, the key question is really whether or not it is possible to find people as motivated and technically able in other communities.

Conclusion & recommendations

It has been shown that the participatory manufacture approach can offer significant savings in the lifecycle costs of a small wind power system and ensure a much more reliable and resilient energy system. In addition to this, it offers the community the chance to be more sustainable as they are not reliant on an engineer travelling from far away every time something goes wrong. However, the fact remains that the amount of maintenance required for small wind turbines is much higher than for solar panels and therefore the following recommendations are made to any organization considering a small wind rural electrification initiative:

- Only communities that are sufficiently organized to be able to perform and pay for maintenance should choose wind power.

- In communities with low income, a link to productive uses of the energy should be made in order to be able to cover maintenance costs. In particular, productive uses that are seasonally compatible with the wind resource, e.g. irrigation during the dry season.

- A network of service centres should be established, so that community members can get access to the knowledge and spare parts to be able to perform repairs without having to travel great distances.

- Clustering wind projects together would allow communities to share knowledge and expertise and reduce travelling time for engineers if called out for major repairs. It would also help raise awareness of the technology in that area.

- Regions with adverse environmental conditions should be avoided or the appropriate preventative measures and/or expected repairs should be budgeted for, i.e. high salinity, heat or humidity (especially the combination of the three) and high frequency of hurricanes and/or lightning strikes.

- Ensure access to the lowest price solar panels, as hybrid systems are much more resilient both meteorologically and technologically than either technology alone.

- Locally manufactured technology can present significant savings over imported technology, but only if an industry that can produce in reasonable quantities and therefore offer the necessary quality can be established.

- Solar panels and deep cycle batteries are currently exempt from import tax and VAT in Nicaragua. If the same were possible for wind turbines, imported turbines could become competitive if a strong enough supply chain to provide the necessary maintenance services could also be created.

- Effective training is necessary for local technicians and community members to empower them and make the project sustainable:

    - Participation in the construction of the wind turbine that will be installed in their community when using locally manufactured technology provides the ideal opportunity for this transfer of knowledge. Involvement in the installation of the technology is also an excellent way of transferring knowledge and increasing the community's sense of ownership of it.

    - Establishment of a renewable energy demonstration centre could help raise awareness of the technology and would also be useful for training purposes.

    - A rolling demonstration program, where the technicians of a community about to install a wind turbine visit a community that has recently had a wind turbine installed, much like the 'campesino a campesino' (farmer to farmer) environmental awareness program that is currently running in rural Nicaragua.

- Sufficiently motivated individuals from within the community must be willing to take on the role of technician (ideally at least three in case one leaves the community and another is busy when a problem occurs)

VII) Acknowledgements

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Jon Sumanik-Leary’s participation in this research was funded by the UK Research Council’s Energy Programme and conducted at the E-Futures Doctoral Training Centre at the University of Sheffield, UK[10].

VIII) References

Leary, J., Howell, R., While, A., Chiroque, J., VerKamp, M., & Pinedo, C. (2012). Post-installation Analysis of Locally Manufactured Small Wind Turbines Case Studies in Peru. Presented at the ICSET 2012, Kathmandu.

Marandin, L., Craig, M., Casillas, C., & Sumanik-Leary, J. (2013). *Small Scale Wind Power in Nicaragua - Market Assessment 2012-2013*. Green Empowerment.

Neves, P., Bennet, C., & Gleditsch, M. (2011). *Assessment of the role of wind turbines in blueEnergy’s portfolio*.

Piggott, H. (2009). *A Wind Turbine Recipe Book*.

US DoE. (2011). *Establishing an In-House Wind Maintenance Program*. US Department of Energy, Energy Efficiency & Renewable, Energy Wind and Water Power Program.

[9] www.windempowerment.org

[10] Find out more about Jon Sumanik-Leary’s research at www.thewindyboy.com