
BRIEFING PAPER 2

IS THERE STILL A ROLE FOR SMALL WIND IN RURAL ELECTRIFICATION PROGRAMMES?

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With contributions from: A. Eales, K. Latoufis, E. van Dam, J. Rivas,
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BRIEFING PAPER 2

IS THERE STILL A ROLE FOR SMALL WIND IN RURAL ELECTRIFICATION PROGRAMMES?

Executive Summary:

In the right context, Small Wind Turbines (SWTs) can offer a valuable complement to solar photovoltaics (PV) or diesel generators, offering diversity in power generation sources and the potential for local manufacture. However, the biggest challenges facing small wind are the high variability in the wind resource (in both space and time) and the high maintenance requirements of SWTs. What is more, PV prices have fallen dramatically in the last decade, resulting in the proliferation of an array of desirable and highly modular solar solutions, such as solar lanterns and Solar Home Systems (SHS). Consequently, outside of high wind regions, SWTs are now rarely directly economically competitive against solar PV. Going forward, SWTs are still likely to have a role to play, but in niche contexts and as a complimentary addition to hybridise solar PV or diesel systems, rather than as a standalone alternative.

Market assessments are an essential first step to determine the relative viability of PV-wind or wind-diesel hybrid systems with PV or diesel systems in particular contexts. In favourable regions, the high maintenance requirements of SWTs can be tackled by providing stable institutional support to empower local champions, establish a decentralised maintenance network and foster the development of a local small wind industry. End users and local technicians should be empowered to carry out as much maintenance as they are able/willing to, especially in remote regions, where frequent long maintenance trips are likely to lead small wind electrification programmes to failure. Sustainable business models should focus on productive applications and addressing the weaknesses of diesel and/or solar generation through hybridisation.

THE OPPORTUNITY FOR SMALL WIND

Globally, 1.1 billion people currently do not have access to grid electricity and many more have inadequate provision [1].

Small-scale decentralised renewable energy solutions such as wind, solar or hydro offer remote communities the opportunity to generate electricity from locally available resources. Solar PV and hydro have a strong track record for rural electrification, however the successful mass-dissemination of SWTs in Inner Mongolia shows that in the right context, small wind power can offer affordable and reliable access to electricity (see Box 1). SWTs offer an additional power generation source (with the potential to generate on cloudy days and at night-time) and the opportunity to manufacture locally.

In the context of a rapidly expanding off-grid solar industry, this paper seeks to explore the opportunities and challenges facing small wind to establish whether it still has a role to play in rural development. If so, then where and how can it make the greatest contribution to sustainable rural electrification?

Diversity in power generation sources

The most resilient energy systems should have a diverse energy mix if the availability of any single resource, or the hardware to convert it into electricity, is uncertain. Battery storage is usually required for off-grid SWTs and PV, as the demand for electricity at any particular moment rarely exactly matches with the availability of the wind/solar resources. SWTs are often used to hybridise (Figure 1):

- diesel/petrol generators, primarily to reduce fuel consumption and offer 24h power; or
- solar PV, if the solar and wind resources are complementary (see Figure 2).

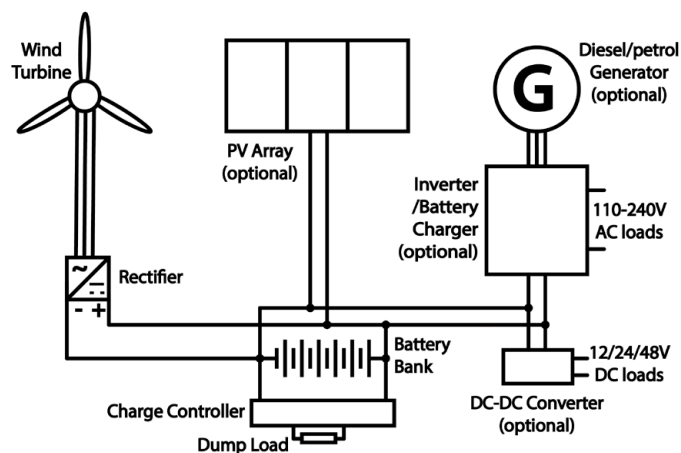


Figure 1 – Schematic of a typical small wind power system and options for hybridisation.

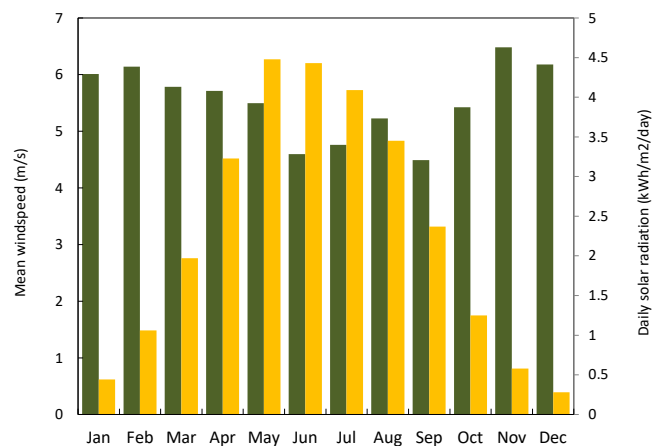


Figure 2 – Monthly wind and solar resource availability at a household (HH) in north-west Scotland [2]. The two resources peak in opposite seasons, so a PV-wind hybrid is more likely to keep the batteries full throughout the year. Daily and diurnal complementarity are not shown, but are also important, i.e. are cloudy days and night time usually windy?

Local manufacture

Local manufacture offers the potential for local job creation, lower cost solutions and building the social infrastructure for maintenance services [3], [4]. PV is almost always imported because of the expertise required for solar cell fabrication, however the recent development of open source designs has empowered many more organisations around the world to manufacture SWTs locally [3], [5], [6]. Moreover imported SWTs are often designed for peak performance (more marketable to grid-connected customers) rather than continuity of supply (more useful for battery-charging systems) [7], [8]. Decentralised forms of manufacturing use more local labour and materials, shifting a greater proportion of the value chain into the local region [9]. Building local technical capacity and a strong supply chain during manufacture and installation also lays the foundation for maintenance services, which further extends livelihood opportunities.

Box 1 – Inner Mongolia Autonomous Region (IMAR), China Small Wind Case Study

Since the 1980's, the IMAR government has enabled rural off-grid HHs to harvest their plentiful wind/solar resources by promoting small-scale, decentralised HH wind/PV systems [10]. This began by supporting R&D, leading to the development of over 20 models of SWTs by local institutions [11]; and forming the high-level New Energy Leading Group to coordinate renewable energy policy [10]. Special attention was given to local manufacture; meeting both herdersmen's HH and productive needs; reducing costs; reliability; and local leadership, with appropriate government support [12].

After a successful demonstration project, the IMAR government offered subsidies to encourage widespread adoption [13]. Herdsmen were able to sell animals to cover the remaining initial purchase costs [14]. In 1984, the New Energy Office was set up to develop policy and coordinate research, production and dissemination. New Energy Service Stations were established in each local area to distribute subsidies, provide information and technical support.

By 2000, IMAR had the highest concentration of SWTs in the world, with 150,000 SWTs providing electricity to one third of its off-grid population [12], [14], [15]. It also had a thriving small wind industry, with 10 manufacturers producing in the 100W-25kW range, supplying IMAR, 20 other Chinese provinces and even exporting [10]–[12], [15]. In IMAR, wind speeds dip in summer, when the solar resource peaks – from 2000 onwards, PV panels were added to hybridise the existing SWTs [15]. This enabled new productive applications, such as meat refrigeration, and extended battery life by preventing over-discharging in summer.



Figure 3 – A group of end-users installing a SWT in IMAR, China in 2009 (photo by Long Seng To).

THE CHALLENGES FACING SMALL WIND

The extreme variability in the wind resource, limited modularity, high maintenance requirements and the falling price of PV all create significant challenges for small wind (Table 1). The following section explores these issues in greater detail, particularly in relation to solar PV.

Factor	SWTs	Solar PV	Micro-hydro	Diesel/petrol
Potential for local manufacture	High	Low	High	Low
Spatial compatibility of resource with off-grid settlements (globally & locally)	Poor	Good	Poor	Transportable fuel
Sensitivity of power production to variation in resource	High	Low	Medium	Transportable fuel
Resource assessment	Complex	Simple	Average	None
Upfront capital (\$/W)	Medium	Med. (prev. high)	Low	Low
O&M (\$/W)	High	Low	Medium	Medium
Fuel costs	None	None	None	High
Modularity	Average	High	Low	Average
Complexity of control system	Average	Simple	Complex	Average
Inverter required for AC?	Yes	Yes	No	No
Civil works	Average	Simple	Complex	Simple
User/operator training requirement	High	Low	High	Average
Susceptibility to environmental hazards	High	Low	Med	Low

Table 1 – Cross-comparison of small wind with the 3 most common small-scale decentralised electrification technologies [2].

Highly variable resource

Compared to solar, far fewer off-grid settlements have sufficient wind resources to justify the installation of SWTs and determining where these places are is more challenging [2], [16]. The wind resource is extremely variable in both space and time. These fluctuations are further magnified, as power production is cubically proportional to the wind resource – **halving solar irradiation halves the power available, halving wind speed leaves just one eighth**. What is more, if there is a choice, most communities tend to settle in forested valleys rather than bare hilltops, which tend to have lower wind resources. Consequently, several pre-installation site visits are usually required to prove that a suitable wind resource exists¹, whilst a desk-study is usually sufficient for solar PV. As a result, in most contexts, the scalability of small wind initiatives is limited. However, vast, windy plains with little vegetation or terrain to obstruct the wind are a notable exception, as the wind resource is high at low hub heights and evenly distributed, making individual site assessments unnecessary.

Limited modularity

Modular technologies can easily be broken down into smaller units, allowing poorer households to start small and gradually increase as their circumstances improve, e.g. solar lantern to solar home system [2]. Solar PV has no moving parts, making it extremely simple and modular, allowing it to reach further into the poorest, most remote and dispersed communities than SWTs. However, the flatter and more open the terrain, the more modular SWTs become, as smaller turbines with shorter towers can be employed on a wider range of sites.

¹ Ideally recording wind speed data at hub height for at least 1 year.

High maintenance requirements

Although manufacturing an SWT is much simpler than a photovoltaic cell, SWTs present more challenges for system design, site selection, transportation, installation and maintenance [2], [17]–[19]. SWTs have many moving parts and by design, sit atop tall towers, exposed to the full force of the weather. As a result, environmental hazards (e.g. lightning strikes, corrosion, hurricanes) all affect SWTs more than solar PV or micro-hydro. Failures are inevitable, necessitating the support of a service network, which is only viable in regions with a critical mass of potential SWT users, however such regions are few and far between due to the high spatial variation in the resource. For local manufacture, producing in low volumes often makes it difficult to achieve the required quality for robust operation.

Box 2: Nicaragua Case Study

On the Caribbean coast of Nicaragua, many SWTs have now been replaced by solar panels, due to poor wind resources and environmental hazards (lightning, corrosion, etc.) causing frequent failures [17]. A lack of access to maintenance services in this remote region resulted in SWTs out of service more often than operational, as although significant efforts had been made to empower community technicians, basic education was limited and most communities can only be reached by a long and expensive boat ride. The lack of wind resources significantly reduced the value that the technology offered to the community, as the little energy they generated was not worth making the journeys for spare parts.

In 2012, a pilot project in the windier, more accessible central highlands was carried out with more comprehensive training to ensure that the community technicians could maintain the system themselves [2], [20]. Productive applications were planned and a community fund set up for maintenance costs.

A market assessment methodology was developed to locate and quantify the potential market for similar systems. However, although Nicaragua has world class wind resources, they are mainly in the highlands (where scalability is limited due to the high spatial variation in the resource) or grid connected regions [21].



Figure 4 – Inspection of the rotor and stator to prevent a potential future failure by the motivated and capable Cuajinicuil technicians. Photo by Jon Leary

Falling cost of solar PV

Whilst the dramatic fall in the price of PV modules has vastly increased the market for both utility-scale and off-grid PV systems, advances made by the big wind industry have not filtered down to the small-scale market to the same extent [22], [23]. 100m diameter wind turbines are fundamentally very different machines to their <5m diameter counterparts and as a result, whilst SWTs used to be more cost-competitive than PV on most sites, the tables have now turned (see Box 3), as investment flows have followed the drive towards solar. Consequently, the small wind market has slowed down significantly [24] and the role of SWTs in rural electrification has shifted towards hybridisation of solar PV, rather than going head to head with other generation sources.

The economics of small scale wind power depend primarily upon the size of the turbine, the wind resource and where/how it is manufactured, installed and maintained. Figure 5 shows that bigger turbines generate cheaper power² and imported turbines are generally more expensive than locally manufactured machines, even when including maintenance costs. However, the wind resource itself has the most dramatic effect on the unit cost of electricity (due to the cubic relationship between power production and wind speed).

The wind turbine/tower and/or solar panels are only a small fraction (1/3) of the total capex of a PV/wind system. The battery bank (1/3) and power electronics (1/3) are equally sizeable investments. Maintenance costs are high for SWTs and over a 15 year lifespan can total as much as the capital costs [2], [5], [18], [25], however the need for maintenance services to be available locally can open up new livelihood opportunities. In fact, on remote sites with untrained users and significant environmental hazards, O&M costs can easily exceed initial investment, as downtime can uptime (see Box 2).

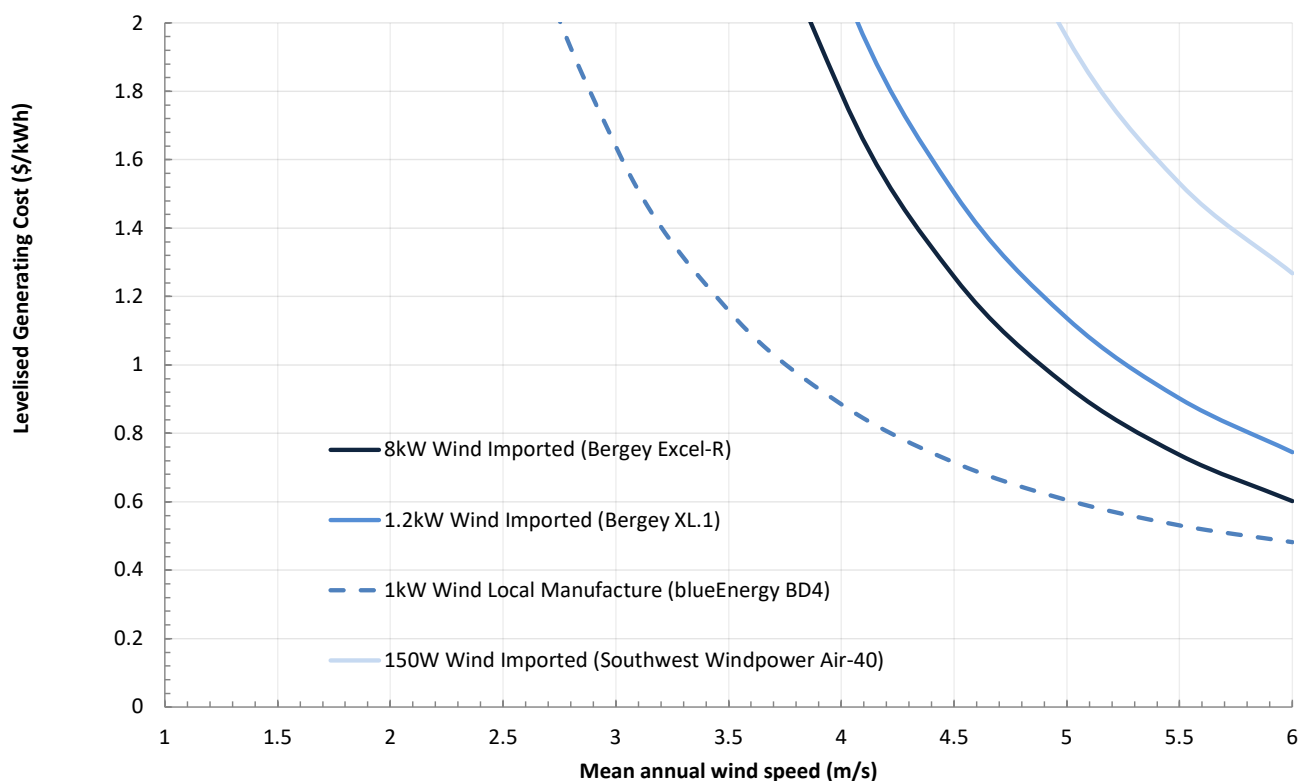


Figure 5 – Influence of turbine size, manufacturing type and wind resource on the unit cost of electricity in Nicaragua in 2012 (see [2] for modelling assumptions).

² SWT power production scales with the square of the radius, whilst the costs increase linearly.

Box 3: Argentina and Falkland Islands/Islas Malvinas Case Studies

The powerful winds that whip around the Southern Ocean create some of the most favourable conditions for wind power generation anywhere in the world. The vast steppe landscapes of the Falkland Islands and Argentina's Chubut province offer high and evenly distributed winds at low hub heights [26]–[29]. In both regions, many sheep farming households (HHs) are too remote for grid connection, leaving decentralised power generation as the only viable option [30], [31].

In Argentina's Chubut province, the 1,500 HWS installed under the PERMER (Renewable Energy for Rural Markets) programme from 2008–2010 soon fell into disrepair [18], [25], [32]. The state retained ownership of the systems and only symbolic payments were collected from the untrained users. Consequently, the centralised system for maintaining the remote decentralised power generation equipment fell apart when external funding was withdrawn, leaving users literally and metaphorically powerless.

85% of Falkland Island farms now use wind-diesel hybrid systems [18], [25]. Stable institutional support from the FIDC (Falkland Islands Development Corporation) since the 1990s enabled the sustainable growth of a small wind ecosystem with a decentralized maintenance network firmly embedded within rural society. A 2-stage subsidy targeted diesel generation's weaknesses: firstly a 24h power battery/inverter system (@50%), then a SWT to reduce fuel consumption (@70%).

However, even in the virtually ideal high wind, low solar context of the Falklands, PV is increasingly attractive [18], [25]. In 1997, the retail price of a 2.5kW Proven/Kingspan SWT could only buy 1.8kW of PV, but by 2012 it could buy 12kW. What is more, a PV array is likely to have few substantial maintenance costs for 20 years, whilst an SWT requires an annual service plus spare parts. However, the solar resource dips to almost nothing in the winter, whilst the wind resource is high all year round, highlighting the value of hybridisation.



Figure 6 – a) A commercial maintenance team in the Falklands carries out a routine annual service on one of the islands' many SWTs (left); and b) a SWT stands still in remote rural Patagonia after the blades fell off and the state-run centralised maintenance team were unable to send anybody to fix it (right). Photos by Jon Leary.

WHERE CAN SMALL WIND CONTRIBUTE SUSTAINABLY TO RURAL ELECTRIFICATION?

One way to overcome many of the barriers facing small wind is to focus on the most viable contexts: off-grid regions with high and consistent wind resources (seasonally and spatially) where small wind electrification programmes can easily be scaled up. To facilitate this process, Sumanik-Leary [2] investigated the critical factors in small wind electrification to develop the decision support tree in Figure 7. In promising regions, a full market assessment can then determine how scalable the technology is and which targeted interventions can help achieve this potential [9], [21], [33].

Alsop et al. [16] used MCDA (Multi-Criteria Decision Analysis) techniques to identify scalable regions for SWTs by comparing specific Global South nations with the ideal context proposed by Sumanik-Leary [2]. The results suggest that future small wind development programmes should focus on Mongolia, South Africa, Western Sahara, Chad, Argentina and other high scoring nations (Figure 8). This national scale study focussed on scalability and therefore many other countries may also have isolated pockets of high potential for small wind.

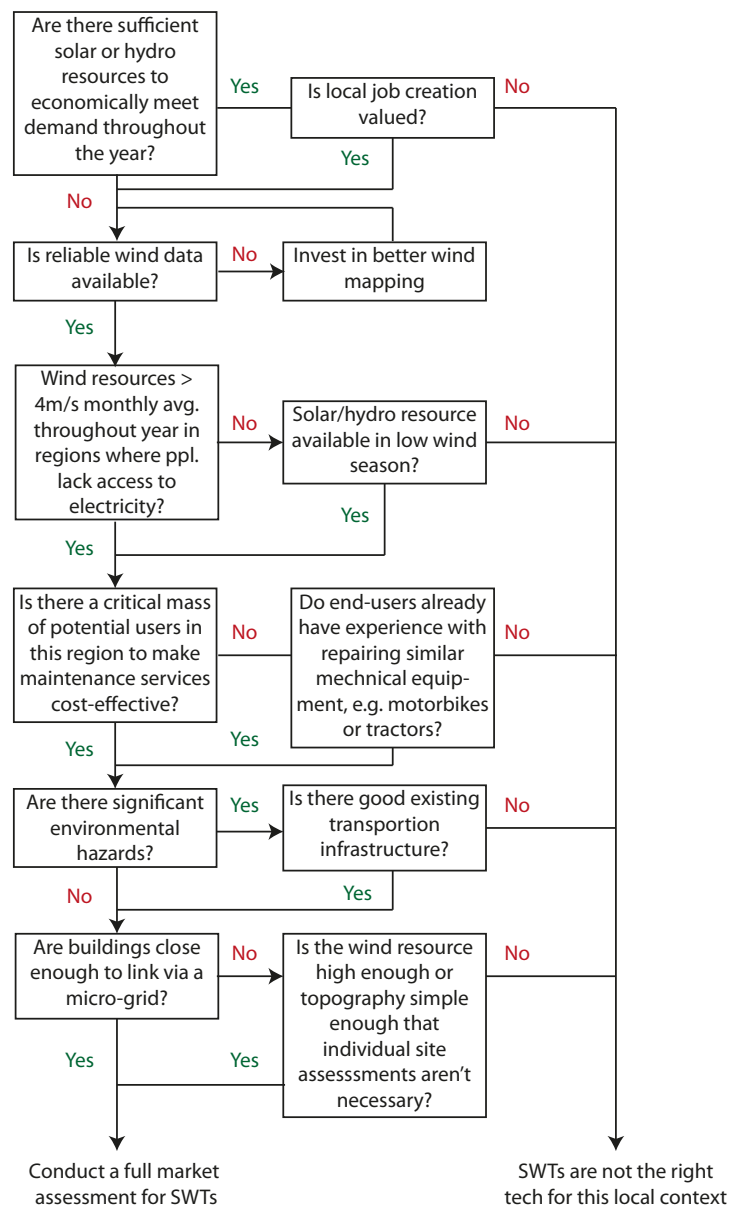


Figure 7 – Decision support tree for the identification for of viable regions for SWT electrification programmes [2].

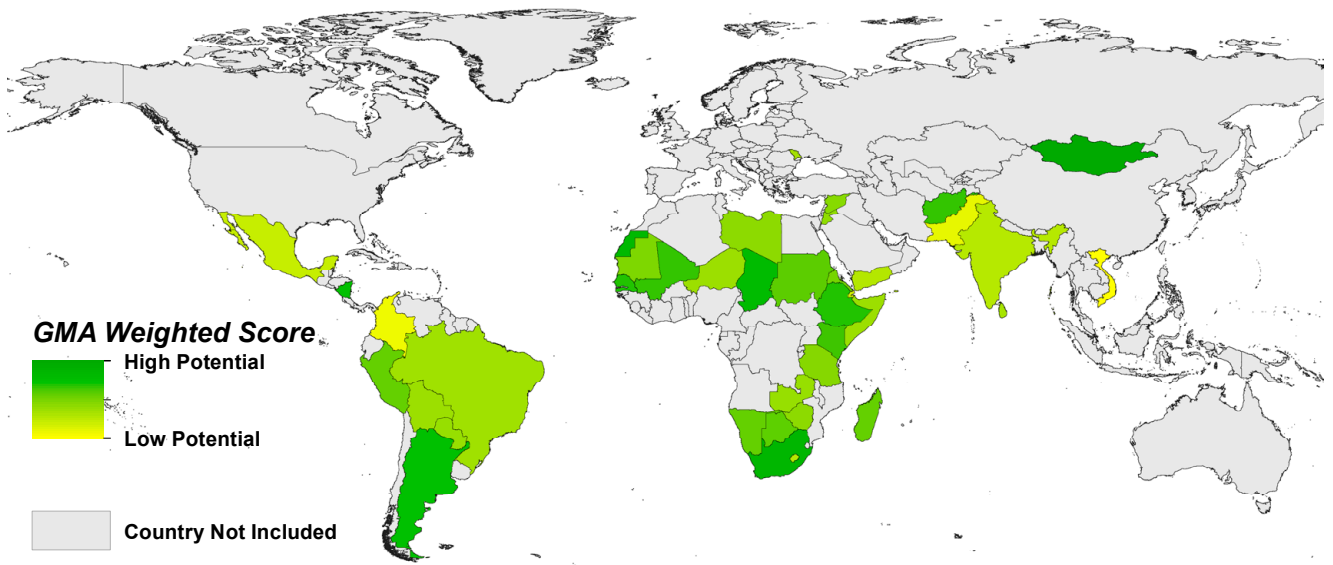
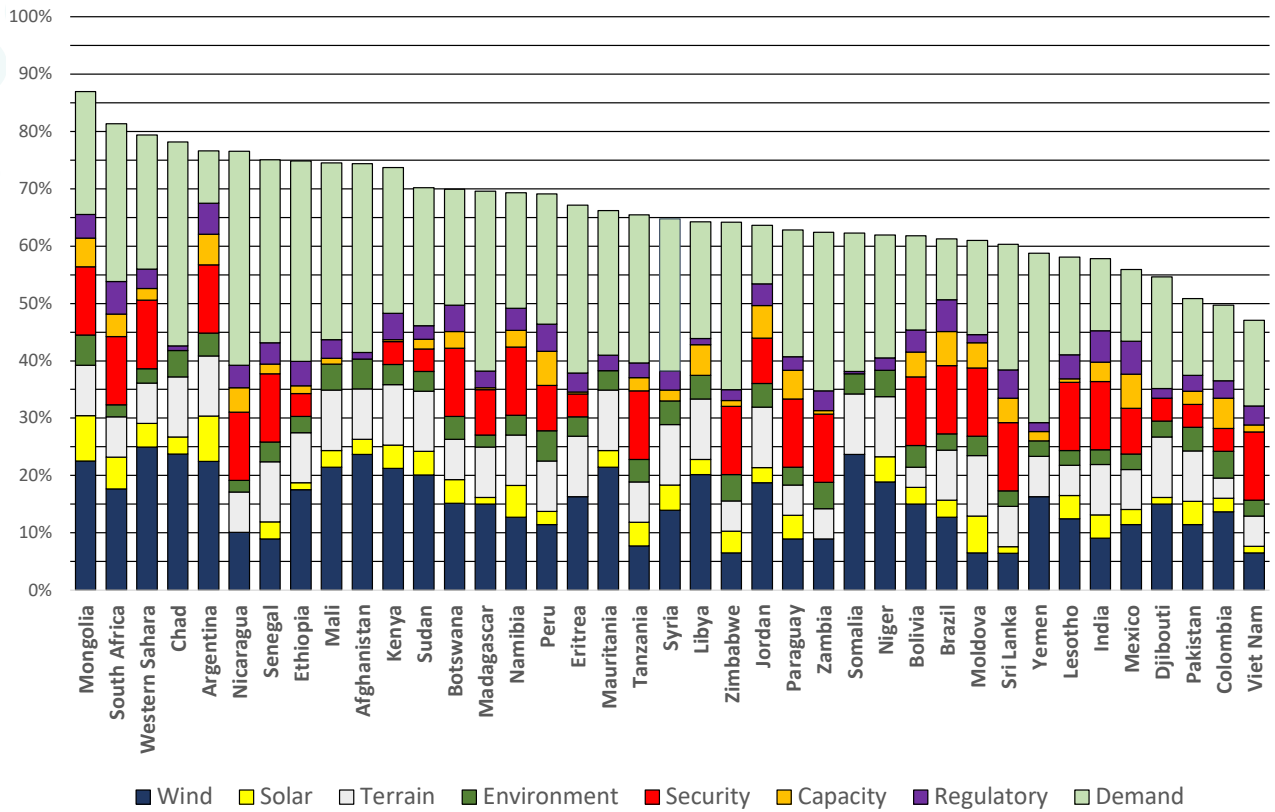


Figure 8 – a) Histogram (above) and b) choropleth map (below) indicating the viability of small wind as a technological option in rural electrification programs in relevant Global South contexts [16].

HOW CAN SMALL WIND CONTRIBUTE SUSTAINABLY TO RURAL ELECTRIFICATION?

In favourable, high wind regions, the major barrier facing small wind is maintenance. High winds offer high energy yields, but also greatly increase wear on SWTs, meaning that only the most robust machines survive. Without the support of a decentralised maintenance network, the lower initial purchase costs of less robust machines are a false economy, as maintenance costs can quickly spiral out of control after the first big storm hits [17], [18], [25].

Once the reputation of the technology is damaged, it can be very difficult to change perceptions. As a result, small wind electrification programmes must be planned with maintenance as the core priority, rather than an afterthought. However, whilst maintenance services increase the total cost of the energy service, they also create local livelihood and capacity building opportunities.

Institutional support and local champions

Strong and consistent institutional support is required to empower local champions and foster the sustainable growth of a small wind industry [12], [14], [18] with developmental goals that go beyond access to energy, encompassing local livelihoods and capacity building. Local champions adapt generic wind power knowledge to their specific context by identifying and tackling context-specific barriers [2], [18], specifically by:

1. carrying out well-targeted feasibility studies;
2. demonstrating and piloting appropriate equipment;
3. establishing a decentralised maintenance network; and
4. creating effective feedback loops from the field to programme designers and manufacturers.

The installation of a SWT is just one step in a long journey towards creating sustainable energy infrastructure in an off-grid region. Maintenance services must be available locally for when something inevitably breaks and each system must continually evolve to meet its user's needs. Standardisation of system components can significantly streamline manufacture, installation and maintenance, but local champions should advise users on how to get the most out of their system by optimising their practices and/or upgrading when necessary. They must be familiar with rural life, so that users are comfortable approaching them and their advice is compatible with local practices.

Decentralised maintenance network

Employing SWTs in locations where long distances must be travelled to obtain maintenance services is likely to result in unsustainably high maintenance costs, downtimes and environmental impacts [4], [17]–[19]. In remote regions, a decentralised maintenance network must be established to ensure technical knowledge, tools and spare parts are available locally. This can be achieved by empowering end-users and community technicians to carry out as much maintenance as they are able/willing to through ownership of the equipment, basic training and establishing service centres in each local area (see Box 1).

Manufacturing SWTs locally not only supports the establishment of such a network by building local technical capacity and establishing supply chains, but also provides valuable new livelihood opportunities. Partnering with established organisations that have links with rural people and relevant technical capacity (e.g. telecoms/power cooperatives) can offer a solid foundation for such a network.

Hybrid systems

Hybridisation can greatly increase the resilience of wind power systems, as SWTs are notoriously unreliable and the wind resource is extremely variable (in both space and time, even in high wind regions) [2], [15], [33]. The dramatic fall in global PV prices means that even in regions of low solar resource, it would now be difficult to justify not including at least a small percentage of PV in every small wind system. The battery bank is the most expensive component in a PV/wind system and extended deep discharges can greatly reduce its lifespan. Many HHs/communities will already own (or at least have access to) a generator, but access to and the cost of fuel may be challenging, creating an opportunity for wind/diesel hybridisation. Small wind programmes should be designed to build upon this existing fossil-based infrastructure by addressing its weaknesses (ongoing fuel requirements and poor efficiency at low load), rather than attempting to totally replace it [18].

Sustainable business models

The ongoing costs of maintaining SWTs and the increasing availability of modular solar solutions (e.g. solar lanterns) for basic HH needs implies that the role of small wind is likely to shift towards strengthening larger systems with productive applications and hybridisation [34]. Such systems typically have a higher power demand and the skills/tools to carry out basic repairs are more likely to be available.

Whilst pay-as-you-go solutions have rapidly scaled solar in the Global South, the hybridisation of mini-grids presents a key opportunity to integrate small wind into this scalable business model. A community technician will also likely be on hand and the scope for finding an open/hilltop site with good wind resource increases.

Market assessments should categorise HHs/communities within the target region and match them with a series of tried and tested system architectures [9], [16], [21], [33]. For example, 100W PV systems for very remote HHs with low technical capacity and energy demand; 1kW PV-wind-diesel hybrid mini-grids for more technically capable and accessible HHs in close proximity, with productive activities and a good wind resource, etc. Important factors include:

- priority energy services and intended patterns of use (HH size, key livelihoods, etc.);
- physical proximity and social relationships with neighbouring HHs;
- ability and willingness to pay for initial purchase and maintenance costs;
- existing energy infrastructure and compatibility with wind power;
- ease of access to a maintenance network (both physically and remotely);
- willingness and capacity to carry out maintenance themselves; and
- wind, solar and hydro resources available on site:
 - excessively windy/turbulent sites increase maintenance requirements,
 - low wind sites offer disappointing energy yields,
 - compatible resources increase the value of hybridisation.



CONCLUSION

This briefing paper has summarised the role of small wind in the power generation mix of windy and remote developing regions. The combination of high maintenance requirements with the extreme variability of the wind resource itself implies that in most scenarios, wind can no longer compete with solar PV; however, in the right context it can offer a valuable complement, bringing diversity in power generation sources and the potential for local manufacture. The need for battery storage makes the unit cost of the electricity from PV/wind systems significantly higher than micro-hydro, however the relative price points are dynamic, so to find the least cost solution for a particular context, current PV, SWTs and battery storage costs should be continually reviewed, ensuring that maintenance costs are properly accounted for.

The niche contexts where SWTs can play the biggest role in bringing energy services to remote regions have high and evenly distributed wind resources, and solar and hydro resources that are not able to meet demand throughout the year alone. A prime example is the vast, arid and sparsely vegetated plains of Argentine Patagonia in the cold and windy southern tip of Latin America. In such favourable contexts, market assessments can identify the contribution small wind can make and provide a roadmap to achieve this. Local champions have a key role to play in realising this potential by finding locally appropriate solutions to adapt generic SWT technology to the unique challenges and opportunities of their local context.

To contribute to the sustainable development of remote, high wind regions, small wind electrification programmes must be planned with maintenance as the core priority. Relying solely on SWTs for electricity generation is not recommended, however they can contribute to the sustainability of rural electrification initiatives by increasing the resilience of PV systems, and/or supporting diesel/petrol systems by reducing fuel costs and offering 24h power. End-users and community technicians should be empowered to carry out as much maintenance as possible by developing ownership, offering basic technical training that integrates maintenance practices with local ways of life and the support of a decentralised maintenance network. A key constraint on the scalability of SWT electrification programmes is reaching a critical mass of potential users in any given region to enable the establishment of such a network. In practice, this is often limited by the availability of the wind resource, which is often concentrated in small patches, emphasising the importance of market assessments to identify regions with high and evenly distributed wind resources and other pre-conditions for scalability.

Local manufacture can not only support the creation of decentralised maintenance networks, but can also offer significant economic, social and environmental advantages over importing commercial SWTs into remote areas. However, strong and stable institutional support is necessary to foster the development of a sustainable small wind industry. New manufacturers/suppliers require experience before they can produce reliable machines/systems, which can be supported through the development of effective feedback loops from end-users to ensure the continual redesign of the product/service to better meet their needs/aspirations.

Finally, even in the most viable regions, each community/HH should be individually assessed to determine whether an SWT is right for them. Isolated HHs with limited technical capacity, low power demand and scarce financial resources may well be much happier, with a simple and reliable solar lantern.

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