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ISSUE BRIEF

Scaling up small wind turbines in India

Barriers and options for the way forward

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Issue briefs focus on policy issues, and clearly draw out the implications of existing evidence for decision-makers.

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HIGHLIGHTS

- Small wind turbines (SWTs) are a distributed renewable energy generation technology. After experiencing initial growth starting in 2010, their uptake has been declining in India since 2017, when subsidies were discontinued.
- This issue brief analyzes the literature on SWTs, gathers insights from multiple roundtable stakeholder consultations on the challenges to their uptake, and provides options to help them scale up in India.
- The stakeholder consultations revealed various reasons for the decline of SWTs, such as the lack of mapping studies, maintenance issues, the lack of standardization and quality control, limited awareness, limited policies and business models, the preference for solar energy, higher costs, and difficulties in testing and certification.
- Collaboration between SWT manufacturers and the formation of consortia appear to be the best way forward. Resource mapping is needed to site SWTs and build awareness by showcasing data from successful projects.
- Exploring alternative revenue streams and financial incentives, implementing application-based installation, and adopting suitable business models can reduce costs. Integrating SWTs into hybrid systems can help them scale.
- Access to test facilities and improvised data acquisition and sharing can enhance research-and-development and certification timelines. Inclusive policies are required that promote connection of SWTs to grids.
- In addition to regular campaigns, inclusion of SWT-specific modules in existing training programs can improve skilling and awareness.

EXECUTIVE SUMMARY

Context

Small wind turbines (SWTs) are an adaptable and flexible option for the generation of renewable electricity. They can be sited at locations with a reasonable wind resource that are unsuitable for large wind projects. SWTs, whether operating individually or as hybrids, are also classified as distributed renewable energy generation (DREG) systems. Hence, in addition to improving the utilization of wind and expanding renewable capacity in line with the 2030 500 GW targets (PIB Delhi 2021), SWTs can also support the Indian government's plans to promote DREG for livelihood applications and contribute toward distributed renewable purchase obligation (RPO) targets.

As of January 2024, India had a cumulative capacity of over 44 GW of large onshore wind installations, behind China, the United States, and Germany, which had 441, 148, and 69 GW, respectively (IRENA 2024). However, the installed capacity of SWTs and small wind-solar hybrid systems in India is only about 3.3–5 MW (MNRE 2019), in contrast to China and the United States, which have installed capacities of 704 MW and 156 MW, respectively (US DOE 2023). Wind-rich states such as Tamil Nadu, Gujarat, and Karnataka, which have large utility-scale wind farms and considerable experience in implementing wind power projects, do not have a proportional number of small wind installations. The installed capacity of small wind systems in Tamil Nadu is only about 257 kW, and the situation in other wind-rich states is similar (e.g., Gujarat 20 kW, Karnataka 39 kW) (MNRE 2019).

Multiple reasons hinder the growth of SWTs in India and limit scale-up of the technology. The potential for SWTs in India is quite large. Although an accurate figure is not available, the World Institute of Sustainable Energy estimates the potential at about 83 GW (WISE 2009), and Kumar et al. (2022) estimate the potential for SWTs in the state of Tamil Nadu alone to be nearly 4 GW. An in-depth understanding of the issues preventing SWT scale-up is necessary. Examining some interventions that could mitigate or overcome these barriers could prove to be a useful exercise.

About this issue brief

This issue brief provides insights into the barriers that prevent large-scale adoption of SWTs in India and describes the interventions that are likely to mitigate or overcome these barriers. The paper first sets the stage with an overview of the current landscape of SWTs in India and their applications, using literature surveys, stakeholder consultations, and roundtable discussions to achieve these goals.

Key overall findings

- Unlike larger turbines, SWTs have multiple applications and benefits. In particular, they can be sited near energy demand centers and operated as either grid-connected or stand-alone units. They also offer benefits in hybrid mode, particularly when coupled with solar photovoltaics (PVs), due to the complementary nature of the seasonal and diurnal availability of wind and solar energy.
- Due to their smaller capacities and operational parameters, they can be classified as distributed renewable energy (DRE) options and promoted for livelihood and other applications under related government schemes. They can also be used to meet RPO requirements from DRE sources; in addition, they improve wind resource utilization and contribute to national and state-level renewable and emission reduction targets.
- The International Electrotechnical Commission (IEC) defines SWTs on the basis of rotor swept area and operational voltages, which generally correspond to turbines with a maximum power rating of 50 kW. However, based on previous policies and schemes in India, turbines up to a capacity of 100 kW are classified as “small.” Typical SWT capacities in India lie between 500 W and 10 kW. The “XIVth List for the Empanelment of Small Wind Turbines” released in 2016 by the National Institute of Wind Energy (NIWE) contained 13 SWT models from seven manufacturers (CECL 2020; NIWE 2016). Currently, there are about 20 SWT suppliers in India.
- SWTs in India were initially imported and installed. During 2014–17, driven by central schemes and the provision of subsidies, there was a greater push for SWTs. This period saw machines being manufactured in India under license from foreign companies.

- After 2017, when subsidies were discontinued, the market shifted: Only the most efficient wind turbines prevailed, and these were limited to specific use cases in select areas. Since then, growth has been slow.
- The cumulative installed capacity of SWTs and SWT hybrids in India, which is about 3.3–5 MW, is low compared with that of other countries with large installations of utility-scale wind turbines. Studies indicate that the potential for growth is high; however, data regarding the overall potential of SWTs across the country are limited.
- Multiple reasons hinder the uptake of SWTs in India. Many of these issues can be addressed through interventions and actions, as discussed in the following sections.

Key barriers

- Comprehensive resource mapping studies that highlight suitable areas and pinpoint locations for SWT installation are limited. Only macro-level studies and wind resource maps are available currently, for example, the 20-m wind potential map by the NIWE (CECL 2020; NIWE n.d.-c).
- The inadequate dealer network, difficulty of accessing remote SWTs for maintenance, and lack of suitable human resources are major challenges affecting existing installations.
- Turbines, components, installation, and maintenance processes require standardization.
- The cost of production is rising, driven by the higher prices of metals (e.g., copper) and composites and import duties on certain components.
- There is a limited choice of business models and innovative go-to-market strategies for SWTs.
- National policies and schemes for SWTs have lapsed, limiting subsidies and incentives.
- The difficulty of obtaining grid connectivity for those aiming to install and operate SWTs is another issue. This is because SWTs are not explicitly included as a renewable option in many of the existing policies and schemes, lack of awareness being one of the reasons for this omission.
- Stakeholders have pointed out that potential end users and the public lack awareness regarding SWTs, and there is resistance to experimenting with new technologies. Testing and certification of new SWT models is currently time consuming and expensive.

Recommendations for key interventions

Resource mapping

A strong consensus emerges from our research and interviews: Granular mapping of resource availability, which should identify ideal locations for SWTs, is essential. The initial efforts could focus on these areas, facilitating successful projects and generating data, learning, and know-how that can be used for further development. Wind measurements and resource estimations in urban areas and built environments should also be conducted to identify suitable SWT locations. The resource mapping study can also identify locations where SWTs may be more viable than solar PVs. Government agencies such as the NIWE can facilitate such studies.

Collaboration and network building

Collaboration between SWT manufacturers is key, along with the formation of consortia for sharing knowledge and resources. These consortia can initially focus on developing SWT projects in regions where SWTs are a good fit due to optimal wind resource and other factors. Later, they can use this learning and experience to develop further projects. This process could also improve awareness of SWTs and their benefits among the public and stakeholders.

Challenges related to maintenance and servicing need to be addressed. Manufacturers should be part of a dealer network or consortium and share resources and expertise. The SWT consortium can train and certify personnel for servicing similar machines from different original equipment manufacturers (OEMs).

The existing manufacturing bases for SWTs and related components, in locations such as Pune, Coimbatore, and Gujarat, can be leveraged.

A committee can be formed with stakeholders such as government officials from both the Ministry of New and Renewable Energy (MNRE) and state nodal agencies, small wind suppliers, telecom companies, users, structural engineers, urban city planners, and other experts for brainstorming, capacity-building, and problem solving in a timely manner.

Technical factors

Well-designed, optimized rotors and standardized components need to be produced with strict quality control measures. Greater research and development (R&D) efforts by SWT manufacturers, start-ups, and research institutes can facilitate the achievement of this goal.

Standardization of data acquisition systems facilitates real-time monitoring of SWT systems. Such systems could enable the collection of reliable, tamper-proof data that could be shared with agencies to minimize testing and empanelment requirements, or the data could be used in distributed renewable energy certificate (DREC) applications.

Economic factors

To reduce the cost of ownership, the usage of non-power-producing components (towers, mounting structures, etc.) in an SWT installation should be optimally designed or planned. Using existing tall towers and structures to offset the need for a support tower is one example of such an approach. Another example of such an approach is minimizing the use of cranes and heavy machinery. To achieve this, the costs could be distributed over a larger project with many turbines, or the turbine could be pre-installed onto a tower hinged on the ground and then the tower raised using pulleys and cables. Support towers could be used to display banner advertisements, which is another method of reducing the overall cost of ownership and minimizing the payback period through additional revenue generation. The potential benefits of operating SWTs in hybrid mode, such as resource optimization and reduced energy storage requirements, should also be explored.

Government stakeholders, the industry, and financial institutions can work together to develop suitable business models for developing SWT projects. Financial institutions can ease the process of granting loans to project developers, end users, and individual consumers aiming to set up SWTs. DRECs can be explored for promoting SWTs. DRECs are emerging as a powerful tool to support DRE in emerging markets, and corporate procurement teams use it as a flexible tool to support DRE projects. Stakeholders also pointed out that corporates are willing to pay premiums for DRECs, which can be leveraged for the development of SWT projects. Goods and Service Tax (GST) exemptions and import duty reductions for required components could be considered for domestic

manufacturers, and limited-period import duty waivers could be considered in order to bring internationally popular models into the Indian market.

Awareness

Awareness of SWTs and their benefits is low among government stakeholders, the general public, industry, and other potential end users. For government stakeholders, data-driven sensitization can help, and for the general public and other stakeholders, regular awareness campaigns, training programs, and workshops could be beneficial. Nodal agencies such as the NIWE and state nodal agencies can facilitate dedicated departments and budgets together with stakeholder discussions to understand issues and implement SWTs for specific applications.

Policy

Showcasing data from successful installations and working closely with stakeholders to raise their awareness is essential. These efforts can help improve the inclusion of SWTs in policies and schemes such as existing rooftop solar schemes and net metering or virtual net-metering arrangements.

States' distribution grid codes have gaps that need to be revised with definitions of production and control functions. These gaps need to be addressed by providing greater clarity and including information pertaining to connecting renewable energy generation options such as small wind, power injection to the grid, details of transformers, and the capacities that can be connected to the grid.

Training and skilling

Existing wind-related courses can incorporate a small-wind-specific module. Courses offered by the NIWE, such as Vayumitra, can include a small-wind-specific module. More training programs need to be developed, and personnel need to be trained to service the various types of machines that are available on the market. Vocational training programs in academic institutions and diploma courses or certifications can also be developed in this regard. Local training modules for technicians should also be developed. Suitable manuals, operator's handbooks, and other materials need to be developed, and government nodal agencies can work with SWT manufacturers and suppliers to develop these.

Testing and certification

The time and costs involved in testing new SWT models are high and need to be reduced. Testing and certification by the NIWE takes about a year and costs about INR 6 lakhs. Access to test facilities, such as wind tunnels, where SWTs can be tested under controlled conditions needs to be improved. Mobile field-testing laboratories using vehicles with equipment and instrumentation could also be considered. To fast-track the certification process of new models, nodal agencies should explore sharing real-time, tamper-proof data directly with the NIWE from active installations as an alternative. This data sharing can preclude or further reduce scrutiny by the NIWE, which will improve the certification timelines. R&D and technology grants can also assist this process.

Note: The numbering system followed in this working paper is the Indian numbering system. Typical values used are lakhs (1 lakh = 100,000) and crores (1 crore = 10 million).

INTRODUCTION

Rationale

Small wind turbines (SWTs), an adaptable and flexible option for the generation of renewable electricity, are used in farmhouses, remote areas, rural areas, telecommunication towers, houses, tall buildings, coastal areas, offshore platforms, and yachts (Kumar et al. 2022). SWTs are easier to install and operate than their larger counterparts and are located near load centers; that is, areas of energy demand. They can also be sited at locations with a reasonable wind resource that are geographically unsuitable for large wind projects due to terrain-related, logistic, or infrastructure-related constraints (Kumar et al. 2022).

As of 2010, about 650,000 SWTs were installed globally, with a total installed capacity of 443 MW (Pitteloud and Gsänger 2017). By 2015, this had increased to 990,000 units and 949 MW of total capacity. The installed capacity as of 2022 is estimated at 1.89 GW, mainly from installations in China (704.32 MW), Denmark (611.09 MW), Italy (200.78 MW), the United States (156.77 MW), and the United Kingdom (141.51 MW). Other countries accounted for the remaining 84.24 MW, with significant contributions from Germany (39.75 MW), Canada (13.47 MW), Japan (12.88 MW), and Argentina (6.5 MW) (US DOE 2023).

SWTs can be used as both stand-alone and grid-connected units. SWTs also find application in hybrid systems, where energy is drawn from multiple sources to address the power requirement. SWTs are also classified as distributed renewable energy generation (DREG) systems due to their operational parameters (Kumar et al. 2022; WINDEXchange n.d.). DREG systems can provide reliable electricity supply to consumers in remote locations and greater overall energy security. SWTs can also help meet the 2030 renewable and emission reduction targets set by the Government of India (GoI). Last but not least, SWTs are generally not burdened with many of the issues associated with expanding large wind farms, such as land availability and acquisition, environmental concerns, the need for extensive micro-siting studies, and logistic and infrastructure requirements.

SWTs functioning as DREG systems can also support the GoI's plans to promote DREG for livelihood applications. In 2022, the GoI released the Framework for Promotion of Decentralized Renewable Energy for Livelihood applications (MNRE 2022). The aim of the policy is to scale up the currently available DRE livelihood applications and support the development of new DRE livelihood applications. The policy defines DRE livelihood applications as those powered by renewable energy (RE)—solar, wind, micro-hydro, biomass, and their combinations—that are directly used for earning livelihoods. SWTs are well placed to facilitate this aim because of their lower operational voltages, ability to integrate well with other renewable sources to form hybrids, proximity to energy demand locations, and their ability to be used by individuals or a community for electricity generation or applications such as grinding grain or pumping water. The GoI has also specified renewable purchase obligation (RPO) targets, specifically from DRE sources (Ministry of Power 2023).

India is a leader in large onshore utility-scale wind installations, with a cumulative capacity of over 46 GW as of June 2024. However, this is not the case with small wind installations. The installed capacity of SWTs and small wind-solar hybrid systems in India is about 3.3 MW (MNRE 2019), mainly from installations that have claimed central financial assistance. However, some projects did not take the subsidy route. Stakeholders estimate the volume of such installations to be almost equal to that of subsidy-based projects. However, data on such installations are limited. Certain sources estimate the current capacity to be about 5 MW (US DOE 2023). In India, windy states, such as Tamil Nadu, Gujarat, and

Karnataka, with large wind farms and experience in the execution of renewable projects do not have a proportional number of small wind installations. The installed capacity of SWTs and wind–solar hybrids in Tamil Nadu is only about 257 kW (MNRE 2019). SWT installations in other wind-rich states such as Gujarat and Karnataka amount to only 20 kW and 39 kW, respectively, based on data from installations that have claimed subsidies. These are mainly restricted to pilot projects, and scaling up has been limited.

The potential for SWTs in India is large, and although precise estimates are not available, the World Institute of Sustainable Energy (WISE) estimates the potential to be approximately 83 GW (WISE 2009). In addition, the SWT potential for Tamil Nadu alone has been estimated at 4 GW (Kumar et al. 2022). This capacity enhancement potential could bring social benefits derived from creating electricity access and decentralized energy generation for livelihood applications.

Yet, for many reasons, the popularity of SWTs in India is low, and as stated above, scaling up has been limited.

Literature review: SWTs in India

A detailed overview of the global small wind energy scenario as of 2017 is presented by Pitteloud and Gsänger (2017). The report details the installed capacity in different countries as of 2017 and also estimates the future market growth of the sector. The information presented is useful for understanding global installed capacities and the historical growth of the sector. However, the report does not address the methods certain countries have used to achieve higher deployment of SWTs. It also provides no insights into why SWTs have not seen a higher uptake in India. This issue brief aims to address this gap.

Roy et al. (2013) provide a preliminary understanding of the challenges to the uptake of SWTs in India. The large variations between the manufacturer-specified energy yield estimates and the actual yield from the SWTs, along with the low capacity factors observed, are highlighted as major technological issues. However, the paper points out that the data and conclusions could also be affected by site-specific issues with the wind resource at the turbine location. Because this publication is outdated, it is necessary to revisit the topic by considering the developments over the last 10 years.

Kumar et al. (2022) mapped the different regions, areas, and clusters in Tamil Nadu where SWTs could be a suitable option. Approximately 6.25 percent (250 kW) of the total estimated potential for SWT has been harnessed in the state. The publication highlights the considerable potential of, various use cases, and applications of SWTs in the country. As with Roy et al. (2013), Kumar et al. (2022) does not explore barriers to the adoption of SWTs in detail, nor does it suggest any options to mitigate the barriers.

In many countries, the economics of SWTs in the absence of targeted financial incentives is a significant barrier that hinders its wider deployment. The capital investment required depends on the specific turbines used, with SWTs having a high levelized cost of electricity. The siting of these turbines has a far higher impact on the annual energy generation of SWTs than on that of large wind turbine rotors. Therefore, the financial viability of SWT deployment is highly dependent on country-specific incentives (Bianchini et al. 2022).

Our literature review indicates that very few studies to date examine the barriers to scaling up SWTs in India.

Research questions and methodology

This issue brief addresses the following questions:

- What are the barriers to large-scale adoption of SWTs in India?
- What interventions are required to mitigate or overcome these barriers?

The methodology followed for the research is as follows:

- We reviewed the literature to map the current situation in the small wind sector in India in terms of installed capacities, available manufacturers and turbine models, technologies used, available schemes, and related policies. This mapping also documents current and past central and state policies pertaining to small wind energy, their implications, expected growth, and challenges.
- We conducted both formal consultations and informal discussions with government officials, project developers, think tanks and civil society organizations (CSOs), academia, community users, the Indian Small Wind Association, and small wind manufacturers

to gain a deeper understanding of SWT challenges. Consultations were conducted over a period of two years (2021 and 2022) and primarily took the form of one-to-one online meetings. The meetings were open-ended but guided by questions pertaining to the small wind sector.

- Roundtable discussions were held with stakeholders to understand the challenges, options, and the way forward for the small wind sector. Two roundtable discussions, one each in 2022 and 2023, were organized with participation from small wind developers, small wind start-ups, members of the Indian Small Wind Association, community small wind programs, government stakeholders, think tanks, and CSOs. The discussions on SWT technology covered aspects such as trends, innovations, gaps, issues, and benefits; gaps in state and national policies; incentives and interventions required; challenges faced by stakeholders; benefits of adoption; and successful applications.
- The first 2.5-hour roundtable discussion was organized on October 25, 2022, in Delhi and involved 14 participants (Appendix A, Tables A-1 and A-2). The aim of the discussion was to deliberate on the potential for small wind energy in India, the technologies available, and policy gaps. The second 2.5-hour roundtable discussion was organized on April 18, 2023, in Chennai (Appendix A, Tables A-3 and A-4). The discussion aimed to build on the first roundtable. It discussed the need for accelerated testing facilities, innovative approaches to approval, and standardization of SWT components. It also covered methods for addressing skill gaps in SWT implementation and operations and maintenance, and tried to formulate recommendations for policies and investments together with programmatic approaches to support the scaling up of SWT adoption in India. The second roundtable discussion had 20 participants. See Appendix A for details of the roundtable discussions.
- The data gathered from these different sources were analyzed by the authors. Information repeated by multiple stakeholders, and thus deemed to be relevant and significant, was identified. This information was then broadly categorized and arranged in order of priority, based on the authors' experience.

SWTs IN INDIA

Overview of the technology

The International Electrotechnical Commission standard IEC 61400-2:2013 defines SWTs as wind power plants that have a rotor swept area greater than or equal to 200 m², generating electricity at voltages below 1,000 V AC or 1,500 V DC for both on-grid and off-grid applications (IEC 2013). This specification approximately corresponds to turbines with a rated power of less than 50 kW. SWTs may be further classified based on parameters such as rated power, and the position of the rotor with respect to the oncoming wind (Wood 2013). Other classifications are based on the axis of rotation, rotor placement, and the type of force causing the rotation. More details are provided in Appendix B and Table B-1.

SWTs are used for many different applications across the world, working as both on-grid and off-grid systems. In on-grid systems, the turbine generates electricity, which is in turn supplied to the grid. In off-grid and decentralized systems, SWTs can be divided into two broad categories: mechanical power and electricity generation. The mechanical power from SWTs is used for pumping water, grinding grain, and other agricultural applications. In the electricity generation category, SWTs find application in the illumination of common spaces, water treatment and desalination, cooking, refrigeration, residential applications, remote housing power, heating and cooling systems, telecom towers, and coastal and marine applications. Figure 1 shows a schematic of the different applications of SWTs. The data gathered from these different sources were analyzed by the authors. Information repeated by multiple stakeholders, and thus deemed to be relevant and significant, was identified. This information was then broadly categorized and arranged in order of priority, based on the authors' experience. Unlike utility-wind projects, detailed wind resource assessment studies are rarely conducted before the construction of SWTs because of the smaller scale of operation and the associated cost constraints. Another difference is that utility-scale projects can be sited at locations with the best wind resource, far away from actual electricity demand centers, with the generated electricity being supplied to the grid. The preferred sites for installation of SWTs are close to the energy demand centers.

Figure 1. Typical applications of small wind turbines in India



Note: DG = diesel generator. PVs = photovoltaics. SWT = small wind turbine.

Source: Literature review and stakeholder consultations.

Status of installations and policies

The installed capacity of SWTs and small wind–solar hybrid systems in India is estimated as 3.3–5 MW (MNRE 2019; US DOE 2023). Appendix C, Table C-1, gives the state-wise breakdown of installed capacities, mainly from installations that have claimed central financial assistance.

Based on the scheme for the promotion of small wind energy and hybrid systems by the Ministry of New and Renewable Energy (MNRE), wind turbines up to a rated capacity of 100 kW can be considered small. According to information from the latest “Revised List of Models & Manufacturers” (RLMMs), utility-scale wind turbines have capacities greater than 225 kW (MNRE 2024). Hence, there is also a need for greater clarity on the exact definition of SWTs. Figure 2 gives a schematic representation of wind turbine capacities and their classification.

Although wind turbines with capacities of 50–100 kW can be considered small according to the technical definitions and policy documents, the typical capacities found in India are between 500 W and 10 kW. The “XIVth List for the Empanelment of Small Wind Turbines,” released in 2016, had 13 SWT models from seven manufacturers or suppliers (CECL 2020; NIWE 2016). More details are provided in Appendix B, Table B-2. Currently, there are about 20 SWT suppliers. Figure 3 shows the models from this list, their capacities, and categorization, and Appendix B gives more information.

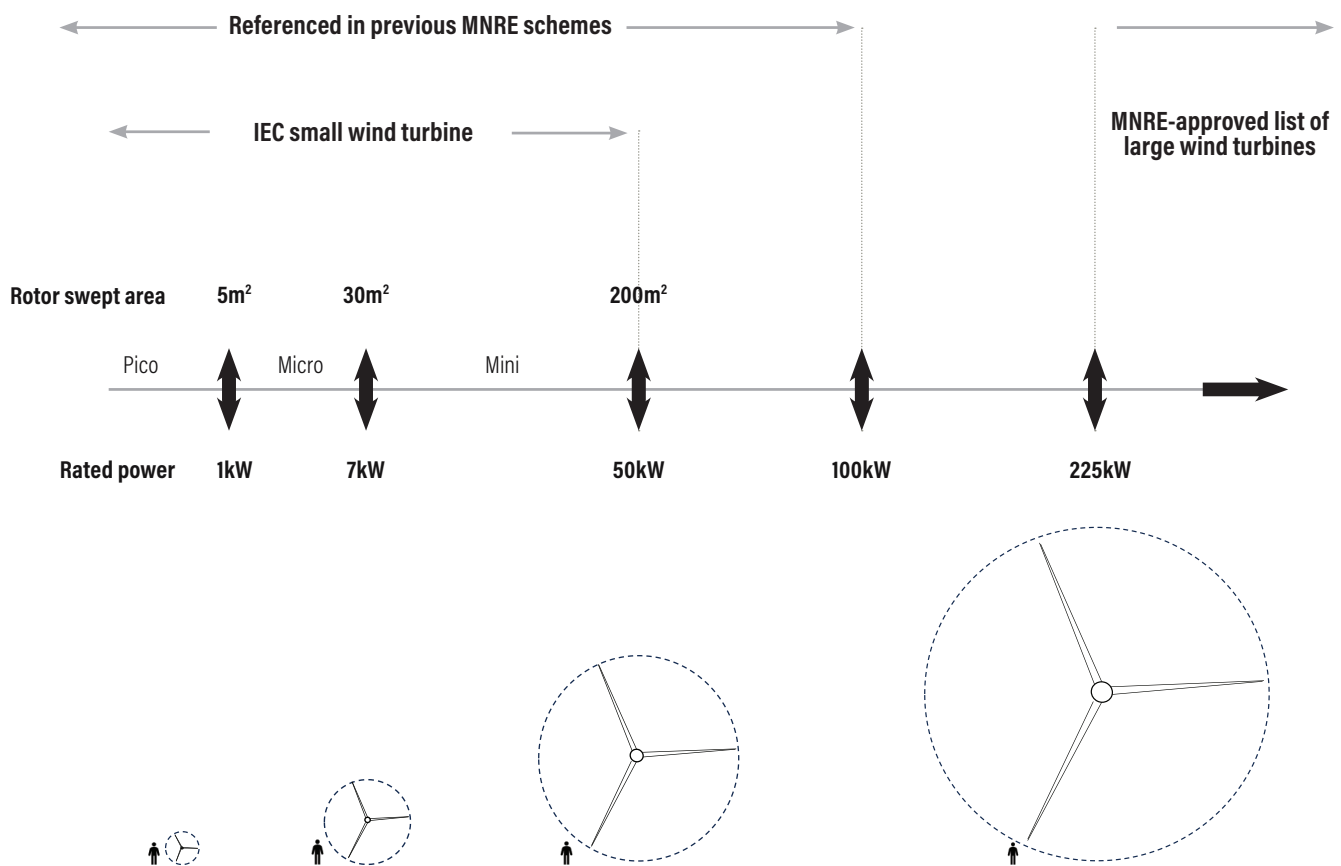
In India, SWTs are used as a source of electricity in remote locations, military installations, industries, educational institutions, household rooftops, and so on. Most of the installed machines have capacities between 1 and 10 kW. Over time, the small wind market in India has gone through three phases. During the first phase, SWTs were primarily imported and installed. Then, after 2010, subsidies led to a greater push for small wind in India, with

machines being manufactured in India under license from foreign companies. After 2017, when the subsidies were discontinued, growth slowed, although efficient SWTs continued to be installed for specific use cases in specific areas. In 2010, the price of installing SWTs was at similar levels to that of solar. The subsequent drop in the price of solar PVs led to faster growth and adoption of solar installations for on-grid, rooftop, and other applications. The MNRE announced a scheme for small wind energy and hybrid systems in 2010 with the target of constructing 25 windmills (SWTs for water pumping, grinding, etc.) (MNRE 2010). The scheme also offered financial assistance of up to INR 1.5 lakh (U.S.\$1,809) per kilowatt of SWT installation for all categories of users. The scheme was modified in 2013 and again in 2016, with the financial assistance reduced to INR 1 lakh per kilowatt and

offered only to community-based users (MNRE 2013). The scheme expired in 2017, and since then, progress has been slow. Appendix C, Table C-2, gives an overview of the supporting schemes and timelines.

Currently, SWTs are installed in India for domestic and industrial uses. Domestic applications require turbines with capacities ranging from 2 to 5 kW, whereas industrial applications require turbines ranging from 20 to 25 kW. Stakeholders are of the opinion that SWTs are a suitable option if they are sited in areas with a good wind resource. Examples of such locations include Maharashtra (Sangli, South Pune), Tamil Nadu (ECR Road and coastal regions), South and West Gujarat, and Karnataka (Belgaum, Davanagere). Wind-solar hybrids are considered a suitable option because they complement each other, and

Figure 2. **Small wind turbine capacity covered by MNRE schemes**



Note: IEC = International Electrotechnical Commission, kW = kilowatt, m²= square meters, MNRE = Ministry of New and Renewable Energy. An indicative representation.
Source: Adapted from IEC (2013) and MNRE (2013).

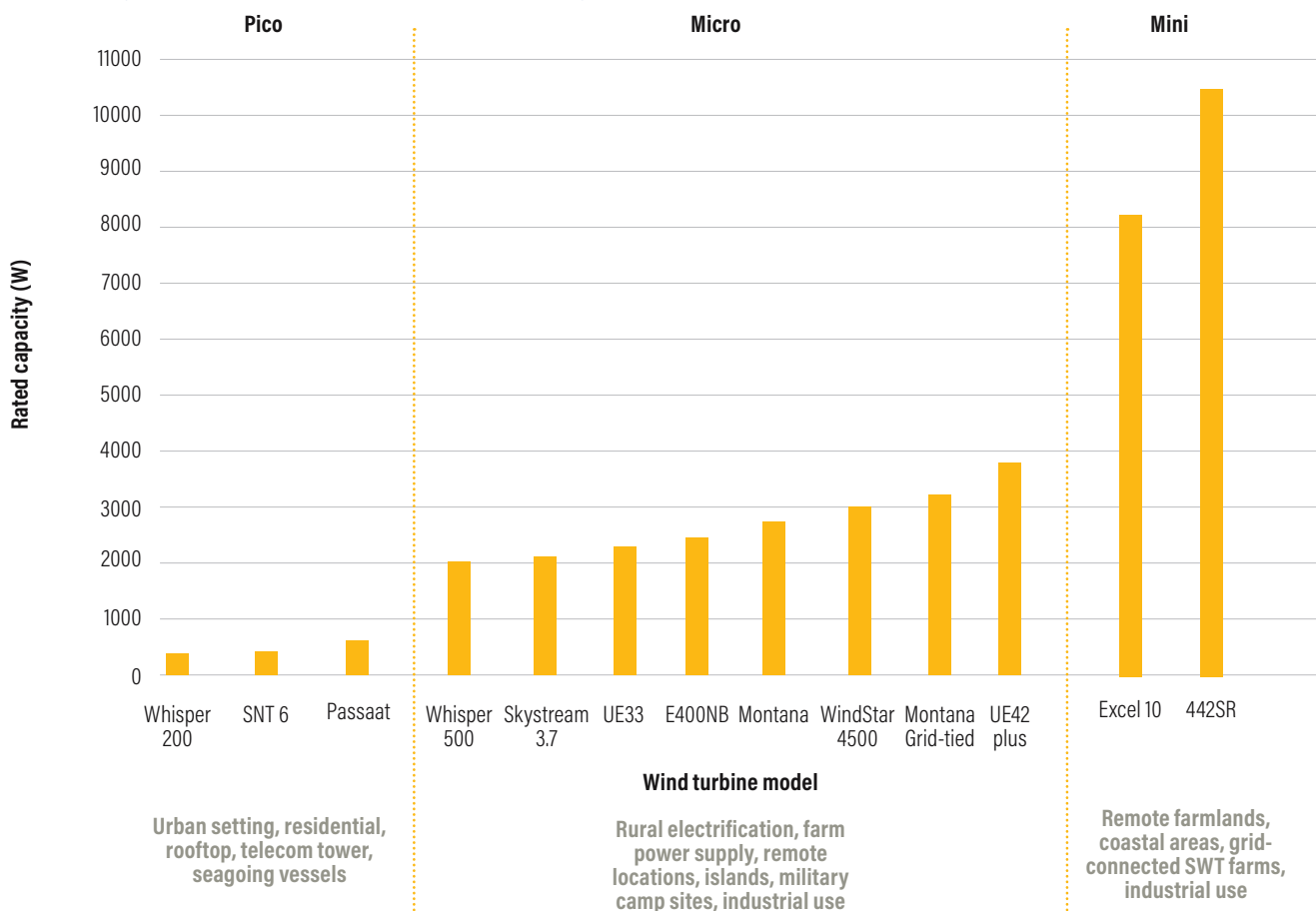
the good wind period in India corresponds to the lean solar period. Based on current solar and wind costs, a ratio of 80–85 percent solar with 15–20 percent wind is generally preferred.

Currently, optimally sited SWTs offer a payback period of about 6 to 8 years, considering tariffs greater than INR 7 per kilowatt-hour, as pointed out by the stakeholders. According to information collected from suppliers, the cost of SWTs ranges from INR 85,000 to 100,000 per kilowatt, depending on the capacity of the machine. Additional charges apply for support towers, and some suppliers include support towers and charge controllers in the previously mentioned price range. The cost of an 18-m lattice tower is about INR 130,000. The annual energy yield per kilowatt is estimated at about 1,800 kWh. The machines generally have a lifespan of 20–25 years and require maintenance once or twice a year.

UNDERSTANDING THE BARRIERS TO SWT ADOPTION

Multiple issues hinder the growth of SWTs in India. The barriers and challenges identified through a literature review and stakeholder consultations (see the “Introduction”) are grouped into the following broad categories: resource mapping, collaboration and network building, technical and economic aspects, awareness, policy, training and skilling, and testing and certification. These are discussed in detail in the following sections and summarized in Appendix B.

Figure 3. **SWT models from the “XIVth List for the Empanelment of Small Wind Turbines” (2016) and typical applications of turbine categories**



Note: SWT = small wind turbine. W = watt.

Source: CECL 2020, NIWE 2016.

Resource mapping

Comprehensive resource mapping studies that highlight suitable locations where SWTs can be successfully deployed are limited. Currently, mapping is limited to macro-level studies and analysis, which cannot be relied upon to make decisions about project development. Available wind speed maps for 20-m hub heights can provide only a general idea of the wind resources available over broad areas, and this is insufficient for making investment decisions. There is also no information on areas where SWTs would be the only viable option for RE generation, such as areas with low solar irradiation but adequate wind potential. Also, as pointed out by participants in the first roundtable discussion (Appendix A, Table A-1), detailed wind resource mapping and studies of the urban built environment, which would be helpful in identifying buildings that could be used to set up wind turbines, are lacking. Detailed mapping studies usually involve setting wind masts and wind monitoring stations and recording wind data over a period of time. In many of these locations, solar may not be an option due to shadow effects or lack of space to install solar panels.

Maintenance and network building

Wind turbines installed at remote locations require regular servicing. Often, these machines are supplied by companies located in other parts of the country. These companies, due to their smaller size and scale of operations, often find it difficult to maintain service personnel at all the locations where they have installed turbines, resulting in irregular servicing and suboptimal machine performance. For example, technicians from, say, Tamil Nadu and Pune are often required to travel great distances to remote regions in the Northeast and Leh (in Ladakh) to service small wind installations, which is cumbersome and prohibitively expensive. Unattended small faults can cascade into large issues over time, leading to extended machine downtime. It has also been pointed out that SWT spare parts are not standardized, which complicates servicing, especially in the case of older SWTs. It is also difficult for turbine owners to find skilled personnel who can service their machines. Turbines are positioned high above the ground, which makes it even more difficult to find skilled service professionals. People are often unwilling to work at these heights, and they also lack training in

safe working practices. Stakeholders from the small wind association and the industry also highlighted the lack of a proper dealer network with trained personnel.

Technical aspects

The technical issues pertaining to the adoption of SWTs in India are primarily related to quality control, the lack of standardization of turbines and components, and installation and maintenance processes. Some stakeholders think that designing indigenous SWTs for the Indian wind regime is a challenge because of the limited knowledge within the Indian SWT manufacturing community. Each installation is unique, and implementation in real-life conditions poses technical challenges and requires that close attention be paid to the deployment context. Deployment is also a learning experience for the installer, who may need to put in time and effort to address the issues that may crop up. However, additional time and effort lead to delays and higher costs. The lack of optimized and standardized designs and processes is another challenge. As pointed out by a small wind manufacturer, because of the smaller market and limited manufacturing of SWTs in India, supply chains for SWT components are lacking, and SWT manufacturers have to make many of the components in-house. This also limits technological advancements and innovation in this sector. Most sites have a single energy accounting meter that does not distinguish between wind and solar generation. Hence, technology-specific contributions and performance data remain limited. For many of the abovementioned technical reasons and servicing issues, the operational life of many horizontal-axis SWT models is reduced.

Economic aspects

The prices of widely used metals and composites, such as aluminum and glass-fiber-reinforced plastics (GFRP) and carbon-fiber-reinforced plastics (CFRP), have increased significantly in recent years, adding to the cost of SWTs. CFRP and GFRP are composite materials used mainly for turbine blades owing to their strength and low weight. In addition, certain components, such as magnets for the generator, are not available in India and must be imported after paying import duties. These duties increase the cost of the machines supplied for use in India and also reduce their competitiveness in the international export market. Overall, higher costs affect project viability. Potential entrants in the SWT business face a limited choice of business models and go-to-market strategies (a plan that

helps a company launch a new product, service, or brand to customers and achieve a competitive advantage). The small wind sector has not seen the price decline and increase in popularity observed in the solar PV sector. Access to loans for setting up small wind projects is also limited. Owing to the discontinuation of subsidies in 2017 and the increased cost of SWT components, the price of SWTs became unattractive to users. There are also additional costs for after-sales service.

Awareness

A number of SWT manufacturers and suppliers pointed out that developers and users in India lack awareness of SWT as an RE option. They noted the scarcity of information explaining how SWTs could benefit the energy landscape in India. Little information exists on certified SWT models available for purchase in India; guidelines for siting, installation, and operation; and benefits for users. Due to this overall lack of awareness, SWTs are not included in many of the RE policies framed by states. SWTs are considered a novel technology, and there is a general resistance to experiment with new ideas, innovations, and concepts. In some cases, the technology is considered unsafe due to the rotating blades and operating noise. People find it difficult to accept new use cases. For example, getting people to permit the installation of an SWT on top of telecom towers and explore new use cases is a challenge.

Policy

There are currently no central policies or schemes that promote SWTs specifically. This may be because the MNRE's previous schemes enjoyed limited success despite offering incentives and setting installation targets. For example, many of the machines installed via the subsidy route did not perform as expected due to the multiple issues mentioned earlier, such as technical aspects, inadequate maintenance, and lack of awareness. Many of the existing policies for promoting decentralized renewables now focus primarily on solar PVs and rooftop solar. Hence, users interested in using SWTs struggle with obtaining project approval or obtaining grid connectivity under net-metering schemes. Currently, no policies or schemes promote domestic manufacturing of SWTs.

The efforts of the small wind industry to sensitize government stakeholders, discuss and resolve issues, and so on, have been limited and, ultimately, unsuccessful. Previous requests to the ministry to make Bharat Sanchar Nigam

Limited (BSNL) telecom towers available for SWT projects did not progress due to bottlenecks and delays in the approval process.

Training and skilling

There is a lack of skilled personnel to install and service SWTs. It is also difficult to find personnel willing to travel to remote locations and work at heights of 15–20 m above the ground, which are typical of SWT installations. No specific training programs on SWTs are offered by organizations such as the NIWE, nor do vocational institutes offer any training on them, as they do for other renewables such as solar. Workers trained to service SWTs are often trained by a manufacturer and can service and work on only one type or brand of machine. The existing workforce with experience on large wind turbines may not be ideal for servicing SWTs due to differences in the scale, size, and technology.

Testing and certification

The testing and certification process for developing a new wind turbine design and launching it in the market is currently time-consuming and expensive. Access to test facilities with the necessary equipment, such as wind tunnels, is difficult because facilities where small wind models and prototypes can be tested are limited to certain government and educational institutions. For example, the fee the NIWE charges to test and certify SWTs is about INR 6 lakhs, which is high for start-ups. Time (and cost) requirements for testing new SWT models are also high (about a year), whereas the testing period for solar modules is only 4–6 weeks.

SWTs: ENTRY POINTS FOR ACTION

Based on our analysis of the various inputs obtained from our literature review and stakeholder consultations, we have identified the following options to promote this sector. They are categorized broadly in line with the barriers identified in this issue brief.

Comprehensive resource mapping and location identification

A comprehensive resource mapping study is one of the main prerequisites for the success of SWTs. The wind resource at the location is the primary factor that determines the success of a wind installation. Even an average wind turbine, if positioned in areas with a good wind resource, will perform well. Even without subsidies and other financial incentives, such projects will be economically viable while delivering renewable electricity. Studies that identify such locations throughout the country at a higher level of granularity—districts and areas within these districts—are essential. Currently, only wind potential maps (20 m, 50 m, etc.) and macro-level studies are available for certain states. Studies and reports offering resolution at the district level will help developers locate suitable location for projects and help policymakers focus their efforts. As pointed out by an SWT supplier, for example, in Khardung La, which is an installation for the Indian Army, it is observed that a 1 kW SWT installation generates up to 16 kWh per day, which is about three times the energy that can be generated from a solar plant of a similar capacity. More such use cases can be explored and tapped. For example, the NIWE website outline multiple case studies and applications for SWTs, small wind-solar hybrids, wind-solar-battery hybrids for cell phone towers and broadcast towers, wind pumps, and so on (NIWE n.d.-b).

Wind energy situated in the built environment is a topic that needs to be explored, and urban wind measurements and resource estimation studies are needed to identify ideal locations in and around cities and within buildings with strong, continuous winds. The resource can be tapped at such locations and used for common-amenity-related electricity requirements. This can be encouraged as part of the builder's mandate.

Also, if new infrastructure developments and buildings in the area shield already installed SWTs and thereby reduce yields, it would be prudent to relocate them to more suitable locations.

Service network building and collaboration

Many of the SWTs currently installed across India are either underperforming or completely stalled, primarily due to lack of maintenance. This situation often leads to a negative impression of SWTs as an RE option, although the technology works well when sited at a location with a suitable wind resource. SWTs, because of their rotating parts, require servicing at least once or twice a year. It is important that servicing be carried out regularly as recommended by the manufacturer. The general failure to follow service schedules is caused in part by the lack of dealer networks, as pointed out by SWT suppliers and government stakeholders. This situation can be addressed if service providers collaborate to manage the maintenance of SWTs across different states, leveraging the local presence of various companies to manage all the installations in their network area, not just their own. Resources and expertise to tackle challenges related to maintenance and servicing could be shared through a collaborative platform. Standardization of parts, to the extent possible, can help cross-utilization between makes and models of different suppliers. There could also be greater collaboration between SWT manufacturers and suppliers of SWT parts and components. For example, certification of machines could be made conditional on suppliers agreeing to be part of a nationwide service network. Users need to define separate payment terms in annual maintenance contracts (AMCs) that keep installers interested in maintaining the installation.

Small wind developers should form a consortium, which could identify regions in India with good small wind potential and suitable applications and focus on successfully developing projects in those areas. The consortium could provide specific training to personnel, enabling them to effectively service machines. The formation of a consortium is one of the best ways to move forward. It has also been suggested that this consortium can be aligned with large wind associations to leverage the expertise and resources of the large onshore wind industry.

A committee or working group of stakeholders such as small wind suppliers, telecom companies, structural engineers, government representatives, and experts could be formed so that new ideas can be discussed and issues addressed.

Technology optimization, standardization, and quality control

SWTs are likely to be positioned close to the demand location, where wind conditions are not always ideal. Therefore, it is key that the design be optimized for the prevailing wind conditions. It is also essential that the machines be reliable and that good-quality turbines and components be used. The use of well-designed and robust rotors and standardized components such as AC-DC converters and AC-DC-AC converters and generators would be a good step forward. All SWTs have a similar construction and face similar issues. A minimum level of quality control and a standardized wind speed rating for turbines should be ensured. The existing manufacturing base of SWTs and related components—Pune, Coimbatore, Hyderabad, Jharkhand, and Gujarat—can be leveraged. Such manufacturing clusters can be further strengthened and new clusters created with the help of OEM support.

The manufacture of turbines using open-source technologies and local materials, in accordance with the tenets of the open-source movement, is a viable option that should be considered.³

Distributed renewable energy certificates (DRECs) are a mechanism for financing and promoting small wind projects. However, their use depends on reliable data, which must be system generated and efficiently collected. SWT suppliers and developers suggest that the future of the DREC industry depends on reliable data acquisition. Good data collection methods and reliable data are essential for monitoring performance and installing DRE systems. Better assessment of system performance and regular monitoring would help build an evidence base supporting the optimal performance of new SWTs. In turn, this evidence could be shared with government stakeholders, or they could directly monitor the evidence, which would increase their confidence in the technology. Stakeholders point out that data-logging hardware is currently a pain point and needs to be improved; for example, data collected by remote monitoring systems can be difficult to access because of power availability and con-

nectivity issues, such as limited Internet coverage for data transfer. Overall, it is necessary to establish standardized procedures for acquiring and recording data on the energy generated by SWTs. The government could provide technology grants to manufacturers for R&D activities. Some stakeholders are also of the opinion that artificial intelligence (AI) can be leveraged for monitoring and data analysis at renewable installations, although specific use cases still need to be evaluated and demonstrated for SWT installations. Assigning SWTs to a central public sector undertaking for its development and growth could help boost the industry.

Mechanisms for cost reduction, access to finance, and business models

Cost is a major factor in selecting an RE option. The price of solar power has declined steadily over recent years due to economies of scale and worldwide operations, whereas the cost of SWTs has either increased or at best remained the same. Innovative mechanisms are needed to reduce the cost of SWTs, along with suitable go-to market strategies. This will ensure a lower payback period on SWT investments, which could significantly accelerate the technology's adoption in India.

One way to achieve cost reduction is by reducing the cost or use of the non-power-producing components of SWT installations. For example, as pointed out by an SWT supplier and renewable project developer, turbines could be mounted on telecom towers, which would reduce costs by eliminating the need to build a separate turbine support tower. Another way to reduce installation costs is to mount SWTs without using cranes and heavy machinery; for example, by mounting the SWT on the support tower (bottom-hinged) when it is still on the ground. The tower along with the turbine could then be pulled into a vertical position using ropes and held in place using guywires. The expense of using cranes and heavy machinery, unless spread over large projects involving many installations, can drive up costs considerably. Other suggestions for better project economics include using higher-capacity SWTs (20–50 kW) for larger wind and wind-solar hybrid projects.

The potential for SWTs in India and its potential market size are immense. Innovative business models and alternative revenue streams need to be explored. For example, small wind towers can be used to display banner advertise-

ments and generate extra revenue. This can help offset the costs of the turbine, reducing the overall cost and lowering the payback period. Once the ecosystem matures, economies of scale will further drive down the costs of components and increase the uptake of small wind. SWTs can be developed that can be installed and maintained using a DIY (do-it-yourself) approach. Smartphone applications and related technologies can be leveraged as part of this effort.

Some SWT suppliers are of the opinion that the current import duty of 28 percent on fully assembled wind turbines is very high, and needs to be reduced. These suppliers point out that only a few companies in India build SWTs, and so their welfare may not be a major concern for the government. In addition, a limited-period waiver (two years to begin with) of import duty on SWT imports may bring in many popular SWT models from around the world and could motivate investment in individual residential/commercial and recharging station applications. However, some start-ups and Indian SWT manufacturers are of the opinion that GST (Goods and Service Tax) exemptions along with subsidies could be provided to Indian manufacturers with a proven track record. Further, import duties for certain items that are not available in India, such as neodymium magnets (import duty: 28 percent), can be reduced to facilitate overall cost reductions. This would help scale production, reduce the cost of machines, and ultimately improve uptake, while supporting the Make in India initiatives of the GoI. They are also of the opinion that financial support should be provided for R&D, testing, and certification. Government support could be offered to facilitate soft loans, which could also be offered to customers opting for SWT installations, through banks and other financial institutions. Income tax deductions could be offered for purchases such as electric vehicles (EVs), and similar provisions could be offered for setting up SWTs and hybrid options with storage.

It is common practice for some customers to demand a free pilot project before offering a larger renewable or energy generation project to SWT suppliers. Some SWT suppliers have suggested that this practice is not viable and should be discontinued. Their reasoning is that such pilots, even when successful, do not pave the way for the promised higher-capacity projects, increasing the financial burden on the SWT developer. Improving the awareness of the general public and potential end users regarding the

technology and its benefits could offer a solution. Also, showcasing other successful installations can help address this situation.

The use of DRECs should be explored for promoting SWTs. DRECs are emerging as a powerful tool to support DRE in emerging markets and offer a flexible tool that corporate procurement teams can use to support DRE projects. This, and the fact that corporates are willing to pay a premium for DRECs, can be leveraged for SWT development. The government can facilitate the creation of a fund for SWTs from DRECs.

Public awareness and government sensitization

The current level of awareness about SWTs and their applications is inadequate among both government officials and the public. It is important to sensitize the central government, state governments, and their agencies to SWTs and their applications. Data covering various aspects of SWT operation need to be collected and deployed, such as power generation profiles, energy generation, and annual energy yields, along with case studies of successful installations and applications that can be presented to policymakers. The use of SWTs as a decentralized option for meeting RPO targets and for livelihood applications can also be highlighted. SWT suppliers and companies can form an SWT consortium or association (by either forming a new association or reviving the currently inactive Indian Small Wind Association [InSWA]) and work closely with government agencies and the concerned central government ministry to develop suitable empanelment criteria for SWT vendors and help chart a path forward. All these measures could help nudge the center and states to formulate policies and financial incentives for SWTs.

Policy framework

Many of the interventions we suggest require policy support, and further development of the sector will depend on a supportive enabling policy framework. Currently, many of the central and state policies tend to be skewed toward solar, given its lower capital costs and favorable project economics. Some of the same energy demand can be met by other sources of DRE, such as SWTs, which in certain locations may be equally suitable or at times more economical than solar. Favorable policies can increase the uptake of SWTs; for example, uniform tariffs for all renewable options. Inclusive policies that allow for a variety of renewable options and technologies in central and state policies is key. The type of renewable power chosen by a user should be specific to that user's location, and inclusion of all renewables in a technology-neutral energy policy would favor appropriate selection while boosting opportunities for SWTs. As an example, SWTs could be included in existing rooftop solar schemes and be eligible for net-metering or virtual net-metering arrangements.

The existing hybrid policy for large-scale systems may not be suitable for SWTs, and more work is required to develop suitable policies and schemes that consider coupling SWTs to other renewable resources as a hybrid option. For example, the recent 2023 RE policy of Gujarat includes provisions for SWTs (Government of Gujarat 2023), and Maharashtra has developed an inclusive renewable net-metering policy. According to this policy, SWTs can be installed by consumers on rooftops or within premises under net-metering or gross-metering arrangements. In addition, developers can avail themselves of central or state government incentives, if available. In sum, robust integrated RE policies that include hybrid technologies and DREGs with specific guidelines for SWTs are an option.

Indian states' distribution grid codes lay down the rules, guidelines, and standards various participants in the system must follow to allow the authorities to plan, develop, maintain, and operate the power system in the most secure, reliable, economical, and efficient manner, while facilitating healthy competition in the generation and supply of electricity. These grid codes currently suffer from gaps and should be revised by including clear definitions of production and control functions. Greater clarity is needed on information pertaining to grid connection of RE generation options such as SWTs, mechanisms for injecting power to the grid, details of transformers, and the capacities that can be connected to the grid.

The InSWA could be more progressive and proactive in bringing together stakeholders to work on policy gaps and solve issues. The InSWA working committee is currently inactive, and measures should be taken to address this. The revived association or consortium should work closely with state nodal agencies to formulate policies for wind-rich states and states with suitable windy coastal areas for the implementation of SWTs.

A small-wind-specific capacity could be set aside from the overall renewable and wind capacity targets. For example, utility-scale onshore wind farms with access to large land banks have very high wind potential harnessed by multi-megawatt wind turbines at high hub heights. The government can mandate that SWTs be used in this ecosystem with designated capacity shares, and this can provide an impetus to the SWT industry.

Training programs and skilling

More training programs and trainers are required to increase awareness and build the work force needed to support small wind. Training and upskilling through government- and private-sector-promoted training programs and courses are required. The training should enable workers to service the different types and brands of machines that are currently in use. The NIWE is in the process of starting a wind-sector-specific training course called Vayumitra (NIWE n.d.-a). Although the course is aimed at the entire wind sector—comprising mainly large wind turbines—there will be overlaps, and a specific small-wind program offering SWT-specific skill sets and training could be added to the regular Vayumitra program. However, employment prospects for those undergoing SWT-specific training might be limited until the SWT industry picks up. Training by an SWT consortium that is independent of OEMs and certification for all the different SWT technologies marketed in India is a possible solution. Moreover, training modules should also be developed for local mechanics and technicians, who should also be able to source spares from the existing supply chain to repair machines.

It has also been pointed out that appropriate site selection and installation of SWTs, especially in the urban setting, is a skill that requires a sound understanding of micro-siting guidelines, the effects of turbulence, wind resource analysis, wind flow modeling, and an understanding of SWT power. These integrated capabilities need to

be further developed within the SWT OEMs and service providers. Appropriate training and skilling can help in this regard.

Test facilities and certification

In the development stage, SWTs need to be tested under controlled conditions at facilities requiring, for example, large wind tunnels, and the facilities should be accessible at nominal cost to the start-ups or companies that need to test their designs. The government can also provide technology or R&D grants to offset the testing costs. Test benches can also be established in good wind farms near the local production points, minimizing the need for OEMs to transport equipment to distant labs. The government can also facilitate access to existing wind tunnels within academic or research institutions, which could promote R&D in the sector.

As pointed out by start-ups and companies developing new SWT models, the process of testing and empanelment of a new SWT currently requires the turbine to be submitted to the NIWE. The turbine is then taken to their test facility, and the whole process takes about a year, costing about INR 6 lakh. An alternative, or complementary, option could be submission of test results to the NIWE from real-life installations (from locations meeting specific standards in terms of terrain flatness, obstacle free, wind availability, etc.). The certificate could be awarded after the data have been evaluated. This option would be feasible only if the data can be transmitted to a server in real time, which can then be accessed by the NIWE with no risk of tampering. This approach could also enable the NIWE to accelerate the approval of wind turbine models.

In addition, mobile field testing using vans with instrumentation or modular testing arrangements through leasing or other mechanisms, similar to the already available solar PV testing setup, can be considered for improving the testing and certification timelines. In this context, it is noteworthy that organizations such as Council of Scientific & Industrial Research–Structural Engineering Research Centre (CSIR-SERC) have performed full-scale testing of utility-scale wind turbines for structural integrity, power curve, and fatigue using mobile vans with instrumentation.

Smaller-capacity SWTs such as Pico and Micro models need accelerated testing procedures and innovative approaches for approval and a go-to-market strategy. Currently, this process is long and difficult. The delays are

also partly because no Indian lab tests SWTs (except the NIWE), even though multiple registered labs operating in India test large wind turbines. It is recommended that all such testing and certification labs be mandated to reserve a specific portion of their testing capacity for SWTs.

CONCLUSION

This issue brief provides an overview of the current landscape of SWTs in India on the basis of information gathered through a literature review, stakeholder consultations, and roundtable discussions. It provides insights into the barriers that are preventing widespread adoption of SWTs in India and suggests interventions that are likely to mitigate or overcome these barriers.

Some of the key barriers we identified include a lack of comprehensive resource mapping studies that highlight areas suitable for SWTs, poor maintenance of turbines, the lack of a dealer network, a shortage of skilled personnel, and a lack of standardization across SWT design and operational standards. Production costs have increased, lengthening the payback period of the machines. Supporting schemes that were earlier available from the central government have lapsed, and existing schemes do not offer a level playing field with other renewable options. For these reasons, as well as an overall lack of awareness, proponents of SWTs face difficulty in implementing new projects and obtaining grid connectivity for SWT installations. Companies developing new models also face challenges regarding the costs and time frames of testing, certification, and empanelment.

To mitigate many of these challenges and promote the uptake of SWTs, we identified multiple options through a consultative process spread over two years. It is likely that there are many locations in India where SWTs are the best option and can perform highly efficiently. More efforts are required to map out these locations because they could provide the setting for the successful deployment and initial validation of small wind projects. Wind energy in the built environment is another area that needs to be explored; urban wind measurements and comprehensive resource estimation studies are needed. Collaboration between SWT manufacturers, the establishment of a consortium for the sector, and the development of a dealer network are essential in order to move forward. By collaborating with the concerned ministry and state nodal authorities, the consortium could catalyze the

creation of policy, standards, and guidelines to maximize the deployment of small wind energy systems. Regarding the technology, there is a need for greater quality control, optimized designs, and standardization of components. Leveraging the existing manufacturing hubs located in Pune, Coimbatore, and Gujarat should be considered.

Innovative methods to bring down the costs of production and ownership of SWTs should be explored, including alternative revenue streams such as placing banner ads on towers and exploiting the opportunities offered by DRECs. Suitable SWT business models, specific to locations and applications, need to be developed, along with improved access to soft loans. Greater emphasis is needed on integrating small wind with other RE technologies in hybrid mode to improve reliability and reduce the costs of energy storage. Awareness needs to be raised about the potential benefits of using SWTs as a renewable option for different use cases. Showcasing successful case studies and working closely with stakeholders from the central government and state governments to sensitize them to the advantages of SWTs could facilitate more inclusive RE policies that place SWTs on an equal footing with other technologies.

India needs to establish more training programs and skill development activities to raise awareness and train personnel to work with SWTs. A small wind training module could be added to related courses offered by the NIWE, which would encourage the development of training materials, operator handbooks, and so on, which are essential. The time frame for testing and certification needs to be improved and the associated costs reduced. Facilities are also required for testing turbines in controlled environments. Companies that need to test new models for R&D application should be able to access these facilities at nominal costs.

APPENDIX A. ROUNDTABLE DISCUSSIONS

The first roundtable discussion was held on October 25, 2022, at the WRI India office in Delhi between 10:30 AM and 1 PM. The aim of the discussion was to deliberate on the potential for small wind energy in India, the available technologies, and policy gaps. An overview of the session is given below.

Table A-1. **Small Wind Energy Roundtable 1: Topics of discussion and speakers**

ACTIVITY	SPEAKER
Presentations: <ul style="list-style-type: none"> • “Overview of Small Wind Turbines in India” by Vaisakh Kumar, WRI India • “SWT Technology and Innovations” by Akshay Jain, EnergyBae • “Small Wind Turbine Solutions” by Amol Shende, Wish Energy Solutions • “Environment and Renewable Energy” by Sarth Jha, Sarthi Marketing 	Lanvin Concessao, WRI India
Discussion 1: SWT technology and infrastructure development <ul style="list-style-type: none"> • What are the technology gaps and issues with the availability of components (supply chain gaps)? • What are the other issues faced by manufacturer, suppliers, and developers of small wind? • What are the benefits of the adoption of small wind turbines? Job creation, local manufacture of components, creation of supply chain, export potential, etc. 	Lead Moderator: Nitish Saini, Clean Energy Access Network (CLEAN)
Discussion 2: State and national policy gaps <ul style="list-style-type: none"> • What is the status of central policies supporting small wind? What are the policy gaps? • What are some examples of state-level policies that have benefited the adoption of small wind? • What policy changes/amends/interventions are required for the development of small wind? 	Lead Moderator: Kajol, WRI India
Closing remarks	Rekha Krishnan, CLEAN

Source: WRI India authors.

Table A-2. **Small Wind Energy Roundtable 1: Participants**

PARTICIPANTS	
Bhukya Ramdas, NIWE	Rekha Krishnan, Clean Energy Access Network (CLEAN)
S. Gomathinayagam, ConsultinGoms	Nitish Saini, CLEAN
Jorge Ayarza, MinVayu, Auroville	Gaurav Upadhyay, CLEAN
Akshay Jain, EnergyBae	Lanvin Concessao, WRI India
Amol Shende, Wish Energy	Abhishek Bhardwaj, WRI India
Suraj Chaudhary, Suraj Solar Enterprise	Vaisakh Suresh Kumar, WRI India
Sarth Jha, Sarthi Marketing	Kajol, WRI India

Source: WRI India authors.

The second roundtable discussion was held on April 18, 2023, at The Grid, Central Avenue, Chennai, between 2 PM and 4:30 PM. The discussion aimed to build on the first roundtable and discussed the need for accelerated testing facilities and innovative approaches to certifying SWTs; standardization of SWT components; methods of addressing skilling gaps with small wind implementation, and operations and maintenance. It also made recommendations for policy, investment, and programmatic approaches to support the scaling up of SWT adoption in India. Table A-3 gives an overview of the roundtable.

Table A-3. **Small Wind Energy Roundtable 2: Topics of discussion and speakers**

ACTIVITY	SPEAKER/MODERATOR
Inaugural session: <ul style="list-style-type: none"> Welcome address Introduction of the participants 	Kajol, WRI India
Introduction and context setting <ul style="list-style-type: none"> Overview of SWTs in India Summary and key takeaways from Roundtable 	Vaisakh Suresh Kumar, WRI India
Discussion 1: Hybridization of SWTs—Viability and technology <ul style="list-style-type: none"> Current trends in SWT adoption in India Potential benefits of hybridization with solar and biomass Challenges faced and potential solutions Cost analysis 	Amol Shende, Wish Energy
Discussion 2: Policy gap, incentives, and scaling of SWT adoption <ul style="list-style-type: none"> Role of state nodal agencies/departments in upscaling the wind energy program Adoption of small wind in solar rooftop programs Need for standardization of SWTs Manual and guidelines for SWT installation Empaneled manufacturers listed by MNRE: Criteria 	Rekha Krishnan, CLEAN
Recap of key points, final thoughts, and recommendations	Vishal Toro, CLEAN

Notes: SWT = small wind turbine; MNRE = Ministry of New and Renewable Energy.

Source: WRI India authors.

Table A-4. **Small Wind Energy Roundtable 2: Participants**

PARTICIPANTS	
S. Gomathinayagam, ConsultinGoms	Venkat Kumar Tangirala
Jorge Ayarza, MinVayu Auroville	Kalpiti Prajapati
Akshay Jain, EnergyBae	Surya Prakash Gajjala
Amol Shende, Wish Energy	Nitish Saini, Clean Energy Access Network (CLEAN)
Uday Kshirsagar, Spitzen Energy	Vishal Toro, CLEAN
Samradnee Deshmukh, CLEAN	Lanvin Concessao, WRI India
Siddharth Arora, Revayu Energy	Sripathi Anirudh, WRI India
Hyndhavi	Vaisakh Suresh Kumar, WRI India

Source: WRI India authors.

APPENDIX B. TECHNICAL ASPECTS OF SMALL WIND TURBINES AND INDIAN SUPPLIERS

The International Electrotechnical Commission standard IEC 61400-2:2013, “Wind turbines—Part 2: Small wind turbines,” applies to wind power plants that have a rotor swept area less than or equal to 200 m², generating electricity at voltages below 1,000 V AC or 1,500 V DC for both on-grid and off-grid applications. This swept area limit generally corresponds to turbines with a maximum power rating of 50 kW. However, standards adopted by some countries have expanded on IEC 61400-2:2013 to include higher-capacity turbines. An example is the ACP 101-1 2021 standard of the United States, which applies to turbines with capacities as high as 150 kW.

IEC 61400-2:2013 subclassifies small wind turbines (SWTs) based on their axis of rotation into horizontal-axis and vertical-axis machines, whereas ACP 101-1 2021 provides subcategories based on capacity. SWTs may be further informally classified based on parameters such as rotor placement (upwind or downwind), the type of force causing the rotation (lift or drag), and the number of blades (2, 3, etc.) (Kumar et al. 2023). Other capacity-related subclassifications generally correspond to power ratings of 7–50 kW, 1–7 kW, and less than 1 kW, which are referred to as Mini, Micro, and Pico turbines, respectively.

Small wind power plants consist of the rotor assembly, generator, support tower, and electronic components. The blades are either individually attached to a central hub (in smaller machines the hub and blades form one unit), which is then attached to the generator shaft. To reduce complexities,

SWTs generally do not have gearboxes and are directly coupled to the generator shaft. The generators are typically permanent-magnet generators. The blades rotate at speeds between 150 and 1,200 rpm, with an average rated power rpm of about 500. The rated power is achieved at a wind speed of 11–12 m/s. SWTs have low cut-in wind speeds, generally between 2 and 3 m/s. Overspeed control in smaller machines is achieved electronically or through a mechanism called furling, in which the rotor is moved away from the direction of the oncoming wind. Some machines also have pitch controls for overspeed protection. The blades can be made of wood or composite materials such as glass-fiber-reinforced plastics (GFRP). Electronics include charge controllers. Support towers could be of the lattice, tubular, or monopole type. Table B-1 summarizes the general aspects of SWTs.

Table B-1. **General aspects of small wind turbines**

DEFINITION IEC 61400-2-2013	<ul style="list-style-type: none"> ▪ Rotor swept area $\leq 200 \text{ m}^2$ ▪ Voltages below 1,000 V AC or 1,500 V DC ▪ Both on-grid and off-grid applications
SUBCLASSIFICATION (BASED ON CAPACITY)	<ul style="list-style-type: none"> ▪ Pico (<1 kW) ▪ Micro (1–7 kW) ▪ Mini (7–50 kW)
APPLICATIONS	<ul style="list-style-type: none"> ▪ Electricity generation: Residential, rural, industrial applications, telecom towers, seagoing vessels, coastal areas, offshore platforms ▪ Mechanical power: Pumping water, grinding grain
USAGE	<ul style="list-style-type: none"> ▪ Off-grid or stand-alone systems ▪ On-grid or grid-connected systems ▪ Can be used in hybrid mode in combination with other clean energy technologies such as solar PV
COMPONENTS	<ul style="list-style-type: none"> ▪ Turbine (rotor assembly, generator, and tail) ▪ Tower ▪ Electronics
TYPES/CLASSIFICATION	<ul style="list-style-type: none"> ▪ Based on capacities: Mini, Micro, Pico ▪ Based on the axis of rotation: Horizontal, vertical ▪ Based on rotor placement with respect to the oncoming wind: Upwind, downwind ▪ Based on the type of force generating rotation: Lift, drag

Table B-1. **General aspects of small wind turbines (cont)**

TURBINE BLADE CONSTRUCTION	<ul style="list-style-type: none"> • Wood • Glass-fiber-reinforced plastic (GFRP) • Carbon-fiber-reinforced plastic (CFRP) • GFRP+CFRP
OVERSPEED PROTECTION	<ul style="list-style-type: none"> • Furling: Moves the plane of rotation of the rotor away from the oncoming wind

Note: kW = kilowatt. IEC = International Electrotechnical Commission. m² = square meters.
Source: IEC (2013), Wood (2013), and literature review.

In accordance with the procedure for empanelment of SWTs with the MNRE or NIWE (CECL 2020), various models were included in the "XIVth List for the Empanelment of Small Wind Turbines" published by the NIWE (CECL 2020; NIWE 2016). SWT models were included in the empanelment list after verifying the availability of test reports in accordance with IEC 61400-2, the objective being to ensure the structural integrity, safety, performance, and quality assurance of SWTs installed

in the country. Installations that claimed subsidies had to use SWTs from the empaneled list published by the NIWE. Table B-2 gives the various on-grid and off-grid models from the previous empaneled list ("XIVth List for the Empanelment of Small Wind Turbines"). Table B-3 provides an indicative list of previous and current SWT manufacturers, suppliers, and start-ups in India.

Table B-2. **Empaneled SWT models (2016)**

MANUFACTURER	MODEL	POWER AT 11 M/S (W)	ANNUAL ENERGY AT 5 M/S (kWh)
GRID-TIED MODELS			
Spitzen Energy Solutions (India) Pvt. Ltd.	Montana	3,310	5,939
Xzeres Corp.	Skystream 3.7	2,100	3,416
	442SR	10,400	16,700
Bergey Wind Power Co LLC	Excel 10	8,900	13,800
Eveready Diversified Products Pvt. Ltd.	E400nb	2,540	3,930
OFF-GRID MODELS			
Spitzen Energy Solutions (India) Pvt. Ltd.	Passaat	845	1,810
	Montana	3,100	6,634
Supernova Technologies Pvt. Ltd.	SNT 6	600	819
Unitron Energy Systems Pvt. Ltd.	UE33	2,300	4,595
	UE42 plus	3,800	6,532
WiSH Energy Solutions Pvt. Ltd.	Whisper 200	570	1,063
	Whisper 500	2,000	3,673
	WindiStar 4500	3,200	4,296

Note: m/s = meters per second. kWh = kilowatt-hour. SWT = small wind turbine. W = watt. The data are based on the XIVth List of Empanelment of 2016. Lists of empaneled turbines were not issued subsequently because schemes that provided financial incentives for SWTs were discontinued by the MNRE. The above list is not representative of the current suppliers and models available in the market.

Source: CECL 2020, NIWE 2016.

Table B-3. **Indicative list of previous and current SWT manufacturers, suppliers, and start-ups in India**

Airstream India	Sandevin Analytics
Alpha Power	Spitzen Energy Solutions
Altem Power	Sun n Wind India
Apeiro Energy	Sunair Power
Archimedes Green Energy	SunWind Innovate
Auroville Wind Systems, MinVayu	Supernova Technologies
Avant Garde Innovations	SVURG Digital Systems
Bergey Wind Power	Trueskill Energen
Digitech Renewable Energy Development Organization	Unitron Energy Systems
EcoAter	Vaigunth Eneretek
E-Hands Energy	Vij Engineers & Consultants
EnergyBae	Vinayak Energy Tech
Eveready Diversified Products	Viviann Electric
HoneyBee Energie	Wind for All
IKYA Innovation	Wind Turbine Systems
IYSERT	Windstream Technologies
LeanWay Energy	WindSun Ecosystems
NTBS Wind Turbine	Wish Energy Solutions (previously Luminous Renewable Energy)
Pawanmitra Aero Energies	XZERES Corp.
Redefine Energy	Yashika Energy
Revayu Energy	Zyklon Power and Infrastructure

Source: CECL (2020), NIWE (2024), literature review, and stakeholder consultations.

APPENDIX C. SMALL WIND TURBINE CUMULATIVE INSTALLATIONS (STATE-WISE) UNDER PREVIOUS SCHEMES

Table C-1. **Cumulative installed capacity of small wind turbines and small wind turbine-solar hybrids in India, by state (as of December 31, 2017)**

STATE	CUMULATIVE INSTALLED CAPACITY (kW)
Maharashtra	1,775
Andhra Pradesh	271
Tamil Nadu	257
Meghalaya	201
Goa	194
Manipur	140
Jammu & Kashmir	96
West Bengal	74
Punjab	50
Karnataka	39
Madhya Pradesh	24
Uttarakhand	24
Mizoram	21
Gujarat	20
Nagaland	20
Sikkim	16
Rajasthan	14
Odisha	13
Haryana	10
Kerala	8
Arunachal Pradesh	7
Assam	6
Puducherry	5
Tripura	2
Total	3,287

Source: CECL 2020, MNRE 2019.

Table C-2. **Overview of financial support schemes for promotion of small wind turbines in India (2010–2016)**

Scheme	Modified scheme for the program on "Small Wind Energy & Hybrid Systems (SWES)"	Sanction for continuation of scheme for program on "Small Wind Energy & Hybrid Systems (SWES)"	Additions/modifications to the administrative sanction order for continuation of the scheme on "Small Wind Energy & Hybrid Systems (SWES)"
Date	April 16, 2010	September 4, 2013	January 15, 2016
Period	2010–12	2012–17	X
Targets	Windmills: 25 nos. Aerogenerator/wind-solar hybrid systems: 500 kW	X	X
Budget	5 crores	50 crores	X
Central Financial Assistance (CFA)	Aerogenerator: INR 1–1.5 lakhs/kW Windmill: 50%–90% of ex-works cost, subject to an upper ceiling.	Aerogenerator: INR 1 lakh/kW	Aerogenerator: INR 1 lakh/kW CFA only to SWES with valid type test reports. Manufacturers to establish manufacturing base in India to obtain MNRE subsidy.
Eligible users	All categories of users including individuals, farmers, NGOs, government agencies, local bodies, autonomous institutions, research organizations, corporate bodies, etc.	Community users	Installation on telecom towers will also be eligible for CFA under the category of community users, subject to conditions.

Note: kW = kilowatt. X = data not specified in the scheme documents. The numbering system followed in this working paper is the Indian numbering system. Typical values used are lakhs (1 lakh = 100,000) and crores (1 crore = 10 million).

Source: CECL 2020; MNRE 2010, 2013.

ENDNOTES

1. As pointed out by consultants, a general rule of thumb is that when the building height-to-width ratio exceeds 5, the wind is likely to go around the building rather than above or over the roof. The induced flow of wind around high-rise building clusters is accelerated and can be explored for energy capture using SWT technology. The effects of turbulence needs to be determined because it can cause significant deviations from the estimated performance values.
2. Microgrid connectivity or the low-tension side of the grid (on the consumer side of the grid) will be suitable for SWTs, according to stakeholders.
3. For example, MinVayu is a project that was begun in 2010 by the Auroville Centre for Scientific Research Trust. The project's aim is to support the power needs of Indian villages by training, supplying, and supporting rural mechanics who can build, install, and maintain low-cost wind turbines. These turbines are specially designed to operate efficiently in the lower wind speed ranges that are common in most regions in India, and they are made of local materials. Only open-source technologies are used.

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Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

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We use our research to inform government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

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