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ADB Working Paper Series

**APPROPRIATE TECHNOLOGIES
FOR REMOVING BARRIERS TO
THE EXPANSION OF RENEWABLE
ENERGY IN ASIA: VERTICAL AXIS
WIND TURBINES**

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Abstract

The availability of inappropriate technologies in Asian countries has been a largely-ignored factor preventing the expansion of renewable energy in Asia. The promotion of certain expensive types of renewable energy with inbuilt deficiencies, which detract from their benefits, has served as a disincentive for switching to renewable energy on a large scale.

Horizontal axis wind turbines (HAWTs) account for the bulk of grid-connected wind turbines, but are expensive, gigantic, difficult to install, operate, repair and maintain, and require a large area of land for their operation. They need fast winds to generate power that is not available all the time and have to be shut down during strong winds that are above their "survival speed". Since they are intermittent sources of power generation, they consequently require backup generators, and these generators usually emit CO₂. Given this reality, it could be concluded that wind turbines are an inappropriate means of power generation, but it is HAWTs, rather than all wind turbines, which have major negative features, making them an inappropriate choice for large-scale power generation, despite their benefits.

Vertical axis wind turbines (VAWTs) are a solution, but they are not yet widely used, and their technology needs further development to address their shortcomings. VAWTs operate with slower wind speeds than the required minimum speed of HAWTs, and with very fast winds. VAWTs are much cheaper and easier to build, install, operate, repair and maintain than HAWTs, do not require a large area of land, and can be installed near each other, in between HAWTs and in urban areas.

Instead of promoting HAWTs, VAWTs should be introduced to Asian countries, where they could also be used in hybrid energy systems with continuous sources of power generation such as hydro dams, and with other intermittent types of renewable energy like solar panels to address their individual intermittency. Investment in their technology should also be encouraged in order to address their shortcomings.

Keywords: renewable energy, wind energy, wind turbines, horizontal axis wind turbines (HAWTs), vertical axis wind turbines (VAWTs), renewable technology

JEL Classification: Q42

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1. INTRODUCTION

Asia has been the world's largest energy-consuming region since the 1990s for a variety of reasons, including an increasing population with improving living standards, expanding urbanization and growing economy. Asia consumed 6,688.6 million tons of oil equivalent (MTOE) in 2018¹, accounting for 48.3%² of the total global energy consumption for that year, equal to 13864.9 MTOE (BP 2019), and the continent is predicted to maintain this status at least in the foreseeable future. This trend will make energy security a major concern for all Asian economies, especially large economies and major trading ones, all of which are heavily dependent on fossil energy for the bulk of their energy demands.

Apart from other considerations, including the financial burden and negative impact on health, Asia's growing consumption of oil, gas and coal has created major environmental problems, which are increasing due to the growing consumption of such energy. In particular, global warming, caused mainly by CO₂ generated from burning fossil energy, is a major challenge globally, but especially in Asia, which has experienced a rapid depletion of its freshwater resources, frequent and extensive droughts, crop failures, forest fires and rising sea levels, among other effects, as reported by the Intergovernmental Panel on Climate Change, and other concerned environmental entities.

By and large, the Asian countries have realized the unsustainable nature of their fossil fuel-dominated energy mixes, and have thus sought to diversify them by adding renewable energy. Despite some progress in this regard, however, varying from one Asian country to another, the share of such energy in the continental energy mix is still too small, 18.5% equal to 1,238.8 MTOE in 2018³ (BP 2019), to contain Asia's phenomenal greenhouse gas (GHG) emissions which accounted for 53% of global emissions in 2018 (Ritchie and Roser 2019) and help reverse global warming. It should be pointed out that this small share consists of emission-free, and thus environmentally-clean types (mainly solar, wind, geothermal and hydro⁴) and unclean renewable energy. Renewable energy therefore does not equal environmentally-clean energy, as some types generate greenhouse gases when used (e.g., biomass such as wood and charcoal), and/or during their production phase (e.g., biofuels).

Various factors have prevented the expansion of renewable energy in Asia, one of which has largely been ignored: the availability of inappropriate renewable energy technologies to the Asian countries in search of green alternatives to polluting fossil energy. In other words, the promotion of certain expensive types of renewable energy with inbuilt power-generation restrictions and deficiencies, which detract from their benefits, has served as a disincentive for switching to renewable energy on a large, and therefore meaningful scale, especially in low-income Asian countries.

Horizontal axis wind turbines (HAWTs), i.e., wind turbines whose rotating axes are horizontal or parallel with the ground, are a blatant example of such inappropriate technologies. They account for the bulk of wind turbines in operation globally, which makes them practically synonymous with wind power. HAWTs are expensive; gigantic;

¹ The author calculated Asia's energy consumption in 2018 by combining the data for Asia and the Pacific and the Middle East regions as provided by BP, 2019.

² Author's calculation based on the data provided in BP, 2019.

³ Author's calculation based on the total renewable consumption, including hydro, for Asia and the Pacific and the Middle East as provided in BP, 2019.

⁴ Hydro has negative environmental effects on water resources and flooded land, among others.

difficult to install, operate, repair and maintain; and require a large land area for their operation, as will be discussed in this paper. More importantly, they need fast winds to generate power, which are not available all the time, not only at ground level, but also at higher levels in many parts of the world, including Asia, and yet the turbines have to be shut down when there are very fast winds blowing at speeds above their “survival speed” (i.e., the maximum wind speed they can tolerate). These expensive wind turbines are consequently not constantly operational, and are therefore intermittent sources of power generation, and unreliable grid-connected power generators. This means that they require backup generators to supply power during shortages caused by their intermittency, and these are, by and large, fossil-fired and thus emit CO₂.

Given this reality, it could be concluded that wind turbines in general are an inappropriate means of power generation for Asia. This is an incorrect conclusion, however, because it is HAWTs, a type of wind turbine with horizontal blades, that have major negative features making them an inappropriate choice for large-scale, grid-connected and emission-free power generation, and not all wind turbines. There is a solution available for these problems, but it is not yet widely used, and therefore its technology needs further development. Vertical axis wind turbines (VAWTs), whose rotational axes stand vertical or perpendicular to the ground, are designed to operate with slower wind speeds than the minimum speed required for HAWTs. Their design also means that they can operate in very fast winds, and even during storms, unlike HAWTs. Briefly, their vertical axis systems mean that air blowing at any speed and from any direction can rotate their blades to generate power even in gusty winds. Available in all sizes and in a variety of shapes, VAWTs are much cheaper and easier to build, transport, install, operate, repair and maintain than HAWTs. They also do not require a large area of land for their operation, and can be installed close together, unlike HAWTs.

Small VAWTs can be used at ground level, or at low levels of elevation, as well as on roof tops, making them suitable for many parts of Asia, and especially residential areas, and they can operate continuously when installed at high levels of elevation with constant wind availability, albeit with fluctuating power generation capabilities as wind speeds fluctuate. VAWTs can operate with slower wind speeds than those required for HAWTs, and can increase their power generation during slow winds when they are clustered into arrays to “create turbulence from one turbine to another, which helps increase the flow around them” (Arcadia, 2017). Under certain circumstances, therefore, VAWTs have the potential to address the intermittent nature of “traditional” wind turbines (HAWTs), and to make them a reliable source of power generation as both off-grid (stand-alone) and grid-connected generators.

Instead of trying to promote HAWTs in Asia despite their mentioned deficiencies, particularly their intermittent nature and the high cost that makes them unaffordable, especially on a large scale, for many low and middle-income Asian countries, various available types of VAWTs should be introduced to the Asian countries. In parallel, investment in their technologies should be encouraged to address their current deficiencies as appropriate and affordable technologies, especially for the low-income Asian countries. In addition to their other positive features, they could also be used in a hybrid energy system, in combination with a continuous source of power generation, such as small and inexpensive run-of-river hydro power generators, which do not require dam building, to offer a combined reliability as an inexpensive source of continuous power generation.

2. LIMITS OF WIND POWER

Wind is an environmentally clean source of energy for power generation in all areas. Wind power has grown significantly, although it is still far below its global potential, leaving room for dramatic expansion as a sustainable alternative to environmentally-unclean oil, gas and coal for power generation. Within this context, Asia has vast potential, as explained in the International Renewable Energy Agency (IRENA) latest report on the topic: the continent could increase its share of installed onshore wind capacity “from 230 gigawatt (GW) in 2018 to over 2600 GW by 2050” (IRENA 2019a). In fact, the report projects a leadership role for Asia in installed wind capacity, accounting by that time for more than 50% of all the global installed onshore wind capacity, followed by North America (23%) and Europe (10%), and over 60% of all the global installed offshore wind capacity followed by Europe (22%) and North America (16%) (IRENA 2019a).

Despite its importance as a type of renewable energy, wind is an intermittent source of power generation. It cannot generate electricity on demand as it is not present all the time in many locations, or, where it is continually present in some locations, its speed and duration of availability fluctuate depending on seasonal, climatic and geographical factors, to affect its power generation capability. It is therefore also not dispatchable according to the decision of its respective power generators (i.e., private or public power-generating companies) based on the need of the targeted power markets at the time.

When wind speed is insufficient for the uninterrupted operation of wind turbines, unless continuous clean renewable energy (mainly hydro) can be used as a backup, fossil-fired generators are still used to meet the required power. Unsurprisingly, as such generators emit CO₂, this counters the whole idea of using wind power as a non-CO₂-emitting renewable energy, and increases the cost of building and operating wind farms.

Given the variable nature of wind energy and its fluctuations beyond human control, it is important to choose a wind turbine technology which can address the issue as far as possible, and generate dispatchable power to its targeted power markets. In short, the objective should be to turn wind into a controllable and, thus, dispatchable type of environmentally-clean energy, similar to hydro and geothermal energy.

3. HORIZONTAL AXIS WIND TURBINES (HAWTS)

Without a doubt, HAWTs are a useful means of environmentally-clean power generation, accounting for the bulk of the wind turbines in operation globally. There are a wide variety of HAWTs, ranging from small versions for off-grid installment, for limited private power consumption (e.g., with a generating capacity of less than 100W for basic residential use) to large grid-connected versions such as offshore turbines of 6 MW generating capacity (Faizan 2020). The latter account for the majority of operational HAWTs globally, which are the focus of this paper (Figure 1).

Figure 1: Horizontal Axis Wind Turbines (HAWTs)

Source: Courtesy of Vestas Wind Systems A/S. 2020. Copenhagen, Denmark. https://www.vestas.com/~media/vestas/media/image%20download/highress%20images%20for%20download/v112_macarthur_aus_3.jpg.

As the most common means of CO₂-emission-free power generation, along with photovoltaic solar panels and hydro, wind energy has become synonymous with HAWTs, which has certainly helped decrease global reliance on environmentally-polluting sources since the 1990s. The usefulness of HAWTs and their necessity as an alternative source of power generation to fossil energy is evident in the phenomenal increase in global installed onshore and offshore wind-generation capacity “by a factor of almost 75 in the past two decades, jumping from 7.5 gigawatts (GW) in 1997 to some 564 GW by 2018”, according to IRENA’s 2019 statistics (IRENA 2020a). Their global growth has been an indispensable factor in reducing emissions of greenhouse gases (GHGs), of which CO₂ emitted by fossil fuels comprises the largest share. Such a reduction is an absolute necessity for containing global warming, and as a prelude to eventual efforts to reverse this devastating phenomenon.

Among the many indicators of fossil energy’s destructive nature for the survival of planet Earth as a habitable place for all its living creatures, the increasingly frequent occurrence of forest fires on all continents, and their growing scale and scope of devastation are clear indicators of the unsustainable nature of the existing global pattern of energy consumption characterized by heavy reliance on CO₂-emitting oil, gas and coal, which accounted for 84.7% (11,743.6 MTOE) of the global energy mix of 13,864.9 MTOE in 2018 (BP 2019). Despite the limitations of the existing environmentally-clean renewable technologies, including HAWTs, their importance for reducing GHGs as alternative to polluting fossil energy should not be ignored.

The main benefits of HAWTs include providing emission-free power through a renewable, and therefore inexhaustible, source (wind). This is a major contribution to decreasing the existing heavy dependence on fossil energy for power generation, which accounted for 64.49%⁵ of power generation in 2017, when that of wind was 4.38%⁶ (Table 1).

Table 1: Power Generation by Fuel 2017
(GWh)

Total	25,721,078*
Oil	841,878
Gas	5,882,825
Coal	9,863,339
Nuclear	2,636,030
Hydro	4,197,299
Wind	1,127,319
Biofuel	481,529
Solar PV	443,554
Solar Thermal	10,848
Waste	114,043
Geothermal	85,348
Tide	1,044
Other Sources	36,022

Source: Table created by author using data provided in the following source: International Energy Agency (IEA). 2018. Data and statistics – Electricity generation by source, World 1990–2017.

* Author's calculation.

Apart from reducing the mentioned dependency in the same way as other non-CO₂-emitting types of renewable energy used for power generation, namely hydro, geothermal and solar energy, the major advantages of HAWTs can be summarized as follows:

- The tall towers of HAWTs allow “access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%” (Kohilo University 2020).
- They are highly energy efficient, as they “convert more of the wind’s energy into useful mechanical motion because the blades are perpendicular to wind direction, and the blades pick up the energy throughout their range of movement” (Seattle PI 2020).
- HAWTs use existing and proven technologies ready for commercialization, and their cost has been falling rapidly (Nian 2020).
- Their manufacturing, installation, operation, maintenance and decommissioning processes have been well established and are understood by the industry (Nian 2020).
- The problems with HAWTs are also well understood, and the technology has been improved on a regular basis (Nian 2020).

⁵ Author's calculation based on Table 1 data.

⁶ Footnote 5.

The major disadvantages of HAWTs include a host of issues, of which the following are noteworthy:

- HAWTs are heavy, and “massive tower construction is required to support the heavy blades, gearbox, and generator” (Kohilo University 2020).
- Their heavy components (gearbox, rotor shaft and brake assembly) have to be lifted into position (Kohilo University 2020), which is challenging.
- They do not produce well in turbulent winds (Editor 2009).
- As they cannot be installed close to each other because of the resulting turbulence, HAWT farms need large areas of land for their operation, and the tall towers and long blades of HAWTs “work well only in wide-open spaces” (Seattle PI 2020).
- As large areas of land near urban areas are usually unavailable, the use of wilderness and rural areas for such purposes negatively affects these environments through the “industrialization of the countryside” (Szarka 2007).
- To work properly, winds must flow at a right angle to a HAWT’s blades, since they receive “much less energy from the wind” flowing from other directions “than the blades are facing”. HAWTs have a yaw drive to deal with this situation by rotating the direction of the turbines, which “adapts slowly to changing directions because it must turn the entire turbine and propeller assembly” (Seattle PI 2020).
- HAWTs “generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself (Kohilo University 2020).
- Given their need for a yaw mechanism, they are “mechanically more complex than the vertical design. The gyroscopic action of the spinning blades of a horizontal-axis turbine produce stress when the yaw mechanism turns to catch the wind. Over time, the stress can crack the turbine blades and hub” (Seattle PI 2020).
- They require a certain minimum wind speed (about 12-14 km/h equal to about 3.3-3.8 m/s depending on their technologies)⁷ to operate (Hydro Quebec 2020), which is not present all the time.
- They cannot operate when very fast winds blow. In fact, they have to be shut down to avoid damage from winds blowing at speeds above their survival speeds, which vary depending on the specifics of HAWTs. The highest is around 90 km/h, equal to 25/s⁸ (Hydro Quebec 2020).
- Their height makes them “obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition” (Kohilo University 2020).
- They produce a disturbing noise, which reduces their social acceptance (Kern et al. 2019).

⁷ The author converted the source data from km/h to m/s.

⁸ Footnote 7.

- The operation of HAWTs poses real, according to wildlife and forest conservationists, or perceived or exaggerated, according to their producers, threats to wildlife, especially “endangered bird species”, and this became a major obstacle to their rapid expansion in Germany in 2019, for instance (Rotter 2019).
- Finally, HAWTs have been blamed for “decreasing social acceptance and various land-use conflicts” accompanying the expansion of wind energy caused “by the large acoustic and the large visual footprint of conventional Horizontal Axis Wind Turbines” (Kern et al. 2019).

Briefly, HAWTs are generally expensive when compared to fossil power generators, although in parts of the world they could be cost competitive with gas and coal-fired generators (Grantham 2018). As mentioned earlier, they are huge constructions, difficult to transport, install, operate, repair and maintain, and require a large area for their operation which makes them unsuitable for urban operation. These wind turbines are not constantly operational because of their minimum and survival speeds. As intermittent sources of power generation, they are unreliable grid-connected power generators which require backup generators, usually powered through fossil fuels, which result in GHG emissions.

In summary, despite their importance, HAWTs are not the best technology to harness wind energy. Against this background, attention should be paid to other available technologies and whether they could offer better alternatives to fossil energy for power generation.

4. VERTICAL AXIS WIND TURBINES (VAWTS)

VAWTs have been available in a large number of shapes and sizes for decades (Figure 2), however, they account for a fraction of the wind turbines in operation globally. They have generally been used for small-scale power-generation projects and residential settings, particularly in urban areas, and, thus, mainly as stand-alone wind turbines, rather than grid-connected. As a result, they have not been the focus, or even a major focus, of investment or R&D, which have been primarily concentrated on HAWTs, despite their many attractive features that could help provide for the much greater and less expensive harnessing of wind’s kinetic energy for power generation.

For example, unlike HAWTs requiring winds blowing from certain directions, the vertical axis systems of VAWTs mean that “air flowing from any direction or speed can rotate [their] blades” to generate power even in case of “gusty winds” (Arcadia 2017). In other words, they can operate with winds “from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom” (Editor 2009).

VAWTs, unlike HAWTs, which are unable to operate in slow winds, can even increase their power generation when they are “clustered into arrays to create turbulence from one turbine to another, which helps increase the flow around them and augment power generation” (Arcadia 2017). Such augmentation could be quite phenomenal as demonstrated by an aerodynamic model funded by a 2010 California Energy Commission (CEC) grant. This model “proved that modern VAWTs, when placed close together would also create the ‘coupled vortex effect’. The one-meter close spacing and counter rotations let them produce 20 to 30% more energy per pair than from two VAWTs operating separately” (Dvorak 2018). This could even address one of the shortcomings of VAWTs, which has contributed to making HAWTs a more attractive option for power generators. This capability “offsets the problem VAWTs face that

HAWTs don't: Their blades create drag as they return into the wind. Historically, this increase in drag prevented them from realizing more than a 45% efficiency, whereas HAWTs can achieve 50%. With the coupled vortex effect, VAWTs in arrays can theoretically realize the efficiencies of HAWTs" (Dvorak 2018).

Figure 2: Vertical Axis Wind Turbines (VAWTs)



Source: Suraj Gehlot. Blog Theorem. Vertical Axis Wind Turbine (VAWT): Energy for Future!! 17 June 2018. <http://www.blogtheorem.com/vertical-axis-wind-turbine-vawt-energy-for-future>.

Apart from the obvious benefit of augmenting power generation, the ability of VAWTs to operate close to each other in a cluster formation is a major advantage. Compared to HAWTs, which require a large space between turbines in wind farms, their vertical design allows them to be placed close to each other, "so a wind farm does not have to take up as much ground area" (Arcadia 2017). Their ability to operate close to each other in much smaller areas than HAWTs lowers the cost of setting up wind farms to make them a financially attractive choice, especially for low-income Asian countries in search of affordable renewable alternatives to fossil energy to address increased power demand, as well as Asian countries with little available land. They can even be installed in the empty spaces between HAWTs on wind farms to significantly increase the overall power generation of the farms, without negatively affecting the operation of HAWTs, given their high level of tolerance and ability to operate with winds from different directions. This ability has the very important potential to address a major shortcoming of VAWTs, which encourages power generating companies to opt for HAWTs despite their deficiencies and high cost. The inefficiency of VAWTs compared to HAWTs could be remedied, as suggested by a 2017 report in the *Journal of Renewable and Sustainable Energy* cited by *Phys.org* and reported by Arcadia.

Accordingly, “although vertical axis wind turbines produce less energy per tower, they have the potential to generate as much as 10 times more power over a comparative area of land when placed in arrays (Arcadia 2017).

Their versatility, meaning the ability to adapt to many different functions or activities, also means that VAWTs are “ideal for installations where wind conditions are not consistent, or due to public ordinances the turbine cannot be placed high enough to benefit from steady wind” (Editor 2009).

Based on experiences gained in various countries, VAWTs have a wide range of advantages that make them suitable for practically all locations and countries, and especially low and middle-income Asian countries. The following is a comprehensive list of their advantages.

- VAWTs are “powered by wind coming from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom” (Editor 2009).
- Their vertical-axis design allows them “to operate on lower wind speeds than is possible with the horizontal turbine” (Seattle PI 2020).
- They suitable for areas where the wind picks up speed, including hilltops (Seattle PI 2020).
- They are “particularly suitable for areas with extreme weather conditions” (Kohilo University 2020) and “with variable winds and even mountain conditions” (Arcadia 2017).
- VAWTs are suitable for turbulent wind flow (Wong et al. 2017).
- They have scalability, as their “design can be scaled down to small sizes, even as small as what will fit on an urban rooftop” and can therefore be a practical renewable alternative to fossil-fired generators in urban areas where “there may not be room for all renewable energy technologies” (Arcadia 2017).
- They run “well regardless of wind direction”, which makes them “better-suited to urban areas with tall buildings where wind turbulence is a given” and “wind picks up speed between buildings” (Seattle PI 2020).
- They do not experience the stresses that HAWTs must tolerate, which could “crack the turbine blades and hub” (Seattle PI 2020).
- They do not have the mechanical complexity of HAWTs as they do not need to be pointed “in wind direction to be efficient” as a result of which they do not need a “yaw drive and pitch mechanism” (Kohilo University 2020).
- They do not need strong supporting towers, since their generators, gearboxes and other components are placed on the ground (Kohilo University 2020).
- Their production and maintenance costs are low compared to HAWTs (Kohilo University 2020).
- Compared to HAWTs, their installation and transportation from one place to another is easy (Kohilo University 2020). They can be installed in “a vertical system on a level base, such as the ground or the top of a building” (Arcadia, 2017).
- They pose low risk to humans and birds because their blades move at relatively low speeds (Kohilo University 2020), and are safe for “their maintenance workers who do not have to climb as high to reach parts of the tower” (Arcadia 2017).

- They operate more quietly than HAWTs and thus “don’t disturb people in residential neighborhoods” (Arcadia 2017).
- Finally, their “low center of gravity makes them more stable for floating in offshore installations” (Arcadia 2017).

Despite their various advantages, which should make them an attractive option for power generation using wind energy, VAWTs have certain disadvantages, which could be disincentives. The following are the main major issues.

- VAWTs “do not harness the higher wind speeds often found at higher levels”, as they are “lower to the ground” (Arcadia 2017).
- They are more difficult to install on a tower than HWATs (Arcadia 2017).
- A VAWT’s “efficiency is very low compared to HAWTS, as “only one blade of [this type of] wind turbine works at a time” and because of the “additional drag created when their blades rotate” (Kohilo University 2020).
- Some types of VAWTS (e.g., “Eggbeater” or Darrieus turbines) need an external power source to start working (Whittlesey 2017).
- Their low efficiency compared to HATWs and “low self-start ability of VAWTs are always the main drawbacks especially for the lift-type VAWTs” (Wong et al. 2017).
- They have “relative high vibration because the air flow near the ground creates turbulent flow” and the effect of “bearing wear increases which results in the increase of maintenance costs” (Kohilo University 2020).
- Small VAWTs “atop buildings or other structures may be subject to jostling forces, which add lateral stress that warrants ongoing maintenance and the use of stronger, more sturdy materials” (Arcadia 2017).
- Depending on their design, VAWTs “may need guy wires to hold [them] up”, which are “impractical and heavy in farm areas” (Kohilo University 2020).
- There is still the issue of establishing manufacturing facilities and a viable value chain when HAWTs already dominate the market (Nian 2020).

Notwithstanding their mentioned disadvantages, VAWTS can and should be used to harness wind energy on a much larger scale than the current scale. Like HAWTs, and other renewable energy options (e.g., solar), they are not perfect power generators, but they have many advantages, including those mentioned above. Above all, they provide an environmentally-clean option for power generation, especially in low-income countries which cannot afford the large-scale installation of HAWTs despite wanting to reduce their reliance on cheaper, but environmentally unsustainable fossil energy.

The lower cost of VAWTs compared to HAWTs, as a result of their cheaper technologies, the ease of their transportation, installment, repair and maintenance, their use of smaller areas of land for their operation, and the feasibility of their installment on hills and roof tops, and in urban areas, make them particularly suitable for Asia, and its many developing and emerging economies. In addition to the shortages of available funds for renewable energy, restrictions in the bank-dominated financial markets of Asian countries create barriers to the implementation of expensive renewable energy projects, as I discussed in detail in a recent ADBI publication (Peimani 2019). In such a situation, lowering the cost of wind projects surely makes their realization more feasible, which means that VAWTs are a better option than HAWTs for many Asian countries with plans to deal with global warming and the other negative impacts of

fossil energy on their countries by switching to renewable energy for their power requirements.

Of course, as the list of disadvantages indicates, VAWT technologies need further development to address their shortcomings, which have prompted those interested in wind energy to opt for HAWTs for large-scale power generation and consider VAWTs mainly suitable for small-scale projects. As discussed above, however, the emerging VAWTs are believed to be competitive in this regard, while having many benefits to make them more attractive for power generation. In short, most of their disadvantages could potentially be addressed by channeling funds into R&D for VAWTs, rather than continuing to focus on HAWTs.

5. PROMOTING THE RIGHT TECHNOLOGY

Without a doubt, wind energy is necessary for combating global warming to ensure the survival of planet Earth, which requires the replacement of the fossil energy-fueled global economy with an economy fueled by environmentally clean energy to ensure a green, and thus sustainable global economy. The single major means to achieve this objective is a sustainable energy mix. By itself, wind energy cannot fully replace fossil energy for power generation, and nor can any other environmentally-clean (green) renewable source. However, wind is essential for such an energy mix, as it is available all over the world, including in Asia, and thus an indispensable component. The challenge is how to maximize power generation from this sustainable energy, and, in fact, from all other types of green renewable energy, to signify the importance of using the most appropriate wind energy technologies.

As discussed in detail earlier, the two available wind technologies both have pros and cons. At their current level of development, neither is perfect, or suitable for all geographical locations which have different energy needs and means of satisfying them. The issue is therefore not to choose between the two options once and forever, as the only sensible technology for harnessing wind energy. Instead, the issue lies in helping to expand the currently insignificant share of wind energy in the global energy mix, and, in particular, of the global power mix that is heavily dominated by fossil energy. This is a global necessity, but this objective is especially important for Asia, the most populous continent with an ever-increasing energy demand, including for power generation, whose consumption has been increasing especially over the last three decades, and is expected to continue in the foreseeable future. Asia suffers the most from global warming due to its large size, and produces phenomenal GHG emissions, which means that switching to green energy for power generation is understood as a necessity, as evident in the major efforts of the People's Republic of China (PRC), as a clear example, to use renewable and nuclear energy towards this objective. These efforts indicate the PRC has the highest production and installment of wind turbines and other types of renewable energy, such as solar and hydro power generators, in the world. The PRC's total installed emission-free renewable capacity was 685,998 MW in 2018, consisting of hydro (322,871 MW), wind (180,077 MW), photovoltaic solar (175,016 MW), bioenergy (solid biofuels) (8,030 MW) and marine energy (4 MW) (IRENA 2020b).

The task of dealing with expanding air pollution caused by GHG emissions, especially CO₂, which is a growing health hazard in addition to causing and worsening global warming, requires more expansive and faster use of green energy to replace the existing polluting sources. This task cannot be achieved with the current slow, albeit impressive, penetration of clean renewable energy, including wind power, in parts of

the world, especially Asia. It is thus necessary to speed up this process, which requires removing the barriers to such expansion. Within this context, HAWTs are not the best option for the majority of Asian countries for the reasons given above, in spite of their merits as the most developed type of wind technology and their dominance of the global wind sector. Among other things, their high cost, large land requirement and technical complexity mean they are not a realistic option for low and middle-income Asian countries, or for small Asian countries with limited land surface, as evident in the small share of renewable production in the Asian countries in 2017 (Table 1), their absence or near-absent presence in the energy mix of the majority of Asian countries, and their still small role in the richer, larger and more technologically advanced Asian countries such as the PRC, Japan and the Republic of Korea (Table 3). In Asia, including the Middle East, hydropower is clearly the dominant type of renewable energy used, with wind power in second place as shown in Table 2. This is also true in the PRC and Japan, but not the Republic of Korea, where the share of solar energy is slightly larger than that of wind energy.

Table 2: Comparative Share of Wind of Grid-Connected Renewable Energy 2017 in Asia

Region	Total Renewable	Hydropower		Wind		Solar	
		Volume in GWH	Share	Volume in GWH	Share of Total*	Volume in GWH	Share of Total*
Asia	2,394,225	1,696,667	70.86%	367,744	15.35%	208,153	8.69%
Middle East	32,192	27,041	83.99%	810	2.51%	3,979	12.36%
Asia, including Middle East*	2,426,417	1,723,708	71.03%	368,554	15.18%	212,132	8.74%

Source: Table created by author using data provided in the following source: IRENA. 2019b. Renewable Energy Statistics 2019, pp. 3, 7, 11, 14, 33 and 35. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jul/IRENA_Renewable_energy_statistics_2019.pdf.

* Author's calculation.

Table 3: Comparative Share of Wind in Grid-Connected Renewable Energy in Large Asian Countries 2017

Country	Total Renewable	Hydropower		Wind		Solar	
		Volume in GWH	Share	Volume in GWH	Share of Total*	Volume in GWH	Share of Total*
PRC	1,640,511	1,189,840	72.52%	305,015	18.59%	118,267	7.20%
Japan	168,236	90,162	53.59%	6,490	3.85%	55,068	32.73%
Republic of Korea	18,622	7,006	37.62%	2,169	11.64%	7,057	37.89%

Source: Table created by author using data provided in the following source: IRENA. 2019b. Renewable Energy Statistics 2019, pp. 3, 5, 11, 27 and 41. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jul/IRENA_Renewable_energy_statistics_2019.pdf.

* Author's calculation.

Without a doubt, HAWTs are currently more efficient power generators than VAWTs, thanks to the heavy investment in their research and development which has resulted in their improved performance. However, VAWTs have their own merits, as discussed above, and thus, even with their existing technology, they can help the rapid expansion of wind energy in Asia. The feasibility of their use in urban areas, which are the main source of GHG emissions in many parts of Asia, especially, but not exclusively⁹, due to a rapid and continuous increase in power demand when power generators are inside or

⁹ The steady increase in the number of vehicles in the Asian cities is another major, or even *the* major, source of GHG emissions, depending on the case.

near urban areas, can certainly help reduce air pollution and decrease GHG emissions, while meeting part of the demand. The ability to place them close to each other, so that they require much less land for windfarms compared to HAWT windfarms means that they could be set up in close proximity to urban areas where land for power generation is scarce or expensive due to other more profitable land usage.

VAWTs are also ideal for hybrid systems (solar-wind) that can address the intermittency of these two types of clean renewable energy for a wide application. Hybrid systems range from meeting a part or the entire power demand of small consuming units (e.g., small dwellings or farms), to lighting streets. Thanks to the ability of VAWTs to operate in turbulence, and using wind from any direction for their operation, they can help increase the power generation capacity of the existing HAWT wind farms by using the un-utilized spaces in between turbines. The feasibility of addressing their low efficiency by creating a “coupled vortex effect” (Dvorak 2018) also makes them suitable options as grid-connected wind turbines. “Coupled vortex effect” also increase their power generation capability with the same number of turbines in stand-alone cases and raise their profitability.

Needless to say, investing further in VAWTs as a more practical and affordable turbine technology for the needs and realities of the majority of the Asian countries in search of affordable renewable energy technologies can and will certainly improve their challenges and deficiencies. Such investment will turn them into more efficient types of renewable technology for both small power consuming units and large-scale power generation. The improved VAWT technology will enable the faster expansion of wind energy in the major Asian polluting countries, particularly, the PRC and India, where GHG emissions are increasing threats not only to the local and global environments, but also to the population’s health.

Even now, with all their shortcomings, VAWTs can compete with HAWTs through the coupled vortex effect, as they are a less expensive and, therefore, more economically sensible option for power generation beyond their small-scale use today.

6. CONCLUSION

HAWTs, despite their merits and unquestionable contribution to emission-free power generation both in Asia and globally, are not suitable for all locations and not affordable on a large scale for low-income Asian countries, and, of course, many non-Asian countries. VAWTs are affordable and adaptable to many locations, despite having their own challenges. They should thus be used by both low and middle-income Asian countries as an available and economically viable means of generating clean power wherever feasible.

Instead of trying to promote HAWTs in Asia as the main type of technology for harnessing the enormous and inexhaustible wind energy, despite their mentioned deficiencies, the various available types of VAWTs should be introduced to the Asian countries. Depending on the type of power requirements and the geographic, climatic, technological and financial specifics of a given locality in Asia, one or another type of VAWTs may be most suitable.

In parallel to this, investment in VAWT technologies should be encouraged to address their shortcomings as appropriate and affordable technologies, especially in low-income Asian countries. Added to their other positive features, VAWTs could be used in hybrid energy systems in combination with a continuous source of power generation, particularly small and comparatively inexpensive run-of-river hydro power generators,

which do not require large and expensive dam building, to increase their combined reliability as an inexpensive source of continuous power generation. Of course, they can also be combined with another intermittent sources of power, such as solar photovoltaic panels, to address their mutual intermittency, either fully or, at least, to some extent, such as in the form of hybrid solar-wind systems for streetlights. VAWTs are the right technology for this application, and others.

Ultimately, VAWTs are an indispensable type of wind energy technology, which have not yet been fully utilized. Given the intensifying climate change, and especially global warming, with its devastating impact on many parts of Asia, it is crucial to cut GHG emissions at scales much larger than those achieved so far. It is therefore essential to use all types of available emission-free energy to reduce the existing heavy reliance on CO₂-emitting fossil-energy, which is obviously unsustainable. As an available technology, VAWTs should be promoted for their own merits, and also as a supplement to HAWTs to maximize the harnessing of wind energy. Asia, as the world's largest energy consumer, must take advantage of VAWTs as an inexpensive type of turbine suitable for many areas, and particularly its growing urban areas.

7. RECOMMENDATIONS

Certain measures could help expand the currently limited use of VAWTs to maximize the harnessing of wind energy. Energy and environmental policymakers in Asia should consider the following recommendations in their plans for emission-free power generation and curbing GHG emissions by using VAWTs.

- Investment in VAWTs is necessary to make them more efficient, and also suitable not only for small-scale power generation, but especially for large-scale generation.
- To facilitate and encourage such investment, VAWT R&D and expansion plans could be combined with developmental goals for urban, and, especially, rural areas and poverty reduction, to generate constructive employment opportunities and income for the unemployed and/or migrating rural populations, while developing indigenous wind energy technology.
- VAWTs should be promoted as affordable power generators for microgrids, which are essential in many parts of Asia for ending the two interlinked phenomena of energy poverty and underdevelopment, as well as the waste of power through long transmitting cables from large green (e.g., hydro dams) or polluting (e.g., coal-fired plants) power generators to their consuming markets.
- For this purpose, VAWTs should be part of hybrid energy systems to compensate for their intermittency. They could be combined with other emission-free intermittent green power generators, such as concentrated solar and photovoltaic solar, and/or continuous green power generators, including small run-of-river hydro systems and/or geothermal power generators.
- VAWTs should be added to existing HAWT wind farms to maximize the use of space, and address their intermittency to the extent feasible, while increasing their power generation capacity when suitable winds are available for both types of turbines, and compensating for their low or non-existent generation of power when winds with the speeds required for HAWTs are unavailable.

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