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Adverse environmental impacts of wind farm installations and alternative research pathways to their mitigation

Nasimul Eshan Chowdhury [a], Mahmudul Alam Shakib [b], Fei Xu [c], Sayedus Salehin [a], Md Rashidul Islam [d], Arafat A. Bhuiyan [a,*]

[a] Department of Mechanical and Production Engineering, Islamic University of Technology, Board Bazar, Gazipur, 1704, Bangladesh
[b] Department of Mechanical Engineering, University of Iowa, 2404, Iowa City, IA, 52242, USA
[c] Ansys, Inc., Austin, TX, 78746, USA
[d] Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna, 9203, Bangladesh

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ABSTRACT

The world has witnessed an unprecedented growth of WF installation, driven by national and international energy policies. Considering the negative impacts of fossil fuel and associated climate changes, wind is an important form of renewable energy. Nevertheless, the conventional WFs also have some environmental effects. Besides, the conventional WTs lack in performance due to technical limitations. Upon comprehensively reviewing the impacts and the technicalities, this literature focused on the recent developments in the research community to predict the potential research pathways for technical optimization and modification of the relevant policies.

1. Introduction

The world is becoming increasingly more and more aware of the adverse impacts of fossil and nuclear fuel-based power generations, which thrives the enthusiasm for renewable power generation (Park and Kim, 2019). Renewable energy sources are those natural sources that replenish themselves over a short period. They are generally intermittent in nature and location-specific. Which causes the power generated from such sources to be highly dependent on environmental conditions. Due to such constraints, unlike fossil fuels, renewable energy sources cannot provide energy incessantly. However, efforts have been taken in harnessing renewable energy, especially wind. European Wind Energy Association has taken a target to generate 320 GW of wind power by the year 2030 and initiated renewable-friendly policies across its member states to accelerate the installation of renewable power plants (Haas, 2019). In addition to that, wind energy has provided some countries with additional options to diversify their energy source, which could enhance the safety of their energy supply. For instance, according to a report of 2016, Brazil has 41.2% of renewable energy in its energy matrix, 64% of which is hydroelectric. However, Brazil has shown a favorable growth of wind power harness after the severe drought of 2014 (Rotela Junior et al., 2019).

Nevertheless, the current wind technologies contribute to environmental impacts to a certain degree. Among the impacts, change in meteorologic condition(Keith, 2018) and causing deaths to migratory birds due to the collision with Wind Turbines (WTs) (Katzner et al., 2017) are often reported. Harmful byproducts are also frequently emitted through the manufacturing process of these technologies (Rahimizadeh et al., 2019). In Fact, in the case of Global Warming, a typical manufacturing process comprises about 89% of the total impact (Gomaa et al., 2019). Besides, the conventional WTs possess some technical drawbacks, like-electricity distribution (24%), control system failure (19%) (Alhmoud and Wang, 2018).

Due to these facts, some alternatives have been addressed so far. Among them, insect-inspired kites (Khaheshi et al., 2021), various subsystems for drag power kites (Bauer et al., 2019), power kites with inflatable wings (Rushdi et al., 2020), analysis of LIDAR (light direction and ranging) and mesoscale models (Sommerfeld et al., 2019a, 2019b), filtration method of analyzing tethered kite wings (Schmidt et al., 2020), vortex-induced vibration (VIV)-based piezoelectric energy harvester (Shi et al., 2021), and vortex wind generation showed distinct outcomes (Ren et al., 2021). However, from an environmental perspective, some limitations have been observed in the current alternatives. This article aims to address these shortcomings and to propose research pathways accordingly. In this regard, the recent studies on environmental impacts

* Corresponding author.
E-mail address: arafat@iut-dhaka.edu (A.A. Bhuiyan).

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Nomenclature

AA	= Aesthetic attributes
AD	= Abiotic Depletion
AWES	= Airborne wind energy system
CO_2	= Carbon dioxide
CFC-11	= Trichlorofluoromethane
CPRE	= Campaign to Protect Rural England
CVM	= Contingent valuation method
C_2H_4	= Ethylene
DE	= Doppler Effect
1,4-DB	= 4-(2,4-dichlorophenoxy) butyric acid
ESS	= Epworth sleepiness scales
EU	= European Union
FWAT	= Fresh-water aquatic eco-toxicity
WT	= WT
WF	= Wind Farm
GGS	= Ground-gen system
GPS	= Global positioning system
GWP	= Global Warming Potential
HAWT	= Horizontal axis WT
HTP	= Human Toxicity Potential
IC	= Internal combustion
I/Q	= In-phase and quadrature-phase
ISO	= International Organization for Standardization
LAeq,8h	= Eight-hour equivalent sound level
LCA	= Life Cycle Assessment
LIDAR	= light direction and ranging
LWT	= Large Wind Turbine
PO	= Photochemical Oxidation
PA	= Physical attributes
PO_4	= Phosphate
RAM	= Radar Absorbing Material
RAMS	= Regional Atmospheric Modeling System
RSPB	= Royal Society for the Protection of Birds
Sb	= Stibium (Latin word of Antimony)
SO_2	= Sulfur dioxide
SWT	= Small Wind Turbine
VAWT	= Vertical Axis Wind Turbine
WTA	= willingness to accept
WTP	= willingness to pay

and developments on the mentioned alternatives have been reviewed.

There have been several reviews on the impacts of WTs in recent times. Some of them are regarding the health hazards of the WT employees (Karanikas et al., 2021), the impact of WTs on airport facilities (Cuadra et al., 2019), effects of WTs on wildlife (Schöll and Nopp-Mayr, 2021), and impacts on surface temperatures of downwind locations (Moravec et al., 2018). Whereas, reviews like (Nazir et al., 2019), focused on a very narrow geographical region. Considering these factors, this literature attempts to investigate the current research gaps at first by the illustration of the latest studies on these impacts, and then by comparative analysis of the outcomes. However, to gain a more profound and comprehensive understanding, old studies have also been addressed. This study attempted to construct a bridge between old and new studies. We expect this review to benefit the researchers and the policymakers in paving the future for wind energy.

2. Brief history and current status of wind power

The history of harnessing wind power is of more than 3000 years, which can be traced back to ancient Egypt (Varun Kumar, 2015). However, Horizontal Axis WT (HAWT) is a later invention and was first introduced in the Duchy of Normandy in Europe, in the year 1180 (Leung and Yang, 2012). With the invention of the steam engine in the 1700s, utilization of wind energy started declining and was almost completely abandoned after the invention of the internal combustion (IC) engine (Tim, 2015). It was only after 1887 when Prof. James Blyth from Scotland first used the windmill to generate electricity; wind energy started to burgeon (The Science Team, 2017). During the 1920s and 1930s, before the large-scale installation of the power grid, small wind machines (<1 kW) and windmills were seen widely in use for domestic purposes in the rural areas of the USA. The introduction of electric power lines in the 1930s, again diminished the acceptance of these WFs, as its unstable nature made it difficult to be connected to the power grid (U.S. Energy Information Administration, 2021).

However, the oil crisis in the 1970s and the recession in the following years once again boosted the need for wind energy (Ackermann and Söder, 2002). Thus, throughout the history of the progress of wind power, there has been a clear correlation between the oil price and the demand for wind energy. In recent years, attention toward WTs has gained much momentum, as the global installation of wind capacity has

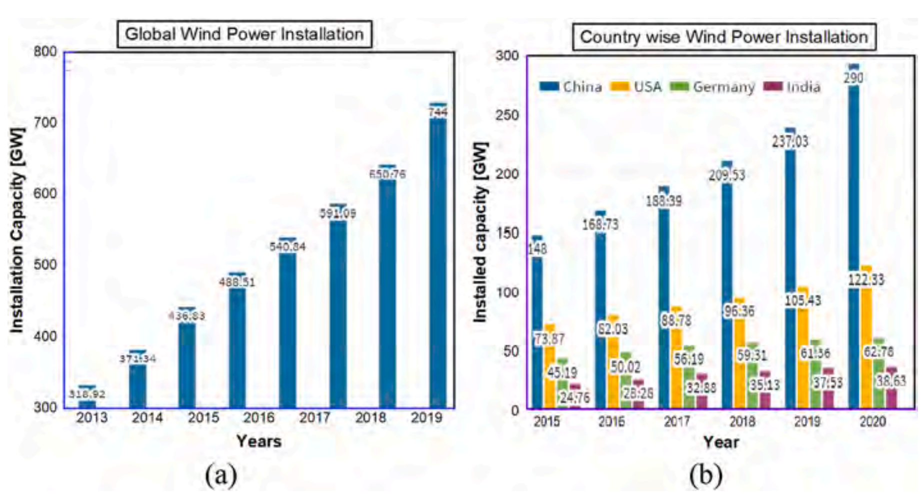

Fig. 1. Statistics of wind energy development in recent years: (a) the increase of WF installation (Worldwide Wind Capacity Reaches, 2020); (b) WF installation of leading countries (Worldwide Wind Capacity Reaches, 2020).

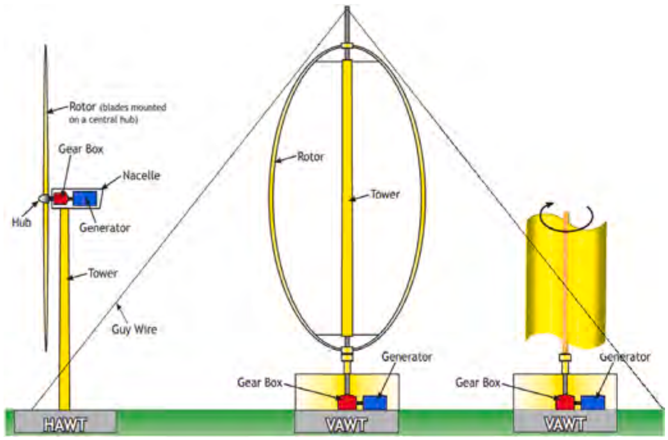

Fig. 2. Some of the most popular WTs in electricity production; Horizontal Axis WT (most left), Darrieus WT (middle), and Savonius WT (right) (TeacherGeek, 2006).

increased significantly, from 318.919 GW (in the year 2013) to 371.336 MW (in the year 2014), and in recent times it reaches to 744 GW, as presented in Fig. 1 (a). The current statistics show positive trends in China, along with some other countries, in wind power installations. USA has the second-highest WF installation after China (290 GW of installation in 2020), with an installed capacity of 122.33 GW in 2020.

Moreover, there were already 115 European offshore wind energy projects in 2019 (Topham et al., 2019). Whereas, by adding another 356 offshore WTs to the grid they reached a total installed offshore capacity of 25 GW in 2020 (WindEurope, 2020). However, the VAWT manufacturing companies were not frequently seen in business until 2006, except Ropatec and Bolzano in Italy (EcoBusinessLinks, 2018). Whereas, the popularity of Off-shore Wind Power is comparatively small, except for Denmark which has the largest offshore WF, located at Horns Rev in the North Sea (Garus, 2015). However, the present statistics indicate that wind energy harnessing has shown a positive trend in recent years.

3. Classification of WTs

WTs can be classified from different aspects. They are mostly classified according to the mechanism and shape of the blades. Fig. 2 shows some of the most prevalent WT types in large-scale power generation. The modern HAWT represents the conventional model for commercial-scale wind power generation. Whereas, Savonius WT and Darrieus WT are mainly used for small-scale wind power generation. According to axis orientation, applied force, and installation location, classifications of WTs are presented respectively as follows (Mishra, 2017):

i. Vertical Axis WT-
   - Darrieus WT: It has straight or curved blades mounted on a vertical frame and uses lift force to rotate.
   - Savonius WT: It uses drag force and looks like an 'S'shaped plate while looking from above.

ii. Horizontal Axis WT-
   - Upwind WTs: In this case, the wind first hits the rotor and then passes through other portions.
   - Downwind WTs: In this case, the rotor is placed in the lee of the tower.

iii. Lift force driven WT-The wind force lifts the blades for the airfoil design. HAWT and Darrieus WT are in this category.

iv. Drag force driven WT-The wind force applies normally on the blades and causes rotation in this model of WTs. Savonius WT is in this category.

v. Off-Shore WT- This type of WT is installed on the shallow sea water bed.

vi. On-Shore Wind Turbine- All the WTs, installed on the ground belong to this category.

To refer to the WTs used in large-scale commercial electricity production, the term Large WT (LWT) is frequently used. LWT normally indicates large-scale HAWT, as it is the most commonly implemented model for power generation (Jin et al., 2015). Among all the HAWT types the 'Three-blade' configuration is the most popular, for its numerous advantages (Hossain and Ali, 2015). Hence, most of the studies on the impacts of LWT have been carried out based on HAWT technology (Saad and Asmuin, 2014).

4. Environmental impacts of LWTs

Many countries still do not have specific environmental protection standards for WTs, as mentioned by Katzner et al. (2017) and Dai et al. (2015). Arnett and May (Arnett and May, 2016) have asserted that the knowledge of environmental impacts of WT is not made publicly available by the developers and manufacturers. This impedes scientific progress and spreads distrust among the general population, making the study on the impacts of WTs very challenging. To overcome this dichotomy and to have an unblemished view of the issue, both the major and minor impacts of WTs have been described in this section.

4.1. The environmental hazard caused during manufacturing

Conventional WTs are regarded as 'zero-emission' during operation. However, there are environmental hazards associated with their manufacturing and disposal processes (Zhu et al., 2014). To date, several researchers: Gkantou et al. (2020) and Li et al.(Li et al., 2021), have authored on Life Cycle Assessment (LCA) of WTs of different sizes, types, and capacities to investigate the environmental impacts of WFs, considering the whole life cycle of the wind power system. In all the studies, the ISO 14040 standard (International Organization for Standardization (International Organization for Standardization, 2021) has been followed, which allows quantifying the overall impact of a WT from an LCA study (Martínez et al., 2009). The LCA determines the environmental impacts of products, processes, or services through production, usage, and disposal (Eriksson et al., 2008). The LCA of WFs is generally assessed in terms of all or most of the following impact categories:

1. Abiotic Depletion (AD): It relates to the extraction of minerals and fossil fuels and deals with the health of humans and the ecosystem. The abiotic depletion factor is determined by minerals and fossil fuels, based on the concentration of reserves and rate of de-accumulation.
2. Fresh-water aquatic eco-toxicity (FWAT): This relates to the impact of toxic substances on air, water, and soil.
3. Global Warming Potential (GWP): Greenhouse gas (GHG) emissions in the entire period of the life cycle of a WT.
4. Ozone layer Depletion Potential: Related to the fraction of UV-B radiation reaching the earth. According to World Meteorological Organization, ozone layer depletion is one of the most vital concerns for the preservation of the global climate system (WMO, 2011).
5. Human Toxicity Potential (HTP): Related to exposure and effects of toxic substances for an infinite time horizon (Martínez et al., 2009), first introduced by Guinee and Heijungs (Guinee and Heijungs, 1993). Studies by Demir et al.(Demir and Taşkin, 2013), Garrett et al.(Garrett and Rønde, 2013) and (Martínez et al., 2009), suggested that the manufacturing stage dominates in HTP. Among the manufactured parts, according to the study of 2009 by Martinez et al. nacelle (Martínez et al., 2009) and

Table 1
Global Warming Potential of WTs in different LCA studies.

Reference	Turbine Size (MW)	GHG Emission Intensity (kg CO_2-eq/kWh)
Martínez et al.(Martínez et al., 2009)	2	0.0080
Tremeac and Meunier (Tremeac and Meunier, 2009)	4.5	0.0158
Garrett and Rønde (Garrett and Rønde, 2013)	2	0.0080
Demir and Taskin (Demir and Taşkin, 2013)	3.02	0.0238
Bonou et al.(Bonou et al., 2016)	2.3	0.0060
Gkantou et al.(Gkantou et al., 2020)	5	0.0096–0.0103
Li et al.(Li et al., 2021)	40	0.0164–0.0282

according to the study of 2013 by Demir et al.(Demir and Taşkin, 2013) the foundation of a WT has the highest HTP value.

6. Marine eco-toxicity: It categorizes the impact related to marine ecosystems.
7. Terrestrial eco-toxicity: It categorizes the impact on terrestrial ecosystems.
8. Photochemical oxidation (PO): This deals with the growth of reactive substances (mainly ozone). The impact potentials are expressed as an equivalent emission of the reference substance ethylene, C_2H_4.
9. Acidification: The potential of acidification is defined as the ratio of the number of H^+ ions, produced per kg of different substances, to the number of H^+ ions, produced per kg of SO_2. The major acidifying substances are SO_2, NO, HCl and NH_3.
10. Eutrophication: This relates to the impacts of excessive levels of macro-nutrients exposure in the environment. Nitrogen (N) and Phosphorus (P) are the two nutrients most implicated in eutrophication.

According to the old LCA studies, like the study of 2008 by Ardente et al. (2008) and Guezuraga et al. (2012), manufacturing is the major source of environmental impacts. Whereas, the study of 2018 by Chipindula et al. (2018), the operation has the lowest impact on the environment. Another aspect is the impact of subsequent treatment and dismantling of waste at the end of the turbine lifetime. Steel, which accounts for 73% (by weight) of an offshore WT and 20.5% (by weight) of an onshore WT (Bonou et al., 2016), is one of the most valuable materials in terms of recycling (Topham et al., 2019). Since steel makes a large share of the material used for the entire WT, an overall positive effect of recycling can be achieved. A 2019 study shows that fiberglass, contributing to 2.3% by weight (Bonou et al., 2016) of an offshore WT, can be recycled into reinforced filaments (Rahimizadeh et al., 2019). Certain materials used in manufacturing WTs can cause adverse impacts on the environment. For example, copper, which comprises 35% of the total weight of the generator, is found to be the most hazardous material used in manufacturing (Chen et al., 2020; Gkantou et al., 2020). Because copper is not biodegradable and is accumulated in plants and animals (greenspec, 2021) and its excessiveness can create metabolic disturbances and growth inhibition in plants (J.C and S, 1991). Consequently, all these factors make the disposal of turbines difficult. However, the alternator plays a critical role in achieving high turbine efficiency. Which necessitates a compromise between WT performances from an economic perspective and an ecological perspective.

In terms of AD, both old and new studies on LCA of WTs reflect that the manufacturing stage has more than 80% of the total impact in abiotic depletion, as mentioned by Garrett et al. (Garrett and Rønde, 2013) and Gkantou et al. (2020). The study of 2009 suggested that among the manufactured parts, rotor (Martínez et al., 2009) have the highest impact. However, the study of 2020 claims that the tower has the highest impact (Gkantou et al., 2020) in abiotic depletion. It can be attributed to the improvement of rotor-material during the last decade.

On the other hand, manufacturing contributes to 94.7% of total GWP according to the study of 2009 by Martinez et al.(Martínez et al., 2009) and 100% according to the study of 2013 by Demir and Taskin (Demir and Taşkin, 2013). A later study by Garrett et al. (Garrett and Rønde, 2013)suggested that the manufacturing stage contributes to GWP by 85%. The percentage has decreased further to 84.7% in the recent study by Gkantou et al. (2020). This decrement alludes to the improvement of the manufacturing process during the past decade. Among all the parts of a WT, Rotor (Martínez et al., 2009), tower (International Journal of Life Cycle Assessment, 2013), and foundation (Demir and Taşkin, 2013) are the major contributors to the overall GWP. However, in these studies, they did not consider the materials needed for major and auxiliary engineering (Li et al., 2021). It is evident from the Comparison of GHG Emission Intensity by different studies, presented in Table 1, that the average GHG Emission Intensity drastically increases with the increase of the size of the WT, which is a clear indication that major development is needed in the manufacturing process of WTs.

To this end, more LCA studies are needed on various types of WTs to lower the uncertainty levels incorporated into WT designs. **S**tudies calculating the life span of the WTs are still in the premature stage, to the extent that some WTs had to be decommissioned well before their expected life span. These studies were conducted assuming a life span of 20 years and not the actual life of the WT. Studies until 2020 also assumed tower height to be up to 150m only. Only a recent study by Gkantou et al. (2020) presented an LCA for the tower height of 185 meters. This implies comprehensive studies are still in demand.

4.2. Impacts on aves and mammals

The term *Aves* refers to the class of flying vertebrates such as birds and bats (Powlesland, 2009). Kunz et al. (2007) conducted a study on the impacts of WTs on the bats and concluded that WTs harm birds. In this study, he took the phenomenon of bat carcasses being eaten by scavengers into consideration. Whereas, they found the then existing evidence to be inconclusive and too scarce to reach any decisive conclusions on mortality of aves from WTs. Kunz et al. (2007) suggested further studies on the mortality of the aves from WTs. Migratory bats tend to collide with the WTs, as suggested by the study of Arnett et al., (2008).The highest mortality rate was reported at low wind speeds and was found among the adult bats, which eliminates the possibility of lacking the maneuvering skills of certain aves (Arnett et al., 2008). The findings of Jourieh et al. (2009) reaffirmed the findings of Arnett et al., (2008).

Avian mortality from WTs is significantly less than from many other factors. For example, according to a USA-based survey, the rate of mortality is about 400 times less than collisions with vehicles, about 30 times less than collisions with communication towers, and about 1200 times less than collisions with transmission lines (Wang et al., 2015). However, the rapid growth of global WT installations makes it an issue of growing concern. A survey was carried out in Østerild Plantation of northwest Jutland in Denmark, based on the Scottish Natural Heritage models, by Therkildsen et al. (2015) to investigate the risk of the collision of some selected species with the WTs. The study focused on migratory birds including whooper swan, pink-footed goose, taiga bean goose, and common crane. The researched birds migrated through a site that had WTs with a maximum height of 250 m and a maximum rotor diameter of 220 m. The Band model has been considered, which assumes an even distribution of bird flights in the area. Besides, miniature GPS data were also used to locate the flying nightjars. The study indicated that these species might actively avoid the WTs, as during the survey (having a duration of more than two years) no carcass of bird was found around that tested area. However, they noted that the possibility of scavengers taking the carcasses away could not be eliminated.

Agudelo et al. (2021) point out that studies conducted on WT-related bird (or bat) casualty in Latin America are even harder to come by, compared to those in the US and Europe. Analyzing data from ten different sources, they concluded that generalization is hard to make. They noticed that the reported fatality among threatened bird and bat species is rather rare. They finalized their study with a hopeful note that more research will be done on this topic to fill in the knowledge gap.

This study found, in light of available research, bats (adult or otherwise) are harmed by WTs. As for aves-mortality, it is possible albeit not prevalent. This study also acknowledges the unavailability of a broad-based dataset concerning the mortality of bats and aves due to fatal collisions with WTs. Primary possible hindrances in the attainment of such a dataset can be: the carcasses benign devoured by scavengers, lack of reports of collision due to either lack of observation or lack of concern, or simply the genuine scarcity of such collisions.

The impact of WFs on the habitat areas of the aves is an issue of even greater concern. Drewitt et al.(Drewitt and Langston, 2006) presented the real-life consequence of the improper selection of WF locations, in terms of avian wildlife habitat. L. Stephen*et al*(Pearce-Higgins et al., 2012). revealed that the construction process hampers the breeding process, as greater noise emits during the process. In addition to that, Piorkowski et al. (2012) prioritized the importance of different impacts of WTs on migratory wildlife and urged to carry out more surveys before coming to any decision about the level of intensity of such occurrence. Bergström et al. (2014) also pointed out the severe harm caused to wildlife due to the construction phase of off-shore WTs.

Several studies further clarified the reasons why WTs disturb the distribution of natural habitat of aves; and concluded that the noises resulting from the construction and the operation of WFs may cause the aves species to relocate their habitats (Shaffer et al., 2016). Marques et al. (2018) reaffirmed the conclusions of Drewitt et al.(Drewitt and Langston, 2006) and pointed out the deterioration of avian wildlife habitat due to the improper selection of WF locations. The appalling scale and severity of this damage were found out by a study on bent winged bats by Millon et al. (2018) and they suggested that the presence of bats can be decreased by up to 95% near the WFs as compared to other natural sites. Similarly, off-shore WTs can also harm marine bird lives (Kelsey et al., 2018).

Fernández-Bellon et al. (2019) reported that the population density of birds near the WFs is significantly smaller, which seems to directly correlate with the size of the WF. Further detail came to light from the findings of Miao et al. (2019) who found out that, the size of WTs is also a critical factor, as the tower height has a positive influence, but blade length has negative impacts on the abundance of breeding birds.

After a thorough review of the existing research, this study concludes, the drastic deterioration andrelocation of aves habitat due to the installation of WTs in their vicinity, is glaringly obvious. To mitigate these impacts, the locations of aves habitat should be considered before the installation of WTs. Another promising research guideline is the findings of Miao et al. (2019) that, the tower height positively and the blade length negatively influence the breeding bird population. The higher altitude allows for greater wind velocity, which can potentially facilitate the generation of the same amount of power with a smaller blade length. This study proposes the conduction of research on the technological and economic viability of higher WTs with smaller blade lengths.

Although not as prominent as the impacts on aves, the WFs do present adverse influences on land and aquatic mammals (Dai et al., 2015). The construction process affects the habitats of wolves in Portugal, where about 39% of WFs are located in the habitats of the Iberian Wolves, as reported by Marques et al. (2018).Moreover, the off-shore WTs were found to affect marine mammals. For instance, Minke whales are stranded due to the sounds produced by WFs (Klain et al., 2018). A Chinese study led by Ningning Song (Song et al., 2021) has concluded that the location (and size) of WTs has a direct correlation with the nest location, height, and density of Magpies. This has a clear negative effect on the habitat of the Magpie. For reducing these impacts, the study suggested increasing the farmland shelterbelt, near the nesting sites.

Acoustic devices are frequently used to reduce the mortality caused by collision, but they have been found ineffective (May et al., 2015). As sound intensity is inversely proportional to the square of the distance, the devices are effective only for small areas. Alternatively, Kingsley et al. presented results on the effectiveness of the blinking lights, located on the towers (Kingsley and Whittam, 2005). Properly locating the WFs is another approach that was proven to be effective and practical (Arnett and May, 2016; Powlesland, 2009). However, WTs become less effective at the less contentious sites, which limits the choices of developers in selecting the locations (Pasqualetti, 2011). The map presented in the study of E. C. Kelsey et al. (2018) revealed that the impacts on marine birds could be considerably reduced by placing the WTs farther from the shore. Although moving the WTs further from shore is already in practice, it increases maintenance complexities and costs. Thus, research is going on to develop an economic and efficient process to access those turbines for maintenance (B Hu et al., 2019). Besides, the turbine operating speed may also play an important role in aves casualties. The study of Arnett et al. (2011) suggested that bat fatalities may be reduced by at least 44% when turbine cut-in speed is raised to 5.0 m/s. Similar to

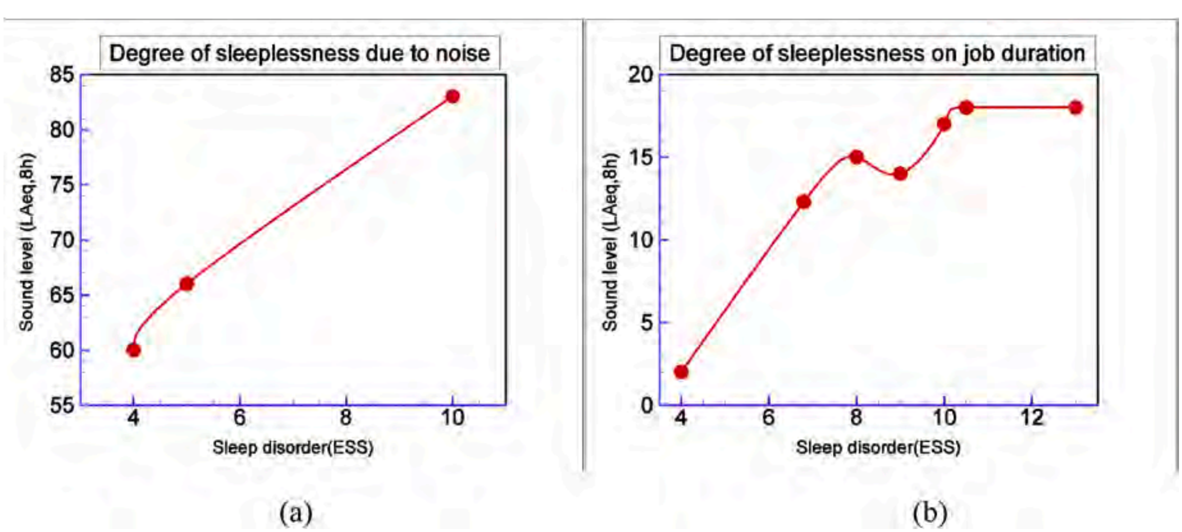

Fig. 3. Statistics of sleep disorder associated with WF noise from (Abbasi et al., 2015)(a) Sleep disorder at different levels of noise. (b) The relation between work experience and sleeplessness for surveyed workers.

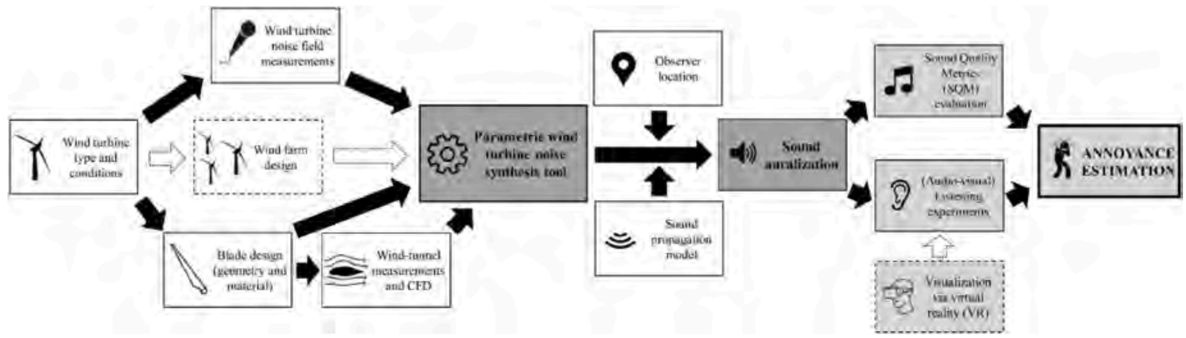

Fig. 4. Block diagram illustrating the concept of perception-based evaluation of WT noise reduction measures. The blocks with dashed lines were not employed in the current study but are considered as future extensions (Merino-Martínez et al., 2021).

the study of Kingsley et al.(Kingsley and Whittam, 2005), where it was suggested to reduce the rotation speed to minimize the possibility of the collision risk. The latter approach has also been proposed by Powlesland, as it helped to avoid motion smear and enhance blade visibility (Powlesland, 2009). Thus, some guidelines have been found for facilitating further mitigation.

iii. Health disturbance

The noise of the WTs causes certain levels of noise (tonal noise, impulse noise, and night-time noise), these are generated from the mechanical and the aerodynamic factors (Rogers et al., 2006). According to Shepherd et al. (2011) (Shepherd et al., 2011), the environment of the houses located within 2 km from WTs and the health of the inhabitants of these houses can have notable impacts. Interestingly, although the WF workers are more exposed to the noises than the inhabitants living near the farm, there are so far, very few research are conducted considering the workers. Karanikas and his team (Karanikas et al., 2021) highlighted that despite constant material, technological and procedural improvements – which diversify and intensify occupational hazards – thorough research on risks incurred by noise is rather scarce.

From the review, some classical yet common procedures have been encountered in investigating the impact. For instance, the Contingent Valuation Method (CVM) involves a question and answer session which asks people to directly report their willingness to pay (WTP) to obtain a specified good, or willingness to accept (WTA) for giving up a good, rather than inferring them from observed behaviors in regular market places (A. et al., 2000). Quechee Test, Multi-criteria Analysis, Spanish method are some other classical methods for the assessment of the visual impacts (Tsoutsos et al., 2006). Quechee Test aims to measure the harm caused by the presence of WTs to the aesthetic impact on the landscape. Multi-criteria analysis is a widely used method that measures the visual impact based on the Physical attributes (PA) and Aesthetic attributes (AA). It has been found that the higher the PA is, the higher is the impact (Tsoutsos et al., 2006)

The survey-based analysis of Abbasi et al.(Abbasi et al., 2015) in which 53 workers of the Manjil WF in Northern Iran participated, reveals the impact of noise from the WF on sleep. The exposure level of the workers was measured in an 8-h equivalent sound level (LAeq, 8h), according to ISO 9612:2009 (ISO 9612:2009, 2021), which is a standard engineering method for measuring workers' exposure to noise in a working environment and calculating the noise exposure level (Johns, 1992). The results suggested an increase in sleep disorders of up to 17% of the workers with one year of experience in the WF. The workers involved in field maintenance can be affected 6.5 times more than the office staff and 3.4 times more than the security personnel, as shown in Fig. 3(a). Moreover, sleeplessness was also found to increase with the duration of exposure, as shown in Fig. 3(b). Note that in Fig. 3, the daytime sleepiness data was measured by Epworth Sleepiness Scales (ESS), for which a number in the range of 10–24 is recognized as

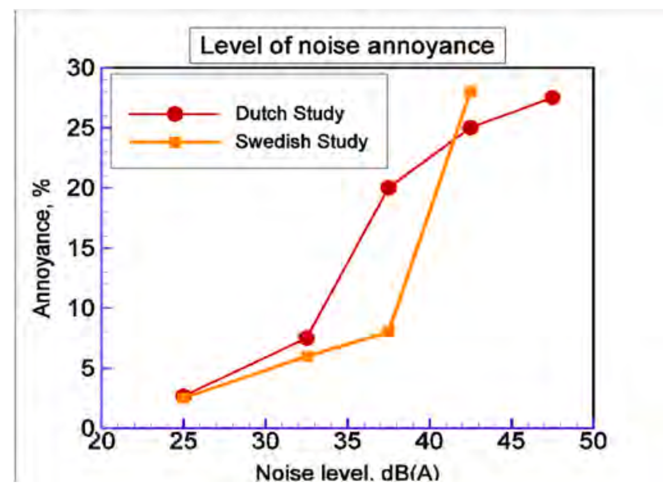

Fig. 5. Comparison between the Dutch and the Swedish studies (Szychowska et al., 2018).

abnormal (high sleepiness). Similar results were also reported by the study of Poulsen et al. (2019).

The study of Karanikas et al. (2021) investigated some issues, such as the hazards due to noise, the flickering of shadows (a rather unique inconvenience), the exposure to the electromagnetic field, styrene, and epoxy pollution, and skeletal and muscular stress. However, the studies are less methodical (instead of using medical experimentation, data is based on worker opinion). Whereas studies done on risks posed by vibration, weather conditions, biological hazards due to welding fumes, and other harmful substances are nonexistent. To get a more comprehensive understanding of noise pollution due to WFs, amplitude modulation of noise is required to be studied. In this regard, the research by Phuc D. Nguyen et al.(Phuc D. Nguyen et al., 2021) involved a year-long accumulation of both meteorological and acoustic data taken from three separate locations. It was found that, despite an increased AM (amplitude modulation) depth of indoor data in the night, indoor AM prevalence was lower than that of outdoors. AM is also found to be time-dependent and it occurs more often in crosswind and downwind direction than that of upwind. To get a better appreciation of the effectiveness of the countermeasures (to reduce noise pollution), Roberto Merino-Martínez et al. (2021) devised and experimentally evaluated a holistic method utilizing using synthetic sound auralization. Fig. 4 illustrates the overall procedure utilized in this study.

The literature found that there is a dramatic change in outcomes in the recent studies as compared to old studies. A survey of 1984 people was carried out by Pedersen et al. (2008) in 2008. They used A-weighted sound pressure levels (Nilsson, 2007) and considered the characteristics of the landscape and the residence, the position of the main roads near the inhabitants, the density of the houses, etc. They noted that WTs produce noticeable sound at night (Pedersen et al., 2008), which is similar to the result of the study conducted in 2007 by van den Berg (van den Berg, 2004). Interestingly, they also stated that those who were benefited economically from WTs have a lower probability of being annoyed by the noises, revealing an influence of psychological factors on these reports. The percentage of respondents who were very annoyed by the noises from WTs was approximately the same for most noise levels except for the band of 32–40 dB(A), reported by another independent Swedish study (Pedersen et al., 2008), as shown in Fig. 5.

The change of landscapes by the WFs **may also** influence residents' mental health. The trade-off between landscape preservation and WF installation was found to be of importance due to the issue (Caporale and Lucia, 2015). The study of Van Den Berg et al.(Frits Van Den Berg et al., 2008) dated back to 2008 and study of 2017 by Szychowska et al. (2018) both reported that the surveyed respondents who could see at least one WT from their dwelling were more likely to be annoyed than those who could not see any turbines at all. As per the analysis of Mirasgedis et al. (2014), they used the Contingent Valuation Method (CVM) to study the visual impact of WTs on the dwellers of South Evia in Greece, the visual impact is a factor that is difficult to quantify.

However, a recent study conducted in 2019, reported that people could wrongly attribute the low-frequency noise, resulting mostly from the wind-caused structural vibration, of their dwellings to be the noise of WFs (Duc Phuc Nguyen et al., 2019). It can be stated that the results illustrated in Fig. 5 might be precise but not accurate. It is rather easy to overestimate the impact on the health of noises emanating from WFs or even wrongly attribute health issues to them; as shown in a Finish study (Turunen et al., 2021). This study takes into account the objections of people living in the vicinity of WTs to compare them with the available scientific evidence. They came to the remarkable conclusion that apart from a minor sleep disorder, other reported issues were found to be ungrounded. As a result, the health disturbances caused by WTs, are too complex to measure accurately, and more robust methodologies need to be developed.

4.4. Communication interference

Doppler radar is a widely used device to measure velocities (A Lute, 2011). During operation, the Doppler radar is usually able to filter out the near-zero frequency shifts to prevent possible interference with the sound carrier of the next lower channel (Korner-Nievergelt et al., 2013). But this type of filter often fails to filter out the signals from WTs, as they sometimes generate much higher frequency shifts. as a result, air surveillance radars (Jenn et al., 2014; A Lute, 2011) and broadcast communication (Norin, 2017) over the past few decades have been reported to be affected by WTs. The radars sometimes can even misinterpret WTs as aircraft, causing challenges in military sectors (Norin and Haase, 2012). Besides, studies on military surveillance radars and civilian air traffic control radars (David W Keith et al., 2004) showed that the velocity of the tip of the turbine blades can frequently reach as high as 100 m/s, strengthening the echoes from the WTs and causing these echoes to take the shape of a signal similar to that of severe weather conditions. As a result, radar may wrongly interpret these echoes as severe storms and winds. The wakes generated by the blades can also cause wrong readings. Moreover, the study of Sengupta and Senior (Sengupta and Senior, 1979) revealed that the WT also affects radio and television signals.

Clutter and blockage are two common disturbances caused by WTs. Clutter refers to the unwanted echoes detected by radar (Baidya Roy et al., 2004). However, the proper definition of clutter depends on the function of the radar. Clutters are in three types:

- Surface Clutter – Signals returning from the ground or sea are considered surface clutter.
- Volume Clutter – Weather and chaff are the common forms of volume clutter.
- Point Clutter – Birds, windmills, and individual tall buildings generate point clutter and are not extended in nature.

Blockage results from the WTs work as obstacles in the searching site of radar, which appear on Doppler radar as flying objects. Norin (2017) investigated these impacts of WTs on a test site with 12 C-band Doppler weather radars. Among them, four radars had been modified to be capable of performing single dual-polarization measurements while for the rest single horizontal polarization measurements were used. Because of the higher sensitivity of the modified radars (data were sampled every 15.625 meters by those four radars, compared to every 167 meters by others), a much higher wrong sampling rate was shown. They found the echo from a stationary point target changes smoothly from pulse to pulse. But for the WTs, the echo changes very sharply between neighboring pulses, making the signal difficult to filter out. This point target signature was found to be independent of the size, model, and yaw angle of the WTs. As a result, the researchers proposed this distinct and repeating signature of WTs to be used to identify and remove the wrong signals. This model may be applicable to operational weather radar signal processors with the presence of WTs. Another mitigation approach mentioned in an old study of 2012 by Jenn and Ton (Jenn and Ton, 2012) proposed to use radar absorbing material (RAM) instead of non-conducting blade material for mitigating faulty reading in the radar. The readings from the WTs on radar could also be identified and potentially eliminated by measuring the rotor speeds (Trockel et al., 2018). In that case, the proposals mentioned in the old studies can be neglected. For instance, Rashid and Brown (Rashid and Brown, 2010) asserted that clutter can be reduced by not placing WTs in line of sight of the radar but arranging them in a radial pattern from the radar. This implies that the impacts on radar have been solved to a great extent in recent times.

4.5. Impacts on local meteorology

Abbasi et al.(S A Abbasi and Abbasi, 2016) showed that excessive installation of WTs can reduce the kinetic energy of local winds so dramatically that it may even cause impacts similar to the greenhouse effect. The turbulence in the wake of the turbines can alter the direction of the high-speed wind near the ground and consequently can enhance local moisture evaporation (David W Keith et al., 2004). Back in 2004, Roy et al. (Baidya Roy et al., 2004) studied the impact of a large virtual WF on the surrounding local meteorology for over synoptic timescales (for typical summertime conditions), to find out whether WFs affect the atmospheric thermodynamics, ground surface heat fluxes, and moisture of the surrounding landscape. Previously for the atmospheric numerical modeling, prognostic (Ivanova and Nadyozhina, 2000) and diagnostic (Magnusson, 1999) models had been used, which showed that the WF significantly affects the wind speed at the typical height of wind-turbine hubs. In the study of Roy et al.(Pielke et al., 1992), they used the Regional Atmospheric Modeling System (RAMS) to simulate the effects of a hypothetical WF in Oklahoma, which integrated several weather numerical models into one single framework for a particular area (Archer and Jacobson, 2003). The RAMS solves a set of equations of microphysics, compressible flow dynamics, non-hydrostatic flow dynamics, and thermodynamics (Baidya Roy et al., 2004). They found that turbulence formed in the wake of the rotors can stimulate vertical mixing which severely affects the vertical distribution of temperature, humidity, surface sensible, and latent heat fluxes. But their result is valid only for relatively humid and cool soil conditions. Moreover, a paper of 2018 by Keith (Keith, 2018) claimed that the thermal impacts from WTs are about ten times stronger than solar photovoltaic systems. From the aforementioned studies, it is evident that WTs affect the meteorological characteristics of their vicinities. Nevertheless, a detailed study published in 2018, by Moravec et al. (2018) suggests that the spatial and

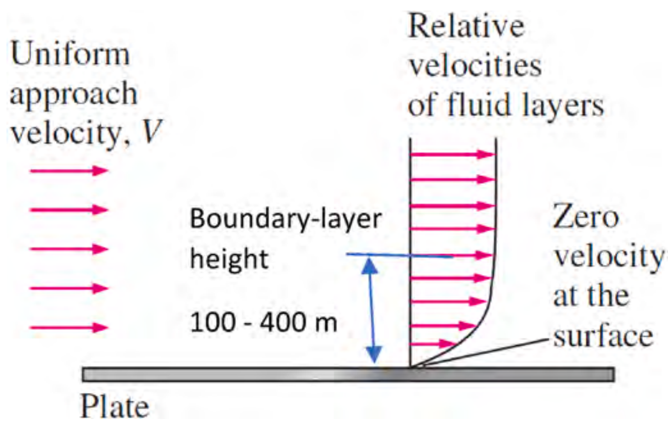

Fig. 6. A schematic presentation of the boundary-layer effect (University of Sydney, 2005).

temporal impacts of WTs are relatively minor, and the land topography impacts more than WTs. They claimed that the WT farms are commonly installed in such places where the impacts from topography are already profound. From the review of old and current studies, it is concluded that to the date the combination of topographical, climactic, and other natural effects makes it challenging to accurately measure the specific impact from WTs.

5. Alternative technologies for wind energy harnessing

In light of the aforementioned impacts of conventional WTs, a significant number of studies have been conducted so far to develop sustainable solutions and technical alternatives.

5.1. Airborne wind energy systems

The total potential power that can be obtained by any wind-harnessing technology can be expressed as $P = \frac{1}{2}\rho A v^3$. Here, ρ is the air density, A is the cross-sectional area of the WT, and v is the wind speed. As a result, the total wind energy per unit area increases with the wind speed and cross-sectional area. The WT hub height has been increased from 20 meters (in the 1980s) to 100 meters in the last few decades, allowing the blade to be elongated greatly. While it has greatly increased the cross-sectional area, the tip of the blades has also reached a height of about 200 meters (Canale et al., 2009). The problem with the tall WTs is that the increasing flow speed through the rotor and the large force arm create a great bending moment that demands heavy base construction (Zhang and Zhang, 2013). On the other hand, with the increase of height, the wind gets stronger and steadier due to the absence of boundary-layer effect and fewer obstructions from ground landscapes (Sommerfeld and Crawford, 2018), (see in Fig. 6).

As a result, the performance of the WTs may be increased dramatically as the height increases (Archer and Jacobson, 2005; Diehl, 2013). As for the altitude above which the boundary-layer effect diminishes, several studies have reported a rich wind energy source, in a range from 100 to 400 m (Bechtle et al., 2019; Sommerfeld et al., 2019). For structural and economic reasons, the conventional WTs are unlikely to be built higher than these altitudes. The Airborne wind energy system (AWES) concept is targeted at resolving the limitation of WTs, resulting from the boundary-layer effect (Haas et al., 2017); as it can harness wind energy at a very high altitude without creating huge bending stresses on the tower and on the base. As all the modern AWES concepts are based on the kite-driven system, it may also be referred to as “kite wind power”. Before the advancement of aerodynamics in the 1900s, controlling an airborne module without an autopilot was a challenging job (Yan, 2017). Later on, Loyd, in 1980, first introduced a practical approach in AWES (Loyd, 1980). The fundamental idea was to connect a kite with a pulley by a tether. The kite will go higher with the wind and the pulley will rotate and this rotation will be used to generate electricity. Afterward, when the velocity of the wind decreases, a motor will rotate the pulley in the opposite direction, winding up the tether and reducing the altitude of the kite to start the cycle again. Which will cause the mechanism to face less drag in the winding phase, delivering a net power output. This way the kite can hover within a specified range (Zhang and Zhang, 2013).

Airborne wind energy systems can mainly be classified into two types (Cherubini et al., 2015): the Ground-Gen and the Fly-Gen systems, based on whether the conversion from the kinetic energy of wind to electric energy takes place in the alternator settled on the ground or in the alternator, installed in the airborne module. Computational studies have also played a role in understanding AWES, as the model of Vlugt et al. (Vlugt et al., 2019) has shown satisfactory results in predicting the power generated by such systems. The recent successful operations of the 20-kW utility-scale Fly-Gen prototype by Makani Power have shown the potential of the model in the electricity market, which motivated the company to work on a 600 kW Fly-Gen model, expected to power about 300 homes (MakaniPower, 2019).

It seems with the advancement of research many farfetched concepts have been abandoned. For instance, Tigner had proposed a concept called ‘multi-tether crosswind kite power’ (Tigner, 2011). The model has helped to attain crosswind speed, which helped to produce power far greater than the conventional Ladder Mill (Lunney et al., 2017). The system has one kite with many tethers connected to separate alternators. For a full revolution of the kite, different generators are in operation for specific periods. Another concept was proposed by Canale et al. (2009) where a set of kites were arranged in a circular pattern in the open air. The generator was installed on the single common base and all the tethers of the kites were connected to it. Among all the models two of them are worth mentioning-

a. Point mass kite model, which represents the kite as a discrete mass moving under the action of an aerodynamic force vector (Diehl, 2013).
b. Four-point kite model (4p model), in which the rotational inertia of the kite is considered making the model more practical in the development and optimization of flight-path control algorithms. (Fechner et al., 2015).

Numerous efforts have been made towards the commercial electricity production of AWES. In addition to the aforementioned *KiteGen* (KiteGen Research, 2019), a company named *KPS* has come up with a dual-kite power concept, where during any time one kite will be in power mode and the other is in retracting mode, delivering relatively less fluctuating electricity than the single-kite models(KPS Energy, 2019b). Another interesting concept is to power ships via AWES in high-altitude winds. In terms of actual applications, the company *Enevate* has shown convincing results with its 100-kW commercial model, as an alternative to diesel generators for remote rural areas. An AWES model with a 40 m^2 kite designed by *Kitepower* with a capacity of 100 kW has already been tested (Schmehl, 2018). In comparison, the successful operation of EK30 by *EnerKíte* with an average output of 30 kW for hundreds of hours is closer to actual production (EnerKite, 2019). Apart from these technical advantages, the kite wind power concept seems to possess ecologically and socially friendly aspects, as the deployment of the model does not impose significant environmental or societal pressures (Chang, 2018). It was also pointed out by Langley et al.(R. Langley and Go, 2015) that by its nature the kite wind power generates fewer noises and visual interferences. They further emphasized that as most birds mostly fly below 500m, the chance of collision between aves and AWES is significantly lower. This claim has also been confirmed by Bruinzeel et al.(Leo Bruinzeel Jaap Bosch, 2018).

From the previously reviewed literature, several basic advantages of kite power have been found over the traditional WTs:

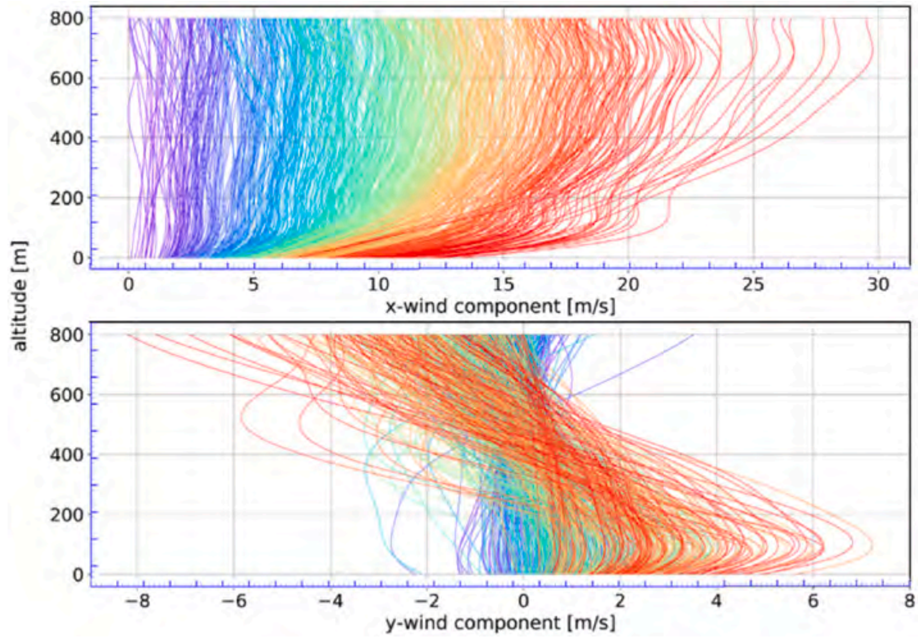

Fig. 7. Changing of wind speeds with altitude (Malz et al., 2020a, 2020b).

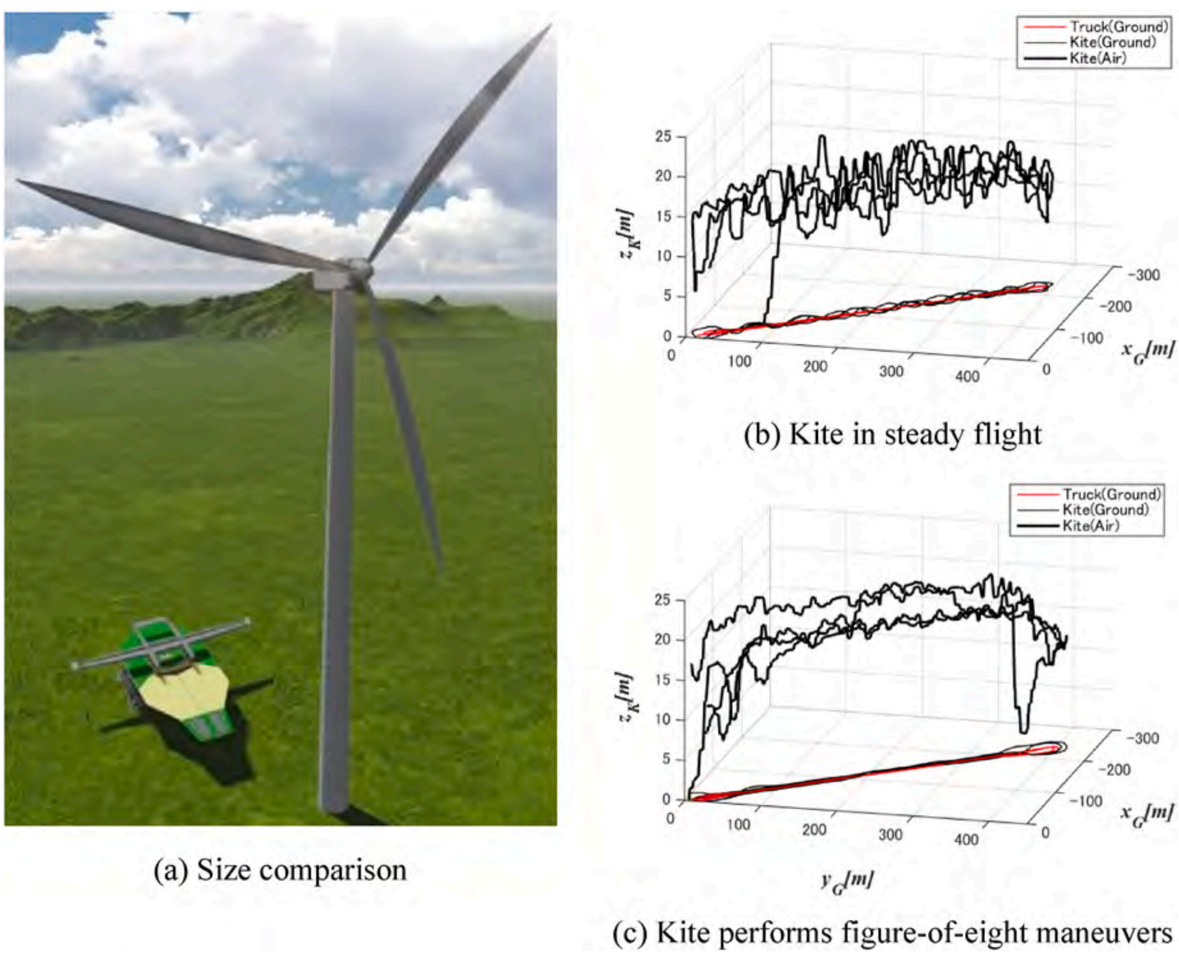

Fig. 8. Size comparison between typical AWES and conventional HAWT (a) (Vermillion et al., 2021). The volume occupied by typical AWES in flight (b)(c) (Rushdi et al., 2020).

a. The kite operates at a much higher altitude (around 500m) which enables it to cover a vast area. Due to less influence of *boundary-layer effect* at high altitudes, it receives stronger wind than conventional WTs.
b. The kite can operate over a wide range of altitudes, allowing it to harness the maximum potential wind power. With this technique, the wind power density can potentially be increased by a factor of two, for 95% of the operation time (Bechtle et al., 2019). The study of Fechner et al.(Fechner and Schmehl, 2018) has shown convincing results regarding the increase of efficiency by improving flight control logic.
c. Its mechanisms are less complex than conventional WT, resulting in less maintenance (Fechner et al., 2015).

A remarkable aspect of an air-borne system is that it can harness winds of different directions and of a wide range of altitudes. Moreover, kites hovering around the height of 500 meters can avoid stalls by avoiding zero velocity wind with slight compensation of altitude, as found in the survey of Philip et al.(Bechtle et al., 2019). Although, the paper of Göransson et al.(Malz et al., 2020a, 2020b) showed that the power harnessing capability of the airborne system is not very advantageous, as its power output is similar and, in some cases, lower than conventional WTs; the wind data was limited to the height of 400 m. An air-borne system can reach a much higher altitude utilizing better wind speed (Bechtle et al., 2019); even the old model of Makani Power, named Wing 7, released in 2011; could rich a height of 550m (newatlas, 2011). Moreover, the paper (Malz et al., 2020a, 2020b) used a simplified equation for calculating the power output, the proposed equation of Gaunaa et al.(Trevisi et al., 2020) is more convenient in this regard. Even if both vertical and horizontal wind speeds are considered, it is apparent that wind speed dramatically increases with altitude, as illustrated in Fig. 7 (the color is only for differentiating among the various values of horizontal component.

The control dynamics of the kite is a critical issue for its higher degree of freedom of motion as compared to conventional WTs. This makes the computation of the motion of the kite a challenging task. To speed up the task, Malz and her team (Malz et al., 2020a, 2020b) presented a specific Homotopy-following-path algorithm (HPbd) that allows solving a set of non-linear programs with a single initialization, which is an Optimal Control Problem (OCP) solving model. The model is at least 20 times faster than the Homotopy-Path-initialization algorithm, as presented in the study of Malz et al.(Malz et al., 2020a, 2020b). Moreover, variational integration is another faster tool for simulating the control dynamics, as Kakavand et al.(Kakavand and Nikoobin, 2021) suggested. The study has also shown the computation to be much faster in case of discretizing the tether into multiple small linear segments. On the contrary, E. Schmidt et al. (2020) used the Kalman filter in an online real-time responsive model for the same prospect. Although the driven result has been validated against an unverified simulation from the research of Fagiano et al.(Canale et al., 2009), the attempt is a good step forward in using real-time models (M Cobb et al., 2019). Because the uncertainties in the wind behavior lead to major deviation in the outcomes of pre-estimation-based OCP solving models. A robust control logic, comprising of the winch control has been presented by Sebastian et al.(Rapp et al., 2019). However, one shortcoming in the approach is that the tension of the tether is the only variable of the winch controller, resulting in significant deviation; since due to the wind profile difference the drag on the tether can rich much higher than drag on the kite.

Although much development has been made regarding the control, the colossal space covered by the airborne system is a pressing concern. Because the airborne system cannot be simply arranged in rows with optimum clearance, as wrongly assumed in the genetic algorithm-based research of Roquea et al.(Roque et al., 2020). Wind motion varies with location and these irregular wind motions can easily cause entanglement to the tethers (Aull et al., 2020). As a result, the whole airborne system covers a rather vast space, compared to conventional WTs, which is wrongly presented in the review of Vermillion et al. (Vermillion et al., 2021); not considering the space hovered by the kite (shown in Fig. 8 (a)). According to the presented data, though in steady wind speed the trajectory typical occupies a narrow space of around 20m in height and of around 600m in length, still it vastly exceeds the space covered by conventional WTs (shown in Fig. 8(b)). In the case of turbulent wind, the flight path takes a figure-of-eight pattern, widening the occupied space; decreasing the kite population further (shown in Fig. 8(c)).

Besides, the induction of the wakes of upstream kites on the winds, heading towards the successive kites is another challenge in control dynamics, which has rarely been taken into account in designing models (T. Haas et al., 2019). In this regard, a dedicated space of semi-sphere with a radius equal to the length of the tether should be considered in designing multi unites model (Vermillion et al., 2021). In this prospect, the online trajectory optimization algorithm, like the one of Barton et al. (M K Cobb et al., 2020) is very demanding, as it can offer the optimum compact layout for clustered airborne systems. Moreover, the recent model, similar to the Daisy Kite model, proposed by Beaupoil et al. (Beaupoil, 2020) can solve the issue, as the model is fur more compact. The comprehensive observation on Daisy Kite of Amiri et al.(Tulloch et al., 2020) is worth mentioning for detail. Apart from this, the irregularities in the timing of switching between the traction and the retraction phase lead to adversities in power generation. However, Elena et al.(Malz et al., 2018) have presented a demanding solution by fixing the orbit time, the performance loss does not exceed 4%. Besides, the pumping mode, not exceeding the loss of 1.4%, is less sensitive in fixing the orbiting times than the drag mode.

Another aspect rarely considered in control dynamics is the launching and landing phase. Although the phase covers a little portion of the whole flight time, to date no matured technique has been addressed. To date, all the prescribed methods require human intervention, making the control system semi-automated (Vermillion et al., 2021), except the model of Schnez et al.(Fagiano and Schnez, 2017). The comparative research of Schnez et al.(Fagiano and Schnez, 2017) suggested that the linear take-off method is both economic and technically effective, where a winch is used for both accelerating the launching pad of the kite and harnessing the power. Although the model requires on-board propulsion for assisting the take-off and control of the kite, the paper claimed that the overall cost and the energy consumption are within the acceptance.

Apart from the sensitivity of the control, the kite aerodynamics also plays a key role in harnessing power, as the study of Filippo et al.(Trevisi et al., 2021) suggested. A remarkable outcome of the study is the insignificant impact of wind conditions on aerodynamics. Similarly, the aspect ratio also plays a vital role in the performance, as being inversely proportional to the power generation, shown by the machine learning-based non-linear inverse model of Aull et al. (2020). Elsewhere, a robust experiment by Wijnja et al. (2018) represented a direct relationship between the tether tension and the fluttering behavior of the kite. Although, for simplification they have ignored the curvature of the tether, the discovered relationship has insignificant effects for the simplicity. The issue of fluttering gets more complicated in the case of the soft kite, since the research of Oehler et al.(Oehler and Schmehl, 2019) claimed that fluttering deforms in the shape of the kite, causing a severe change in aerodynamics. As the kite needs to withstand the fluttering (Wijnja et al., 2018), its joints need to be flexible, apart from being durable enough to withstand the drag and the tension. The durability of the kite, the proposal of 3d printed point-fused joint with spikes, seems appealing; as the test of Ali Khaheshi et al. (2021) showed that the load-bearing capacity of any flexible joint can be increased three times by introducing gap contacts and spikes. Although the tether has been assumed to be straight for simplicity, the algorithm used in the model has been found effective in finding out an optimized design for the kite, which uses trial and error technique to draw the relationship among the geometric parameters based on the characteristics of wind and the power output. Although the profile of the cable plays a vital role in reducing drag, the profile of the boarding lines is another rarely investigated aspect. The research of Dunker et al. (2015) (Dunker, 2018) illustrates that a helical strake braiding yields less drag than a thinner line with a round cross-section. The tether has often been assumed as a straight elasticity rod for simplicity. However, due to gravity, the tether can never be straight and this curvature of the tether exhibits elasticity along with its elasticity, as prominent in the study of Vermillion et al. (Vermillion et al., 2021) and Aull et al.(Aull and Cohen, 2021). Another poor assumption is the consideration of the tether and kite junction to be close to the center of gravity of the kite, which might not be always possible for the suitability of controlling the angle of attack (Rapp et al., 2019). Another overlooking element is the gravity itself, which causes a major flaw in the result; as the simulated result of Rolf et al.(Vlugt et al., 2019) suggested. Being verified against the data from the 20 KW model of 'kite power', hovering at the altitude of 720m; the simulation model is reliable.

Eventually, the above-discussed mathematical models can be implemented in transducer operated control logics, mentioned in the study of Bauer et al. (2019) and Rushdi et al.(Rushdi et al., 2020). Moreover, the models can further be used in the recently developed simulators, like the one proposed by Kakavand et al.(Kakavand and Nikoobin, 2021), which can measure power transmission with 98% accuracy. As the airborne models are scaling up, the failure analysis is getting demanding. In this context, a rare predictive failure analysis by Salma et al. (2020) is worth mentioning. Although the presented result for a 100 KW ground generation-based system is very limited, the work can pave the future research.

The literature predicts that the AWES concept will be commercially accepted by the investors in near future. Which necessitates a thorough investigation to bring forth the possible optimization, before mistakenly implementing in abundance, as it happened in the case of conventional WTs (Khan and Rehan, 2016). Moreover, it poses serious safety concerns on the nearby passengers and transport system. For example, the UK Air Navigation Order raised a concern with the visual acquisition of cables, which can be a great hazard for airplanes (Mariano, 2019; Lunney et al., 2017). A reliable automated control system of kite wind power may be able to solve the safety problem. The recent studies on stability in the flight path (Sánchez-Arriaga et al., 2019; Li et al., 2018; Malz et al., 2018) and the studies on the fuzzy control method of the kite flight, like the study of Dief et al. (2018) and of Mayouf et al. (2014), have successfully contributed to the development of a robust control system. Some studies are only applicable to the Ground-Gen system (Licitra et al., 2019; EnerKite, 2019) and the Fly-Gen system (Zanelli et al., 2018)(Zanelli et al., 2017) respectively, while the studies of Malz et al. (2018) and Sanchez-Arriaga*et al*(Sánchez-Arriaga et al., 2019). cover both types of AWES. For avoiding tether collision with the ground, the modeling of the landing of the kite wind power by Koenemann et al. (2017) is a novel approach for kite flight control. The small-scale prototype of Fagiano et al.also showed a remarkable result of successful repetition of take-offs in a very compact space (Fagiano et al., 2017). The moving horizon scheme presented by Girrbach*et al*(Girrbach et al., 2019). can help in designing an efficient calibration for the flight path. Moreover, the reference model given by Malz et al. (2019) has provided a benchmark and guideline for future studies on the kite flight controls. With all these efforts, there are still some critical issues that are needed to be addressed. The AWES face a high possibility of a thunder attack for its operating height. The study of the noise and impacts of the kite on the radar is yet to be carried out (Megahed, 2014). Once these issues are solved, kite power can be a breakthrough in mass-scale power generation (Bechtle et al., 2019).

5.2. Bladeless wind power

The vortex generated by the wind passing through a rigid body can cause oscillation to a rigid body (Elshaer et al., 2017). The vortex, generated during WT operation, can adversely influence the other turbines downstream and is one of the reasons to have restrictions on the minimum distance between the WTs (Jourieh et al., 2009). Wake can also affect the yaw mechanism and can drastically decrease the efficiency of WTs (power losses of more than 80%), even in very low turbulence (Schepers et al., 2012). Several classical studies, like the study of Lvanell et al.(Ivanell et al., 2010), Jourieh et al. (2009) and Troldborg et al. (2010) showed that the WTs need to be spread over a large distance to avoid turbulence and wake effect, as shown in Fig. 9. However, sparsely located WTs add a huge cost to the installation price for a WF power plant.

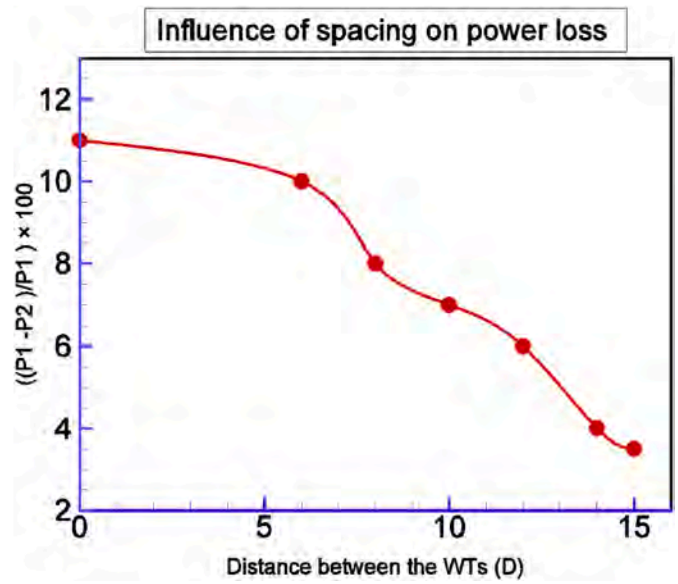

Fig. 9. Power loss as a function of WTs spacing. D is the diameter of the WTs and ((P1–P2)/P1) × 100 represents the percentage of power gained by the WT from the wind velocity. P1 and P2 are the power of the upstream and the downstream turbines, respectively (Jourieh et al., 2009).

A new technology named vortex bladeless wind power has been introduced by Yáñez, which effectively uses these undesirable vortexes to generate electricity (Yáñez, 2018). Some studies, like the one of Chizfahm et al. (2018) and of Yu*et al.*(Yu et al., 2017), have referred to this technology as promising for future wind energy. The core mechanism of the bladeless wind power system is a vertical column that is oscillated by the vortexes in the wind and the column reciprocates as a linear alternator to generate electricity. Another remarkable advantage of the technology is that the efficiency increases noticeably if the devices are located closer to each other, as the devices themselves also generate eddies that cause more oscillation for the other devices nearby. Yáñez managed to match up the natural frequency of the model with the frequency of the swirling wind to create the "constructive interference" (Yáñez, 2018), which maximizes the flow-induced oscillations in the structures (Yáñez, 2018). To make it feasible for the domestic sector, in their recent design, the column floats in the magnet field which reduces friction as well as eliminates the use of lubrication, lowering the maintenance cost. Moreover, this streamlined model, as shown in Fig. 10, has fewer moving parts making it less noisy, as compared to the HAWTs and VAWTs.

The European Union's Commission's Executive Agency for Small and Medium-sized Enterprises (EASME) funded a research team for the concept of bladeless WTs in its Horizon 2020 program to save energy and protect bird populations (EASME, 2020). Besides, the concept has drawn attention from the companies like Barcelona Supercomputing Center (BSC), Altair, and Microgravity Institute of the Universidad Politécnica of Madrid (vortex, 2019). Although it may appear that the device cannot produce significant power due to its size, see in Fig. 11, Yazdi asserted that with the gain-scheduling nonlinear model predictive

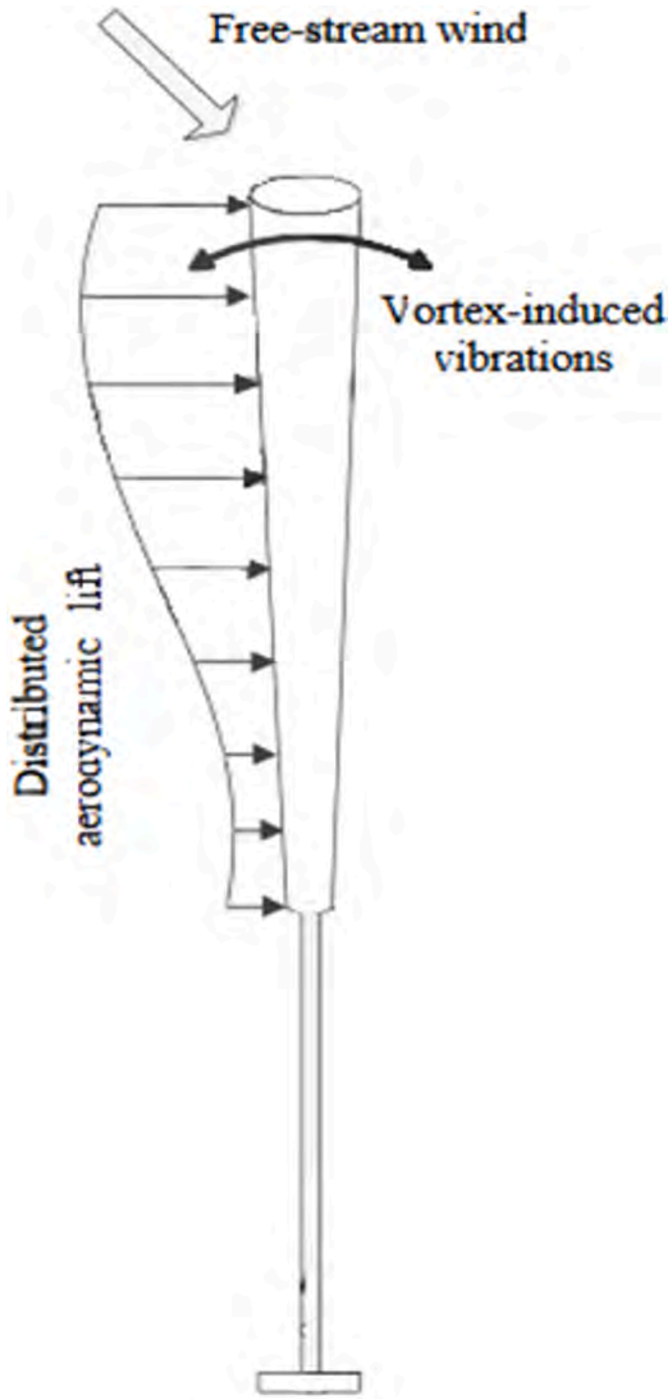

Fig. 10. Mechanism of a bladeless WT (Tiwari and Mishra, 2012).

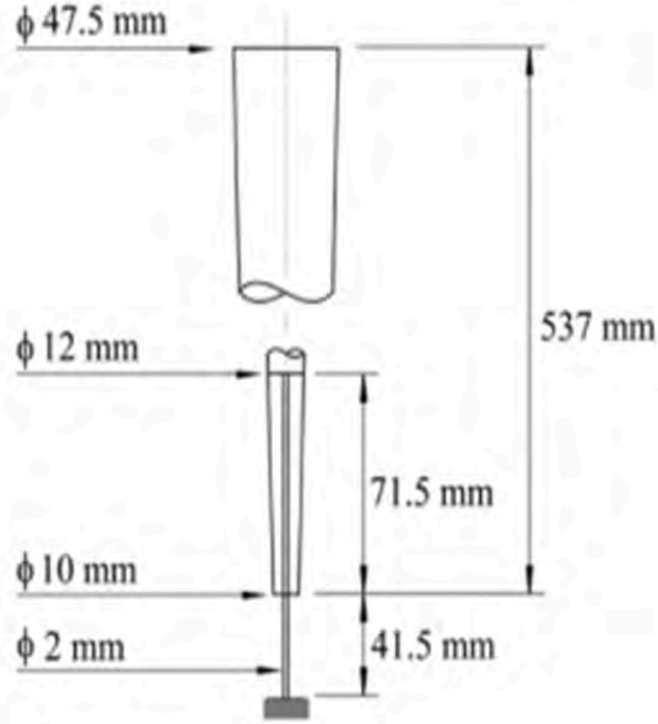

Fig. 11. Schematic representation of the vortex-bladeless experimental device (Cajas et al., 2016).

controller (GS-NMPC), the power output of a single device can reach up to 1 kW, without enlarging the conventional size of the device (Yazdi, 2018). The study of Hu et al.(Hu et al., 2018) and Chizfahm et al. (2018) showed that the efficiency of the technology can be enhanced by further modifications, which makes it even closer to practical applications. The study of El-Shahat et al. (2018) showed that the model could be integrated into the Nano grid. Moreover, the model is expected to produce more energy in a congested arrangement. However, inventor David Yanez predicted that the model is not suitable for low-velocity wind (directindustry, 2021). However, introducing piezoelectric devices in the bladeless system showed an effective result in producing electricity in the recent experiment of Tianyi et al.(Shi et al., 2021). However, structural modification of the vibrating body can be vital in increasing performance, as claimed by the studies of Zewei et al.(Ren et al., 2021); where ultra-stretchable electrode film has been implemented in the convex-shaped triboelectric nanogenerator for wind power harnessing.

Moreover, by perforating the structure they have achieved nearly 56.3% more electric power output under certain wind conditions. Besides, the concept can be redefined for better harnessing the low-speed wind, as the model of new patent of U.S. Army Corps of Engineers; where the model can feasibly harness energy from slow-moving breeze (TechLink, 2019). The bladeless wind energy model is considered, theoretically, to be visually less intrusive and safer for aves, than the conventional turbines. Consequently, the concept has attracted positive attentions from two of the UK wind energy industry’s most vocal critics, the RSPB and the CPRE (Bates, 2015). Due to no spinning blades and fewer moving parts, the model poses smaller collision risks for birds and less CO_2 footprints, as studies of Martin et al.(Martin, 2016) and of Demirbas et al. (Demirbas and Andejany, 2017), have suggested. Besides, the concept requires less maintenance than conventional WTs (Demirbas and Andejany, 2017). From the review, the concept seems to be viable for micro power generation, as its power output has been recorded near 1 KW (Yazdi, 2018),(Martin, 2016). The main focus of further research should be on scaling up the model, and on the studies, like life cycle assessment and impacts on health.

iii. Small-scale VAWT

The study of Ishugah et al. (2014) proposed to use of small VAWTs for backup power generation in the urban area. In addition to that, the initial research (Li et al., 2021) and the subsequent research (Xu, Li, Zheng, et al., 2021a, 2021b) of Wenhao, focused on the feasibility of installation of different configurations of small VAWTs in urban buildings. Jie et al.(Shi et al., 2021) suggested that the harness can be more effective for off-shore VAWTs, as with proper pitching the power output can increase by 115%. However, the higher maintenance cost of off-shore WT can reach up to 5–10 times that of on-shore WFs (Bussel

Fig. 12. France's vertical WT (Danao et al., 2013).

et al., 2001). From a couple of studies, VAWT and HAWT have been found to have both advantages and disadvantages in different aspects. The following points are provided to analyze its feasibility as an alternative.

- VAWTs are quieter than HAWTs. VAWTs make sounds measuring around 38 dB, which can be compared to a whispered conversation. On the other hand, HAWTs normally generate sounds around 95 dB, which can be compared to sounds that one listens from a car passing by (Saad and Asmuin, 2014).
- A large VAWT needs long guide wires for stability, especially for those having the so-called "egg beater" design, as shown in Fig. 12. A VAWT WF of commercial-scale requires more materials in construction, to compete in power generation with a conventional farm equipped with HAWTs (Danao et al., 2013).
- Generally, HAWTs are used where the wind is relatively steady, as reported in the study of Eriksson et al. (2008) and Islam et al. (2013). In comparison, VAWTs can utilize highly unsteady and turbulent wind flows (Danao et al., 2013). VAWTs are more suitable for residential applications, where the wind is mainly turbulent, as prominent from the study of Kumar et al. (2016) and Tummala et al. (2016).
- Small VAWTs, which can be classified as SWTs, are considered to be not harmful to birds according to studies of Minderman et al. (2012) and Krijgsveld et al. (2009).
- VAWTs can be more energy-consuming and emission-intensive, compared to HAWTs; according to studies of Lombardi et al. (2018)and Uddin et al.(Uddin and Kumar, 2014). However, the embodied energy of VAWTs could be reduced to 36% with the thermoplastic turbine and 40% with fiberglass turbine, reducing environmental impacts to more than 15% on average (Uddin and Kumar, 2014).

Table 2
Summary of the drawbacks of the present technology and the possible solutions.

Drawbacks	Impacts	Possible Research Pathways
Hazardous manufacturing process.	The manufacturing of the WT affects the ecosystem (Gkantou et al., 2020).	The practice of proper recycling of materials should be emphasized and inspired. However, a robust LCA of the airborne concept is very demanding in this regard. Because, the materials that are required to manufacture the model, with the same power output, are much less, as the kite system is much small in comparison to conventional WTs, as shown in Fig. 8 (Vermillion et al., 2021).
Harmful to the aves and mammals.	While passing by the WTs, the aves often collide with the rotors (May et al., 2015). The WF also harms the breeding process (Shaffer et al., 2016).	Because of fewer moving parts and smaller cross-section along aves line of flight, bladeless wind energy generators (wind kites) are less intrusive to birds and lead to fewer collisions as attested by Martin et al.(Martin, 2016) and of Demirbas et al. (Demirbas and Andejany, 2017). Its increased efficiency through modifications may make it an economically competitive option as well (Hu et al., 2018)(Chizfahm et al., 2018). Miao et al.(Miao et al., 2019) pointed out the positive impact of the tower height and the negative influence of blade length on the breeding bird population. This study asserts: as higher altitude allows for greater wind velocity, it may potentially facilitate the generation of the same amount of power with a smaller blade length. This study proposes the conduction of research on the technological and economic viability of higher WTs with smaller blade lengths.
Less energy density, due to the wake effect.	For economic reasons, WTs are located close to each other in the WF (Ivanell et al., 2010). However, the wakes of a WT negatively influence the efficiency of other downstream WTs. This limits the maximum density for the WTs in a WF.	Though the energy loss by wakes can be mitigated by altering the alignment of WTs (Cossu, 2021), research is needed to quantify the energy, missed by this alteration. The vortex bladeless model can be a feasible solution, as it can utilize the wake to produce power (Rostami and Armandei, 2017). The research on the integration of piezoelectric devices can enhance the feasibility of the model (Shi et al., 2021), making the model a potential research topic.
Noise pollution.	The noise of the WTs has an impact on human health, such as sleep disorders, visual disturbances, etc (Lee et al., 2011). However, from the recent studies, it seems that the noise emission from Wts has been wrongly exaggerated,	The small-size VAWTs are less noisy than HAWTs (Saad and Asmuin, 2014). However, commercialization of the model requires enhancing the energy production to a standard level, which requires more study on its performance. Besides, the airborne model and the

(continued on next page)

Table 2 (*continued*)

Drawbacks	Impacts	Possible Research Pathways
	as the real noise from Wts is much less than wrongly guessed by the observer (Nguyen et al., 2019).	bladeless model can also be viable research topics in this regard.
Interference with the radar systems.	WTs disturb the reading of nearby radars and other signal transmission systems (A Lute, 2011).	According to the observation of this paper, to some extent, the problem has already been solved, as no recent studies have been encountered concerning the issue.
Low ground wind speeds.	The wind speed is drastically reduced near the earth's surface by the boundary-layer effect. This hinders the attainment of optimal performance by the WTs (Diehl, 2013).	The airborne wind power technology may solve this problem as it hovers at a high altitude and can operate in the high-velocity wind (Sommerfeld et al., 2019). Although Haas et al. previously suggested the impact of kites on wake formation not to be insignificant (Haas et al., 2017), their subsequent study claimed the impact can be neglected (T. Haas et al., 2019). The concept requires further studies for achieving commercial-scale power generation.
Lightning strikes	WTs are highly vulnerable to lightning strikes (Goud et al., 2018).	For lightning protection, the blades of the WTs are needed to be reinforced (Mat Daud et al., 2018). Besides, the basement needs a good earthling system, as it experiences severe lighting impacts (Goud et al., 2018).
Environmental factors on Blades Design	The icing on the blade can drastically decrease the performance (Pellegrini et al., 2021). Besides, as wind energy is more available in the cold region of the Northern Hemisphere, the factor is worth considering (Manatbayev et al., 2021).	Environmental factors should be considered in the studies of blade optimization (Tjahjana et al., 2021).

The bottom line is that according to current reviews, similar to the concept of bladeless wind, the VAWTs are best suited for small-scale domestic power generation. The study of Dominicus et al. (Tjahjana et al., 2021) showed that there is yet scope for development in the optimization of the blade, as the slotted blades showed a significant increase in performance compared to the conventional counterpart. In fact, optimized blade design for the cold region is very demanding, as study shows that the northern part of 'Tropic of Cancer' is high in wind power index (Jung and Schindler, 2021) and icing severely hampers the blade performance (Manatbayev et al., 2021). Besides, survey on wind index in densely constructed urban areas is also limited (Pellegrini et al., 2021), which is a key element in the feasibility of the micro wind concept.

6. Drawbacks and possible solutions

In this section, some of the most comprehensive research has been discussed to summarize the review. Table 2 briefly illustrates only the outstandingly promising pathways among the mitigation approaches.

7. Conclusions

The installations of WFs have substantially increased in the past few decades to meet the growing market need for renewable energy. However, conventional wind harness technologies possess drawbacks and environmental impacts, as marked in this study. For paving the future research in mitigating the issues, this review has identified some research gaps, in the basis of the comprehensive studies on environmental impacts. Moreover, it has also shown that significant tasks are also required to formulate more standard protocols and regulations. Eventually, it is expected from both researchers and policy makers that, based on the mentioned pathways, further investigation and studies will be carried out to come up with more environment-friendly wind power generation technologies and protocols that are more robust.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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