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Review of the environmental effects of deploying small wind turbines in cities

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Abstract. As the uptake of renewable energy systems increases in cities, attention is drawn to urban Small Urban Wind Turbine (SUWT) implementations. Their installation in cities and replacement of current energy sources can contribute to the mitigation of climate change through reduced local emissions and fewer energy losses, and to resilience through energy independence. These benefits can be directly linked to the UN Sustainability Goals. However, the exploitation of the wind potential using SUWTs in urban areas poses challenges given the variability in the urban morphology and materiality, and their effect on wind patterns. In addition, SUWTs may pose challenges in terms of noise, aesthetics, or safety amongst others. The understanding of the potential environmental effects of urban wind energy harvesting is still limited. Therefore, examining the environmental effect of SUWTs could contribute to establishing necessary regulations and gaining social acceptance, ultimately accelerating deployment. In this paper, we review the recent literature in four databases to identify the potential environmental effects of SUWTs. These effects are classified across two scales: the macro-scale for global effects, and the micro-scale for local effects. The review of the literature shows that the effects are strongly related to the technology of the turbines and the installation location, among other factors.…

1. Introduction

Urban wind energy harvesting can have several advantages including energy independence, financial savings, reduced local emissions, reduced grid load, and fewer energy losses [1]. The Wind Turbines (WTs) to be installed in cities for that purpose need to be specifically designed and planned for cities. The urban morphology and thermal gradients affect wind flow characteristics within the urban canopy layer where wind flow is highly turbulent and wind speed is generally low [2]. Sudden changes in urban morphology can also produce wind gusts, unusual wind shear, and changes in atmospheric stability which can degrade their performance. To ensure performance and durability, Small Urban Wind Turbines (SUWTs) must be adapted for cities and be installed in locations where high wind speeds are consistently present and where safety can be guaranteed [3]. The positioning of SUWTs is therefore critical to aim for a desirable performance. For example, in the case of roof geometry, gable roofs, under the same weather conditions usually result in more wind power than flat ones [4].

SUWTs differ significantly from large WTs, especially with regard to their size and axis of rotation. Although there is yet not a universally accepted classification, small WTs are often grouped based on their rotor diameter size: i) micro for diameters lesser than 1.4 m, ii) mini for diameters between 1.4 m and 3.0 m, and iii) domestic for diameters between 3 m and 10 m. Regarding the axis of rotation, WTs are distinguished as Horizontal-Axis Wind Turbine (HAWT), which have their axis positioned horizontally -this is the case with most onshore and offshore WTs, and Vertical-Axis Wind Turbine (VAWT), which have their axis of rotation positioned vertically -as is the case with most SUWTs. One major advantage of VAWTs is that they do not need to position the blade facing the wind direction, as they can exploit wind coming from any direction. As a result, they do not need a yaw system (horizontal rotation), which simplifies their construction, operation, and maintenance. Furthermore, VAWTs have low cut-in wind speed (speed at which they start to operate and harvest wind energy), and lower noise levels than HAWTs. Also, VAWTs require less urban space for their installation, particularly vertically, making them more suitable for urban areas with building codes that include height restrictions [2]. Therefore, micro, mini, and domestic VAWTs are more suitable for urban installation.

Despite being considered a clean technology, wind energy can also have negative effects [5]. The performance and acceptance of WT installations vary depending on the wind potential, the installation cost and financial risks, concerns for public safety, or the potential public annoyance driven by noise for example [1].

SUWT environmental effects

Macro-scale

Climate change
Raw material depletion

Micro-scale

Built structures
Micro climate
Safety
Air quality
Urban wildlife
Visual effect
Noise

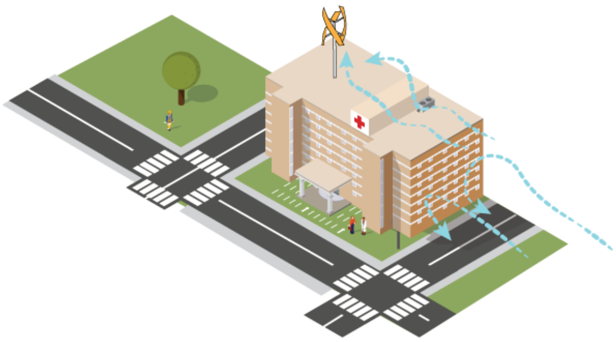

Fig 1. Environmental effects of SUWTs identified by the review.

By conducting a search in four databases, i.e., Scopus, Web of Science, PubMed and Google Scholar with 22 keywords grouped in three sets which combine the wind energy, the urban setting and the environmental effects, we identified possible environmental effects of deploying SUWTs in cities (see Fig. 1). These environmental effects may manifest at macro-scale and micro-scale. The macro-scale affects the whole planet, which has an impact on the overall justification for the proposed wind energy harvesting approach, i.e., the introduction of wind turbines in the cities, whereas the micro-scale affects the fine positioning of SUWT in the cities, to ensure minimum environmental effects and thus social acceptance. At the macro-scale the net environmental effect is expected to be positive but negative effects are identified, such as resource depletion. At micro-scale, there is a variety of environmental effects identified that need to be examined further. These effects concern the effects on the built structures, for example through the SUWT vibrations, the effect on health and safety, on the air quality and the microclimate, the urban wildlife, the noise effect, and the visual effects due to the presence of SUWTs, light or flickering light effects. The review process identified papers on these effects, many of which also concern the WTs, but the case of SUWT is much less examined, although there are differences that make this examination imperative.

2. Effects at micro-scale

There are micro-scale environmental effects that are to be considered when planning SUWT installations. SUWTs need to be installed at urban locations where urban wind energy can be harvested effectively. Negative effects might affect social acceptability. Also, to reduce or eliminate the negative effects, enhanced installation specifications or relocation to potentially non-ideal sites, implementation of demanding material or additional equipment such as dampers or sound insulators, may be required [17]. These environmental compensations also bear financial costs which may be internalized and thus affect the cost of SUWTs. So local effects of SUWTs need to be addressed, and also be economically justified [18].

The weight of commercially available SUWTs ranges from 100 kg to 10.000 kg, with the most common weight ranging between 200 and 500 kg. When positioned on buildings, SUWTs transfer additional loads to the structure which may require the installation of structural reinforcements. Under highly turbulent winds, SUWT structures need to be strong enough to withstand instantaneous and long-term wind fatigue loads, as well as strong wind gusts [19]. VAWTs are expected to have less of an effect on the load-bearing structure than HAWTs since the torque is nondirectional [20]. Vibrations are produced during the operation of SUWTs and may be transmitted to the building. With the addition of dampers, up to 90% of the vibration frequencies can be absorbed [21], however individual assessment for each installation might be needed [22]. In the case of wind turbines integrated within new buildings, the vibration effects are less challenging given that the structural design and dimensioning accounted for SUWTs. SUWTs installed in open public spaces, in contrast to the ones installed on buildings, result in minor structural challenges.

SUWTs do not contribute to higher air pollution concentrations aside from potential construction dust release during the retrofitting works performed on existing buildings or localized dispersion of pollutants due to wind alteration [23]. SUWTs can contribute to the improvement of air quality, or mitigation of heat exhaust by replacing existing energy sources such as those using burning coal, oil, or gas on a small scale, e.g., boilers. Therefore, SUWT implantations could also provide a positive local environmental effect such as local air quality improvement [24].

Large-scale wind farms affect local atmospheric conditions by taking up kinetic energy from the wind field and creating turbulent fluxes and vertical mixing [25]. The same effect has been found in meso-scale studies [25, 26]. The examination of the effects induced by SUWTs in the local micrometeorology at fine granularity is yet to be developed, although changes over the height of the buildings have been identified, the effect at the pedestrian level seems to be negligible [27].

The effect SUWTs play in urban wildlife has been identified as important for social acceptance [28] but has not been examined. Within urban environments, the number of endangered species may be smaller than in rural contexts, but the challenges SUWTs can pose to local wildlife are not negligible. In the case of rural and suburban settings, some limited prior literature has also highlighted potential hazards for urban bird species and bats [29]. There might also be indirect negative effects of SUWT installations on local wildlife due to noise pollution. The affection rate differs depending on the animal species, as they have different sensitivities to distinct frequency bands. The effects can range from physical damage to their ears, to stress responses, changes in foraging, avoidance of noisy areas and subsequent habitat migration, changes in reproductive success, and in vocal communication [30]. Yet again, such research is focused mainly on non-urban areas and HAWTs. Since SUWTs operate in different environments and have different operational characteristics, further investigation of similar effects on local wildlife is necessary.

Safety issues arise during the construction, operation, and decommissioning of SUWTs. The most dangerous event during operation is when a blade or a blade fragment detaches from a SUWT and is projected possibly at long distances and high speeds [31]. For this reason, the turbines are taken out of the circuit at high wind and cease to operate [9]. Some SUWT models can operate without this limitation and absorb high wind speeds, thus mitigating this risk. When SUWTs are installed in cold climates, ice fragments may also form on the blades and be projected by the rotation. The safety concerns associated with falling ice fragments have been studied and are not negligible [32]. So, the installation of SUWT is not without safety concerns.

Research on health effects associated with the implementation of SUWTs is limited, as most prior literature has only reported health problems associated with long-term exposure to wind farms [33, 34]. There have been reports about dizziness, migraines, fainting, insomnia, and poor sleep quality, when living or working in proximity to large WTs [35]. Therefore the effect of SUWTs on health is currently an open research topic and an evaluation of the effects induced by SUWTs on health is developed [30, 36].

Noise is an environmental stressor that may cause health issues, even as serious as stroke [37]. Noise pollution is the most widely covered possible negative effect of SUWTs [16, 38]. The effect of WT noise on citizen health has also been associated with their attitude [31]. It is important to consider the subjective “noise annoyance” that arises when a sound source is perceived as annoying, irritating, or unwanted (“WT syndrome”) mostly because it is visible [37]. Exposure to noise produced by SUWTs is a result of a combination of factors linked to the source of the noise, and also factors linked to the local conditions of the specific urban environment [31]. SUWTs produce noise at high frequencies [39] whilst infrasound and low frequencies are the frequencies being mostly investigated so far [31], with no conclusive results. Generally, the sound level of SUWTs, is less than that of horizontal turbines [40]. Intermittency and rhythm are reported to be the components of SUWTs that cause most noise annoyance [39]. Noise from SUWTs is perceived as more disturbing in areas where background noise is low [31]. To accurately capture urban noise gradients, high spatial resolution studies are necessary given that up to 13 dBA differences may exist between building facades that have a high and low SUWT noise pollution exposure [41]. Conflicting evidence arises for sleep disturbance, yet most existing literature agrees that no relation exists between SUWT noise exposure, and sleep deprivation [31]. Several manufacturers, especially those based on novel SUWT technologies, report very low or zero noise emissions [31]. However, while there is not sufficient evidence on the effect that SUWT noise may produce on self-reported quality of life or health [37], prior literature agrees that SUWT-induced noise pollution cannot be overlooked.

SUWT installations can produce visual obstructions or visual annoyances in urban environments [42]. Most importantly, SUWT-induced visual pollution, needs to be evaluated through positivist metrics, e.g. studying the proximity and geometry of SUWTs, as well as subjectivist metrics, e.g. studying social values, or personal background and interests [43]. Prior literature has also reported that SUWT visibility seems to be more important for citizens than SUWT proximity [44]. Ducted SUWTs are starting to be proposed as a less visually intrusive option as they can be grouped in a row on a roof, or spaced at intervals within a partition wall, and thus tend to blend with the neighbouring urban fabric [45]. Light pollution is related to the flickering effects of light projected over the wind turbine blades [46]. Visual and light pollution are interrelated and are mostly examined jointly.

3. Discussion and Conclusions

The possible macro- and micro-scale environmental effects of the deployment of SUWTs have been reviewed. At the macro-scale level, the deployment of SUWTs is expected to be positive but the net environmental gain needs to be calculated through LCA. Also, issues of resource depletion and material recovery of recycling still need to be addressed.

At the micro-level, the structural implications of SUWT installations need to be clearly established to enable their deployment on existing buildings. Such studies can result in guidelines at a local level in terms of structural engineering and design for SUWTs. SUWTs present a health and safety risk. During their operation, SUWTs can fail and endanger people, especially by falling parts. Additionally, in cold climates, ice may accumulate on the blades and be detached at high speeds while in operation, and then reach pedestrians or vehicles. More research is needed to better quantify the effect of SUWTs on the local air quality and microclimate, as their installation on lowrise or medium-rise buildings might affect the wind flow and the dispersion of pollutants at the street level, though only high-rise buildings have been studied so far. The effects of SUWTs on ecosystems still suffer from several research gaps. While existing literature on large-scale and small non-urban wind turbines has reported collisions with birds and bats, and behavioral changes in animals due to the noise of wind turbines, such research has not been conducted for SUWTs. It is important to better understand the combined visual and noise effects of SUWTs on people. Life-threatening or severe effects on human health do not seem to be yet substantiated, however non-severe health conditions such as sleep disturbance, driven by the annoyance from both factors separately as well as in combination, need further addressing. The visual effect may also concern the light or flickering effect. Besides the possible health issues, there is also the aesthetic intrusion aspect, especially when heritage buildings are involved. The noise effect also requires further studies to evaluate how the propagation of the sound level and its frequencies may affect not only humans, but also the urban fauna.

In summary, several research gaps still need to be addressed to deploy SUWTs in urban settings in a safe manner, for humans and other living beings. The complex interplay of different effects and performance metrics might result in guidelines that prescribe the deployment of SUWTs to certain urban areas, might limit the use of certain technologies, and might prohibit the installation of SUWTs due to structural safety reasons.

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