Wind Turbine Technology: A Strategy to Mitigate Air Pollution through Utilising Wind Energy

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Abstract. The drive to increase the implementation of alternative sustainable sources is a continuous challenge. The rising awareness of environmental impacts has led the public to demand the development of eco-friendly and dependable long-term solutions. Wind energy is acknowledged as among the best renewable energy sources with proven capabilities. The key contributing factor in defining the harnessing effectiveness is the wind availability and efficiency of the wind turbines at the specific wind conditions. But due to the non-uniform wind distribution and the limitations of the existing wind turbines at low wind speeds, countries with lower wind speed are still far away from exploiting wind energy.

According to the World Energy Commission, the use of one million kWh of wind power can save 600 tons of CO2 emission. An examination into current energy data for Malaysia indicates that only 0.23% of the wind and solar power combined is employed for electricity production as of 2017. This is due to very low wind speed in this region throughout the year. It is also a leading factor to air-pollutants being suspended in the atmosphere for a longer period. It will impact an imbalance in the environmental conditions, such as acid rain, global warming, rise in sea-level and fluctuating sea levels.

This paper reports an investigation into the potential impact of utilizing the advantages of wind energy technology in low speed wind regions as an air-pollutant free energy source, to contribute to the overall reduction of the Air Pollutant Index (API) in localized, impacted areas of Malaysia. This research conducted presents the strategy to utilize low speed wind turbines to decrease air pollution while the system is either On-grid or Off-grid.

Keyword: Malaysia, Air pollution, Wind Energy, Environment

1. Introduction

Advancements in industrialisation and population growth over the past decades have increased the demand for energy. Conventional energy sources, mainly fossil fuels, are heavily exploited due to its capability to meet the rising demands. However, the effects of the by-products of fossil-fuels pose a greater concern in the long-term as it is a key contributor to global warming due to the significant carbon emissions and heat trap within the atmosphere causing environmental imbalance. With that, there has been a greater need for studies and technologies that opt to utilize alternative energy sources in order to combat the negative existing and future environmental conditions. The focus is to ensure that the
demand for energy is met, but not at the expense of environmental sustainability. The operation lifecycle should include parameters such as: minimizing wastage, decrease pollutants in the atmosphere, and ensuring the preservation of flora and fauna. One of the many sources of renewable energy is wind energy. There has been doubts and speculations to move towards adopting this technology because it has yet to mature in the industry; however, there are many research conducted to assess and prove its competence in the present and future applications. The wind energy conversion is a simple system that makes use of the natural wind and hence can be installed easily in various types of regions [1], [2]. In addition, wind energy technology can mitigate the adverse effects of air pollution and redirect towards sustainable future. A study was conducted in West Michigan Wind Assessment, where the statistics show that if only 20% wind energy is to be integrated into the grid, it will keep the CO$_2$ emissions from increasing substantially until 2030, as shown in Figure 1 [3]. In addition, CO$_2$ footprints of various resources for power plants, fossil fuels and renewables including nuclear energy are presented in Figure 2 and 3, respectively. The chart reflects a mean of 0.4% of CO$_2$ emissions are produced by wind energy, it is almost as low as hydro and nuclear, valued at 0.2% and 0.3% respectively. Considering previously mentioned benefits of the wind turbines, it is the most environment-friendly, alternative energy with a high potential [4].

![Figure 1. Prediction of Carbon emissions with reference to wind energy.](image1)

![Figure 2. Cumulative CO$_2$ percentage of power generation using fossil fuels.](image2)

![Figure 3. Cumulative CO$_2$ percentage of power generation using renewables and nuclear energy.](image3)
A significant milestone in the history of climate change mitigation was presented in the Paris Agreement in 2016, where an agreement has been made to keep global temperature rise below 2 °C [5]. Several developing countries in the South-East Asian region like Malaysia, Brunei, and Indonesia are trying to tackle the environmental issue and preserve their fossil reserves by promoting renewables as major source of energy. Being a tropical country, Malaysia has an abundance of solar power but a very limited and low wind potential thus many demonstration projects failed involving wind - evidence for the scarce wind speed in this region.

Rate of pollution generated per day has passed the threshold of depending solely on the oxygen exchange by plants. Furthermore, most of the current air purification methods are designed for either industries or fossil refineries. Hence, there is a need for solutions for further purification practice utilizing alternate energy sources to reduce pollution. Therefore, this study reviews the crucial aspects like politics, economics and technology of wind exploitation. Furthermore, presents a brief contrast mentioning the issues in energy deployment and conceptual strategies to utilize wind solutions as the resource to mitigate air pollution.

2. Review

Wind energy exploitation is largely affected by social barriers which constrain technological and economic potential. The deployment is not only affected by its availability, but also by ecological, spatial and social constraints, and through the limitation of integration into power grid [6]. Consequently, inaccurate site selection and scarcity of wind lead to the failure of wind turbines in Malaysia. Nevertheless, the regions with higher altitudes in Malaysia still have wind potential to fulfil the energy demand with minimal ecological effect by the installation of a turbine in such an isolated region.

The distinction between waste and pollution can be comprehended through studying recycling and processing of byproducts by ecological and economic systems. Numerous attempts have been made to convert pollution into waste (recyclable), which might seem like an easy idea, but it is very difficult to implement in economies dominated by fossil fuel. Henceforth, wind energy is assessed concerning a few common influencing parameters like politics, economics, and technology to continue taking advantage of using green energy for a cleaner environment.

2.1. Political and Economics

Energy is the most profitable sector, especially based on fossils but it also increases capital at a very high cost of environmental damage [7]. Therefore, unclean air in modern cities is the impact of a lack in the monitoring and processing of pollution. Since profits can be increased from un-attended pollution, pro-corporate politics often provide subsidies or tax exemptions to attract foreign or local companies. Economies have been dominated by fossils for a long time and countries linked to their harvesting are seeing economic development, thus causing a reluctance to change. However, fossils are non-renewable and leave a negative impact on the natural habitat; so, several countries have considered alternate energy solutions to protect the environment with adequate contribution to satisfy the energy demand. Considering the benefits, the wind is the optimal renewable resource and concerning the potential, its employment has been intensified globally but still lacks awareness. Since majority of wind operations are implemented in isolated areas, many local people do not allow such establishments due to not being aesthetic and pleasing machines in their backyard [8]. Few massive conflicts which tremendously affected the wind sectors are usually, due to resistance from inhabitants [9].

A comparative study was reviewed to examine the factors influencing both domestic and foreign investments in wind energy. The report confirms that domestic investment is dependent on economic support while regulatory support is a concern for foreign development investment (FDI). Hence, having access to finance, trade openness and general investment restrictions determine the influence of FDI in an economy. Therefore, developing countries often rely on domestic investment because of their dependability on institutional aspects like local government effectiveness, corruption control, and the rule of law [10]. Technologically advanced organizations, from Asia and Europe, have high consultation costs, thus making other countries to use their knowledge.
2.2. Advancement in Technology
Various methods have been deployed into current non-renewable energy processes to attempt to prevent air pollution, monitor and recover the resource. It is performed by implementing further controls, such as chemicals, biodegradation, adsorption. [11]. A brief contrast of various effective pollution control equipment, based on either particulate or gaseous contaminants are presented in Figure 4 [12], [13]; but deciding an ideal device is difficult, as each case is unique. Therefore, an additional system should be designed upon analyzing the characteristics of a particulate and flow behavior in an environment. For example, a researcher has developed a tool based on street-light that generates its own electricity while cleansing the air, installed below lights [14].

![Figure 4. Techniques and tools used for air pollution control.](image)

3. Results and discussions
Annual haze problems in Malaysia from burning of palm fields causes Air Pollution Index (API) value ranging from 100 (moderate) to above 150 (hazardous) is a major concern among people. The government has reduced impact of haze through cloud seeding, confining people in closed areas and raising concerns with Indonesia. However, this requires a lot of administrative processes, preparation and acceptable forecast to be successful. A common effective process is to perform cloud seeding for rain as it clears the haze with water droplets. This approach is expensive; hence its use is limited to critical situations. The current year-round API levels are generally around the boundary of good to moderate, which does not pose an alarming situation. Nevertheless, over the long term, it is unhealthy for inhabitants of that region.

Therefore, the crucial measure to control pollution is to implement political and economic policies aimed to promote greener energy solutions. The foremost apprehension for any nation is the deficiency in environmental knowledge, specifically related to climate change. Thus, awareness among the government officials and locals is necessary for a clean environment. Generally, the locals avoid or lose interest in renewables because of poor regulations on the land prices for wind turbines. For example, the initial allotment is usually higher than the later land prices. Moreover, the fear of land being destroyed and the cases of birds being affected by such establishment makes the process quite savvy. Likewise, the awareness level in political party representatives and providing higher incentives to provincial officials can improve the adherence towards government efforts for renewables in the country. Additionally, this can lessen the investment fear, provide considerate energy budget and help to set suitable targets by the central government. Moreover, a criteria catalogue that considers techno-economic, environmental and socio-political restrictions. Higher feed-in tariffs have been noticed to
increases the electricity cost which will reduce the acceptance of the wind energy. Thus, economic inefficiency and expansion cost can be improved by having a legal framework condition to define wind sites. Also, a continuous consultation can help to mitigate the trade-off policies.

Advanced technological methods can help to reduce real-time air pollution without affecting energy production. State-of-the-art concepts proposing either single equipment or combination of few can be easily integrated with wind turbines. These approaches require a complex system design for operation and regular maintenance cycle to retain the optimal efficiency of the purification system. Another problem of such installations is the safety of human, animals and birds, as any slip-up can lead to dangerous scenarios.

The tower in a wind turbine is mostly empty, with exception to a few power cables and staircase, therefore, the space of this area can be occupied to install a purification solution. With that, a few design concepts are proposed considering the literature, with an installation of a purification system being either inside the tower or outside. The first approach proposes an electrostatic precipitator installed underground next to the turbine as shown in Figure 5. This is an effective solution as it removes particulates with size of 1µm from the air, but since it requires high supply voltage, it is not safe to be installed in areas exposed to life forms. The second approach is to use of baghouse filter unit designed for wind turbines tower with air inlet being just behind the blade for better flow rate while the outlet on the other side, as shown in Figure 6. The unit consists of small tubular filters arranged linearly on a vibrating assembly from which the particulates will be removed when the air passes through and collected at the bottom in a collection box. The wet collectors are very efficient solutions to extract haze but due to the wind farms being in isolated areas it is difficult to have a setup of such water supply, hence these options are not considered in this discussion.

Likewise, few researchers have used carbon nanofibers to capture CO₂ from the atmosphere. The process operates in the presence of lithium carbonate and lithium oxide, upon exposure to electric current it will give oxygen and carbon storage on one of the electrodes without any further emission. However, due to the requirement of chemicals and monitoring, it is not yet feasible to deploy on a major scale. But it has a promising future in sequestering CO2 and providing a cost-effective approach to develop carbon nanofibers [15].
4. Conclusions
This paper reviews the influence of socio-political, economic and technological aspects of wind energy exploitation. It can be seen that the effectiveness of the solution for air pollution control and mitigation is concurrent with the efforts to replace as much conventional energy sources with renewables, in this case study: wind energy. However, in order to fully adopt wind technology on a large scale, turbine design and innovation are necessary to maximize the energy extraction efficiency; it is susceptible to various regions of wind speed. Also, political and economic efforts are essential to control pollution. Similarly, future research is necessary for purification concepts to make them more suitable, compact and efficient.

Acknowledgement
I would like thank my supervisor and University of Nottingham to provide this opportunity to present my ideas for air pollution mitigation.

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