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THE POTENTIAL OF GREENHOUSE GAS EMISSION REDUCTION USING WIND ENERGY TECHNOLOGY AT SELECTED SITES IN MALAYSIA

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Abstract: Wind energy is one of the five fuels that can support the reduction of greenhouse gases and climate change impact. Wind energy is one of the most promising renewable energy sources that can be exploited to succeed in 1/20 of the renewable energy mix in Malaysia. This study aimed to determine the value of GHG savings on wind energy potential based on Meteorological Aerodrome Report (METAR) data in Malaysia to establish a suitable wind farm in Kudat and Langkawi Island that can potentially generate electricity. The wind speed data were collected from the METAR report broadcasted hourly. Wind speed extrapolation was based on the selected wind turbine generator (WTG) with 950 kW and 60 kW capacity. The prospect of wind energy was analysed using the Weibull distribution to determine the parameter of shape (k) and scale (c) from the wind speed frequency distribution. Finally, the Annual Energy Production (AEP) and the GHG savings were estimated. Based on the study, the annual reduction of GHG emissions ranges from 150 to 1,300 tonnes of CO_2 per year. The ten-year projection roughly estimates about 1,500 to 13,000 tonnes of CO_2 per year. Implementing a low-carbon, cost-effective energy source would undoubtedly enhance Malaysia's sustainable energy system, as proposed by the United Nations Sustainable Development Goals 7.

Keywords: Climate change, greenhouse gas savings, renewable energy, Sustainable Development Goals.

Introduction

Wind power as a form of green electricity source to fulfil the demands for energy supply will be plentiful for millennia. As a solution to decarbonise the global energy system, generating green power from wind has captured the attention of researchers because of its free and non-polluting characteristics. Malaysia is a country that has numerous offshore islands scattered along the coast in the form of a mountainous spine running from the Thai border to the south. At the same time, the interior of East Malaysia is also generally hilly (Lawan *et al*., 2013). Plus, Malaysia is located in the equatorial region. The climate is oriented by the monsoons, including the northeast and southwest monsoon that occur annually. The northeast monsoon happens from around November until April. Meanwhile, the southwest monsoon occurs from October until May.

Renewable energy and climate change have a dynamic role and a positive effect on greenhouse gas (GHG) emissions that have become a new agenda reflected in the Paris Agreement. As a growing country, increased energy demand has compelled the government to utilise less expensive energy supplies for electricity generation (Abdul Latif *et al.,* 2021). A carbon dioxide (CO_2) decrease is the desired effect of a carbon-free future. Climate change mitigation could be achieved through wind energy required expansion of wind energy installed capacity. By developing strategies to decarbonise their energy system and, in some cases, propose net-zero emissions by 2050 (Barthelmie & Pryor, 2021). There are limited studies about wind farms in Malaysia compared to other countries, as Malaysia has yet to commercially implement the wind energy sector (Albani *et al*., 2013a). Also, the effects of greenhouse gas emissions on the environment and human health are from anthropogenic activities. It is critical to address the decrease in GHG emissions, which has significant social, economic and environmental implications for the country since it combats the effects of climate change (Raimundo *et al.*, 2018). The use of renewable energy could aid in reducing these harmful greenhouse gases. This paper investigated the potential amount of GHG a wind turbine could reduce in Malaysia.

Materials and Methods

Meteorological Aerodrome Report (METAR) Data

METAR stands for Meteorological Aerodrome Report, the international meteorological code for an aviation routine weather report (WHO, 2015). Typically, the weather report is collected and broadcast hourly (NOAA, 2019). In this study, the selected METAR stations were Langkawi Island and Kudat. A wind energy assessment was performed on data from these sites since there were no discrepancies and null values for these stations.

Wind Speed Analysis

In this study, the power-law index (PLI) value was gathered from the report by Albani and Ibrahim (2017) using Equation 1. The Hellman power law equation determined the wind speed at desired heights. Typically, the extrapolation of vertical wind speed is gathered at a height of 10 to 100 meters.

$$V_2 = V_1\left(\frac{Z_2}{Z_1}\right)^{\alpha} \quad \textbf{(1)}$$

where V is the wind speed to height, Z_1 is the reference wind speed to reference height V_1, V_2 is the desired wind speed to the desired height and α is the PLI. The values of α, V_1, Z_1 and Z_2 were inserted into the equation.

The Two Parameter Weibull probability distribution function with its parameter was estimated and plotted according to Equations 2, 3 and 4. It shows the time or probability of the wind speed dominating a specific direction. The annual energy production (AEP) is a known method based on the two-parameter Weibull distribution function.

$$k = \left(\frac{\sigma}{v}\right)^{-1.086}, (1 \le k \le 10) \quad \textbf{(2)}$$

Γ(1+1/k) is the value of the gamma

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \text{ function for (1+1/k).} \quad \textbf{(3)}$$

$$p(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp^{-\left(\frac{v}{c}\right)^{k}} \quad \textbf{(4)}$$

The k parameter is a dimensionless shape factor. At the same time, c is a scale parameter measured in m/s. Both of these factors affect the shape of the Weibull distribution.

Annual Energy Production (AEP)

The computation of annual energy production (AEP) through the capacity factor formula provides the electricity produced annually (Equation 5).

$$CF = \frac{AEP}{8760P_r} \quad \textbf{(5)}$$

where CF is the capacity factor, AEP is the generated total power, P_r is the rated power of the wind turbine and T is the time in hours. The calculated CF was then used to calculate the annual energy of the wind turbine using Equation 6.

$$CF = \frac{AEP}{TP_R} \quad \textbf{(6)}$$

Greenhouse Gas Emission Reduction

After the AEP was calculated, the value of GHG emission reduction was obtained to evaluate the effectiveness of wind energy in reducing GHG. The emission factor of 660g/kWh from the average Malaysian national electricity generation mix was used for this GHG emission calculation (Albani & Ibrahim, 2017). Hassan *et al*. (2011) reported that the CO_2 emission factors were estimated to be 1.18, 0.85 and 0.53 kg/

kWh for electricity generated from coal, oil and gas, respectively. The GHG emission formula is stated in Equation 7.

$$G = \frac{660AEP}{1{,}000{,}000} \quad \textbf{(7)}$$

where G is the GHG emission reduction in tonne/CO_2/year, AEP in kWh/year.

Results and Discussion

Wind Energy Assessment

Wind Speed Analysis

Kudat recorded higher wind speeds than Langkawi Island based on the METAR data. The average wind speed at 10 m height was 2.49 m/s, the maximum wind speed was captured at 20.14 m/s and the minimum wind speed was 3.60 m/s. As for Langkawi, the average wind speed at 10 m height was 1.66 m/s, the maximum wind speed was captured at 8.20 m/s and the minimum wind speed was 0.50 m/s. Table 1 shows the location and elevation of study sites, the average data of extrapolated wind speeds at the wind turbine hub height, where the wind speed data in Kudat at 65 m height was 5.19 m/s and at 60 m height was 5.03 m/s. Meanwhile, on Langkawi Island, the wind speed data at 65 m height was 4.09 m/s and at 60 m was 3.94 m/s.

The factors that affect the power results of the wind turbine are because of the location of Langkawi Island in terms of geographical and meteorological factors. The results from Langkawi Island were the lowest regarding wind speed and power potential. Albani *et al*. (2013b) clarified that the low wind speed occurred during the southwest monsoon due to long-distance travel from the Indian Ocean to Langkawi Island. This developed a large frictional force on the wind with the water surface that led to the formation of a large wave because of its location on the West Coast. Therefore, the electricity generation needs to be hybridised with the wind turbine generator and Solar Photovoltaic (PV) to harvest the energy at maximum capacity since Langkawi Island has low power potential.

Table 1: The location and elevation of METAR stations (5) and monthly average wind speed extrapolation in Kudat and Langkawi Island at the hub height of the selected wind turbines

Location	**Latitude (°N)**	**Longitude (°E)**	**Height AMSL (m)**	**PLI**	**Hub Height**	**Month/Year**												
						Jan 2015	Feb 2015	Mar 2015	Apr 2015	May 2015	June 2015	July 2015	Aug 2015	Sept 2015	Oct 2015	Nov 2015	Dec 2015	**Avg**
Kudat	6°55'	116° 50'	3.0	0.28	10 m	3.09	3.02	1.76	2.68	2.08	2.26	2.54	2.84	2.44	2.44	2.09	2.71	**2.49**
					65 m	6.29	6.15	6.34	5.45	4.24	4.38	5.18	5.21	4.19	4.99	4.30	5.55	**5.19**
					60 m	6.10	5.97	6.15	5.30	4.11	4.24	5.02	5.05	4.06	4.83	4.17	5.38	**5.03**
						Aug 2014	Sept 2014	Oct 2014	Nov 2014	Dec 2014	Jan 2015	Feb 2015	Mar 2015	Apr 2015	May 2015	June 2015	July 2015	**Avg**
Langkawi	6° 20'	99° 44'	6.4	0.48	10 m	1.42	1.47	1.26	1.50	2.08	2.29	2.43	2.00	1.37	1.21	1.18	1.66	**1.66**
					65 m	3.49	3.62	3.13	3.72	5.12	5.63	5.98	4.94	3.40	3.01	2.96	4.12	**4.09**
					60 m	3.36	3.49	3.02	3.58	4.93	5.42	5.76	4.75	3.27	2.89	2.84	3.96	**3.94**

The application of small wind turbines (SWT) gives the unique opportunity to access an unexplored market while causing no environmental damage. In delivering such helpful power, the power output from the wind turbine needs to be controlled by the wind turbine's design, for example, cut-in wind speeds, cut-out wind speeds and rated wind speeds. Thus, the selected wind turbines in this study generally had cut-in speeds in the range of 2.5 to 3.5 m/s and the cut-out speeds ranged from 20 to 25 m/s. The rated power output is produced from the wind turbines when the wind speed is approximately above the rated wind speed of the machine. A small wind turbine can produce enough electricity annually and be cost-effective. Small-scale wind turbines range from 5 kW to 15 kW and comprise stand-alone or grid-connected systems usually used for domestic, community and small wind energy projects. According to the Pacific Northwest National Laboratory (PNNL) classification system, from 3-4 m/s, most wind turbines start to generate electricity; rated power is generated at around 15 m/s, shutdown to avoid damage to the wind turbine occurs at 25 m/s and above.

Weibull Parameter

The results from the *k* parameter for data at 65 m hub height in Kudat and Langkawi Island were 2.29 and 1.38 (Table 2). Meanwhile, the value of the *c* parameter for 65-meter height data in Kudat and Langkawi Island was 5.52 m/s and 4.48 m/s. Meanwhile, the value of k and c parameters at a 60-meter height in Kudat were 2.31 and 5.36 m/s, and Langkawi Island's results for k and c parameters were 1.39 and 4.32 m/s. The hub height of 60 m results of k and c parameters in Kudat were 2.31 and 5.36 m/s. For a hub height of 65 m, the k and c parameters were 1.38 and 4.48 m/s; meanwhile, for hub heights of 60 m, k and c parameters were 1.39 and 4.32 m/s.

This is a reasonably good approximation over the range $1 \leq k \leq 10$, which indicates wind stability. The value of k in this range of 1 to 3.5 also indicates a narrower frequency distribution as the wind is steadier and has fewer variables. The coefficient of skewness approached zero (no tail) because the shape parameter was between 2.6 and 3.7. Furthermore, the wind distribution profile is one of the primary keys to wind energy resource assessment for a region of a particular country. On the plotted Weibull distribution graph, it was found that a few occurrences are likely monsoons of South Asia force.

The PDF of the wind regime's curve indicates the most frequent wind velocity in the particular regime. It can be easily seen from the curve [Figure 1 (a)] in the Kudat region that the most frequent wind speed values ranged from 5 m/s to 7 m/s. The wind speed bins fit the Weibull PDF and were positively skewed. The Weibull PDF graph [Figure 1 (a)] shows an approximately normal distribution.

Table 2: Site parameters in Kudat and Langkawi Island at 65 m and 60 m

Location	Kudat		Langkawi	
Hub height	65 m	60 m	65 m	60 m
Standard deviation	0.80	0.78	1.06	0.98
c (m/s)	5.52	5.36	4.48	4.32
k (dimensionless)	2.29	2.31	1.38	1.39
Weibull probability density function	0.998	0.997	0.956	0.954

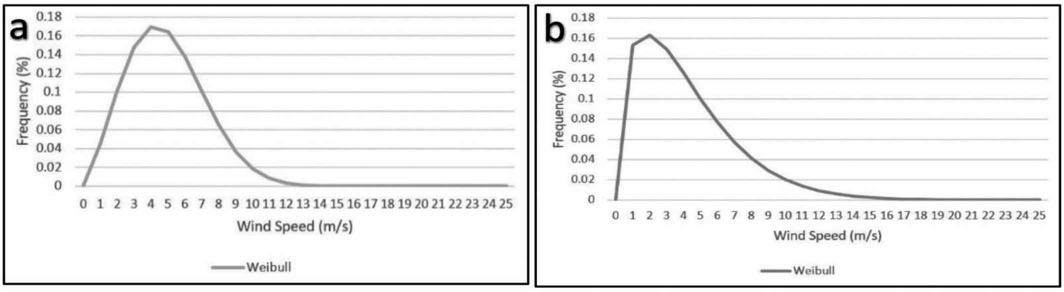

Figure 1: Kudat (a) and Langkawi Island (b) Weibull PDF versus Wind Speed Frequency using a 950-kW wind turbine generator

Figure 1 (b) illustrates the Weibull distribution of Langkawi Island. The Weibull shows a positively skewed distribution, and the highest wind speed frequency in Langkawi occurred at 3 m/s, approximately 0.18 m/s. The most frequent wind speeds for Langkawi Island ranged from 2 m/s to 4 m/s.

The kurtosis is distributed normally with a positively skewed trend. Figure 2 (a) shows a normal kurtosis distribution in which the highest wind speed distribution takes place at 6 m/s, and the frequency was 0.14 using 60 kW WTG in Kudat. Figure 2 (b) shows the wind power density and Weibull PDF in Langkawi Island. The highest frequency of wind speed occurred at 3 m/s.

The Weibull distribution model had been used purposely to evaluate wind speed distribution. Usually, this method is used in practical studies related to wind energy modelling. The Weibull PDF can accurately represent the wind speed distribution at a chosen location (Mohammadi *et al*., 2014; El-Naggar *et al*., 2015; Lawan *et al*., 2015; Khattak *et al*., 2016). This is consistent with earlier worldwide research findings suggesting the Weibull PDF be a fair depiction of the wind regime at a given location.

Capacity Factor

The expression of AEP and the energy produced by two types of wind turbines are presented in Table 3. It aims to specify the amount of electricity each WTG generates when running at its maximum capacity for the year. It depicts the values for capacity factors of 60 kW WTG, which have a high potential to be installed in Kudat and Langkawi Island, with scores of 44.66% and 21.11%, respectively. The power curves of wind turbines were modelled using a fifth-order polynomial to compute energy output results.

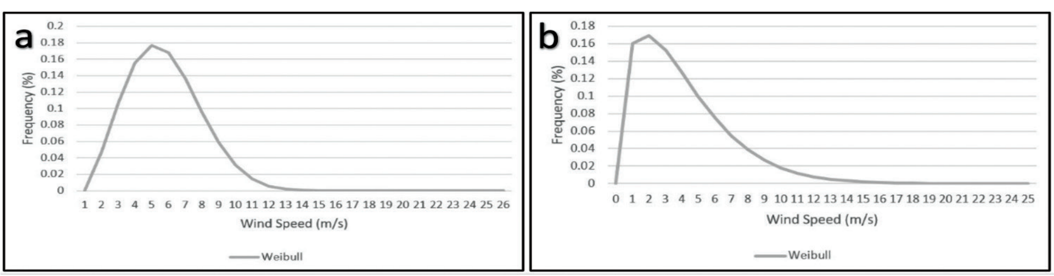

Figure 2: Kudat (a) and Langkawi Island (b) Weibull PDF versus Wind Speed Frequency using 60 kW wind turbine generator

Table 3: Capacity factor of the wind turbine generator

Stations	Capacity Factor (%)	
	950 kW WTG	**60 kW WTG**
Kudat	21.73	44.66
Langkawi Island	15.25	21.11
Power curve (Fifth order polynomial)	$y = -0.2176x^5 + 6.8218x^4 - 81.772x^3 + 482.74x^2 - 1354.7x + 1443.9$	$y = -0.0104x^5 + 0.303x^4 - 3.4706x^3 + 20.947x^2 - 60.894x + 68.393$
R^2	0.9999	0.9995

The determinant of the capacity factor is the blade's airfoil which influences the wind turbine's characteristics such as cut-in speed, cut-out speed and rated power. Typically, the capacity factor of commercial wind turbines is only between 20 to 35%. Therefore, the selection of WTG in Kudat and Langkawi Island is within range of their capacity to operate.

The power curve is a crucial part of information where the wind turbine output is estimated. The wind turbine power curve was gained from the manufacturer, which was then modelled in a polynomial equation. As shown in Table 3, the R-squared value for 950 kW WTG was 0.999 while 60 kW WTG was 0.9995. Therefore, it is a good regression line to estimate power output from wind speed.

Energy Analysis and Greenhouse Gas Savings

The value of power densities according to the maximum value of the hub height of the WTG is depicted in Table 4. In Kudat, the energy values for 950 kW WTG and 60 kW WTG were 120.95 W/m^2 and 108.90 W/m^2 for the Weibull function. Langkawi Island could also extract energy but at low values of 129.95 W/m^2 and 115.18 W/m^2.

Energy density depends on the power per unit area. It is essential to note that the values of power densities of 10 m – 65 m and 10 m – 60 m fall within the class "less than 200 W/m^2" based on the United States standard wind association category of the National Renewable Energy Laboratory (NREL). This indicates the possibility of running small-scale wind-driven systems in the area. Thus, the amount of GHG savings in Kudat for the two WTG of 950 kW resulted in a higher GHG emission reduction than 60 kW WTG, which were 1,206.14 tonne/CO_2/year and 154.91 tonne/CO_2/year. Regarding Langkawi Island, the total GHG savings for 950 kW WTG was 846.50 tonne/CO_2/year; for 60 kW WTG was 73.24 tonne/CO_2/year.

Table 4: Energy analysis and GHG emission reduction

Location	Kudat		Langkawi Island	
Wind turbine generator (kW)	950	60	950	60
Wind power density (W/m^2)	120.95	108.90	129.25	115.18
Annual energy production (kWh/m^2/year)	1827492.06	234708.30	1282577.21	110967.60
GHG savings (tonne/CO_2/year)	1206.14	154.91	846.50	73.24

Wind Regime at Selected Sites

Wind direction is critical for conducting wind energy research and demonstrating the effect of geographical variables on the wind. It is an important factor to consider when evaluating the feasibility of a particular location for urban wind energy. The wind rose application shows the average energy content in a particular location where the dominant high energy flows originate. The wind direction is illustrated in a rose diagram and the frequencies concerning cardinal directions from which the wind blows. The observed wind data directions [Figure 3 (a)] in 2015, which is the most probable wind direction for the north-east winds showed the most prevailing wind speeds to be 8.8 m/s to 11 m/s.

Meanwhile, wind frequencies of 8.4%, 6.03% and 4.02% allowed the wind turbines to operate. Figure 3 (b) illustrates that 9.85% of prevailing wind speeds at the northeast winds sector were about 5.70 m/s to 8.80 m/s. Approximately 11.18% of calm wind affected wind turbine energy production; this could be due to the site's location which is situated at the coastline.

The direction of the wind rose is vital to conduct wind energy assessments and displaying the wind direction to consider the suitability of the location. The wind roses analysis is to determine the origin of the most dominant wind energy flow. Thus, once the position of the wind turbine is established, obstacles such as trees or tall buildings can be reduced.

The annual reduction in GHG emission based on both WTG was in the range of 150 to 1,300 tonne/CO_2 per year, which means that the projection for ten years is about 1,500 to 13,000 tonne/CO_2 per year through rough estimation. In 2020, India was expected to harness its wind energy up to 338 TWh, which would mean a CO_2 reduction of 203 tonnes in GHG emissions. The study found that the CO_2 emission reduction with 950 kW WTG in one year for 900 kW electricity generation would save 1,206 tonne/CO_2/year. Global Wind Energy Council (GWEC) and the ambitious scenario found that the energy capacity in 2012 was 680 TWh (CO_2 savings is 408 million tons). The energy projection of 2,400 GW by 2030 could result in annual CO_2 savings of more than 3.2 billion tons globally. Even under the most stringent climate regime, one-fifth of all emission reductions of Annex I countries such as Europe, the United States, China and India could be met by wind energy alone.

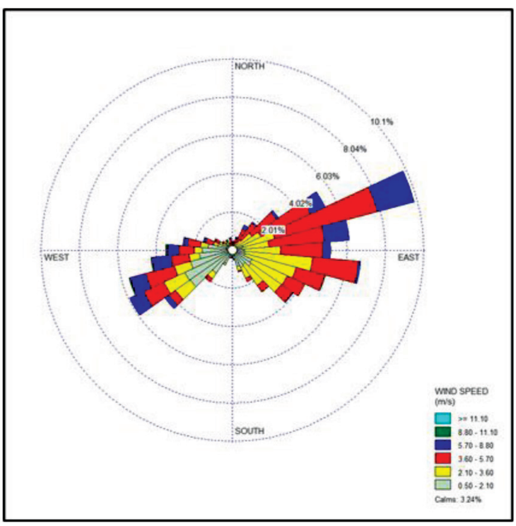

Figure 3 (a): Kudat wind rose

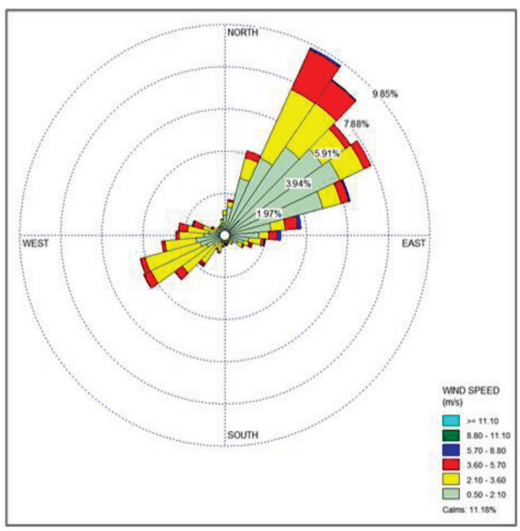

Figure 3 (b): Langkawi Island wind rose

Wind energy is one of the climate change mitigation efforts. According to Deng *et al.* (2018), public concerns about climate change are low due to the unexpectedly high costs of mitigation efforts. Generally, people like to have cheap energy and generate electricity without harmful consequences. However, the latter is not at the top of their priority list. Therefore, the government needs to play its role by educating people about the aggressive emissions of GHG into the atmosphere and gaining the support of the public to make mitigation efforts a success. During the initial stage of the deployment of wind power in Malaysia, the government needs to give support and incentives, as this is a capital-intensive investment (Abdullah *et al.,* 2019). There could lead to improvements in health-related climate changes and aid the preservation of Malaysia's diversity. Efforts to mitigate GHG emissions have improved health outcomes such as air pollution-related diseases, communicable diseases and non-communicable diseases. Besides adaptation to climate change, the mitigation effort is the most significant path (Wang & Smith, 1999; Cifuentes *et al*., 2001; McMichael, 2013; Deng *et al*., 2018). The advantages of supplying power to the region include decreasing energy security and air pollution, increasing economic impact, improving food security, and diversifying ecosystems. However, not all fifth fuels have the same potential to reduce GHG emissions. For example, coal used to generate electricity in Malaysia could lead to long-term effects on the public's health such as reductions in life expectancy and respiratory hospital admission. Wind power generation, on the other hand, if combined with other clean and free energy, would result in multiple benefits for health such as reduced risks of asthma, chronic bronchitis, hospitalisation and cardiac health problems. Cifuentes *et al*. (2001) emphasised that if the GHG mitigation action were forged to a specific application of alternative energy production technology, it would benefit the public worldwide. Thus, the energy rebound effect from wind technology which has been found in several studies can significantly offset some energy savings and decarbonisation.

Therefore, the most profitable way to reduce CO_2 emissions in the power sector is to manage energy demands. Mainly, electricity demands need to be reduced due to electricity consumption generated from fossil fuels. In other words, to reduce CO_2 emissions, electricity consumption needs to lessen. Due to a persistent economic boom laced with a higher population surge and urbanisation, electricity consumption has increased in all parts of Malaysia, albeit the demand is thought to double the current generation. In 2040, electricity demand and consumption are expected to increase by 4.2%. The largest contributor to renewable energy is hydropower, with 15% of the country's total energy and the second energy source is solar (Afrouzi *et al.,* 2021).

In response to sustainability and resilience towards climate change, the government of Malaysia set a new framework to diversify the collection of RE, especially on wind energy. One of the strategies out of 15 planning documents is to enhance adaptation and mitigate climate change, as reported to UNFCCC. In line with the positive growth of RE in Malaysia, albeit the political rhetoric intertwined with climate change, air quality and energy supply issues, Ma *et al*. (2013) discussed the co-benefits of health and energy generation. They found wind power a sensible choice for China as a win-win situation between climate change and other developmental goals in cities. Furthermore, the wind turbine location in Xinjiang Uygur Autonomous Region is China's most extensive wind base. It estimated good reductions in CO_2 emissions and showed significant water savings compared to coal-fired power. Taking the example of China's idea as there would be a good idea to harness wind energy efficiently while Afrouzi *et al.* (2021) suggested maintaining the balanced well-being of Malaysia's unique ecosystem.

Malaysia needs to have specific policies on wind power as its potential has not been fully explored. Due to its location in the equatorial region, Malaysia experiences low wind speeds. Despite that, modern wind turbines can still generate electricity with the proper technology. From the Malaysia 3rd National Communication Report (Ministry of Energy, Science, Technology, Environment and Climate Change, 2018), through the Ambitious (AMB) scenario, large hydropower with 8,129 MW and RE initiatives of about 5,055 MW is planned to be installed by 2030. For example, the 2030 projection of wind turbine installation to achieve the 5,055 MW excludes all of the RE sources installed. The target reduction of GHG emissions would need about six wind turbines through 950 kW WTG if the target were computed from 2020 to 2030 in Kudat and Langkawi Island. On condition that the reduction of GHG emission follows the 45% (approximately 139 517 ktoe) of GHG emission as the predicted emission of GHG in the year 2020 is 310 038 ktoe. Therefore, a total of 68 wind turbines need to be installed. This paper determined the value of GHG savings on wind energy potential based on METAR data in Malaysia to establish successful wind farm locations in Kudat and Langkawi that can generate electricity. However, understanding the interrelationships between sustainable development and renewable energy is still inadequate. Therefore, there is a need for the global opportunity to create international cooperation that supports least developed and developing countries towards accessibility of renewable energy to utilise and maximise its potential. Additionally, the lack of information and access to raw data for future renewable resource deployment needs improvement.

Conclusion

Conventional energy sources overshadow the overwhelming vision of minimising the emissions of GHG. Coal is a significant pollutant that causes concerns over pollution and air quality, the need for climate change mitigation action, and the rising climate-health problems in the community. Even though many dissenting studies conclude that Malaysia has no potential to generate wind energy, the manufacturer has already designed various wind turbines suitable for generating electricity for low wind speed wind farms. Despite the minor environmental impacts of wind energy, it is considered a green energy source with no GHG emissions. The GHG emission reduction for 950 kW WTG and 60 kW WTG in Kudat is 1,206.14 tonne/CO_2/year and 154.91 tonne/CO_2/year. Meanwhile, on Langkawi Island, the GHG emission reduction for 950 kW WTG and 60 kW WTG are 846.50 tonne/CO_2/year and 73.24 tonne/CO_2/year. Therefore, the annual reduction of GHG emissions ranges from 150 to 1,300 tonnes of CO_2 per year. The ten-year projection is a rough estimation of about 1,500 to 13,000 tonnes of CO_2 per year. The theoretical analysis showed that 950 kW WTG would be the best wind turbine to generate electricity in Kudat and this could be the best solution for reducing Malaysia's CO_2 emissions. A comprehensive wind resource assessment should be assessed on average GHG emission reductions of similar projects conducted over the previous five years. Furthermore, wind energy development and GHG emission reduction analysis would be best analysed with a Life Cycle Assessment. Additionally, long-term research programs should utilise wind energy in Malaysia to achieve the Sustainable Development Goal's vision. With the support of the Malaysian government, the wind power industry could experience positive growth, become delightfully crucial in the world economy and be advantageous to human health.

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