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Life Cycle Cost Analysis And Payback Period of 12-Kw Wind Turbine For a Remote Telecommunications Base Station In Malaysia

A. Azmi[1], Abdi Hanra Sebayang[2,3,*], and Aditiya Harjon[4]
[1] Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2] Department of Mechanical Engineering, Politeknik Negeri Medan, 20155 Medan, Indonesia
[3] Center of Renewable Energy, Department of Mechanical Engineering, Politeknik Negeri Medan, 20155 Medan, Indonesia
[4] Department of Mechanical Engineering, Sampoerna University, Jakarta, 12780, Indonesia
*Corresponding author: abdisebayang@yahoo.co.id

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Abstract – Owing to the unavailability of electricity in many remote areas in Peninsular and East Malaysia, these areas do not have access to telephone signals. In remote areas, a diesel generator is used as the power source for the telecommunications base station. Hence, the continuous supply of diesel (which is a fossil fuel) is necessary in these remote areas. In this study, an attempt is made to assess the potential of replacing diesel-generated electricity with wind energy, which is renewable energy. Life cycle cost analysis is carried out, and the payback period of a wind energy system is determined for a remote telecommunications base station in Malaysia. The load characteristics and wind data are obtained from the Mersing Meteorological Station, Malaysia, and it was found that the annual load and base load are 12 kW. Hence, a 12-kW wind turbine is selected for the life cycle cost analysis at the site. The results show that the total specific cost of the 12-kW wind turbine is MYR 0.27/kWh based on a discount rate of 5% and electricity tariff in Malaysia of MYR 0.28/kWh. The payback period and discounted payback period of the 12-kW wind turbine are estimated to be 11.8 and 18.2 yr, respectively. Based on the load characteristics in Mersing, Malaysia, the 12-kW wind turbine is economically viable for the remote telecommunications base station. Nonetheless, the 12-kW wind turbine is not economically viable because the simple payback period is greater than 1/3 of the wind turbine's lifetime, which is 20 years. The 12-kW wind turbine, on the other hand, is suitable for use as a remote telecommunications base station.

Keywords: wind energy; life cycle cost analysis; cost-benefit analysis; techno-economic analysis.

Introduction

There are many causes of global warming (use of fossil fuels, deforestation, intensive farming, waste disposal, mining, and overconsumption), all of which are human activities. Hence, renewable energy programs and energy efficiency strategies are only among the solutions rather than the only solution. One of the ways to reduce global warming and decelerate its effect on climate change is to reduce greenhouse gas emissions. Greenhouse gas emissions can be reduced by implementing energy efficiency strategies and renewable energy programs. Various energy efficiency strategies have been implemented worldwide to reduce energy consumption and greenhouse gas emissions (Benito and Alonso, 2018; Barma et al., 2017). Renewable energy programs have been implemented successfully in many developed countries and a number of developing countries (Terrapon-Pfaff et al., 2014; Kabir and Khan, 2020). Renewable energy refers to non-depleting energy sources available in nature that can be harnessed for the benefit of humankind. Hence, the dependency on fossil fuels can be reduced by substituting nonrenewable ones with renewable energy. The use of renewable energy for power generation has been discussed in detail in recent studies (Chhawchharia et al., 2018; Chuang et al., 2019; Shayesteh et al., 2018). In this regard, wind energy is one of the most viable renewable sources. The feasibility of wind energy for power generation has been demonstrated in the following studies (Ünlü et al., 2018; Varela-Vázquez et al., 2019).

Wind energy systems are more reliable than fossil fuel-based power generation systems because they do not require frequent maintenance and are inherently safer owing to the automatic stop features in the event of a failure. More importantly, wind energy systems do not pollute the environment (Hossain et al., 2018). Wind energy system reduces greenhouse gas emissions by 93% compared with diesel fuel system (Fleck and Huot, 2009; Hemmati, 2017). The grid connection issues of small wind turbines in the built environment have been discussed in depth by Driesen. It has been forecasted that there will be small changes in wind energy sources by the end of the 21st century because of the increase in extreme wind speeds and gradual decrease in polar ice sheets and icing frequencies (Pryor and Barthelmie, 2010). By considering the greenhouse gas emissions, energy payback period, and cost of electricity generated by different types of renewable energy sources, it has been shown that wind energy is one of the most sustainable sources for electricity generation (Djørup et al., 2018).

Renewable energy is one of the important energy sources in rural areas where there is a lack of access to electricity because these areas are located far from the electricity grid. The implementation of renewable energy systems in rural areas can be found in the following studies (Daneshvar et al., 2018; Enslev et al., 2018). One of the applications of renewable energy systems is for remote telecommunication systems. The use of renewable energy sources such as wind, solar, biofuels, and biomass will make communications more accessible and will reduce the reliance on fossil fuels in remote areas. It is particularly challenging to search for reliable, cost-effective solutions to increase access to telecommunications services in remote areas for the following reasons: (1) lack of access to electricity in remote areas and (2) the high cost of distribution of telecommunications networks. Integrating different energy sources and conversion systems is necessary to fulfill the sustained load demands of mobile base stations. One of the promising renewable energy solutions for remote areas is wind energy systems. The use of hybrid standalone wind-diesel systems will be more cost-effective for telecommunications service providers compared with the use of diesel power generators in remote areas. Wind energy systems may not be technically viable at all sites because wind is unpredictable, and wind speeds may be low at some sites.

For this reason, hybrid renewable energy-diesel systems are attractive. The economic aspects of hybrid renewable energy technologies make them promising for power generation. A hybrid energy system comprises multiple energy sources, power conditioning equipment, a controller, and an optional energy storage system. Hybrid energy systems are becoming famous for power generation in remote areas owing to the advancements in renewable energy technologies and fluctuations in oil prices over the years. Hence, much effort is needed to develop renewable energy systems, improve their performance, and establish techniques to accurately predict their output and reliably integrate them with conventional power generation systems (Nema et al., 2009). The following studies have discussed implementing hybrid energy systems for power generation (Bayat et al., 2018; Ceran, 2019;. Several studies have been carried out on energy sources for telecommunications base stations (Chuang et al., 2019). This paper attempts to expand the body of knowledge to assess the potential of replacing diesel-generated electricity with wind energy, which is renewable energy. However, it is noted that there is very little information available in the literature on how life cycle cost analysis is carried out and the payback period of a wind energy system is determined for a remote telecommunications base station in Malaysia. In this study, life cycle cost analysis is carried out, and the payback period of a wind energy system is determined for a remote telecommunications base station in Malaysia.

Material and Method

Survey Data

Site selection and wind speed data

The site selected for this study is Mersing, Malaysia (2.43°N, 103.83°E), with an elevation of 12 m (Wikipedia, 2023; Liang, 2002). Based on the wind speed data obtained from the Mersing Meteorological Station, the annual wind speed is typically low, and there are seasonal variations in the wind speed. The annual wind speed is less than 3.1 m/s at a height of 10 m; therefore, this site can be classified as "Wind Power Class 1". The wind power class indicates that the local wind speed is very low compared with the annual wind speeds of more than 5 m/s recommended for wind turbines in the United States of America and Europe. Table 1 shows the wind speed data obtained from the Mersing Meteorological Station, Malaysia. Mersing is selected for this study because the Mersing Meteorological Station has been established since 1900, and therefore, the wind speed data can be obtained easily. In addition, the load and energy consumption data are readily available for analysis.

Table 1. Wind speed data in Mersing, Malaysia

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Velocity range (m/s)	**Duration, *t* (h)**	**Percentage of occurrences (%)**	**Mean velocity, *U* (m/s)**	**Energy per unit area = $0.5\varrho U^3 t$ (Wh/m²)**	**Percentage of annual energy (%)**
< 1.0	493	5.6	0.5	38	0.0
1.0–1.9	1568	17.9	1.5	2930	0.6
2.0–2.9	2101	24.0	2.5	18940	3.7
3.0– 3.9	1661	19.0	3.5	41811	8.1
4.0– 4.9	626	7.1	4.5	33815	6.5
5.0– 5.9	858	9.8	5.5	85141	16.5
6.0– 6.9	715	8.2	6.5	117610	22.7
7.0– 7.9	447	5.1	7.5	113302	21.9
8.0– 8.9	189	2.2	8.5	69902	13.5
9.0–9.9	65	0.7	9.5	33626	6.5
> 10.0	37	0.4	—	—	0.0
Sum	8760	—	—	517115	—

Annual wind power density = 517,115 / (365×24) = 59.0 W/m²
Note: Wind density, ϱ = 1.226 kg/m³; Height measured from ground level, h = 13.4 m.

Energy system for remote telecommunications base station

The energy for telecommunications base stations is usually supplied from the electricity grid. However, such is not the case in remote areas because these areas are located far from the electricity grid. Hence, there is a critical need for renewable energy systems for power generation in these areas. This study chooses a hybrid energy system for the remote telecommunications base station, where wind and diesel are used as the energy sources. The suitable combinations of hybrid energy system components for different telecommunications base stations are presented in Table 2 (Nema et al., 2009; Santos and González, 2019). Wind energy analysis gives significant information to those involved in renewable energy studies (Santos and González, 2019). The wind speed distribution is one of the wind characteristics that are of great importance not only for structural and environmental design and analysis but also for assessing the wind energy potential and performance of the wind energy conversion system (Jung and Schindler, 2018).

Table 2. Hybrid energy system components for different types of telecommunications base station

Type of telecommunications base station	**Site power required**	**Suitable combination of hybrid energy system components**
GSM BS 2/2/2	0.6–1.8 W	5-kW solar photovoltaic module + 8.1-kW BWC-Excel wind turbine
GSM BS 4/4/4	0.9–2.3 kW	2-kW solar photovoltaic module + 7.5(2)-kW BWC-Excel wind turbine
UMTS Node B Macro/Fiber 4/4/4	1.3–1.7 kW	4-kW solar photovoltaic module + 4.2(2)-kW wind turbine
Large WiMax	1.3–1.6 kW	5-kW solar photovoltaic module + 7.5-kW BWC-Excel wind turbine

Major components and costs of the wind turbine

A wind turbine is a rotating machine that converts the wind's kinetic energy into mechanical energy. There are two common types of wind turbines: (1) horizontal-axis wind turbines and (2) vertical-axis wind turbines. Figure 1 shows the major components of a wind turbine, such as nacelle, blades, generator, tower, and other auxiliary components. The costs of the wind turbine components are tabulated in Table 3. A small wind energy system is often defined as a system whose power production is less than or equal to 100 kW (Edwards et al., 2004; Figaj et al., 2020). The performance of a wind energy conversion system is dependent on the subsystems such as the wind turbine (aerodynamics system), gears (mechanical system), and generator (electrical system). It is worth noting that ~75% of the total cost of wind energy generated by the wind turbine is upfront costs, such as the costs of the wind turbine, foundation, electrical equipment, and grid connection. For this reason, wind turbine is capital-intensive compared with conventional fossil fuel-based technologies such as natural gas power plants (Bansal et al., 2002; Feng and Shen, 2017; Gjorgiev and Sansavini, 2017; European Wind Energy Association, 2009).

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Figure 2 shows the important parameters for techno-economic analysis of wind turbines such as depletion rate, project lifetime, and capital cost (including the costs of the wind turbines, foundations, and road construction) (European Wind Energy Association, 2009). The wind speed data, power consumption data, cost analysis, simple payback period, and other supporting data are also crucial for the techno-economic analysis of wind turbines. Table 4 shows the input data and capital cost of the wind turbine.

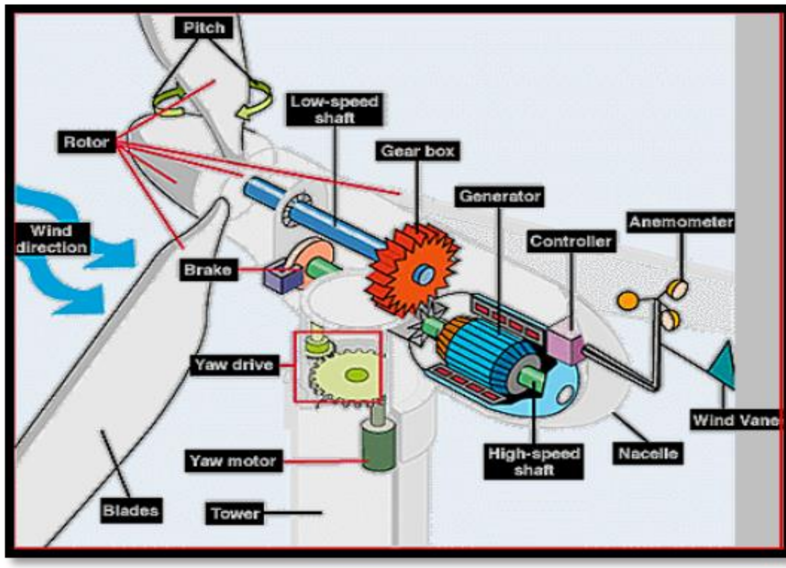

Figure 1. Major components of a wind turbine (Sterzinger and Svrcek, 2004)

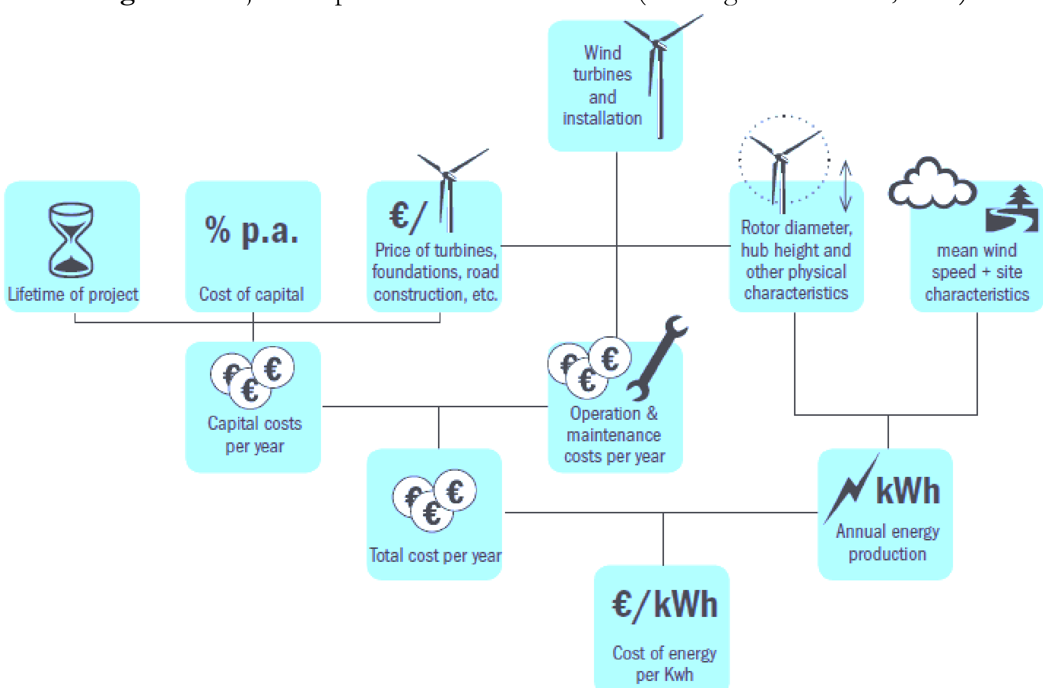

Figure 2. Cost of wind energy (European Wind Energy Association, 2009).

Table 3. Costs of the wind turbine components

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Component	**Component cost (%)**	**Major component cost (%)**
Rotor		28
• Blades (3)	16.6	
• Hub	7.2	
• Pitch mechanisms and bearings	4.0	
Drivetrain and nacelle		46
• Transmission system		
▪ Gearbox	13.4	
▪ Mainshaft	2.3	
▪ Mainshaft bearing and block	1.3	
▪ Elastomeric mounting system	0.3	
▪ Generator isolation mounts	0.1	
• Support structure	3.8	
• Generator cooling system	0.3	
• Brake system, hydraulics	0.6	
• Coupling	0.3	
• Nacelle cover	1.9	
• Generator	6.7	
• Variable-speed electronics	6.9	
• Transformer	2.5	
• Cable	2.0	
• Switchgear	1.4	
• Yaw drives and bearings	1.8	
• Control and safety system	0.8	
Tower	20.6	21
Foundation	5.4	5
Total	100	100

Table 4. Input data and capital cost of the wind turbine

Description	**Value**
Discount rate (%)	5
Capital cost of the wind turbine (MYR)	144,576.90
Lifetime of the wind turbine specified by the manufacturer (yr)	20
Energy loss during conversion of the wind turbine (%)	5
Electricity tariff in Malaysia (MYR/kWh)	0.28
Average annual operations and maintenance cost (MYR/yr)	4036.50

Methodology

Mobile remote telecommunications base station

Renewable energy systems, which were first developed to reduce the dependency on fossil fuels in some countries, have now become an international priority. A number of countries that have implemented renewable energy programs for many years are now replacing or modifying their existing programs with innovative technologies. Solar and wind energy are promising energy sources because they are replenishing, able, and sustainable. The wind energy industry is gearing towards huge wind turbines. Therefore, this study's challenge is searching for a cost-effective mobile remote telecommunications base station solution. The main advantage of a wind energy system is that it can support a remote telecommunications base station without a significant impact on cost. However, owing to the fluctuations in wind energy (considering that wind is unpredictable), it is essential to use a hybrid energy system with a diesel power generator as the backup power source during periods of very low wind speeds or in the absence of winds. A wind energy system requires additional space to build a building and tower to house the wind turbine. Figure 3 shows the concept of the hybrid wind energy-diesel system for the remote telecommunications base station, where the electricity generated from the wind energy system and

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diesel power generator is fed into the alternating current side of the network (Cîrstea et al., 2018; Dehghani-Sanij et al., 2022, Liao et al., 2022).

The diesel power generator is a backup to ensure continuous power supply for the remote telecommunications base station during low wind speeds or in the absence of winds. This minor modification is important for the proposed standalone energy supply, considering the availability of wind at the site. This study aims to calculate the cost-benefit of wind energy for a remote telecommunications base station in Malaysia. The cost-benefit analysis is described in detail in the following section.

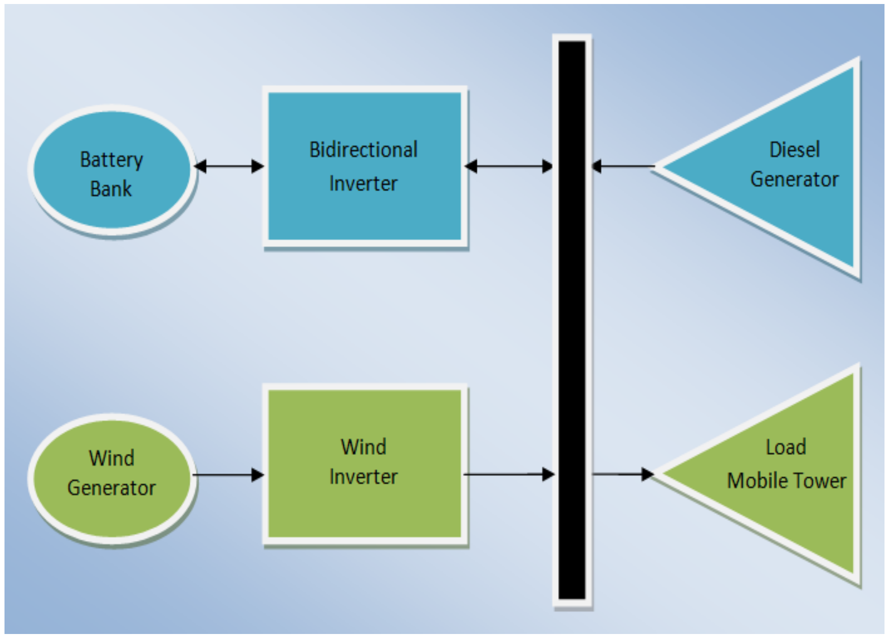

Figure 3. Conceptual diagram of the hybrid wind energy-diesel system for Malaysia's remote telecommunications base station.

Cost-benefit analysis

A cost-benefit analysis evaluates the potential of using wind energy to supply power for the remote telecommunications base station. The equations used for the cost-benefit analysis and payback period are presented in the following subsections.

Annual operating hour

The annual operating hour (*AOH*) of the wind turbine for power generation is the product of the number of days per year (*NOD*) and the number of operating hours of the turbine per day (*OH*), as follows:

$$AOH = NOD \times OH \tag{1}$$

Load factor

The load factor (*LF*) of the wind turbine is the average operating load (*AL*) divided by the peak operating load (*PL*) of the wind turbine, as follows:

$$LF = \frac{AL}{PL} \tag{2}$$

Total annual energy

The total annual energy (*TAE*) of the wind turbine is the product of its peak load (*PL*), annual operating hour (*AOH*), and load factor (*LF*), as follows:

$$TAE = PL \times AOH \times LF \tag{3}$$

Energy generated by the wind turbine

The energy generated by the wind turbine (*EGT*) is the total annual energy (*TAE*) of the wind turbine multiplied by the generator efficiency (η_{gen}), as follows:

$$GT = \eta_{gen} \times TAE \tag{4}$$

Base load energy

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The base load energy (*BLE*) of the wind turbine is the base load (*BL*) multiplied by the annual operating hour (*AOH*) of the wind turbine. Hence, the base load can be determined by rearranging the following equation:

$$BLE = BL \times AOH \quad (5)$$

Annual energy

The annual energy (*AE*) generated by the wind turbine is a product of the instantaneous power (*IP*) required, annual duration (*AD*) of wind at a particular wind speed, and wind probability (*WP*), as follows:

$$AE = IP \times AD \times WP \quad (6)$$

Capital recovery factor

The capital recovery factor (*CRF*) is the relationship between the actual discount rate and lifespan of the wind turbine, which is expressed as:

$$CRF = \frac{d \times (1 + d)^L}{(1 + d)^{L-1}} \quad (7)$$

Annuitized cost of the wind turbine

The annuitized cost of the wind turbine is a product of the capital recovery factor (*CRF*) and the capital cost of the wind turbine (*CCT*), as follows:

$$ACT = CRF \times CCT \quad (8)$$

Energy loss

It is assumed that there will be some losses during energy conversion for the wind turbine. Therefore, it is necessary to include the percentage of energy loss (*PEL*) in the calculation. Hence, the energy loss (*EL*) is the percentage of energy loss (*PEL*) multiplied by the total annual energy (*TAE*) generated by the wind turbine, as follows:

$$EL = PEL \times TAE \quad (9)$$

Net useful energy

The net helpful energy (*NUE*) is the energy generated by the wind turbine (*EGT*) multiplied by the energy loss (*EL*), as follows:

$$NUE = EGT \times EL \quad (10)$$

Capital cost

The capital cost (*CC*) is the annuitized cost of the wind turbine (*ACT*) divided by the net useful energy (*NUE*), as follows:

$$CC = \frac{ACT}{NUE} \quad (11)$$

Operations and maintenance cost

The operations and maintenance cost (*OMC*) per unit of electricity generated by the wind turbine is the maintenance cost (*MC*) divided by the energy generated by the wind turbine (*EGT*), as follows:

$$OMC = \frac{MC}{EGT} \quad (12)$$

Total specific cost

The total specific cost (TSC) of the wind turbine is the sum of its capital cost (*CC*) of the turbine and operations and maintenance cost (*OMC*), as follows:

$$\mathrm{TSC} = \mathrm{CC} + \mathrm{OMC} \quad (13)$$

Energy is replaced by wind energy annually.

The energy replaced by wind energy annually (*ERW*) is the power generated by the wind turbine annually. This parameter varies on a case-by-case basis. In this study, the energy replaced by wind energy annually is the net useful energy (*NUE*) generated by the wind turbine:

$$ERW = NUE \quad (14)$$

Cost of supplying wind energy

The cost of supplying wind energy (*CSW*) is the product of the net useful energy (*NUE*) and operations and maintenance cost (*OMC*), which is expressed as:

$$CSW = NUE \times OMC \quad (15)$$

Cost of supplying wind energy as replacement for fossil fuel energy

The cost of supplying wind energy as a replacement for fossil fuel energy (*CRE*) is the product of the energy replaced by wind energy annually (*ERW*) and electricity tariff (*ET*), as follows:

$$CRE = ERW \times ET \tag{16}$$

It shall be noted that *ET* is the tariff for electricity generated from fossil fuels.

Potential savings obtained from using wind energy

The potential savings obtained from using wind energy (*SBW*) is the cost of supplying wind energy as a replacement for fossil fuel energy (*CRE*) minus the cost of supplying wind energy (*CSW*), as follows:

$$SBW = CRE - CSW \tag{17}$$

Net savings, including depreciation

The net savings, including depreciation (*NSD*), the functional savings obtained from using the wind turbine (*SBW*) minus the annuitized cost of the wind turbine (*ACT*), as follows:

$$NSD = SBW - ACT \tag{18}$$

Net present value

The net present value (*NPV*) is the ratio of the net savings, including depreciation (*NSD*), to the capital recovery factor (*CRF*), as follows:

$$NPV = \frac{NSD}{CRF} \tag{19}$$

Present worth factor

The present worth factor (*PWF*) is the value to be received in the future cash flow to obtain the current present value. The present worth factor is given by:

$$\mathrm{PWF} = \sum_{t=1}^{N} \frac{1}{(1+d)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+\mathrm{d})^N}\right] \tag{20}$$

Life cycle cost

Life cycle cost analysis is used to calculate the cost of a system or product over its entire lifetime. In this study, life cycle cost analysis is used to determine the cost of the wind turbine over its lifetime. The life cycle cost (*LCC*) is the sum of the investment cost and the annual operations and maintenance cost discounted over the lifetime of the wind turbine, as follows:

$$LCC = CCT + \sum_{t=1}^{N} \frac{\mathrm{O\&M}_t}{(1-d)^t} \tag{21}$$

If the operating expenses of the wind turbine are assumed to be constant over time, the *LCC* of the wind turbine can be simplified as:

$$\mathrm{LCC} = \mathrm{CCT} + (\mathrm{PWF} \times \mathrm{OMC}) \tag{22}$$

Simple payback period

The simple payback period (*PP*) of using the wind turbine is the capital cost of the wind turbine (*CCT*) divided by the potential savings obtained from using the wind turbine (*SBW*), as follows:

$$PP = \frac{CCT}{SBW} \tag{23}$$

Discounted payback period

The discounted payback period (*DPP*) of using the wind turbine is a function of the capital cost of the wind turbine, which is given by the following equation:

$$SBW = \frac{CC \times d \times (1+d)^{DPP}}{(1+d)^{DPP} - 1} \tag{24}$$

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Results

Load and annual energy consumption

In this study, the peak load is 15 kW, the daily base load recorded is 5 kW, and the average load is 7 kW. Hence, the load factor, which is the ratio of the average load to the peak load, is 0.47. Following this, the total annual energy, which is the product of the peak load, annual operating hour, and load factor, is calculated by assuming the annual load factor is equal to the daily base load (Malik and Al-Badi, 2009, Ragheb, 2015, Ragheb, 2017). The load consumption in Mersing is tabulated in Table 5.

Table 5. Load consumption in Mersing, Malaysia

Peak load (kW)	Base load (kW)	Annual operating hour (h)	Load factor	Total annual energy (kWh)	Base load energy (kWh)
15	5	8760	0.47	61758	43800

Selection of the wind turbine

Once the load characteristics in Mersing are determined, the types of wind turbines currently available are compared. It is found that 12-kW wind turbines are suitable for comparison because the specifications of these turbines reasonably match the daily base load and average load in Mersing. Based on the data presented in Table 2, the 12-kW wind turbine is chosen for the analysis because this wind turbine can provide sufficient power for the remote telecommunications base station. The wind turbine model chosen in this study is WePOWER Falcon 12-kW.

Table 6 shows the annual output power generated by the 12-kW wind turbine. The wind probability is calculated based on the average wind speed recorded at the site. The wind speed and the instantaneous power generated by the wind turbine are presented in the first and second columns of Table 6, respectively. As stated in the Annual Energy section, the annual energy is the product of the instantaneous power, annual duration of wind at a particular wind speed, and wind probability. The net average of the annual output power generated by the wind turbine is obtained by summing the annual energy values for all wind speeds.

Table 6. Annual output power generated by the 12-kW wind turbine

Wind speed (m/s)	Instantaneous power (kW)	Annual duration (h)	Wind probability	Annual energy (kWh)
0.0	0.0	493	5.6	0.0
1.1	0.0	1568	17.9	0.0
2.2	0.0	2101	24.0	0.0
3.3	0.8	1661	19.0	25657.5
4.4	1.1	626	7.1	4724.6
5.6	1.4	858	9.8	11771.8
6.7	1.9	715	8.2	10846.6
7.8	2.5	447	5.1	5585.3
8.9	4.0	189	2.2	1663.2
10.0	5.6	65	0.7	252.5
11.1	8.0	12	0.4	38.4
12.2	11.8	0	0.0	0.0
13.3	12.0	0	0.0	0.0
				60,539.8

Figure 4 shows the performance of the WePOWER Falcon 12-kW wind turbine in Mersing, Malaysia, regarding the instantaneous power versus the wind speed. It can be observed that if the wind speed is less than the cut-off speed of the wind turbine (2.7 m/s), the wind turbine will not generate any power.

In Figure 4, the maximum wind speed (12.5 m/s) which wind speed varies from 2 m/s to 14 m/s. So, the WePOWER Falcon 12-kW wind turbine is more prospective with respect to Malaysia, and each point of this curve shows the number of powers the corresponding velocity occurs. From this Figure, it can be easily visualized which site is the best and the most promising; all wind duration curves for the selected sites are given in the Figure. Wind distribution can give a more realistic analysis to determine the characteristics of wind speed

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and the potential of power to generate the wind turbine. This analysis found that WePOWER Falcon 12-kW is a more potential turbine for wind energy applications. The analysis has been done by methods such as power wind and least square methods to find the more efficient method. A summary of the results is presented in Table 7.

Cost-benefit analysis of the wind turbine

Based on the equations presented in the section of Methodology, the annual power generated by the 12-kW wind turbine is determined to be 60,539.8 kWh. The results of the cost-benefit analysis of the 12-kW wind turbine are summarized in Table 8. The total specific cost is MYR 0.27 per kWh of power generated by the wind turbine, whereas the life cycle cost is MYR 1,150,650. Based on the cost-benefit analysis, it can be deduced that the total specific cost is reasonable for the 12-kW wind turbine. The results of the cost-benefit analysis are summarized in Table 9. Based on the results, the wind turbine is economically viable for the remote telecommunications base station even though it is slightly higher in capital cost.

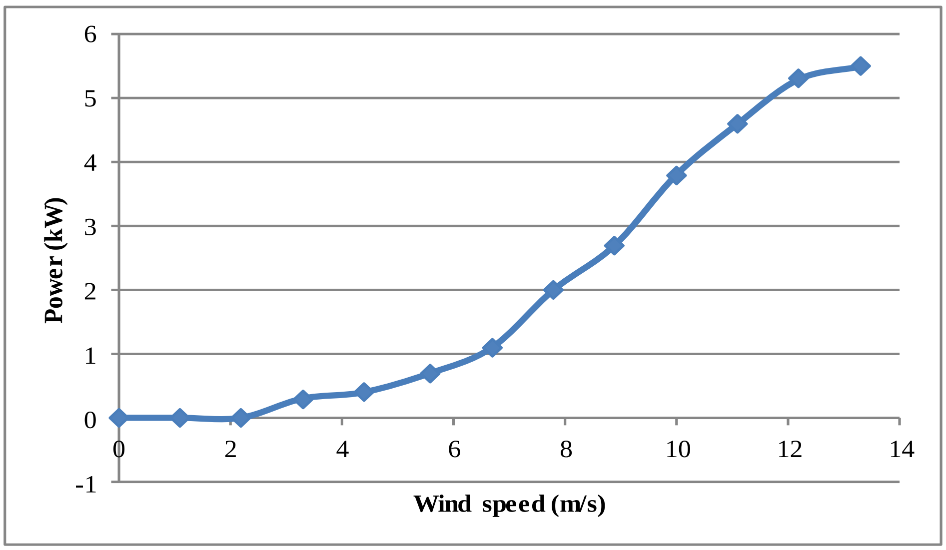

Figure 4. Performance of the WePOWER Falcon 12-kW wind turbine in Mersing, Malaysia

Table 7. Cost of the 12-kW wind turbine

Description	Value
Lifetime of the wind turbine (yr)	20
Discount rate (%)	0.05
Capital recovery factor (%)	0.08
Annuitized cost of the wind turbine (MYR)	11,601.22
Energy generated by the wind turbine (kWh)	60,539.78
Energy loss based on an assumption of 5% (kWh)	30,26.99
Net useful energy (kWh)	57,512.79
Capital cost per kWh (MYR/kWh)	0.20
Annual operations and maintenance cost (MYR/kWh)	0.07
Total specific cost (MYR/kWh)	0.27
Life cycle cost (MYR)	1,150,650

Note: MYR represents Malaysian Ringgit. The values presented for the capital cost per kWh and the total specific cost are those after 20 years.

Table 8. Summary of the statistical analysis of power wind

Method	Data										Analysis of variance
Power wind	0.3	0.4	0.7	1.1	2.0	2.7	3.8	4.6	5.3	5.5	0.9993
Least square	0.5	0.6	0.9	1.3	2.2	2.9	4.0	4.8	5.5	5.7	0.9995

Table 9. Cost-benefit analysis of the 12-kW wind turbine

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Description	Value
Total annual energy (kWh)	61,758.00
Energy replaced by wind energy annually (kWh)	57,512.79
Cost of supplying wind energy (MYR)	3,834.68
Cost of supplying wind energy as replacement of wind energy (MYR)	16,103.58
Potential savings obtained from wind energy (MYR)	12,268.91
Net savings including depreciation (MYR)	667.68
Net present value (MYR)	8,320.78

Note: MYR represents Malaysian ringgit.

Payback period

The simple payback period and discounted payback period of using the 12-kW wind turbine are presented in Table 10. The simple payback period and the discounted payback period are determined to be 11.8 and 18.2 yr, respectively. Thus, the discounted payback period for this wind turbine is approximately 18 yr. Ozoemena et al. (Ozoemena et al., 2018) designed wind turbine for 1.5 MW and it can be seen that the payback time for design variation permanent magnet generators instead of copper wound rotors is 2.8 years and new tower concept using carbon fibre and power production is 6.1 years with the longest payback time.

Table 10. Results of the wind energy analysis

Description	Value
Simple payback period (yr)	11.8
Discounted payback period (yr)	18.2

Discussion

Based on the results obtained in this study, it can be concluded that wind power can be used as the main source of power for a remote telecommunications base station in Malaysia. However, a hybrid wind energy-diesel system is desirable for the remote telecommunications base station because the diesel power generator is needed as backup during periods of low wind speeds or in the absence of winds. The 12-kW wind turbine is economically viable for the remote telecommunications base station based on the load characteristics in Mersing, Malaysia. Nonetheless, in terms of the simple payback period, the 12-kW wind turbine is not economically viable because the simple payback period is higher than 1/3 of the wind turbine lifetime, which is 20 years. Moreover, Haapala and Prempeeda (Haapala and Prempreeda, 2014) reported that energy payback time would be 0.43 years and 0.53 years for 2.0 MW wind turbine model 1 and model 2, respectively, which compares with studies of other multi-megawatt turbines of 0.58 to 0.65 years (Guezuraga et al., 2012, Alsaleh and Sattler, 2019). This indicates that the WePOWER Falcon 12-kW has powerful for wind turbine as the better option when considering life cycle energy use. However, further studies on limiting factors and methods of overcoming them are necessary before remote telecommunications base station can be implemented in Malaysia area.

Conclusion

Based on the discussion, it can be concluded that the life cycle cost analysis and the payback period for a 12-kW wind turbine are 1,150,650 MYR and 11.8 years, respectively. In addition, the discounted payback period, which was determined to be 18.2 years. However, the 12-kW wind turbine is viable to be used for the remote telecommunications base station. Because electricity is unavailable in remote areas, the hybrid wind energy-diesel system is significantly cheaper than developing the necessary infrastructure for electricity distribution in remote areas in Malaysia.

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References

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Alsaleh, A. and Sattler, M. 2019. Comprehensive life cycle assessment of large wind turbines in the US. Clean Technologies and Environmental Policy, 21**,** 887-903.

Bansal, R. C., Bhatti, T. S. and Kothari, D. P. 2002. On some of the design aspects of wind energy conversion systems. Energ Convers Manage, 43**,** 2175-2187.

Barma, M. C., Saidur, R., Rahman, S. M. A., Allouhi, A., Akash, B. A. and Sait, S. M. 2017. A review on boilers energy use, energy savings, and emissions reductions. Renewable and Sustainable Energy Reviews, 79**,** 970-983.

Bayat, P., Baghramian, A. and Bayat, P. 2018. Implementation of hybrid electric vehicle energy management system for two input power sources. Journal of Energy Storage, 17**,** 423-440.

Benito, A. and Alonso, G. 2018. 9 - Energy efficiency and the environment. In: BENITO, A. & ALONSO, G. (eds.) Energy Efficiency in Air Transportation. Butterworth-Heinemann.

Ceran, B. 2019. The concept of use of PV/WT/FC hybrid power generation system for smoothing the energy profile of the consumer. Energy, 167**,** 853-865.

Chhawchharia, S., Sahoo, S. K., Balamurugan, M., Sukchai, S. and Yanine, F. 2018. Investigation of wireless power transfer applications with a focus on renewable energy. Renewable and Sustainable Energy Reviews, 91**,** 888-902.

Chuang, M.-T., Chang, S.-Y., Hsiao, T.-C., Lu, Y.-R. and Yang, T.-Y. 2019. Analyzing major renewable energy sources and power stability in Taiwan by 2030. Energy Policy, 125**,** 293-306.

Cîrstea, Ş. D., Martiş, C. S., Cîrstea, A., Constantinescu-Dobra, A. and Fülöp, M. T. 2018. Current situation and future perspectives of the Romanian renewable energy. Energies, 11**,** 3289.

Daneshvar, M., Pesaran, M. and Mohammadi-Ivatloo, B. 2018. Transactive energy integration in future smart rural network electrification. Journal of Cleaner Production, 190**,** 645-654.

Dehghani-Sanij, A., Al-Haq, A., Bastian, J., Luehr, G., Nathwani, J., Dusseault, M. and Leonenko, Y. 2022. Assessment of current developments and future prospects of wind energy in Canada. Sustainable Energy Technologies and Assessments, 50**,** 101819.

Djørup, S., Thellufsen, J. Z. and Sorknæs, P. 2018. The electricity market in a renewable energy system. Energy, 162**,** 148-157.

Edwards, J. L., Wiser, R., Bolinger, M. and Forsyth, T. 2004. Evaluating state markets for residential wind systems: Results from an economic and policy analysis tool, http://repositories.cdlib.org/lbnl/LBNL-56344/, 2023.

Enslev, L., Mirsal, L. and Winthereik, B. R. 2018. Anticipatory infrastructural practices: The coming of electricity in rural Kenya. Energy Research & Social Science, 44**,** 130-137.

European Wind Energy Association, E. 2009. The Economics of Wind Energy, http://www.ewea.org/, 2023.

Feng, J. and Shen, W. Z. 2017. Design optimization of offshore wind farms with multiple types of wind turbines. Applied Energy, 205**,** 1283-1297.

Figaj, R., Żołądek, M. and Goryl, W. 2020. Dynamic simulation and energy economic analysis of a household hybrid ground-solar-wind system using TRNSYS software. Energies, 13**,** 3523.

Fleck, B. and Huot, M. 2009. Comparative life-cycle assessment of a small wind turbine for residential off-grid use. Renew Energ, 34**,** 2688-2696.

Gjorgiev, B. and Sansavini, G. 2017. Water-energy nexus: Impact on electrical energy conversion and mitigation by smart water resources management. Energy Conversion and Management, 148**,** 1114-1126.

Guezuraga, B., Zauner, R. and Pölz, W. 2012. Life cycle assessment of two different 2 MW class wind turbines. Renewable Energy, 37**,** 37-44.

Haapala, K. R. and Prempreeda, P. 2014. Comparative life cycle assessment of 2.0 MW wind turbines. International Journal of Sustainable Manufacturing, 3**,** 170-185.

Hajiaghasi, S., Salemnia, A. and Hamzeh, M. 2019. Hybrid energy storage system for microgrids applications: A review. Journal of Energy Storage, 21**,** 543-570.

Hemmati, R. 2017. Technical and economic analysis of home energy management system incorporating small-scale wind turbine and battery energy storage system. Journal of Cleaner Production, 159**,** 106-118.

Hossain, M. L., Abu-Siada, A. and Muyeen, S. M. 2018. Methods for Advanced Wind Turbine Condition Monitoring and Early Diagnosis: A Literature Review. Energies, 11**,** 1-14.

doi: 10.13170/aijst.12.2.33010

Jung, C. and Schindler, D. 2018. Sensitivity analysis of the system of wind speed distributions. Energy Conversion and Management, 177**,** 376-384.

Kabir, Z. and Khan, I. 2020. Environmental impact assessment of waste to energy projects in developing countries: General guidelines in the context of Bangladesh. Sustainable Energy Technologies and Assessments, 37**,** 100619.

Liang, C. K. 2002. Local meteorological data in Malaysia, http://www.windturbine-analysis.netfirms.com/about-localwind.htm, 2023.

Liao, D., Zhu, S.-P., Correia, J. A., Jesus, A. M., Veljkovic, M. and Berto, F. 2022. Fatigue reliability of wind turbines: historical perspectives, recent developments, and future prospects. Renewable Energy.

Malik, A. and Al-Badi, A. H. 2009. Economics of Wind turbine as an energy fuel saver - A case study for remote application in oman. Energy, 34**,** 1573-1578.

Nema, P., Nema, R. K. and Rangnekar, S. 2009. A current and future state of art development of hybrid energy system using wind and PV-solar: A review. Renew Sust Energ Rev, 13**,** 2096-2103.

Ozoemena, M., Cheung, W. M. and Hasan, R. 2018. Comparative LCA of technology improvement opportunities for a 1.5-MW wind turbine in the context of an onshore wind farm. Clean Technologies and Environmental Policy, 20**,** 173-190.

Pryor, S. C. and Barthelmie, R. J. 2010. Climate change impacts on wind energy: A review. Renew Sust Energ Rev, 14**,** 430-437.

Ragheb, M. 2015. Economics of wind energy. Wind Power Systems, Course NPRE, 475.

Ragheb, M. 2017. Economics of wind power generation. Wind Energy Engineering. Elsevier.

Santos, M. and González, M. 2019. Factors that influence the performance of wind farms. Renewable Energy, 135**,** 643-651.

Shayesteh, E., Yu, J. and Hilber, P. 2018. Maintenance optimization of power systems with renewable energy sources integrated. Energy, 149**,** 577-586.

Sterzinger, G. and Svrcek, M. 2004. Wind Turbine Development: Location of Manufacturing Activity. Renewable Energy Policy Project.

Terrapon-Pfaff, J., Dienst, C., König, J. and Ortiz, W. 2014. A cross-sectional review: Impacts and sustainability of small-scale renewable energy projects in developing countries. Renewable and Sustainable Energy Reviews, 40**,** 1-10.

Ünlü, M., Özkale, C., Çelik, C. and Saraç, H. İ. 2018. Optimal energy production from wind and hydroelectric power plants AU - Opan, Mücahit. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects**,** 1-14.

Varela-Vázquez, P., Sánchez-Carreira, M. D. C. and Rodil-Marzábal, Ó. 2019. A novel systemic approach for analysing offshore wind energy implementation. Journal of Cleaner Production, 212**,** 1310-1318.

Wikipedia 2023. Mersing's longitude-latitude In: WIKIPEDIA (ed.) The Free Encyclopedia.