Article

Techno-Economic Analysis of a Wind-Energy-Based Charging Station for Electric Vehicles in High-Rise Buildings in Malaysia

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Abstract: Renewable energy sources have become necessary for long-term energy sustainability due to the increased demand for electric cars and worrisome rises in carbon dioxide emissions from traditional energy sources. Furthermore, transportation is one of the sectors that uses the most energy on the planet, accounting for 24% of overall consumption. Fossil fuels are still the dominant energy source for balancing global demand/supply dynamics. Supporting laws and regulations have enhanced the first phase of environmentally friendly energy-resource consumption. This has spurred the development of new solutions that cut greenhouse-gas emissions and reduce the air pollution produced by internal combustion engines that are fuelled by fossil fuels. Wind energy is one of the clean energy sources that may be utilised for this purpose. Wind energy has been used to power electric-car-charging infrastructure, generally in a hybrid mode with another renewable source. This research examines the possibility of using wind energy as a standalone energy source to support electric-vehicle-charging infrastructure. Using data from Malacca, Malaysia, and HOMER software, the project will build and optimise a standalone wind-powered charging station. An RC-5K-A wind turbine coupled to a battery and converter is the appropriate choice for the system. The findings demonstrate that the turbine can produce 214,272 kWh per year at the cost of USD 0.081/kWh, confirming wind's future feasibility as an energy-infrastructure support source.

Keywords: charging station; electric vehicles; high-rise buildings; small-scale turbines; techno-financial evaluation; wind energy

1. Introduction

Climate change and global warming are two of the most pressing issues of our day. As a result, the average atmospheric temperature is increasing. If this trend continues, the planet's potential to sustain life will be lost in the future. The primary causes of such consequences are anthropogenic actions undertaken by humans [1]. As seen in Figure 1, Malaysia's energy and electricity sectors account for 60% of the country's greenhouse-gas emissions [2,3]. The usage of traditional energy resources to charge EVs has serious environmental repercussions [4]. Severe concerns are being expressed in the present in regard to the rise in sea levels, the increases in the global air temperature, and the melting of the Arctic and Antarctic ice sheets; thus, many researchers have investigated wind energy in Malaysia [5,6].
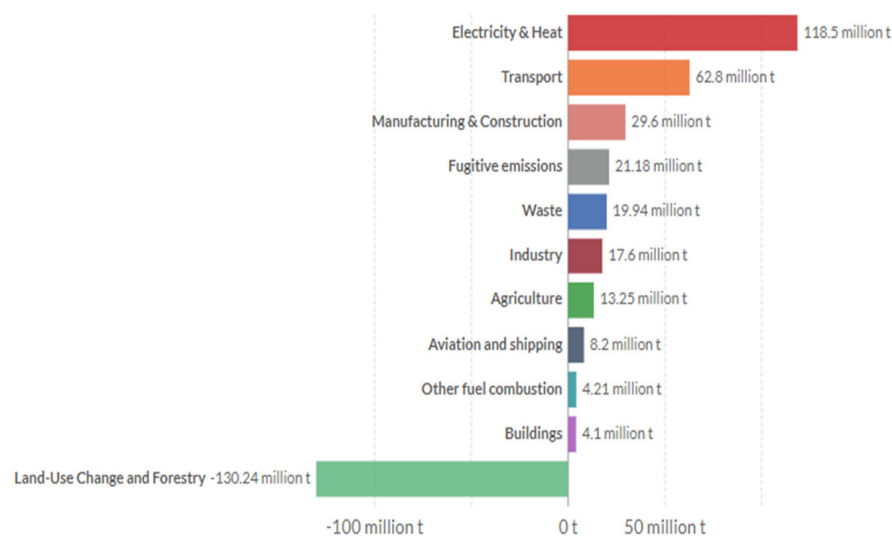
Figure 1. Greenhouse-gas emission by sector in Malaysia in 2016 [2].

Malaysia is currently looking for another alternative resource for generating electricity after having been dependent on coal and fuel. Coal and fuel are non-renewable resources, and their prices are rising in the global market due to supply shortages and political issues [7]. Malaysia has taken steps to explore renewable energy resources as alternatives for generating electricity. Wind energy is the fastest-growing energy technology in the world, and it is considered to be one resource that meets the needs of modern societies in reducing their dependence on coal and diesel, whilst simultaneously delivering a substantial reduction in greenhouse-gas emissions [8].

Malaysia is in a low-wind region compared to other countries. Monthly mean wind speeds range between 1.5 and 4.5 m per second [9–11]. Despite that, the first wind farm in Malaysia, which was set up on Pulau Terumbu, Layang-Layang, Sabah, has demonstrated that wind energy is applicable only in certain locations in Malaysia, mainly in coastal areas (e.g., Kudat, Mersing, Langkawi, and Terengganu), with an average wind speed of 4–7 m/s. In most of the coastal cities in Malaysia, good wind speeds for small-scale turbines have been observed, but only at high elevations (60–90 m) [12].

Large-scale wind farms are not a feasible solution for renewable energy in Malaysia due to the low wind speeds in the country [13]. The ideal approach to utilizing wind energy in Malaysia is to implement small-scale wind turbines (WT) that provide around 3–10 kW of electricity [12]. According to [14], the power needed to charge 3 EVs overnight is estimated to be 9.6 kW to reach an 80% state of charge [15]. Thus, the main aim of this paper is to investigate the feasibility of using a hybrid system consisting of a small-scale WT with a battery storage bank at a high elevation to power an electric-vehicle charging station in Malacca, Malaysia. The contribution of this study is a case study of small-scale wind-energy generators at high elevations, which have not been sufficiently analysed in Malaysia. Moreover, the study investigates the feasibility of EV charging based on small-scale wind turbines. Researchers, investors, and policymakers in regions with low wind speeds can benefit from this study's findings.

This paper is organized as follows: Section 2 discusses wind energy and wind speeds in Malacca. Section 3 provides a description of the system configuration used in this study. Section 4 discusses the energy consumption of the proposed charging station. Section 5 discusses the assessment criteria and parameters used in the evaluation process. Section 6 provides details about the system design using HOMER software, followed by results and a discussion in Section 7.

2. Wind Energy in Malacca

2.1. Site

Malacca is a state with a total size of 1664 square kilometres (642 sq. mi). It is located on the Malay Peninsula's southwestern coast, opposite Sumatra, with the states of Negeri Sembilan and Johor to the north and west, and Johor to the east. Malacca is located approximately two-thirds down the west coast, 148 km (92 miles) south of Kuala Lumpur, and it commands a pivotal position on the Malacca Straits. Except for a few tiny hills [16,17], Malacca is predominantly a lowland area with an average elevation of less than 50 m above sea level. From north to south, the Malacca River closely follows the state's central line. The Kesang River serves as Malacca's eastern boundary with Johor. The wind farm is located in Malacca City (the capital of the state), which is situated at 2.2985° N 102.2835° E. The site elevation is 100 m above the ground [16,17].

2.2. Wind Speed Data Set

In this study, for a period of 1 year from 1 January 2020 to 31 December 2020, we gathered average hourly data, including wind speed and direction, relative humidity, temperature, and atmospheric pressure, from the Malaysian Meteorological Department (MMD) at Malacca International Airport. The data were collected at an altitude of 10 m and were constantly monitored for an average of 1 h before being uploaded to an electronic data-gathering system. The graph below illustrates the average wind speed at Malacca International Airport's 10-metre hub-height. The average wind speed in Malacca at an altitude of 10 m is shown in Figure 2.
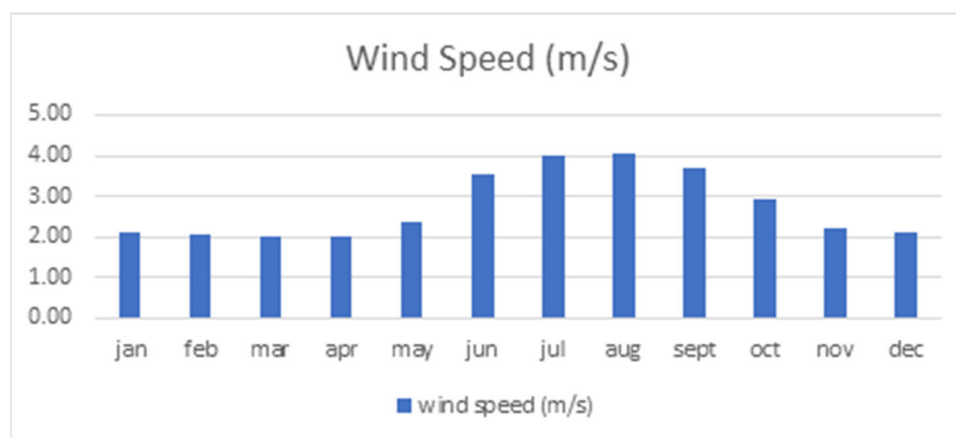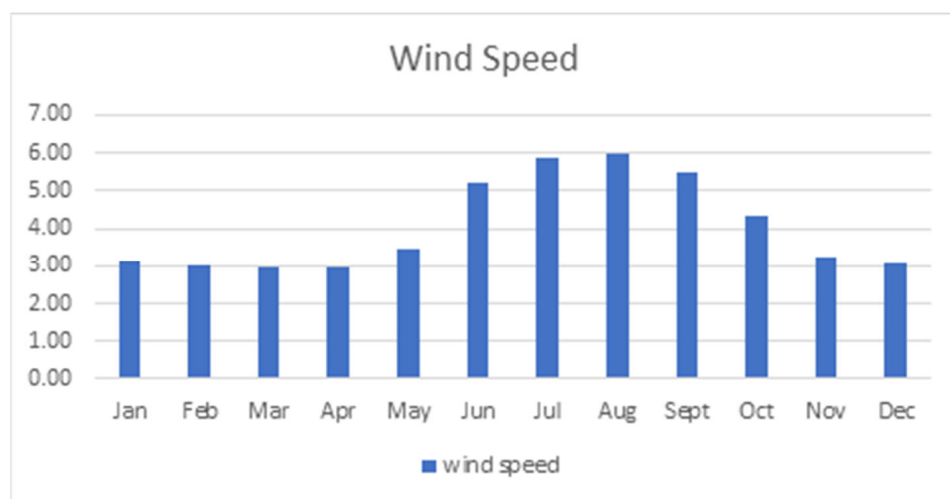

Figure 2. Wind speed at an altitude of 10 m.

Because the wind speed was provided by Malacca International Airport at an altitude of 10 m, the data were converted to that of the desired height using the power law. Equation (1) represents the wind speed data in terms of the turbine hub-height [2]:

$$v_2 = v_1 \left(\frac{h_2}{h_1} \right)^{\alpha},$$

(1)

where v_2 denotes the wind speed at h_2, v_1 is the reference wind speed at h_1, and α is the power law exponent. The exponent is a highly changeable number in practice. The number ranges from less than 0.10 for territories devoid of impediments, such as water or ice, to more than 0.25 for tropical or densely wooded areas [18]; the usual value for places devoid of obstacles would be 0.143. As a result, the value was set at 0.143 in this study [19]. The data were transformed to an elevation of 100 m since that is the height of the intended building where we plan to implement the WT. The transformed wind speed at a 100 m hub-height is shown in Figure 3, along with the original data for reference, using the power law described above [20].

Figure 3. Wind speed at an altitude of 100 m.

3. System Description and Specifications

3.1. Selection of Wind Turbine

Due to the low wind speed, as shown in Figure 2 above, RC-5K-A, a 5 kW WT, was selected for the study. This WT is an up-wind, horizontal-axis, three-bladed turbine. The hub of this WT is located at a height of 20 m and is estimated to serve for 20 years [21]. The initial cost of one WT is estimated to be USD 2000, and the replacement cost is USD 1500, with annual operation and maintenance costs of USD 200 [22]. Table 1 summarizes all of the technical parameters for the selected WT.

Table 1. Technical parameters for the RC-5K-A turbine.

Parameter	Value
Rated power	5 KW
Cut-in wind speed	2.01 m/s
Rated wind speed	4 m/s
Cut-off wind speed	10 m/s
Capital cost	USD 2000
Replacement cost	USD 1500
Operation and maintenance costs	USD 200
Lifetime	20 years

3.2. Storage Battery

The battery bank used in this hybrid system is the NEC DSS 510 kWh, with one battery per string. The chosen battery has a 510 kWh capacity with a nominal bus voltage of 720 V. HOMER assumes that the properties of the battery remain constant throughout the battery's lifetime and are not affected by external factors, such as temperature. The estimated lifetime of this specific battery is around 5000 charging cycles [23]. The cost of a single battery is USD 3000, and the replacement cost is USD 2500, with operation and maintenance costs of USD 300.

4. Charging-Station Energy Consumption

The electric load profile is the primary determinant in the design and optimisation of an integrated hybrid energy system. Thus, it is critical to understand how load varies from weekdays to weekends and from season to season in order to design a hybrid system that maximises resource use while maintaining a low system cost [24].

Charging infrastructures are determined by the relationships between driving requirements, charging equipment utilisation, EV stock, and technological capabilities. Population density, driving ranges, and charging habits are all distinct characteristics that have a direct

impact on the placement of EV-supply equipment and charging rates for electric, low-duty cars. Table 2 compares two charging modes, slow and fast charging, to determine the charging rate of an electric vehicle [25].

Table 2. Different type of charging outlets and their power ratings.

	Connector Type	Typical Power Ratings (kW)	Range of Charging per Hour (Miles)
AC	Type 1	3.7 7	12.5 25
	Type 2	3.7 7 22	12.5 25 75
DC	CHAdeMO	50 100	75 150
	Combined Charging System (CCS)	50 150 350	75 225 525
	Type 2	150 250	225 375

Considering all of the previous information, and assuming that a slow port would charge 6 cars from 0% to 50% daily, which is sufficient for daily usage for the average person (150 km range), each 1 of the 6 charging ports would be charging a car to 50% capacity in a duration of 9 h, starting at 10 pm and finishing at 6 am, as shown in Figure 4. No fast-charging port will be implemented due to the wind-speed constraints of Malaysia and small-scale WTs. In addition to that consideration, all of the cars have a 66 kWh battery (the standard battery for Tesla cars) [26]. The decision was to use as the most realistic demand estimation a daily consumption of 198 kWh for the slow ports, using a type 2 AC charger with a 7 kW charging rate, for implementation in this project. This brings the total capacity of the charging port to 42 kW and the energy consumption to a total of 198 kWh daily.
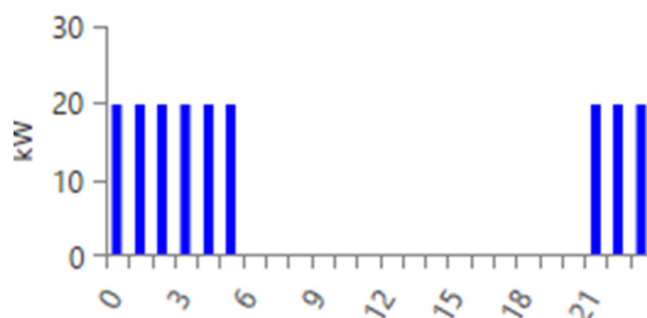
Figure 4. Daily load profile.

5. Economic Parameters and Assessment Criteria

Economic analysis is critical for recommending the appropriate component combination for the HRES. This objective will be accomplished through the use of the HOMER programme. The following are some economic aspects that must be considered when constructing the system [27].

5.1. Discount Rate

The discount rate is used to count future cash flows. It is applied because money gained in the future is less valuable than money acquired in the present. Money should earn more money over time, a concept referred to as the "time value of money". Bank Negara

Malaysia is the official department that sets the value of the discount rate in Malaysia. The discount rate applied in this study is 6.75%, as indicated by BNM for the year 2021 [28].

5.2. Inflation Rate

Inflation is defined as an increase in the Consumer Price Index (CPI), which is a weighted average of different items' prices. Annual inflation refers to the percentage change in the CPI from the same month from the previous year. Malaysia's inflation rate for 2021 was 2%, and this is the rate that was used in this analysis [29].

5.3. Cost of Energy (COE)

The COE of an energy-generating asset may be defined as the average total cost of installation and maintenance per unit of total power generated over a predetermined lifespan. Alternatively, the COE may be regarded as the lowest average cost at which the electricity generated by the resource is projected to be sold. COE is specified in Equation (2) [30]:

$$COE = \frac{\text{Net present value of total cos t over lifetime}}{\text{Net present calue of electric energy produced over lifetime}}, \tag{2}$$

5.4. HOMER Software

HOMER is an acronym for Hybrid Optimization of Multiple Electric Renewables. It is a software application developed by the National Renewable Energy Laboratory (NREL) in the United States of America for the purpose of designing and evaluating off-grid and on-grid power systems for remote, standalone, and distributed generation applications [29].

HOMER software includes three distinct capabilities: simulation, optimization, and sensitivity analysis. The output replicates all possible component combinations based on various circumstances. In this study, the RES was developed around a WT, a battery band, and a load profile [31].

6. System Design

The designed system consists of a WT to generate power. Since the output of this WT is AC, it is fed directly to the load, the excess energy is then converted to DC through the converter, and then it is stored in the battery energy storage system (BESS) as backup energy. As shown in Figure 5, a converter is used to control the conversion between the AC and DC buses.
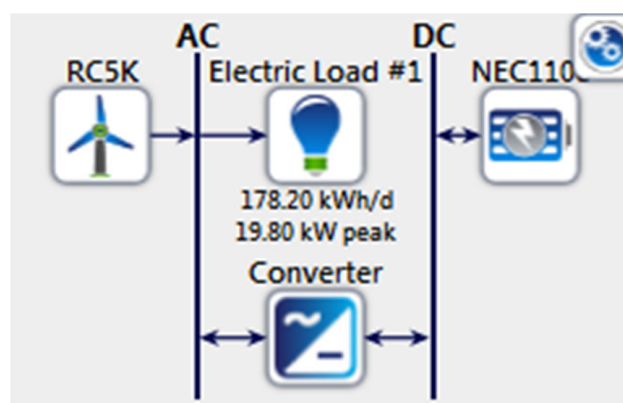
**Figure 5.** Schematic diagram for the system.

6.1. Wind Turbine

The chosen WT for the wind-farm design is the RC-5K-A with an AC bus. As shown in the figure below, two WTs are utilized in this project, with a rated capacity of 10 kW. As it is illustrated in Table 3, the capital cost of the WT is USD 2000, replacement cost is USD 1500, and the operating and maintenance cost is USD 200 (per year).

Table 3. Selected wind turbine specification.

Specification	Details
Name	RC-5K-A
Abbreviation	RC5K
Rated capacity	10 kW
Manufacturer	Generic
Quantity needed	2
Capital	USD 2000
Replacement	USD 1500
Operating and Maintenance	USD 200 (per year)

The WT power curve is shown in Figure 6, where the cut-in speed is 1.5 (m/s), the cut-out speed is 10 (m/s), and the peak output of the current turbine ranges from 4 (m/s) to 6.5 (m/s), with power output of 5 kW.
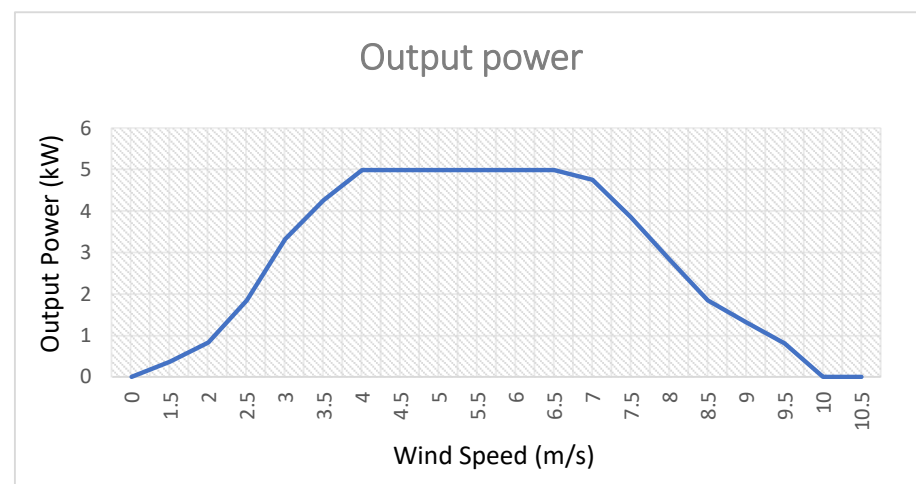
Figure 6. The RC-5K-A power curve.

6.2. Energy Storage System

The selected battery is used to store and release energy to the load. The output power of the WT will be stored in the battery. An NEC DSS 510 kWh 1108 kW battery is utilized in this system and has a nominal capacity of 510 kWh, which is sufficient to run the system alone for 3 days in case of a production failure. This battery has a capital cost of USD 3000, a replacement cost of USD 2500, and the operating and maintenance costs are USD 300 (per year), as shown in Table 4.

Table 4. Battery storage specifications.

Specification	Details
Name	NEC DSS 510 kWh
Nominal Voltage	720 v
Nominal Capacity	510 kWh
Nominal Capacity	708 Ah
Quantity needed	1
Capital	USD 3000
Replacement	USD 2500
Operating and Maintenance	USD 300 (per year)

6.3. System Converter

A converter is used to maintain the flow of energy between the AC and DC components. The converter connects the AC and DC buses, where the converter controls the conversion between AC and DC [32]. Besides that, the converter controls the system operation by choosing the best mode of operation at the most appropriate time without any power interruption [33]. Table 5 shows that the capital cost is USD 500, the replacement cost is USD 400, and the operating and maintenance costs are USD 50 (per year). Table 5 highlights the specifications for the converter used in this system

Table 5. Converter specifications.

Specification	Details
Name	System Converter
Capital	USD 500
Replacement	USD 400
Operations and Maintenance	USD 50 (per year)

7. Results and Discussion

This section includes a discussion of the HOMER optimization results as well as a technical and economic analysis of the standalone WT system. The optimization results from HOMER are highlighted in Table 6.

Table 6. Optimized system results based on the HOMER simulation.

Label	Value
RC5K	15
NEC DSS 510 kWh	1
Convertor (kW)	21.4
Dispatch	CC
COE (USD)	USD 0.081
NPC (USD)	USD 76,855
Operating cost (USD/year)	USD 3299
Initial capital (USD)	USD 28,717
Ren Frac (%)	100
Total Fuel (L/year)	0
Production (kWh/year)	214,272
Primary load kWh/year	650,117

The simulation results generated by HOMER show all of the possible configurations for the proposed system discussed above. The WT and battery system targeted in this project consist of 15 units of WTs, one string (720 V) of battery with a 510 kWh capacity, and a 21.4 kW converter. The total NPC is USD 76,855.33, with a cost of energy (COE) of USD 0.081/kWh, which is at the same level as the price of energy in Malaysia, as shown in Tables 6 and 7.

Table 7. RES system architecture.

Component	Name	Size	Unit
Storage	NEC DSS 510 kWh	1	strings
Wind turbine	RC-5K-A	15	each
System converter	System Converter	21.4	kW
Dispatch strategy	HOMER Cycle Charging		

The penetration of renewable energy for this system is 100% since it is a standalone system with no grid connection. The electricity production by the WT in Malacca is 214,272 kWh/year, as shown in Table 6, which is adequate for the proposed charging station. Since the WTs are dependent on wind speed, in the period between June and September, the electricity generation will be higher due to the high wind speeds during the monsoon season in Malaysia.

8. Conclusions

Annually, the average wind speed in Malacca is about 2.29 m/s at the 10-metre hub-height according to MMD data. Based on power law calculations, the wind power is about 3.373 m/s at the 100-metre hub-height. The current electricity tariff in Malaysia is about USD 0.087 per kWh; these are key parameters in determining the feasibility of a WT. Therefore, using this as a site-specific parameter, the feasibility study was undertaken using a software package, HOMER. The finding of this study is that the annual production of the wind-powered EV-charging station would be 214,272 kWh annually, which would be sufficient for the proposed load. The total installed capacity of renewable energy is 75 kW, comprising 15 units of a 5 kW WT. The total capital costs and COE of the project are USD 28,717 and USD 0.081/kWh, respectively.

In summary, the study established that the suggested, small-scale WT for an EV-charging station would be technically possible and economically viable as a source of renewable energy using 5 kW WTs under the condition of using it at a high elevation to compensate for the low wind speeds common to Malaysia.

The study's primary limitations are, first and foremost, the accuracy of the wind data. Unless and until real wind-speed measurements are taken at the suggested site, it is quite conceivable that the actual wind speed is different. The second limitation is that data on the turbine's price and power curve, which are required to determine yearly energy output, can only be acquired from the makers. As a result, there is a chance that they have overstated the values on their turbines' information sheets in order to facilitate the sale of their products.

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Abbreviations

HOMER	Hybrid Optimization of Multiple Electric Renewables
EV	Electric Vehicle
M	Metre

WT	Wind Turbine
kW	Kilowatt
Sq. mi.	Square Mile
MMD	Malaysian Meteorological Department
CPI	Consumer Price Index
COE	Cost of Energy
RES	Renewable Energy System
BESS	Battery Energy Storage System
AC	Alternating Current
DC	Direct Current
USD	United States Dollar
NPC	Net Present Cost
Ren Frac	Renewable Energy Fraction
BNM	Bank Negara Malaysia

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