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ASSESSMENT AND CHARACTERISATION OF RENEWABLE ENERGY RESOURCES: A CASE STUDY IN TERENGGANU, MALAYSIA

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Abstract: Accurate information on the renewable energy density at a given location is essential for the development of renewable energy-based projects. This information is used in the design of a project, in cost analysis, and in calculations on the efficiency of a project. As the renewable energy data are not available for most areas in Malaysia, this study is significant for establishing renewable energy data for Terengganu, Malaysia. The data used in the present study obtained from 2004 to 2008 were used to investigate the solar potentials, and also dataset from 2004 to 2007 were used to investigate the wind potentials and the dataset from 1998 to 2010 were used to investigate the wave potentials. MATLAB was used to process raw data to generate useful renewable energy characteristics. The average yearly cumulative irradiation for Terengganu was 6905.8 MJ/m^2 per year. The monthly average clearness index varied between 0.42 and 0.64. The average clearness index value was approximately 0.53. High wind speed was recorded during the northeast monsoon at an average of 3.9m/s. The potential wind power generated reached 84.55 W/m^2 with a probability time factor value of 0.68. Therefore, small wind machines could be used to provide power during northeast monsoon. The total wave energy density was found to be 17.69 MWh/m in an average year. It may be concluded that regions along the coast of Terengganu can consider northeast monsoon period for wave energy exploitation. Adoption of solar and wave technology in Terengganu will be very advantageous based on solar and wave power densities. The wind power density in Terengganu was seen to be less encouraging. Compared with wind power potential, solar and wave resources were seen to be well distributed more evenly throughout the year. This was seen as a favourable indication for erection of hybrid renewable energy systems in the study location.

KEYWORDS: wind energy, wave energy, solar energy, hybrid energy system

Introduction

Renewable energy is being seriously considered for satisfying a significant part of energy demand in Malaysia and globally. Further, with the increase in energy demand, the issue of energy shortage becomes critical. Since there is more and more concern on energy conservation and environmental protection, interest has been increasingly focused on the use of renewable energy. Renewable energy, as a clean energy source, is abundant in Malaysia.

An accurate knowledge of the renewable energy data at a particular geographical location is of vital importance for the development of renewable energy devices and their performance estimations (Abdul Majeed Muzathik *et al*., 2010). The average values of the hourly, daily and monthly global irradiations on a horizontal surface are needed in many applications of solar energy designs (Kamaruzzaman and Othman, 1992; Li. and Lam, 2000; Wong and Chow, 2001; Kumar and Umanand, 2005). The clearness indexes of the area, in addition to other meteorological information such as wind speed and air temperature for a specific period, are also important to assess the feasibility of a solar-driven project. Malaysia is one of the countries which has abundant solar energy. The annual average daily solar irradiations for Malaysia have a magnitude of 4.21–5.56 kWhm^{-2}, and the sunshine duration is more than 2200 hours per year (Abdul Majeed Muzathik *et al*., 2010).

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Wind is the fastest growing energy source in the world today. Over the past decade, annual worldwide growth in installed wind capacity is near 30% (currently over 94,000 MW have been installed) (Boyle, 2004). However, the development of new wind projects continues to be hampered by the lack of reliable and accurate wind data in many parts of the world. Such data are needed to enable governments, private developers and others to determine the priority that should be given to wind energy utilisation and to identify potential areas that might be suitable for development (Boyle, 2004). The distribution of wind speeds is another important requirement for the design of wind farms, power generators and other applications such as irrigation.

Wind speed and direction, roughness of the terrain, seasonal cycles, air pressure or temperature and obstacles affect the amount of wind energy available at any site. A continuous record of wind data over a year cycle would be sufficient to realise its potential. Several studies have shown substantial results regarding the wind energy potential in Malaysia, where wind regimes have been identified in some areas, with energy potential estimates (Lee, 1993; Sopian *et al*., 1995; Ibrahim *et al*., 2009).

On the other hand, the ocean waves contain the highest energy density and this allows for substantial energy generation in relatively small areas from a virtually inexhaustible energy source. Ocean wave energy has the potential to become commercially viable quicker than other renewable technologies, achieving the fastest growth rate of all energy sources and generating significant wealth (Clement *et al*., 2002; Duckers, 2004). Wave energy presents a number of advantages with respect to other renewable energy sources such as high availability factor, compared with other resources, resource predictability, high power density, relatively high utilisation factor and low environmental and visual impact (Henfridsson *et al*., 2007). Ocean wave energy has not yet been exploited to any significant extent in Malaysia, or elsewhere in the world. From a global perspective, it is seen that the highest energy ocean waves are concentrated off the western coasts in the 40°–60° latitude ranging from North to South. Waves are bigger and more powerful along the western part of the Earth because of the prevailing west-to-east winds. The annual average power density in the wave fronts varies in these areas between 30 and 70 kW/m, with peaks up to 100 kW/m in southwest of Ireland, in the Southern Ocean (Wan *et al*., 2009).

Waves at different places have certain characters and energy densities. The amount of energy that can be created using wave technologies varies from day-to-day and site-to-site, depending on locations and weather conditions. Nevertheless, wave energy can be accurately predicted within a period of a few days. In the design stages of a wave energy converter (WEC), to ensure that it will convert the energy efficiently over a sufficient wave period range, while accommodating the large distribution of powers, the knowledge of the statistical characteristics of the local wave climate is essential. Therefore, it is important to map the available energy to optimise the benefits from prospective developments.

Malaysia has the opportunity to utilise the solar, wind and wave energies effectively, promoting a clean environment, and developing renewable energy technologies in the country. However, using potentially clean energy resources on a large scale comes with technical challenges like regional availability, intermittence, and some inconvenience. A hybrid, renewable energy system could be an elegant solution to these challenges.

Unfortunately, for many developing countries like Malaysia, renewable energy measurements are not easily available due to the high equipment costs, maintenance and calibration requirements of the measuring equipment. As this literature review shows, although renewable energy potential have been reported for few cities of Malaysia, reliable and yearlong renewable energy data is still needed for the state of Terengganu to utilise the available renewable energies. This study addresses this need and is significant for establishing renewable energy data for Terengganu, Malaysia.

Data and Methodology

The geographical co-ordinates of the study site are 4° 13.6′ N latitude 103°26.1’ E longitude and 5.2 m altitude. The solar energy potentials around Kuala Terengganu were studied by statistically analysing the long-term, hourly solar and metrological data. The hourly measured meteorological data of year 2004 to 2008 was chosen to investigate the solar energy characterisation in the study area. The measured global solar radiation data were checked for errors and inconsistencies. The purpose of data quality control is to eliminate spurious data and inaccurate measurements. In the database, there were missing and invalid measurements and they were identified. To complete the data, missing and atypical data were replaced with the values of preceding or subsequent hours of the day by interpolation. From the raw data stored, the mean, maximum and minimum hourly values of solar irradiance, clearness index and air temperature were calculated. From the hourly data set, daily and monthly statistics were made for the solar radiation, clearness index and air temperature data.

The hourly measured wind speed, direction and temperature data from 2004 to 2007 were used to investigate the wind power potentials. The hourly, daily and monthly wind speeds and wind power density were assessed. The wind power and operating possibilities of the study location has been studied. The integrated hourly time-series data from multiple months, excluding incomplete data were combined for validation. Data were manually validated to remove outlier events due to failure of instruments etc., and statistically analysed.

The wave climate investigation was based on data collected (wave height, wave period and wave direction) at study area covering the period from 1998 to 2010. The primary datasets collected for this study were acquired from underwater fixed platform, from 2008 to 2010, at latitude 5 ° 35.0' N and longitude 102 ° 55.5' E. Secondary data sets were obtained from Malaysian Meteorology Department, which is covering the period from 1998 to 2009. The time series data consists of the wave height, the wave period, and wave direction.

MATLAB was used to process raw data to generate useful renewable energy characteristics, using simple MATLAB programs based on slandered equations. Furthermore, graphs were plotted by using the MATLAB and EXCEL functions.

Results and Discussion

Solar Energy

Daily averages for each month and peak daily global solar radiations for a complete year are shown in Figure 1. The month of April had the highest monthly average daily irradiation of 6566 Wh/m^2/day and the highest daily peak in solar irradiation of 7560.0 Wh/m^2/day. December had the lowest monthly average daily solar irradiation of 3715.0 Wh/m^2/day. The average yearly cumulative irradiation for Terengganu was 6905.8 MJ/m^2 per year. In an average year, the dry period (February to May and September) contributes about 47.19% of the annual total. The worst month (December) contributes least, being responsible for only about 5.89%.

The amount of solar radiation varies from one place to another owing to the attenuating properties of the atmosphere and the diverse geographical characteristics of the location. Generally, from the collected data, it is clear that the daily average and maximum global radiations as well as temperatures are higher from February to September and lower from October to January. The daily maximum global irradiance of 1139 W/m^2 was recorded on April 5, 2004, while the highest daily solar irradiation of 8089.30 Wh/m^2/day was recorded on March 5, 2007. Daily mean solar irradiance values were high during the periods of February to May and July to October. The annual averaged minimum and maximum values of monthly mean of daily global solar irradiation on a horizontal surface are 12.95 MJ/m^2/day in December and 23.63 MJ/m^2/day in April, respectively, with an annual average value of 19.15 MJ/m^2/day. Further, the highest daily average maximum and minimum solar irradiation were 27.02 MJ/m^2/day and 6.46 MJ/m^2/day on 11 April and 24 December, respectively.

The study shows that during the northeast monsoon the air temperature was lower than 30.0°C when the solar radiation was lower than 5000 Wh/m^2/day. The highest daily maximum and monthly average temperatures were 34.5°C and 29.4°C in August and April, 2008, respectively. The minimum daily average temperature recorded was 22.8°C in February 2008.

Figure 2 shows the daily variations of the clearness index for Kuala Terengganu throughout the year. It is observed that clearness index is relatively low from November through January and then it increases to a maximum (0.76) in April. There is a slight drop in the level of clearness index in June/July, with a distinct maximum in April. The variation in clearness index is attributed to the level of humidity and position of the sun relative to the site. It is the rainy season, from November through January, with generally high levels of moisture in the air from December through February (which reduces atmospheric transparency). The air is dry in April and May, which results in the observed peak. In general, the clearness index varies between 0.06 and 0.76 during one complete year. During the northeast monsoon, the clearness indexes are very low; for other periods almost clear sky condition exists.

The monthly averaged clearness index is maximum (0.64) during the dry hot season and lowest (0.42) during the rainy season. The average clearness index value was approximately 0.53. It was observed that the major seasons (dry and rainy) are reflected in the solar climate of Terengganu. The clearness of the sky is generally higher during the dry season. During the northeast monsoon, when both the clearness index and temperature are low, global solar radiation is likely to be low. Due to the low clearness index the solar radiation energy reduces dramatically.

When the monthly mean clearness indexes of other cities (Kuching, Kota Kinabalu, Kota Baru, Senai, Bayan Lepas, Kuala Lumpur, Petaling Jaya and Bandar Baru Bangi) of Malaysia (Kamaruzzaman and Othman, 1992) are compared with Kuala Terengganu monthly mean clearness index and it is clear that the monthly average clearness index over the course of the year is higher for Kuala Terengganu (Muzathik *et al*., 2011), though in some months Kota Kinabalu and Bayan Lepas cities have higher monthly mean clearness index values.

Wind Energy

A knowledge of the seasons and also with the times of the day, wind speed variations are important to get an idea about the amount and time of availability of wind power (Muzathik *et al*., 2009). These variations are required for the design of energy storage and load scheduling with other generating systems. Figure 3 shows the hourly average wind speeds and temperature in a day of July and December 2004 in Kuala Terengganu, Malaysia. These variations are related to the differences in the warming of the earth's surface during the daily radiation cycle. A typical variation consists of the increase of the wind speed during the day, followed by its decrease from midnight to dawn. These diurnal variations in the wind speed are influenced by the location and altitude in relation to the sea level.

The most remarkable characteristic of wind at the station is the difference in speed throughout the 24 hour period. In northeast monsoon, the wind speeds are generally higher from midnight till afternoon and lower in the evenings. On the other hand, in southwest monsoon, the trend is slightly different when wind speeds are higher in the afternoon until late evening and lower from night until noon. In southwest monsoon, from 10:00 hour the wind speed increases up to reach its maximum between 17:00 and 18:00 hours. Wind speeds start to decrease at 19:00 hour, later it decreases under the average value. The lowest value was registered after 01:00 hour. In northeast monsoon, from 23:00 hour, the wind speed increases to reach its maximum between 08:00 and 09:00 hours. It starts to decrease at 16:00 hour; and later to below the average value. The lowest value was registered after 21:00 hour. Wind speeds undergo noticeable variations between northeast monsoon and southwest seasons. The station registered a temperature without noticeable differences between day and night. On the other hand, independent of the considered season, the daily wind speed average was almost constant.

Figure 4 shows the typical monthly average hourly wind speed over the study period at Kuala Terengganu. Monthly behaviour of the temporal annual series shows a similar pattern. The highest monthly mean wind speed was 5.20 m/s in January 2007 while the lowest mean wind speed was 2.00 m/s in June 2005. Annual mean

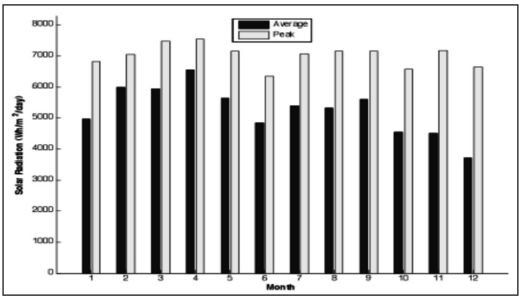

Figure 1: Monthly average and monthly peak daily total solar irradiation.

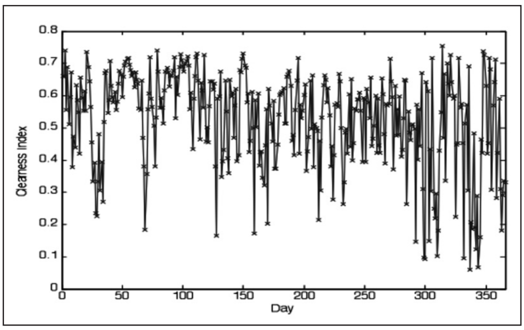

Figure 2: Daily average clearness index variation throughout the year.

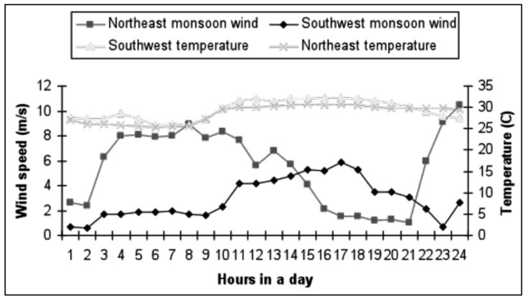

Figure 3: Hourly average wind speeds and temperature on July and December 2004 in Kuala Terengganu.

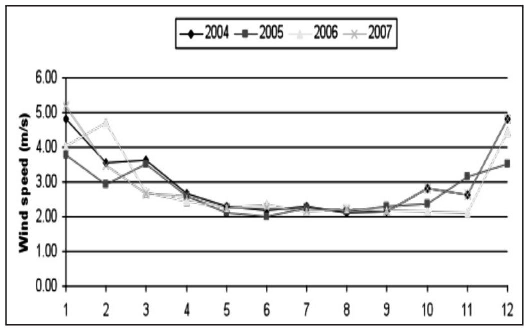

Figure 4: Monthly average wind speeds between the years 2004 and 2007 in Kuala Terengganu.

wind speed for the study period was 2.90 m/s. The monthly average wind speeds were higher during the northeast monsoon months as expected compared to other months. This clearly reflects that a wind-energy conversion system would produce appreciably more energy during the northeast monsoon months.

The frequency distribution of hourly average wind speed for a complete year is presented in Figure 5. The frequency is highly peaked in the range 1-6 m/s. This indicates that most of the wind energy at Kuala Terengganu lies in this range. This distribution of wind speed is important in determining the percentage of time during whole year, the power that could be generated from a wind machine. Moreover, this information can be used to determine the amount of power which can be generated in a given speed band. Hence it indicates the wind-power potential of Kuala Terengganu for wind-power applications.

The correlation between the wind-turbine height and wind velocity must be established before installing the turbine. In this study, 18 m height was used as reference for wind speed calculation at deferent heights. Figure 6 shows the wind velocities at 10m, 30 m, 50 m and 100 m above ground level.

Turbulence intensity of wind was calculated at 18 m and the monthly values were analysed. The annual average turbulence intensity was 0.58. No significant seasonal variation in turbulence intensity was observed. The turbulence in the wind is caused by dissipation of wind's kinetic energy into thermal energy via the creation and destruction of progressively smaller eddies. The range of wind speeds is high at Kuala Terengganu and as a result standard deviation of the wind speed is very high, mainly due to the low average wind speeds combined with monsoons. On analysis, the turbulence intensity was seen to be at an unacceptable level.

Figure 7a indicates the directions of all wind speeds for entire period of four years and Figure 7b, indicates the direction of wind with speeds exceeding 2.5 m/s for the entire period. For power-producing wind, the prevalent directions are those corresponding to the S, SE, NW and E sectors. Kuala Terengganu is located in the tropical

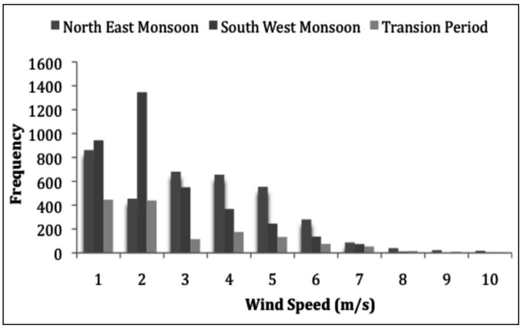

Figure 5: Frequency distribution of hourly average wind speed for whole year.

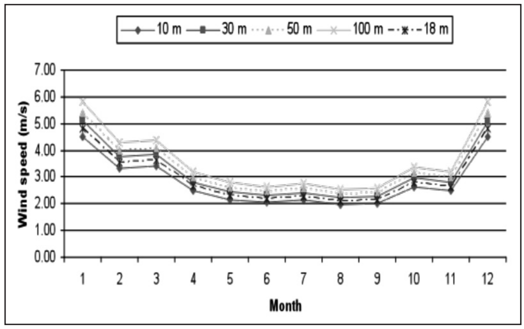

Figure 6: Monthly average wind speed at different heights of 10, 18, 30, 50 and 100 m.

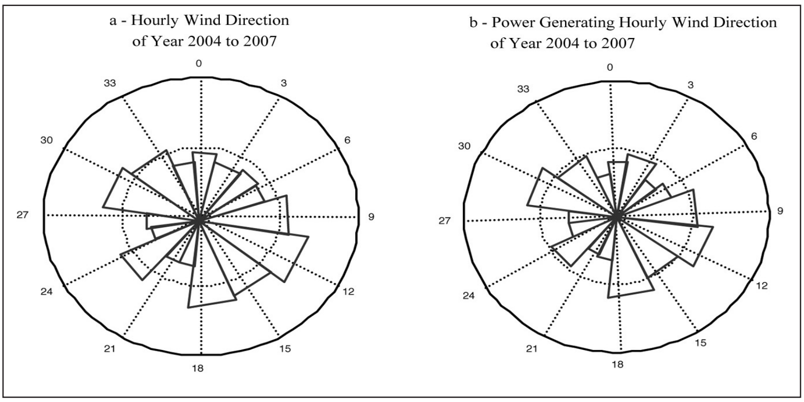

Figure 7: Wind roses showing wind direction, a– all wind direction and b- wind direction with wind speed exceeding 2.5m/s.

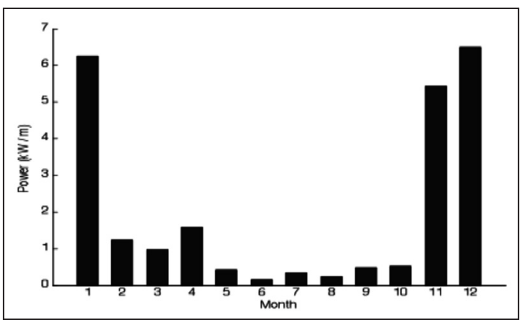

Figure 8: Monthly average wave power density (kW/m).

area slightly to the north of the Equator and is generally under the influence of the trade wind that blows from NE and SE. The wind-direction data are important to evaluate the feasibility of any wind-energy project to obtain the highest power production.

Wave Energy

The coast of Terengganu was selected to study the wave-energy potential and the results from the measurements are presented below. They include the classes of significant wave height, maximum wave height, mean and peak periods and also the wave-direction distributions, corresponding to whole years and monsoon seasons. In order to show the random variability in the actual situation, the joint significant wave height (H_s) and peak wave period (T_p) and distributions were studied considering eleven significant wave height intervals and eight peak periods. Further, the joint H_s and mean wave period (T_{mean}) distribution was also studied considering similar number of intervals as joint H_s and T_p distribution (Muzathik *et al*., 2010). Ascribing each two-hourly sea state to the appropriate interval, the percentage of the total time in an average year corresponding to the different intervals was obtained. A similar analysis was carried out combining mean wave direction (θ_m) and significant wave heights.

These analyses show that, more than 60% of the annual wave energy is provided by mid-height waves, with significant wave heights between 0.2 m and 1.2 m. With regard to the wave period, waves with peak periods between 2 and 8 s

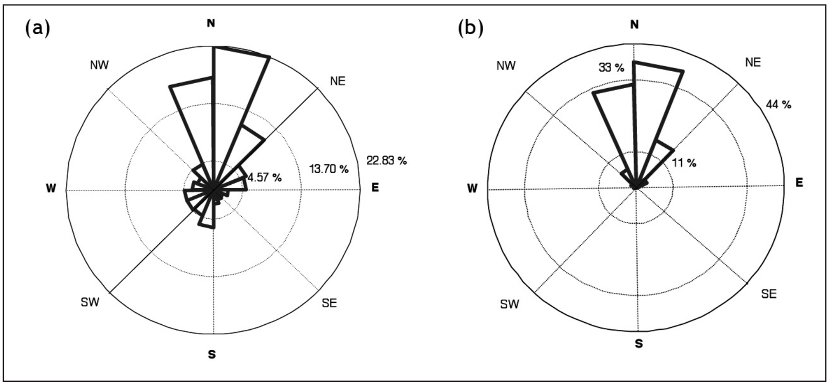

Figure 9: Percentage of total wave energy vs mean wave direction (a) for whole year, (b) for northeast monsoon season at study area.

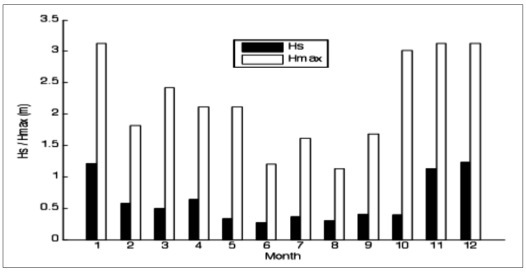

Figure 10: Variation of monthly averaged H_s and H_{max} at study area.

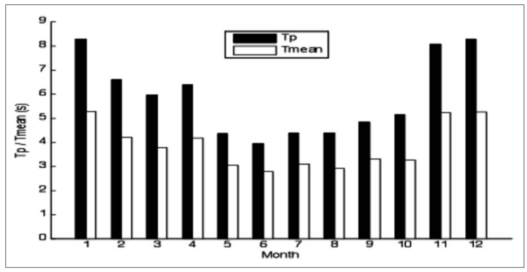

Figure 11: Monthly averaged T_{mean} and T_p variation at study area.

accounted for more than 70% of the total wave energy. Further, the studies reveal that the annual average wave-energy density was 17.69 MWh/m and the average wave-power density was 4.04 kW/m. While calculating the wave power for the coast of Terengganu, the averaged values of H_s =1.22 m and T_p=5.87 s, based on available wave-power density may be considered.

For better visualisation, the average wave-power densities are plotted in bar charts for latitude 5º 35.0' N and longitude 102º 55.5' E, as shown in Figure 8. It is observed that monthly average wave power density vary between 0.15 kW/m and 6.49 kW/m. From this, it can be seen that the wave power and stirring month in a year are not much different in the coast of Terengganu. In addition, it can be observed that, in general, monthly mean wave power is lower in the middle of the year when compared to that in the start and end of the year.

The main directions in terms of wave energy for whole year are N, which accounts for more than 40%, followed at some distance by NE, SW and S (Figure 9a). It was seen that the maximum wave energy potential is available during northeast monsoon season. The main directions of N and NE, accounted for more than 80% of the total wave energy (Figure9b). This may be used as a reference for this area.

Figure 10 shows monthly averaged H_s and H_{max} variation. It is observed that maximum wave heights vary between 1.13 m and 3.13 m and monthly mean significant wave height varies between 0.27 m and 1.24 m. From this, it can be seen that the wave heights and stirring month in a year are not remarkably different in the coast of Terengganu. Also, it can be observed that, in general, monthly mean significant wave height is lower in the middle of the year when compared to that in the start and end of the year.

Figure 11 shows monthly averaged T_{mean} and T_p variation. It is observed that the wave mean period varies between 2.76 s and 5.28 s and monthly averaged wave peak period varies between 3.94 s and 8.28 s. It can be seen that the wave periods and stirring month in a year are not remarkably different in the coast of Terengganu. In addition, it can be observed that, in general, monthly mean wave periods value is similar in the whole year.

Hybrid Renewable Energy Sources

Most renewable energy sources vary seasonally and all of them vary from year to year. Sunlight, wind and wave vary with locations also. These inherent resource characteristics make it imperative for careful evaluation of energy needs when considering renewable energy systems. Use of renewable energy requires careful matching of conversion technology to resource availability and energy demands. Although it is usually obvious to the inhabitants of an area that one form of renewable energy is more plentiful than another, it is important to conduct an inventory of renewable energy resources before selecting technologies that may be deployed to convert these resources to usable energy forms.

Table 1 presents the solar, wind and wave power densities for the study area. The maximum solar-power density (273.5 W/m^2) occurs in April and least (149.9 W/m^2) in December. The annual long-term solar-power density is 221.7 W/m^2. The annual mean of the solar-energy density is 18.92 MJ/m^2/day. Adoption of solar technology in Terengganu will be very advantageous because solar energy is the most pollution free and almost unlimited in availability.

Table 1 show that the annual mean daily wind-power density is 14.4 W/m^2. This corresponds to the daily energy density of 1.24 MJ/m^2/day. The wind-power density in Terengganu is less encouraging. The calculated wave-power density is least in June (i.e. unlike the solar-power density) and in November, December and January reaches more than 5000 W/m wave-front. The annual mean value of the wave-power density is 2011.7 W/m.

Identification and optimum combination of the renewable energy sources are the most important factors for hybrid renewable energy systems. According to Babarit *et al*. (2006) and John *et al*. (2007), regions having >170 W/m^2 solar-power density or >150 W/m^2 wind-power density or > 5000 W/m wave-power density are considered to be rich in renewable energy resources.

The wind resource in Terengganu remains substantial for nearly all the months, while the northeast monsoon offers better conditions for wind-energy exploitation. Compared with wind-power potential, solar resources in the study area are distributed more evenly. Most months boast reasonably good solar radiation, promising possibilities for small-scale, complementary solar-wind system development. At the same time, nearly all days receive significant solar radiation more than 3600 Wh/m^2/day. Within the study area, solar potential appears encouraging for solar-power generation. In general, solar energy is a renewable energy source, having the highest energy density followed by wave and wind for the study area of Terengganu. Further, it is interesting to note from Table 1 that the energy potential is scattered over all the months; this is encouraging for adopting a hybrid renewable energy system for the region.

Table 1: Available solar, wind and wave power densities in Terengganu.

Month	Solar power (W/m^2)	Wind power (W/m^2)	Wave power (W/m)
January	214.2	55.0	6256.2
February	250.1	30.9	1242.6
March	259.5	18.8	0972.9
April	273.5	10.5	1589.5
May	226.9	06.9	0410.5
June	212.3	06.5	0148.5
July	222.3	06.8	0344.2
August	232.7	06.3	0232.7
September	233.1	06.7	0480.5
October	198.9	08.9	0528.4
November	187.0	11.3	5443.0
December	149.9	47.6	6491.6
Annual	**221.7**	**14.4**	**2011.7**

Conclusion

Generation of average solar-radiation data is very important for the calculations concerning many solar applications. Daily average solar-radiation data show that the month of April had the highest monthly average daily irradiation of 6566.0 Wh/m^2/day and the highest daily peak in solar irradiation of 7560.0 Wh/m^2/day. December had the lowest monthly average daily solar irradiation of 3715.0 Wh/m^2/day. The average yearly cumulative irradiation for Terengganu was 6905.8 MJ/m^2 per year. The clearness index varies between 0.06 and 0.76 during one complete year. In northeast monsoon, the clearness indexes were very low, but other periods almost clear sky conditions existed. The monthly average clearness index varied between 0.42 and 0.64. The average clearness index value was approximately 0.53.

It is quite evident from the results of wind-energy study in Terengganu that the potential of renewable energy options of wind energy cannot be overlooked especially during the northeast monsoon season when the average wind speeds are around 3.9m/s. The study reveiled that the average daily wind energy was 344.44 Wh/m^2/day. An array of small wind machines (kW range) could be used to provide power during the northeast monsoon periods.

The investigation shows that the coast of Terengganu could provide a source of low wave power. The total wave-energy density was found to be 17.69 MWh/m in an average year. It may be concluded that regions along the coast of Terengganu can consider northeast monsoon period for wave energy exploitation. The main direction in terms of wave-energy for the whole year is seen to be northerly, which may be used as a reference for this area.

Adoption of solar and wave technology in Terengganu will be very advantageous based on solar and wave-power densities. Compared with wind-power potential, solar and wave resources are distributed more evenly throughout the year. In general, solar energy is an alternative energy source with the highest energy density followed by wave and wind-energy sources for the study area. The renewable energy potential is seen to be spread over all the months; this fares favourably for a hybrid renewable energy system adaptation. Availability of long coastal stretches in Terengganu makes this coastal region conducive for wave-energy exploitation. WEC erections can be experimented with in this region. Further evaluation of energy needs for the village habitats must be carried out. Feasibility of meeting the demands by solar, wind and wave energy must be researched upon. Such projects will not only be exemplar but also economically complementing to the energy demands of a developing nation.

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