Renewable Energy 59 (2013) 210–219

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Potential application of renewable energy for rural electrification in Malaysia

H. Borhanazad [a,*], S. Mekhilef [a], R. Saidur [b], G. Boroumandjazi [b]

[a] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 11 June 2012
Accepted 25 March 2013
Available online 26 April 2013

Keywords:
Renewable energy
Rural electrification
Policy

ABSTRACT

Energy poverty and lack of electricity in rural areas exacerbate the poverty of the developing countries. In Malaysia, 3.8% of the population lives below the poverty line and most of them are settled in rural areas. The electricity coverage in poor states is about 79% in comparison with 99.62% in Peninsular Malaysia. The renewable energy sources can be considered the best alternative to reduce the energy poverty of the rural areas where the grid extension through a difficult terrain and thick jungle is not possible or economic. In this study, the potential for applying renewable sources – solar, wind and hydropower – for rural electrification is investigated, especially in the poorest States. A comparative study on rural electrification policies, in order to have community approval, appropriate siting and financial benefits for the rural community, while considering the three categories of social, institutional and economic issues, is also examined. Finally, the Malaysian policies of rural electrification by applying renewable sources are explained. It is found that in Malaysia, with a maximum solar radiation of about 6.027 kWh/m^2 per day in Sabah and 5.303 kWh/m^2 per day in Sarawak, the potential for applying solar energy for electrification is too high. However, the potential for micro-hydropower in Sabah and Sarawak is found to be 3182 kW and 6317 kW through 18 and 22 sites, respectively.

1. Introduction

The hot and humid country of Malaysia with a latitude of 3.164°N and 101.7°E, can be considered as entirely equatorial. The ambient temperature varies from 27 °C to 33 °C, whereas the average solar radiation is about 4500 Wh/m^2 per day. Malaysia has a population of 28.3 million people [1], and, based on the statistics for 2009, 3.8% of them live below the poverty line [2]. Although the overall percentage of poor people in Malaysia is low, there is a large gap between incomes in the urban areas and rural areas. Approximately 71.3% of the Malaysian population are settled in the urban areas whereas 28.7% live in the rural areas [1,3]. Fig. 1 shows the level of urbanization by State in Malaysia in 2010. It can be clearly seen that urbanization in Kelantan is very low with only 42.4% in comparison with Kuala Lumpur and Putrajaya, which are 100% urbanized.

The standard of living in urban areas is higher than the rural areas. It is estimated that 8.4% of people in the rural areas live below the poverty line, while only 1.7% of those in urban areas live below the poverty line [4]. The majority of poor people are Bumiputera, who are living in the least developed States of Malaysia with a concentration on the agricultural sector. With the outline of poverty percentage in different States, summarized in Table 1, it can be seen that Sabah is one of the poorest States in Malaysia with 19.2% poverty in 2009, which is followed by Perlis, Sarawak and Kedah with 6%, 5.3%, 5.1%, respectively.

Energy poverty and lack of electricity in the rural areas exacerbate the poverty of the developing countries. The technology for sustainable development can be considered efficient tools to reduce energy poverty whenever they are conducted based on an appropriate policy. Nevertheless, grid extension through the difficult terrains and thick jungle to serve a small village is not feasible and economic [5]. Due to the high cost of distribution and associated transmission loss, grid power supply in rural areas is not economically viable. Among more than 10,000 schools in Malaysia, 809 schools are not supplied with a 24-h electricity. Most of these schools are located in Sabah and Sarawak and there are no plans to connect them to the grid within the next five to ten years [6]. The off-grid electricity, which can be generated by solar, wind or hydro technology, provides the opportunity to expand the capacity of rural electrification and has distinct advantages for the community as a cost-effective strategy and reliable source of energy. For instance, by applying solar hybrid systems, 78 of the aforementioned schools in Sabah were electrified in 2008. However, the installation, technical and social issues should be considered to avoid project failure [7].

* Corresponding author. Tel.: +603 79674462; fax: +603 79675317.
E-mail addresses: hanieh_borhanazad@yahoo.com, h.b.azad@gmail.com (H. Borhanazad), Saad@um.edu.my (S. Mekhilef), saidur@um.edu.my (R. Saidur), Gh.boroumand@gmail.com (G. Boroumandjazi).

0960-1481/$ – see front matter
http://dx.doi.org/10.1016/j.renene.2013.03.039

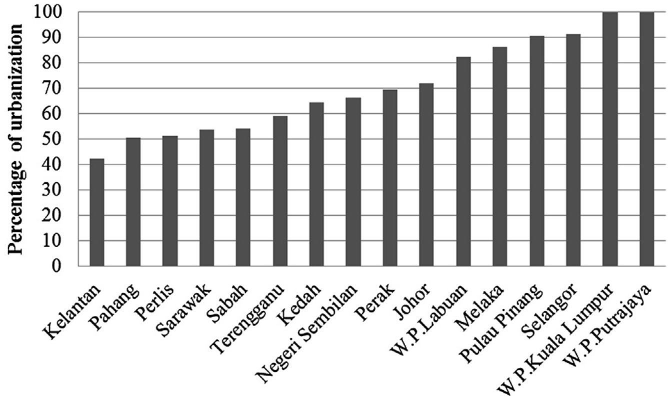

Fig. 1. Rate of urbanization in States of Malaysia, 2010 [1].

To investigate the potential of reducing energy poverty in rural area of Malaysia with the aid of off-grid electrification, the current status of energy and electrification in rural areas is explained. Moreover, the potential of solar, wind and hydropower energy in rural areas is investigated. Finally, the policies of rural electrification in Malaysia and the conducted programme under these policies are described. It may be reported that to the best knowledge of the authors, there is no work on the potential role of renewable energy to reduce poverty in the rural areas in Malaysia. Therefore, this study is expected to fill this gap.

2. Current electrification status of rural areas in Malaysia

As mentioned, electrification is generally seen as one of the key indicators that can reduce poverty. Table 2 shows the urban and rural electricity supply by State in Malaysia in 2000. Sabah and Sarawak with 67.05% and 66.91%, respectively, have the lowest level of electrification in the rural areas. Moreover, Table 3 indicates that the level of electrification in Sabah and Sarawak is very low (by only 82.51% and 78.74%, respectively) in comparison with electrification of Malaysia with 99.62% in 2010 [8].

Therefore, based on the information presented, there is a significant link between the energy and poverty. Energy can be considered the centre of poverty. Electrification in rural areas affects the poverty in certain States as well as the whole country.

Table 1
Incidence of poverty by ethnicity, strata and state (in percentage), Malaysia [4].

	2002	2004	2007	2009
Malaysia	6	5.7	3.6	3.8
Ethnic				
Bumiputera	9	8.3	5.1	5.3
Chinese	1	0.6	0.6	0.6
Indians	2.7	2.9	2.5	2.5
Others	8.5	6.9	9.8	6.7
Strata				
Urban	2.3	2.5	2	1.7
Rural	13.5	11.9	7.1	8.4
State				
Johor	2.5	2	1.5	1.3
Kedah	9.7	7	3.1	5.3
Kelantan	17.8	10.6	7.2	4.8
Melaka	1.8	1.8	1.8	0.5
N. Sembilan	2.6	1.4	1.3	0.7
Pahang	9.4	4	1.7	2.1
P. Pinang	1.2	0.3	1.4	1.2
Perak	6.2	4.9	3.4	3.5
Perlis	8.9	6.3	7	6
Selangor	1.1	1	0.7	0.7
Terengganu	14.9	15.4	6.5	4
Sabah	16	23	16	19.2
Sarawak	11.3	7.5	4.2	5.3
Kuala Lumpur	0.5	1.5	1.5	0.7
Putrajaya	–	–	–	–

Table 2
Electricity supply in urban and rural areas [9].

State	Urban	Rural	State	Urban	Rural
Johor	99.53	98.22	Perlis	99.63	99.17
Kedah	99.84	98.58	P. Pinang	99.84	99.16
Kelantan	99.52	97.5	Sabah	89.65	67.05
Melaka	99.9	99.28	Sarawak	93.96	66.91
N. Sembilan	99.61	98.6	Selangor	99.39	97.92
Pahang	99.63	93.96	Terengganu	99.65	98.24
Perak	99.64	96.11	W.P. Kuala Lumpur	99.76	–

Energy in Malaysia is supplied by five main sources – natural gas, oil, coal, hydro, and renewable energy – which are tabulated in Table 4. Coal with 26,177 GWh has the highest contribution in electricity production and is followed by gas with 61,910 GWh. Renewable resources, such as hydro and solar photovoltaic also provide 7459 GWh and 1 GWh, respectively.

Despite being amply endowed with renewable energy sources, the capacity, especially for solar and biomass energy, is grossly underutilized. Malaysia has the potential for using wind, tidal, photovoltaic renewable resources in remote area and islands, especially those that are not connected to the national grid.

3. Potential for applying renewable energy in rural areas of Malaysia

Malaysia has an abundant potential for using renewable energy resources, such as solar, wind, hydro, biomass, and tidal [11–13]. However, they have not been applied yet and endeavours for research and development in this area are still continuing. Table 5 reveals all the conducted projects in Malaysia to electrify rural areas by applying the renewable energy. It can be observed that solar systems play an important role in solving the energy crisis problems in rural areas.

As can be seen the solar hybrid systems, which are an integration of two or more power sources, are applied to supply the electricity of 78 sites. The installed systems are the combination of PV arrays with diesel generators and operate with solar inventors [6].

Fig. 2 illustrates the capacity of RE systems installed in different locations by the Ministry of Rural Areas. Although the highest capacity of implemented renewable energy systems belongs to Sabah, with 3565 kW from 2004 to 2010, the access level to 24-h electricity in Sabah was estimated to be still only 81% in 2010, compared with 98.6% electrification of Malaysia for the same year [14].

3.1. Solar energy

The potential for applying solar energy in Malaysia, especially in the rural areas, is investigated in this section and the amount of solar radiation in different States is also compared. Moreover, the barriers and limitations for applying PV panels in the rural areas are explained.

3.1.1. Potential of solar energy in Malaysia

Solar radiation data in Malaysia have been the subject of earlier studies. Malaysia's climatic conditions are desirable for extending

Table 3
Level of electrification in Malaysia [8].

Region	Total no. of houses	Houses connected with 24 h supply	Coverage (%)
Peninsular Malaysia	1,656,800	1,650,492	99.62
Sabah	311,780	257,780	82.51
Sarawak	278,110	218,992	78.74

Table 4
The sources of electricity production in Malaysia [10].

Source	Electricity (GWh)
Coal	26,177
Oil	1845
Gas	61,910
Biomass	0
Waste	0
Nuclear	0
Hydro*	7459
Geothermal	0
Solar PV	1
Solar thermal	0
Wind	0
Tidal energy	0
Other sources	0
Total production	97,392

*Includes production from pumped storage plants.

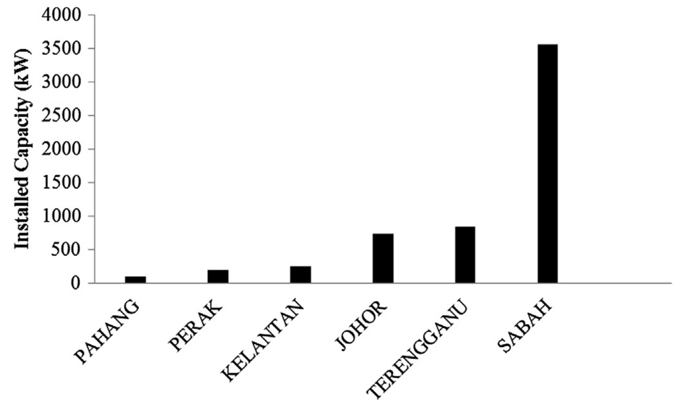

Fig. 2. Capacity of installed hybrid RE systems in rural areas in Malaysia (2004–2010).

Table 5
Renewable energy systems in the rural areas of Malaysia [8].

Year	State	Project name	No. of houses	Type of system	Capacity installed (kW)
2004	Johor	Pulau Besar, Mersing	20	Solar hybrid	45
		Pulau Pemanggil, Mersing	32	Solar hybrid	50
		Pulau Sibu, Mersing	68	Solar hybrid	100
		Pulau Aur, Mersing	42	Solar hybrid	50
		Total	162		
2005	Johor	Pulau Tinggi, Mersing	37	Solar hybrid	50
		Total	37		
	Perak	RPS Dala, Hulu Perak	150	Solar hybrid	200
	Pahang	Kg Org Asli Ganuh, Rompin	56	Solar hybrid	100
	Kelantan	Kg Org Asli Blau, Gua Musang	54	Solar hybrid	100
		Pos Pulat, Gua Musang	48	Solar hybrid	50
		Kg Org Asli Aring 5, Gua Musang	70	Solar hybrid	100
		Total	378		
	Sabah	Kg Pegalungan, Nabawan	76	Solar hybrid	100
		Kg Monsok Tengah, Tambunan	16	Solar hybrid	45
		Kg Monsok Ulu, Tambunan	19	Solar hybrid	45
		Kg Sinulihan, Tuaran	44	Solar hybrid	50
		Total	155		
2006	Sabah	Kg Meligan, Sipitang	140	Solar hybrid	200
		Kg Lubukan, Semporna	40	Solar hybrid	75
		Total	180		
	Johor	Kg Org Asli Sg Peroh, Kluang	18	Solar hybrid	45
		Kg Org Asli Tg Tuan, Mersing	24	Solar hybrid	45
		Kg Org Asli Tanah Abang, Mersing	81	Solar hybrid	150
		Kg Peta, Mersing	58	Solar hybrid	100
		Kg Punan, Mersing	60	Solar hybrid	100
		Total	241		
2007	Sabah	Kg. Karakit dan Pekan Karakit	63	Solar hybrid	850
		Kg Lok Tohok	108	Solar hybrid	
		Kg. Perpaduan	118	Solar hybrid	
		Kg. Singahmata	32	Solar hybrid	
		Kg. Batu Layar (termasuk PPMS)	251	Solar hybrid	
		Kg. Batu Putih	30	Solar hybrid	
		Total	602		
2007	Terengganu	Pulau Perhentian Kecil, Terengganu	420	Wind Turbine Hybrid with solar	850
		Total	420		
2007–2009	Sabah	Rancangan Kalabakan	315	Solar hybrid	1200
		Kg. Sg Tuda	20	Solar hybrid	
		Pekan Kalabakan	95	Solar hybrid	
		Kg. Murut Kalabakan	75	Solar hybrid	
		Kg. Murut Ulu Kalabakan	49	Solar hybrid	
		FELDA Kalabakan	100	Solar hybrid	
		Total	654		
2009–2010	Sabah	Kg. Kuamut	270	Solar hybrid	1000
		Kg. Kuamut Laut		Solar hybrid	
		Kg. Batu Laut		Solar hybrid	
		Kg. Batu Darat		Solar hybrid	
		Total	270		
	Grand Total		3099		

the utilisation of PV systems due to the high amount of solar radiation received throughout the year [15,16]. Solar radiation in Malaysia is relatively high based on the world standards. It is estimated that Malaysia's solar power is four times that of the world fossil fuel resources [17].

Malaysia's solar radiation amount ranges from 0.61 kWh/m^2 per day in December to 6.8k Wh/m^2 in August and November. The north region and a few places in east Malaysia receive the highest amount of solar radiation with an average of more than 3 kWh/m^2 throughout the year [18]. The lowest irradiance value is in the Klang Valley, whereas Penang and Kota Kinabalu have the highest measured solar radiation [19]. It is estimated that one square metre of solar panel in Malaysia can result in an annual reduction of 40 kg of CO_2 [20]. Fig. 3 provides information on solar radiation in different States of Malaysia. It can be seen from the figure that Sabah, Perlis and Kedah, which are classified among the poor States, with a low level of urbanization have sufficient solar resources to support solar energy applications in remote areas.

The major application of solar energy in the rural areas of Malaysia is stand-alone PV systems, where the technology costs are highly subsidized. The graphs below (Figs. 4–8) represent the daily solar radiation in the four poorest States of Malaysia [21]. It can be seen that the received solar energy in Sabah is between 4.25 kWh/m^2 and 5.29 kWh/m^2 per day and in Sarawak, Kedah, Perlis the average amount is equal to 5.12 kWh/m^2, 5.48 kWh/m^2 and 5.26 kWh/m^2, respectively. The average solar radiation of these States reveals the high potential of the poor States to use PV systems for electrification.

3.1.1.1. Statistical analysis of solar energy potential. From the above bar charts the average solar radiation for the selected cities is calculated, also the peak solar hours (PSH) are calculated. PSH is used to express solar irradiation in a particular location when the sun is shining at its maximum value for a certain number of hours. Since the peak solar radiation is 1 kW/m^2, the number of peak sun hours is numerically equal to the daily solar radiation in kWh/m^2. For instance, the daily output of solar array can be approximately estimated to be 535.3 Wh, if we assume that a 100 Wp solar array is installed in Sabah with an average solar radiation of 5.35 kWh/m^2/d.

The annual energy output can also be calculated based on the CEI-IEC 61724 methodology for monitoring the photovoltaic system performance by using the following formula [22].

$$\text{Annual Energy Output}\left(\frac{\text{kWh}}{\text{kWp}}\right) = \text{Global inplane irradiation}\left(\left(\text{kWh/m}^2\right)/\text{year}\right) \times \text{Performance ratio} \quad (1)$$

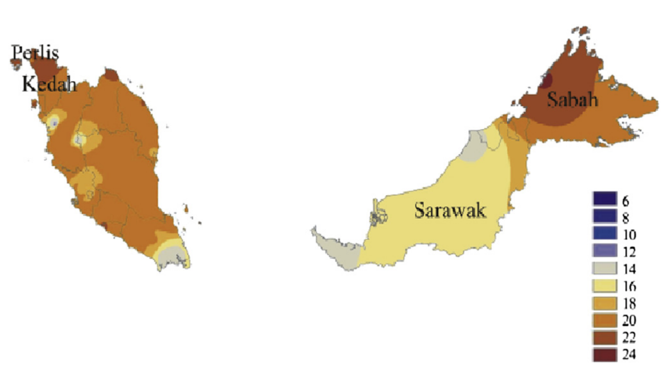

Fig. 3. Annual average solar radiation (Mj/m^2/day) (note that to convert Mj/m^2/day to kWh/m^2/day, it should be divided by 3.6).

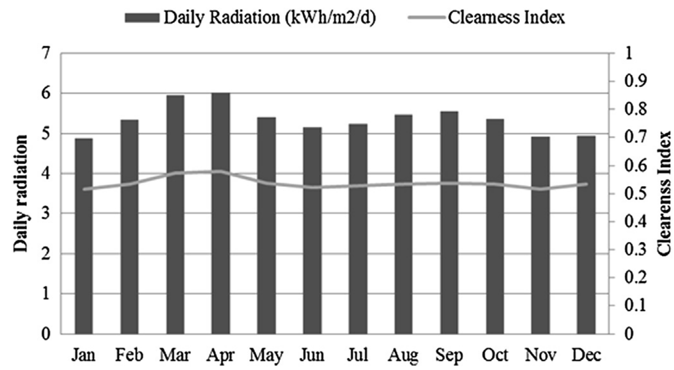

Fig. 4. Sabah average daily energy received.

Table 6 illustrates the potential of using solar system in selected States in Malaysia, such as Sabah, which is currently the poorest of Malaysia's States. It shows that, in Malaysia, the potential for applying solar energy for electrification is too high. For instance, Sabah and Kedah, with an average solar radiation of about 5.35 and 5.51 kWh/m^2/d, have the possibility of producing 1465 and 1509 kWh/kWp per year, respectively. Moreover, the daily energy generated from a photovoltaic (PV) panel is estimated to be more that 500 Wh in each State, which can satisfy the primary household energy consumption.

3.1.2. Barriers to using PV panels for rural areas in Malaysia

Despite the efforts in remote areas, electrification progress and success rates are still too low. There are some barriers, which affect the performance of PV panels in rural areas in Malaysia that are investigated in the following part.

The dirt, dust, tree debris, moss, sap, bugs, bird droppings, water spots, and mould, etc. on the solar panels have a significant impact on the performance of solar power systems. Cleaning the panels is also a problem, first, because of the height of PV panels to get rich access to the sunlight and then because of the growth of moss and grass in a short time on the panels, which causes an extra cost for the owner to clean the panels [23].

In addition, surrounding trees grow quickly and will shade the panels, so the performance of PV panels decrease. Solar PV panels, which are mounted on high poles, are also found to attract lightning strikes, the destructive voltage which destroys the electronic components [24]. Furthermore, the bypass diodes, which are mounted in the termination box under each panel, usually crack because of the high humidity, heat, and short-circuiting.

One of the major drawbacks of using solar cells in Malaysia is heating up and decreasing the power output of the solar cells during the hot days. In addition, the climate in tropical regions

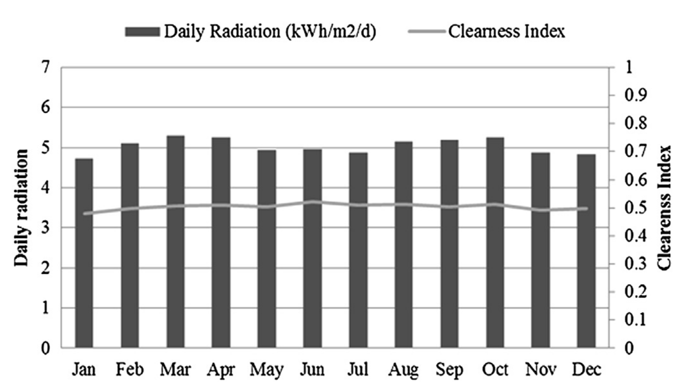

Fig. 5. Sarawak average daily solar energy received.

makes the lifespan of solar panels shorter and makes it unfavourable by an average of two months per year due to the rainy and cloudy days. For instance, in the highlands of Bario, Sarawak, heavy rain, which continues for several cloudy days, causes battery banks to run out of charge sooner.

Moreover, remote people are generally not technically inclined and cannot understand operation manuals written in a foreign language. To solve this problem, a centralized system could be operated and maintained by a couple of trained literate villagers.

3.2. Wind energy

Wind can be considered as another free available energy source that can be utilized for the electrification in Malaysia. The potential of wind energy in different States of Malaysia is investigated in subsection 3.2.1. The barriers to applying the wind energy in the rural areas are explained in subsection 3.2.2.

3.2.1. Potential for wind energy in Malaysia

In the early 1980s, a study on Malaysia's wind energy was undertaken in University Kebansaan Malaysia (UKM). Solar Energy Research Group from UKM collected wind data from ten stations in the whole country for a period of 10 years from 1982 to 1991. The data studied include the hourly wind speed in stations, which are mostly located at airports and near coasts, where land and sea breezes may influence the wind regime [25]. The study shows that, due to Malaysia's location, the mean wind speed is low and no more than 2 m/s. However, the wind does not blow uniformly, and varies according to the month and region. The strongest wind blows on the East Coast of Peninsular Malaysia. The maximum speeds occur in the afternoon and minimum speeds occur just before sunrise [25]. Although the average flow of wind is light in Malaysia, it can generate a high amount of energy, especially on remote islands or the East Coast States of Malaysia, which experiences a wind speed of about 15.4 m/s during strong surges of cold air from north Sabah and Sarawak. Moreover, it has a high potential of wind energy, which can reach 10.2 m/s during October–March [26]. The greatest wind power potential is for Mersing and Kuala Terengganu, which are located on the East Coast of Peninsular Malaysia. In Sabah, the wind direction in two stations – Kota Kinabalu and Tawau – is consistent throughout the year. Kota Kinabalu has higher wind power densities at the end of the year; whereas Labuan station shows that the wind power densities are higher at the beginning of the year [25]. Figs. 9–13 illustrate the wind speed data for some of the poorest cities in Malaysia from 2007 to 2010 [27].

In analysing these data, it can be seen that small wind machines could be used to provide electricity on the East Coast of Peninsular Malaysia and the offshore islands, which do not have access to the national grid [25]. According to the research in 2003, the annual offshore wind speed for Malaysian waters is around 1.2 m/s–4.1 m/s [28]. In 2005, in Terumbu Layang Layang, the first wind turbine on the island off East Malaysia was demonstrated to have a capacity of 150 kW [29,30]. In recent years, TNB installed two wind turbines (100 kW) in Pulau Perhentian for energy generation. In addition, the Ministry of Rural and Regional Development installed eight small wind turbine units (5–100 kW) for the community in Sabah and Sarawak [31].

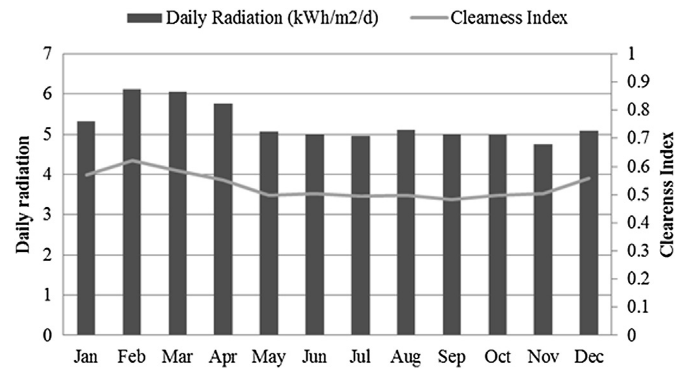

Fig. 7. Perlis average daily solar energy received.

Fig. 14 represents the frequency of wind speeds at Mersing, which has the highest potential for wind in Peninsular Malaysia, for 2008 and 2009. The data show that the most frequent wind speed is between 2 and 3 m/s. However, the calculated value for the highest power density is for wind speeds higher than 6 m/s. This means that wind power is not a good option as a reliable or practical source of energy for Malaysia's remote areas.

Evaluation of the wind power and energy per unit area, are important information in the assessment of wind power project. In this way, the wind data at 10 m above ground level related to the selected States were taken from the Meteorological Department of Malaysia for a period of 12 years from 1989 to 2011, and then the average monthly wind speed at the reference height was changed from 10 m to 70 m, which is appropriate for the height of wind turbines in rural areas.

The power available in the wind can be calculated by [32]:

$$P = \frac{1}{2}\overline{\rho}V^3C_p \tag{2}$$

where V is the monthly wind speed (m/s), C_p is the coefficient by Betz limit, which can achieve the maximum value of 59% for all types of wind turbines, $\overline{\rho}$ is the corrected monthly air density (kg/m^3) and can be estimated by the following equation:

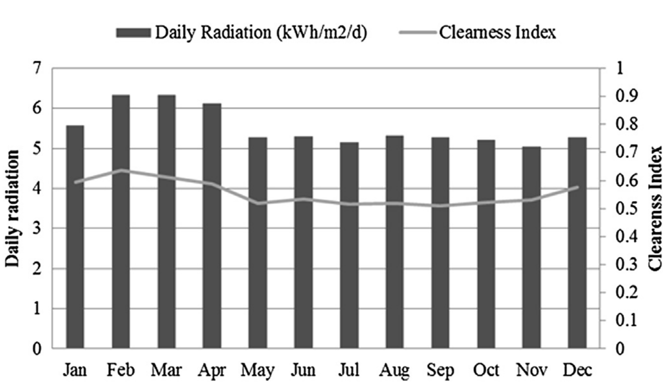

Fig. 6. Kedah average daily solar energy received.

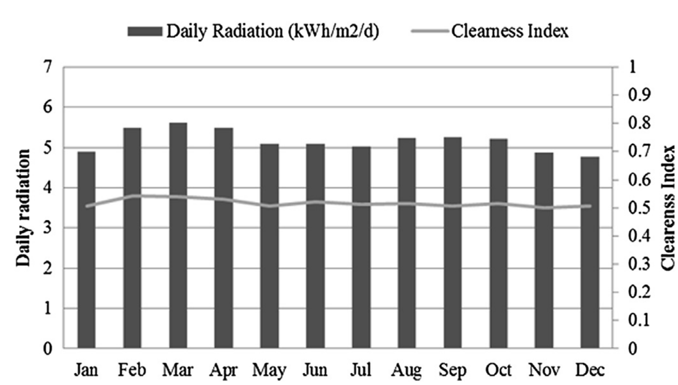

Fig. 8. Malaysia average daily solar energy received.

Table 6
Potential of solar energy in selected States in Malaysia.

Provinces	Solar radiation ($kWh/m^2/d$)	Peak solar hours	Daily energy output (Wh)	Annual energy output (kWh/kW_p)
Sabah	5.35	5.353	535.3	1465.475
Sarawak	5.04	5.041	504.1	1380.161
Kedah	5.51	5.512	551.2	1509.064
Perlis	5.26	5.265	526.5	1441.394
Peninsular Malaysia	5.16	5.166	516.6	1414.27

$$\overline{\rho} = \frac{\overline{P}}{R_d \overline{T}} \quad (3)$$

in which $\overline{P}$ is the monthly mean air pressure (N/m^2), $\overline{T}$ is the monthly mean air temperature (K), and R_d is the specific gas constant for air (287 J/kg K).

By applying Eq. (3), the total potential of wind in specific regions can be estimated. Table 7 shows the estimated power output of selected States in Malaysia. From the obtained data, it can be concluded that it is important to choose a suitable wind turbine for low wind speed as well as wind energy potential of the region to increase the performance of wind energy power generators in remote areas.

3.2.2. Barriers to using wind turbines for rural areas in Malaysia

Since the wind resources are very poor, the use of wind turbines is rare in Malaysia. However, a few small turbines, such as those in Sabah and Sarawak, which were installed by the Ministry of Rural and Regional Development, are being used in hybrid systems, integrated with solar panels or diesel generators. Another barrier to using wind turbines in Malaysia is lightning activities, in as much as Malaysia's experience of lightning activities ranks as among the highest in the world [23]. Therefore, strikes by lightning and damage to the electronic components, especially in hybrid systems, is one of the major barriers to using wind turbines in Malaysia's rural areas. Fig. 15 shows a wind turbine in Sarawak, which is mounted on a steel pole about 30 m high. Standing above tall trees to gain clear access to the wind, this turbine was damaged by lightning shortly after installation, and has now been replaced by a diesel generator.

3.3. Hydropower

Hydropower is one of the most cost-effective, reliable, predictable and least environmentally intrusive among all renewable energy technologies that can be considered for rural electrification in less developed countries. Considering the average annual rainfall in Malaysia, hydropower can be considered as one of the most appropriate renewable sources for rural electrification. The following section presents the potential for hydropower and mini-hydropower in Malaysia and the most common barriers that are usually faced.

3.3.1. Potential for hydropower in Malaysia

Malaysia, with 150 river systems in Peninsular Malaysia and 50 rivers in Sabah and Sarawak is blessed with an abundance of water resources. Malaysia's average annual rainfall is estimated as being 2000 mm compared with the world's average annual rainfall, which is 750 mm. Consequently, Malaysia's potential for hydropower is very high [33]. Hydropower is the only renewable energy that is commercially viable on a large scale in Malaysia. The renewable energy resource potential for hydropower was estimated to be RM 506 million/year in 2009. Hydropower technology is multipurpose and can be used for water supply, flood control, electric power and improvement of navigation. In addition, the system is cheap and pollution free. Malaysia has a significant amount of hydropower resources, and potential hydropower is estimated at 29,000 MW [34]. The installed capacity of major hydropower stations in Malaysia is summarized in Table 8. The total installed capacity of hydropower in Sarawak was reported to be 108 MW in 2009. Sarawak plans to increase the hydropower capacity to 3500 MW by 2015, 7723 MW by 2020, and 20 GW by 2030 [35].

The hydropower technology applied for rural (off-grid) energy can be classified into Mini-hydro, Micro-hydro and Pico-hydro, based on their plant size. Micro-hydro turbines ranging from 1 kW to 100 kW in size and weighing less than 20 kg, making them

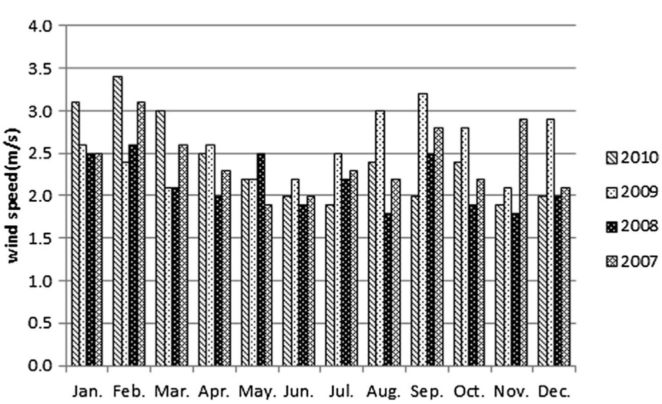

Fig. 9. Mean monthly wind speed in Kudat station (Sabah).

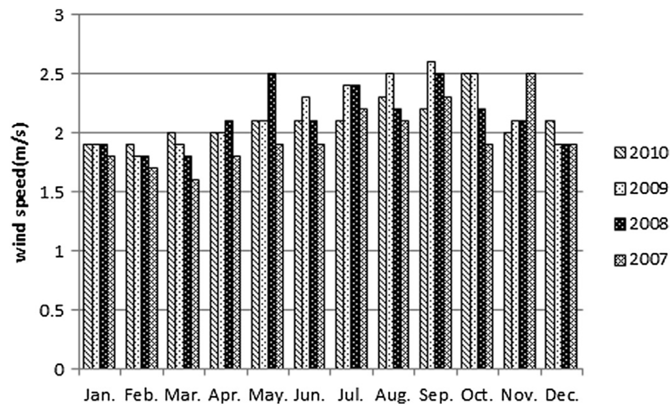

Fig. 10. Mean monthly wind speed in Kota Kinabalu station (Sabah).

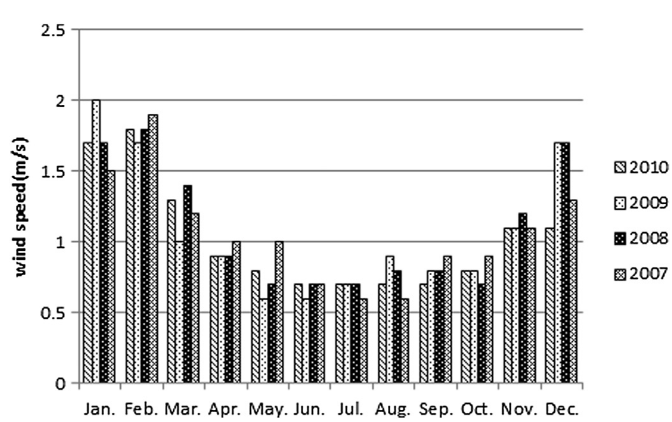

Fig. 11. Mean monthly wind speed in Chuping Station (Perlis)

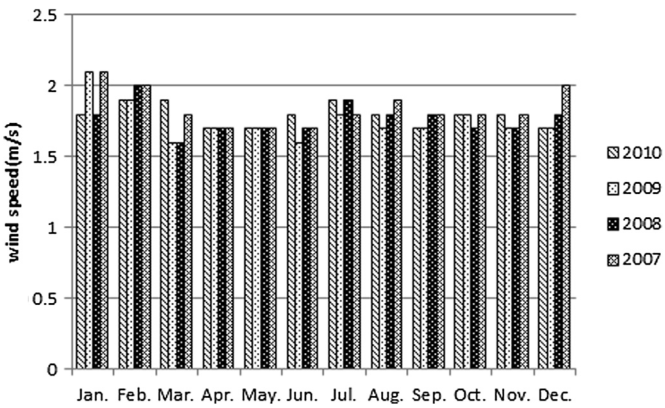

Fig. 12. Mean monthly wind speed in Kuching station (Sarawak).

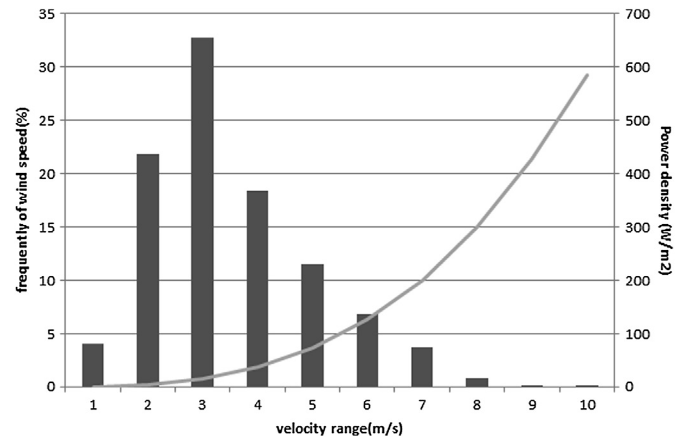

Fig. 14. Wind speed histogram and wind power density at Mersing in 2008 and 2009 (70 m above sea level).

transportable for repairing or fixing, are desirable for rural areas. In addition, from the village point of view, in comparison with the diesel generators, micro-hydro turbines can be used in the hot and humid climate of Malaysia to produce electricity [20]. The micro-hydro generation potential is estimated to be 3182 kW and 5317.6 kW in Sabah and Sarawak, respectively, whilst the total estimated micro-hydro potential for Malaysia is reported to be 28.9 MW. The plant capacities of 100 kW–1 MW are considered as Mini-hydro technologies [36]. The amount of generated electricity by mini-hydropower plant in Malaysia from 1976 to 2008 is illustrated in Fig. 16 [33].

3.3.2. Barriers to using hydropower for rural areas in Malaysia

Since among the hydropower technologies, the mini-hydro and micro-hydro are determined to be applicable in rural areas, the barriers to their application are investigated in this subsection. Although micro-hydropower can be used as the most significant renewable energy (RE) resource in Malaysia, there are some barriers that affect the benefits of this natural resource in rural areas that can be pointed out. Most turbines require a static head of 10 m or more. It is impossible to use the conventional micro-hydro in flat countries where there is little elevation [23]. Hydropower requires expensive civil works, long piping, and expensive control systems. Long transmission lines are not applicable for rural electrification in less developed countries. In addition, the design and installation are done by foreign experts [23]. The capital cost is the common barrier in the mini- and micro-hydro projects, which can be reduced by using locally manufactured components, sizing appropriately and designing correctly.

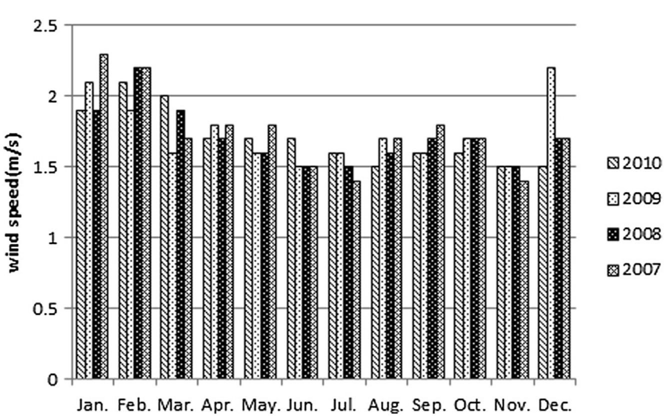

Fig. 13. Mean monthly wind speed in Alor Setar Station (Kedah).

4. Issues related to rural area electrification applying renewable energy

One of the important conditions for the success in rural electrification programmes is good coordination among institutions dealing with these issues at the national level [37]. Many of the common issues to implement renewable energy fall into one of three main categories: 1) economic, 2) legal and regulatory, and 3) financial and institution, which are classified in Table 9 [38,39].

The worldwide progress of rural electrification is very slow. The main reasons for that are high upfront equipment assets and decentralized electricity supply grids that are gradually being extended [37,40–42]. Furthermore, the high cost of transmission and distribution, low electricity demand, low consumption and over dependence on donors make it difficult to extend RE in rural areas [43]. Besides the financial and economic problems, the political problems can also affect the grid extension projects [39]. The factors that can affect the success of a project can be categorized as social, institutional, economic, policy, economic/social, and institutional. Table 10 is a summary of the effective factors, the issues and respective advantages [39].

In summary of the aforementioned, in order to increase the success of renewable energy projects, it is important to ensure certain financial benefits, appropriate siting and community approval for the rural community that is confronted with the renewable energy power plants.

4.1. Policies and issues of renewable energy in Malaysia's rural areas

Renewable energy is one of the best ways to provide electricity for those living in rural communities. It is a key factor to make the right to development a right for all [44]. Many developing countries conduct the rural electrification plans and policies to extend the

Table 7
Wind energy potential.

	Wind speed range at height 70 m (m/s)		Corrected air density (kg/m^3)	Annual available power (kW/m^2)
Sabah, Kota Kinabalu	2.24	3.16	1.12	62.90
Sabah, Kudat	1.71	3.83	1.15	91.71
Sarawak	0.92	2.37	1.15	21.31
Kedah	1.18	2.37	1.15	22.63
Perlis	1.32	2.50	1.15	27.11

Fig. 15. Small wind turbine in Sarawak [23].

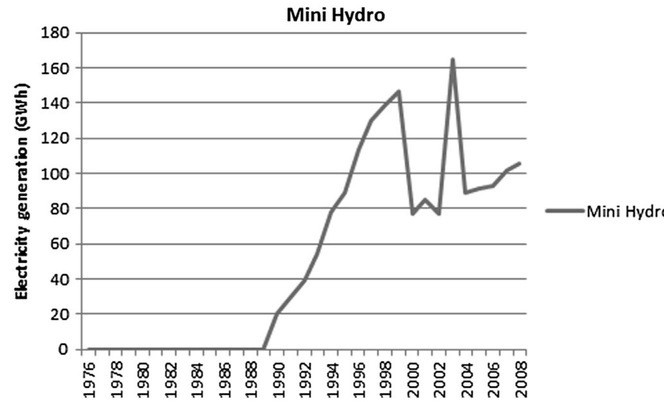

Fig. 16. Electricity generation (GWh) of mini-hydro in Malaysia.

grid connection and improve the standard of living for those who do not have access to an electricity supply. Since in many areas extending the grid connection would be costly and impractical, the advantages of off-grid renewable energy in these areas are taken into account by the policies and rural development programmes. Due to the high initial cost of the systems, the rural electrification with the aid of renewable sources is supported financially [45].

In 2004, about 80% of 300,000 Malaysian poor households were living in five states with the highest concentration in Sabah and Sarawak, where extending the electricity grid is impossible [46]. Enhancing disparities between urban and rural areas is one of the main issues that are considered in Malaysia's energy policy [46]. Primarily, the advantages of natural renewable resources were taken into account by the policy makers and public policy advocates in the 7th Malaysia Plan (1996–2000). In the 7th Malaysia Plan the Government allocated 22.2% of the total allocation to rural development and solar power installations for rural electrification [47,48]. Moreover, in 2000, renewable energy was introduced as the fifth energy supply in order to decrease the dependency of the country on the main energy resources [49]. The fifth-fuel policy was formulated under the 8th Malaysia Plan (2001–2005) to reach the target of 5% electricity generation by renewable energy by 2005 [49]. Utilization of renewable energy for rural electrification, mainly in Sabah and Sarawak, was promoted under the 9th Malaysia Plan (2006–2010). Increasing the quality of life of around 59,960 housing units in rural communities was one of the main goals addressed in the 9th plan [48,50,51]. The main emphasis of the 10th Malaysia Plan (2011–2015) is on increasing the renewable energy market share. It is estimated that by 2030, the share of renewable energy in Malaysia will increase from around 1% to 5.9% of total energy demand [49,52,53]. In order to support the policy plans, some of the strategies and projects that were implemented in Malaysia are investigated. As the initial programme, it can be pointed out that the small renewable energy programme, which was launched in May 2001, was designed "to develop smaller scale systems, especially mini-hydro and solar, which would reach hard-to-access population" [49,54].

Moreover, the Ministry of Rural Development, as the coordinator and planner of rural development programmes and strategies, provided electricity for traditional villages and remote areas under the BELB programme, which either connects the villages to a grid connection or implements a renewable power plan for them [46]. In order to balance the gap between the electrification coverage of Sabah–Sarawak and Peninsular Malaysia, this programme offered financial support based on two methods: 1) grid connection with the limitation of 33 kV delivery line for the villages with a large number of houses, including schools, clinics and other facilities, and 2) alternative resources, such as solar photovoltaic, Gen-Set, solar hybrid for villages with a distance of 10 km or more from the nearest 11 kV grid line and for those for which there is no plan for a grid connection within the next five years [8].

The estimated project costs for an electricity generating ceiling rate of 50 kW for solar hybrid systems are tabulated in Table 11 [8].

It should be mentioned that the presented cost estimations are based on the currency exchange rate of 1 USD = RM 3.80. All the

Table 8
The installed capacity of major hydropower stations in Malaysia [35].

Station	Installed capacity (MW)	Total (MW)
1. Terengganu		
Stesen Janakuasa Sultan Mahmud Kenyir	4 × 100	400
2. Perak		
Stesen Janakuasa Temenggor	4 × 87	348
Stesen Janakuasa Bersia	3 × 24	72
Stesen Janakuasa Kenering	3 × 40	120
Chenderoh	3 × 10.7 + 1 × 8.4	40
3. Pahang		
Stesen Janakuasa Sultan Yussuf, Jor	4 × 25	100
Stesen Janakuasa Sultan Idris II, Woh	3 × 50	150
Cameron Highland Scheme		11.9
4. Kelantan		
Pergau	4 × 50	600
Kenerong Upper	2 × 6	12
Kenerong Lower	2 × 4	8
5. Sabah		
Tenom Pangi	3 × 22	66
6. Sarawak		
Batang Ai	4 × 23.5	94
Total		2091

Table 9
The common issues in rural electrification.

Category	Issues
Economic	Lack of subsidies, high initial capital cost, and high transaction costs for small decentralized system, lack of pricing policies.
Legal and regulatory	Inadequate legal framework, onerous requirements for small power producer set by utility.
Financial and institution	Lack of access to credit for both consumers and investors, lack of sufficient technical, geographical, and/or commercial information by market participants to make sound economic decisions.

Table 10
The effective factors, issues and advantages.

Categories	Issues	Advantages
Social	Ownership	• Reduces maintenance costs • Overcomes tampering • Reduces overuse of the system • Maximizes the benefits
Institutional	Regular maintenance and monitoring	• Increases the system lifetime • Reduces the failure of operation of the system • Improves user's confidence level on the system
	Designing the system according to need	• Increases system reliability and life • Increases the number of users that are able to purchase or pay for the systems
Economic, financing and policy	Innovative financing and smart subsidies	• Improves the affordability of the systems for users • Helps to scale up the programme
Policy	Proper policies and government collaboration	• Increases private sector • Participation helps achieve programme success
Economic/social	Links the system with productive use	• Increases system durability • Makes the system maintenance free

Table 11
Estimated project cost according to the Ministry of Rural and Regional Development.

Number of houses	Cost estimate
20–29	RM 1,000,000
30–39	RM 1,100,000
40–49	RM 1,200,000
50–59	RM 1,300,000
60–100	RM 1,500,000

considered equipment and items are government tax exempted and the transportation cost is considered based on the land or water routes.

5. Conclusion

To investigate the potential for decreasing the energy poverty of the rural area of Malaysia with the aid of off-grid electrification, the current status of energy and electrification in rural areas is investigated. The percentage of electricity coverage, the solar radiation intensity, wind speed and hydro potential of different States in Malaysia were analysed. The potential renewable energy sources of four selected States are summarized in the following table.

City	Annual energy available by solar (kWh/kWp)	Annual power available by wind (kW/m^2)	Annual power available by micro-hydro (kW)
Sabah	1465.475	62.904	3182 from 18 sites
Sarawak	1380.161	91.715	6317 from 22 sites
Kedah	1509.064	21.316	496.7 from 5 sites
Perlis	1441.394	22.633	No site

It can be clearly seen that in Sabah and Sarawak, with lowest electricity coverage and highest concentration of poor people, the potential for applying renewable energy is too high. Among the renewable energy sources, the highest potential belongs to solar energy and hydropower. Although the average annual wind velocity may be slow in Malaysia, it can be a good alternative source for generating energy, especially on remote islands or the East Coast States of Malaysia. However, the potential for utilizing the renewable sources is too high in Malaysia, as the hot and humid climate of the country causes some problems and barriers in implementing the electrification projects. Moreover, to gain the benefit of such systems in rural areas, different issues – social, institutional and economic – must be considered and cooperation sought, otherwise it would be ineffective.

Acknowledgements

The authors would like to thank Ministry of Higher Education of Malaysia and University of Malaya for providing financial support under the research grant No.UM.C/HIR/MOHE/ENG/16001-00-D000024. The authors would also like to thank Mr Ramdan bin Baba from the Ministry of Rural and Regional Development of Malaysia, Mrs Sharifah Faridah Syed Mahbar from the Malaysian Meteorological Department and Mr Mohsen Hamidi, for all the help and cooperation during this study.

References

[1] Population and Housing Census, Malaysia. 2010 census: population distribution and basic demography characteristics 2010.
[2] The World Bank, Countries and economics, Malaysia. Available at: http://data.worldbank.org/country/malaysia; 2009.
[3] World Bank staff estimates based on United Nations, world urbanization prospects. Available at: www.indexmundi.com/facts/malaysia/urban-population; 2009.
[4] Household income & poverty statistics. Available at: http://www.epu.gov.my/household-income-poverty; 2009.
[5] Sreeraj ES, Chatterjee K, Bandyopadhyay S. Design of isolated renewable hybrid power systems. Sol Energy 2010;84(7):1124–36.
[6] Mahmud AM. Evaluation of the solar hybrid system for rural schools in Sabah Malaysia. In: Power and energy (PECon), IEEE international conference Dec. 2010. p. 628–33.
[7] Foster R, Witcher J, Nelson V, Ghassemi M, Mimbela LE, Ghassemi A. Wind energy: renewable energy and the environment. CRC; 2009.
[8] Ministry of Rural and Regional Development. Available at: http://www.rurallink.gov.my/electricity; 2012.
[9] Time series economic statistics "social indicators" Malaysia qualities of life-Quality of life at the states level 2004.
[10] Electricity/heat in Malaysia. Kuala Lumpur: Ministry of Energy, Water and Communications. Available at: http://www.iea.org/country; 2008.
[11] Hussein I, Raman N. Reconnaissance studies of micro hydro potential in Malaysia. In: Proceedings of the international conference on energy and sustainable development: issues and strategies (ESD), 2–4 June 2010.
[12] Johari A, Hafshar SS, Ramli M, Hashim H. Potential use of solar photovoltaic in Peninsular Malaysia. In: Paper presented at the Clean Energy and Technology (CET), IEEE first conference on 27–29 June 2011.
[13] Lim YS, Koh SL. Analytical assessments on the potential of harnessing tidal currents for electricity generation in Malaysia. Renew Energ 2010;35(5):1024–32.
[14] The report Sabah. Oxford Business Group; 2011.
[15] Ministry of Science, Technology and Innovation (MOSTI) Malaysia Meteorological Department. Available at: http://www.met.gov.my/; 2011.
[16] Jais A. National identity: survey on University of Malaya Special Preparatory Program of Japan (SPPJ). In: Proceedings of international conference on humanities, historical and social sciences 2010. p. 478–81.
[17] Azhari AW, Sopian K, Zaharim A, Al ghoul M. A new approach for predicting solar radiation in tropical environment using satellite images – case study of Malaysia. WSEAS Trans Environ Dev 2008;4(4).
[18] Gurmit S, Hee Boon F. Blowing in the wind: Malaysia's renewable energy scene. A CETDEM report funded by DANCED Malaysia. Malaysia, Petaling Jaya: Centre for Environment, Technology & Development; 1996.
[19] Choy Yee Keong. Energy demand, economic growth, and energy efficiency — the Bakun dam-induced sustainable energy policy revisited. Energy Policy 2005;33(5):679–89.
[20] Sovacool BK, Drupady IM. Examining the Small Renewable Energy Power (SREP) program in Malaysia. Energy Policy 2011;39(11):7244–56.
[21] Kernan PA. Outlook for non-residential HVAC equipment. ASHRAE J 2011;25(2):24–7.
[22] Jensen HR. Compared assessment of selected environmental indicators of photovoltaic electricity in selected OECD cities and Malaysia cities. Malaysia: Pusat Tenaga Malaysia; 2006.
[23] Anyi M, Kirke B, Ali S. Remote community electrification in Sarawak, Malaysia. Renew Energ 2010;35(7):1609–13.

[24] Ng KL, Low YH, Ong TA, Dublin N, Razack AH. A prospective study of significance of haematuria in University Malaya Medical Centre. Int J Urol 2010;17(1):299–300.
[25] Sopian K, Othman MYHJ, Wirsat A. The wind energy potential of Malaysia. Renew Energ 1995;6(8):1005–16.
[26] Shafie SM, Mahlia TMI, Masjuki HH, Andriyana A. Current energy usage and sustainable energy in Malaysia: a review. Renew Sust Energ Rev 2011;15(9):4370–7.
[27] Monthly mean surface wind speed. Malaysian Meteorological Department; 1989–2011.
[28] Chiang EP, Zainal ZA, Aswatha Narayana PA, Seetharamu KN. Potential of renewable wave and offshore wind energy sources in Malaysia. Mar Technol 2003.
[29] Darus ZM, Hashim NA, Abdul Manan SN, Rahman MAA, Abdul Maulud KN, Karim OA. The development of hybrid integrated renewable energy system (wind and solar) for sustainable living at Perhentian Island, Malaysia. Euro J Social Sci 2009;9(4):557–63.
[30] Sopian K, Othman MY, Yatim B, Daud WRW. Future directions in Malaysian environment friendly renewable energy technologies research and development. ISESCO Technol Vis 2000;1:30–6.
[31] Ong HC, Mahlia TMI, Masjuki HH. A review on energy scenario and sustainable energy in Malaysia. Renew Sust Energ Rev 2011;15(1):639–47.
[32] Ahmed AS. Wind energy as a potential generation source at Ras Benas, Egypt. Renew Sust Energ Rev 2010;14(8):2167–73.
[33] Shekarchian M, Moghavvemi M, Mahlia TMI, Mazandarani A. A review on the pattern of electricity generation and emission in Malaysia from 1976 to 2008. Renew Sust Energ Rev 2011;15(6):2629–42.
[34] Wong EW, Mohd YMY, Bt MM, Anbazhagan D, Ong SY, Sekaran SD. Disruption of adeB gene has a greater effect on resistance to meropenems than adeA gene in Acinetobacter spp. isolated from University Malaya Medical Centre. Singapore Med J 2009;50(8):822–6.
[35] Stockwell AJ. The crucible of the Malayan nation: the University and the making of a New Malaya, 1938–62. Modern Asian Stud 2009;43(5):1149–87.
[36] Technology Depository Agency. Provided by offset management services division, MiGHT. Available at: www.might.org.my/tda/Publications; 2012.
[37] Tamin S, Anuar N, Lim Y, Abidin I, Azman W. The outcome and survival with medical and surgical treatment of infective endocarditis in University Malaya. Int J Antimicrob Agents 2009;33(2):S9.
[38] Karunakaran R, Raja NS, Hafeez A, Puthucheary SD. Group B Streptococcus infection: epidemiology, serotypes, and antimicrobial susceptibility of selected isolates in the population beyond infancy (excluding females with genital tract- and pregnancy-related isolates) at the University Malaya Medical Centre, Kuala Lumpur. Jpn J Infect Dis 2009;62(3):192–4.
[39] Urmee T, Harries D, Schlapfer A. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. Renew Energ 2009;34(2):354–7.
[40] Haanyika CM. Rural electrification policy and institutional linkages. Energy Policy 2006;34(17):2977–93.
[41] Hatano Y. Renewable energy: will it become competitive?. EU Infrastructure E-magazine3. Available at: http://www.epu.gov.my/household-income-poverty; 2006.
[42] Thevarajah M, Nadzirnah MN, Chew YY. Interference of hemoglobinA1c (HbA1c) detection using ion-exchange high performance liquid chromatography (HPLC) method by clinically silent hemoglobin variant in University Malaya Medical Centre (UMMC) – a case report. Clin Biochem 2009;42(4–5):430–4.
[43] Kadri NA, Raha MG, Abu Osman NA, Abas WABW. The first decade of Biomedical Engineering degree program at the University of Malaya: experiences and achievements. In: . 4th Kuala Lumpur international conference on biomedical engineering 2008;vol. 21(1–2). p. 69–72.
[44] Leete R. Rural electrification and development. Available at: www.undp.org.my; 2007.
[45] Intermediate Technology Development Group. Sustainable energy for poverty reduction: an action plan. Intermediate Technology Development Group, Green Peace; 2002.
[46] Sovacool BK, Bulan LC. Energy security and hydropower development in Malaysia: the drivers and challenges facing the Sarawak Corridor of Renewable Energy (SCORE). Renew Energ 2012;40(1):113–29.
[47] Ab Kadir MZA, Rafeeu Y, Adam NM. Prospective scenarios for the full solar energy development in Malaysia. Renew Sust Energ Rev 2010;14(9):3023–31.
[48] Naidu G. Infrastructure and rural development in Malaysia. Available at: www.cirdap.org.sg; 2011.
[49] Islam MR, Saidur R, Rahim NA, Solangi KH. Renewable energy research in Malaysia. Eng E-Trans 2009;4:69–72.
[50] Haris AH. Current status & prospects of PV power generation in Malaysia. In: IEA PVPS workshop. Korea: JEJU; 2009.
[51] Hashim H, Ho WS. Renewable energy policies and initiatives for a sustainable energy future in Malaysia. Renew Sust Energ Rev 2011;15(9):4780–7.
[52] Oh TH, Pang SY, Chua SC. Energy policy and alternative energy in Malaysia: issues and challenges for sustainable growth. Renew Sust Energ Rev 2010;14(4):1241–52.
[53] Saidur R, Rahim NA, Masjuki HH, Mekhilef S, Ping HW, Jamaluddin MF. End-use energy analysis in the Malaysian industrial sector. Energy 2009;34(2):153–8.
[54] Sovacool BK, Valentine SV. Bending bamboo: restructuring rural electrification in Sarawak, Malaysia. Energ Sust Dev 2011;15(3):240–53.