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REVIEW

Impact of renewable energy on rural electrification in Malaysia: a review

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Abstract Malaysia is rich in renewable energy (RE) resources. Hybrid systems of these resources can contribute strongly to the electrification and sustainable development of rural areas that do not have access to electricity grids. The integration of the generation of hybrid renewable power in remote and rural areas supplies the required power demand and mitigates emissions. Thus, this study reviews the latest literature (theses, journals articles, and conference proceedings) on the need for electricity in remote rural communities, on hybrid RE systems, on environmental impact, and on economic regulation in Malaysia. Power in this country is mainly generated by fossil fuels that emit high concentrations of greenhouse gases. Thus, RE is a potential alternative for to electrify rural areas, to meet current and future energy demands, and to mitigate emissions. Moreover, Malaysia has pledged to reduce its carbon-emission intensity by a maximum of 40 % (2005 level) by the year 2020. Therefore, the implementation of RE technologies in this country is significantly aided by RE projects, research and development activities, technologies, energy policies, and future direction. This review concludes that solar, wind, hydro, and biomass energy, as well as a hybrid of these, can effectively electrify rural areas.

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Introduction

Energy is fundamental to the support and encouragement of the economy and to the modernization of a country. Therefore, the demand for it and the corresponding dependence on fossil fuel have increased significantly in both the developed and developing countries (Carneiro and Ferreira 2012). In fact, global energy demand increases so rapidly that it is projected to increase from 14.5×10^{10} MW in 2007 to 21.8×10^{10} MW in 2035 (i.e., an increase of 49 %) (Hasanuzzaman et al. 2012). Therefore, international researchers aim to fulfill this demand, given that the lack of electricity in rural areas intensifies poverty in developing countries. According to the international energy agency (IEA), nearly 1.3×10^9 people live without electricity, which constitutes 18 % of the global population (IEA 2013). For instance, the electrification rate in Thailand is approximately 88 %, and the rural areas encounter more electrification problems than the urban areas do (Limmeechokchai 2014). The same is true in India, where 68 % of citizens reside in villages (Viral et al. 2013). In Ghana, the electrification problem affects 82 % of rural households and 48 % of communities. However, this issue can be alleviated once the grid-connected system is completed (GME 2014). In Indonesia, which reported an electrification rate of 71 % in 2013, most of the population reside on small islands or along the countryside. Thus, the demand for electricity in this area increases quickly; nonetheless, it is mostly met by and can be enhanced through renewable energy (RE) such as solar energy (Nicola et al. 2013). In Africa, the majority of the population continues to reside in rural and remote areas. As

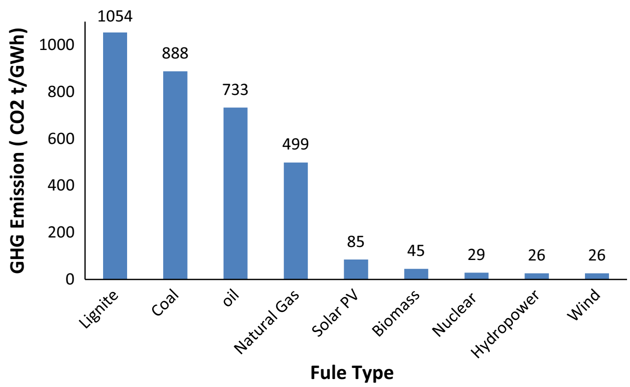

Fig. 1 Mean CO_2 emission rate of different types of fuel (WNA 2011)

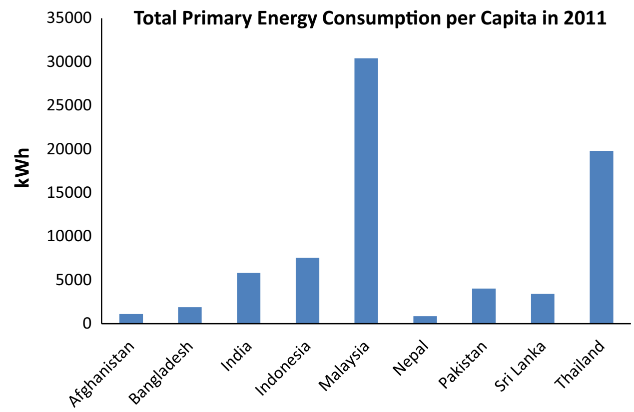

Fig. 2 Comparison of different Asian countries in terms of per capita energy consumption in 2011 (EIA 2014)

a result, the importance of electricity increases daily, particularly in South Africa. The electrification rate in this region is approximately 75 %, and the citizens of this area generally live in rural areas without access to electricity (Kusakana 2014). However, the electrification problem can be resolved with the use of RE, especially solar energy. This rural electrification program effectively installs solar home systems in South Africa, and it has its merit as a method. Despite the advantages of solar energy use in the rural and remote areas of South Africa, this method remains limited (Lemaire 2011). Thus, the rural areas in developing countries must face the corresponding challenges induced by electricity problems. Economically, this problem is a significant in the rural areas of Kenya; nonetheless, the photovoltaic services of the grid-connected electrical system constitute an economically friendly solution (Abdullah 2012). In Malaysia, 809 out of more than 10×10^3 schools lack 24-h electricity. Most of these schools are located in Sabah and Sarawak (Mahmud 2010). The capacity of rural electrification can be expanded by the renewable electricity generated from solar panels, wind turbines, and micro hydro power plants. Furthermore, the use of RE is considerably advantageous for the community as a cost-effective strategy and as a reliable source of energy. Global climate change is also induced because of the alarming rate of excessive greenhouse gas (GHG) emission. The intergovernmental panel on climate change (IPCC) states that the amount of CO_2 emitted globally from various sources is approximately 27×10^9 *t*; of this, roughly, an amount of 10×10^9 *t* is released by electricity generation, which corresponds to approximately 37 % of global emission. This substantial increase in CO_2 emission prompts the construction of many new power-generating facilities that may limit GHG emissions (Klemeš and Varbanov 2012). Nonetheless, the different electricity generation technologies affect the fuel used, the environment, and other parameters in various positive and negative ways. Figure 1 shows the amount of GHG emitted by each technology (WNA 2011).

The per capita power consumption of Malaysia is the highest among the developing economies in the Asian region. Figure 2 depicts the total primary energy consumption of some Asian developing countries per capita in 2011 (EIA 2014). This consumption is expected to increase further as the country develops (FMT 2013). In particular, the estimated increase in electricity generation is 5.3 % from 2005 to 2030 in Malaysia as a result of strong economic growth (Vision 2020). RE can contribute significantly to meeting this demand (Maroušek et al. 2014). It is mostly accessible in isolated areas; thus, it suitably supplies electricity to such areas. Many advanced countries spend extravagantly on RE and the development of its technology. The RE resources that have been established are solar photovoltaic (PV), wind, and hydro. In Malaysia, the rural areas in Sabah and Sarawak mainly utilize RE as electricity sources. The 10th Malaysia Plan (2011–2015) emphasizes the increase in the share of RE from approximately 1 to 5.9 % by 2030 (Borhanazad et al. 2013). Thus, various research intuitions [e.g., UM Power Energy Dedicated Advanced Centre (UMPEDAC), the University of Malaysia; Renewable Energy Research Group, International Islamic University Malaysia; Centre of Research & Innovation In Sustainable Energy, Universiti Teknologi MARA; Solar Energy Research Institute, and Universiti Kebangsaan Malaysia] investigate solar, wind, hydro, biomass RE systems, hybrid renewable power generation, and rural electrification. The important components of rural electrification in Malaysia are RE-based power generation, optimization, hybrid power, system integration, and monitoring.

Solar irradiance is abundant in Malaysia, where the annual average irradiance in Malaysia is 1,643 kWh/m^2. Thus, this country is among the leading users of solar PV in the world (Chua and Oh 2010). Sabah and Sarawak encounter high volumes of rainfall that average 3,540 mm/year. This large amount of water can be a source of hydropower (Pimentel 2008). Moreover, the northern wind in the area reaches roughly 15 m/s. International interest has increased with respect to rural electrification by hybrid renewable systems, including large-scale PV, wind, and hydro. The combination of PV, wind, hydro, and biomass energy may enhance rural electrification significantly while reducing environmental pollution (Afshar et al. 2012). Thus, the application of hybrid power generation is promising especially in rural areas, where transport and communication are difficult (Shiroudi et al. 2012).

This review investigates the energy usage, RE resources, potential applications, suitable hybrid systems of renewable energy generation, the impact of energy generation on the environment, and the energy policy in Malaysia. It also identifies the factors that influence the existing power supply crisis and summarizes the present energy scenario, infrastructure, and conventional resources.

Effect of energy generation

The modern world uses energy everywhere, such as in travel, industry, buildings, lighting, and cooling. Energy demand is projected to raise from 1.6×10^4 MW in 2012 to 2×10^4 MW by 2020. This increase is prompted by the country's new economic model, that is, the economic transformation program (ETP) and the strong GDP growth (Yang et al. 2014). In 2011, the International Energy Outlook projected that worldwide energy consumption will increase from 1.4×10^{11} MWh (5.3×10^{20} J) in 2008 to 2.3×10^{11} MWh (8.1×10^{20} J) in 2035 for a significant growth of 53 %. Furthermore, energy demand will continue to increase by 85 % between 2008 and 2035 in countries outside the organization for economic cooperation and development (non-OECD), which is more than five times the energy required by OECD countries (USIEO 2013). This increase ultimately heightens fuel consumption and GHG emission. According to the World Nuclear Association (WNA), approximately 37 % of global CO_2 emission originates from electricity generation plants. Electricity demand is projected to increase by 43 % in the next 20 years (WNA 2011). Therefore, alternative sources of energy are essential. Solar, wind, and hydro systems are the most promising power generation technologies because they are eco-friendly (Mahesha and Kaushik 2012). Energy demand is increasingly volatile, thus influencing the national growth of many developing countries (Rashidi et al. 2014). The environmental impact is considerable given the excessive use of energy by the modern world. Each form of energy generation emits GHGs, but the amount of RE emitted is considerably negligible (Fig. 1). To produce electricity, Malaysia depends greatly on fossil fuels; crude oil generated almost 94.5 % of its electricity in 2009 (Shafie et al. 2011). The demand per capita increased sharply. Figure 3 illustrates the electricity demand trends in Malaysia between 1980 and 2010 (ST 2013).

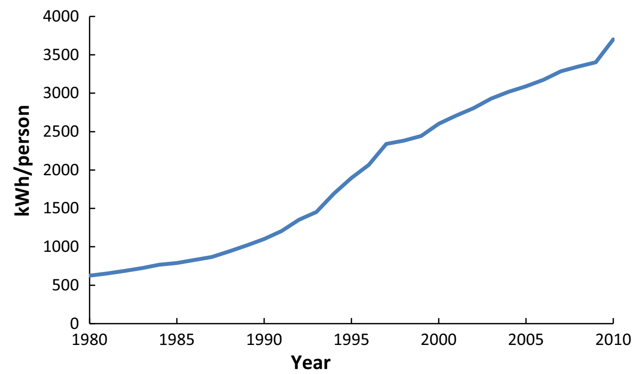

Fig. 3 Electricity demand per capita in Malaysia (ST 2013)

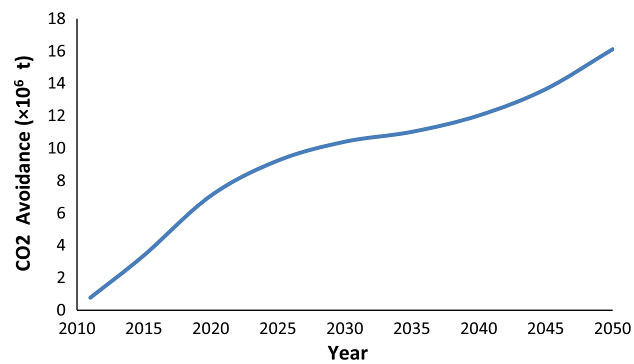

Fig. 4 SMART targets of the Malaysian policy on CO_2 emission reduction (Hashim and Ho 2011)

To meet this increasing demand and to address the consequent environmental issues, the Malaysian government implemented the RE Policies Act of 2011. Figure 4 depicts the specific, measurable, attainable, realistic, and time-based (SMART) targets of the policy in relation to the reduction of CO_2 emission. The three main objectives of the Ministry of Energy in developing the energy sector are (Hashim and Ho 2011): (a) safe, secure, and efficient supply, (b) the optimized use and limited waste of energy, and (c) reduced negative impact on the environment.

Potentiality of solar energy

Malaysia experiences abundant sunshine throughout the year; thus, it is an appropriate environment for the

Table 1 Solar energy applications and technologies

S/N	Name of technology	Application	References
1	Solar PV	PV module-generated electricity for isolated locations in big cities and rural areas	
2	Concentrated solar power (CSP)	Heat from concentrated solar power drives heat engines (steam turbines) and produce electricity. Approximately 1,789 MW CSP base power stations have been added to the national grid in Spain as of 2013	CSP (2013)
3	Solar water heating	Solar thermal energy is mainly used to heat household and swimming-pool water. China aims to increase the generation of solar water heating power by up to 210 GW by 2020	Werner et al. (2008)
4	Solar heating, cooling, and ventilation	The U.S. saves 30 and 50 % off commercial and residential energies, respectively, using this technology	HCCCBS (2008)
5	Solar water treatment	Wastewater is treated without using either chemicals or energy. This technology is applied to the drinking water of roughly two million people	Tadesse et al. (2003)
6	Solar cooking	This technology is used when nominal fuel is required or when the risk of an accidental fire is high. Approximately two billion people still cook over open fires.	SODIS (2008)
7	Transportation and reconnaissance	Solar energy was successfully used to operate boats, cars, and aircrafts	Goebel (2011)
8	Day lighting	If properly implemented, solar energy can reduce lighting-related energy consumption by 25 %.	Apte et al. (2008)

development of solar energy. Solar PV is a highly promising RE option (Chua and Oh 2012); a PV system in Kuala Lumpur receives nearly 30 % more irradiation than Germany does. In particular, the amount of solar irradiation received in ranges from 1,400 to 1,900 kWh/m^2/year geometrically. Meanwhile, the average daily solar irradiation ranges between 4.21 and 5.56 kWh/m^2/year. The estimated maximum solar irradiation is 6.8 kWh/m^2 in August and in November, whereas the minimum is 0.61 kWh/m^2 in December (Mekhilef 2010). However, PV is too expensive for mass production, although the potential use of solar PV power is remarkable especially in the rural

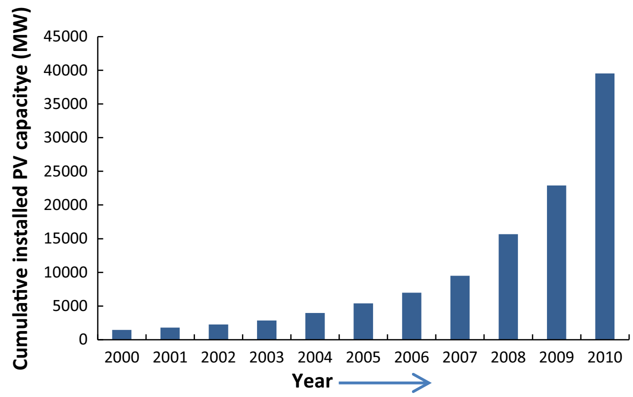

Fig. 5 Development of the global cumulative installed capacity of PV (2000–2010) (Bawakyillenuo 2012)

areas of Malaysia (Ahmad et al. 2011). The solar PV system has been applied to rural electrification since the 1980s by the National Electricity Board in Malaysia. Moreover, the Ministry of Rural Development has provided PV systems for rural electrification since the late 1990s. Remote areas without grid-connections receive electricity from renewable sources and other options such as diesel genset (Chong et al. 2011).

Malaysia is estimated to be capable of producing electricity that is statistically equivalent to the country's 2005 requirements. The effective planning and design of PV systems enable long-term output and minimal maintenance (Nashed et al. 2013). In line with this information, the Malaysia building integrated photovoltaic (MBIPV) project was started in July 2005 (Muhammad-Sukki et al. 2012) to reduce the long-term cost of BIPV in the country. The investment return period is 1.6–2.2 years for rooftop systems. CO_2 mitigation ranges from 20 *t* to 40 *t* in rooftop installations, and approximately 1,652 kWp of PV systems have been successfully installed in Malaysia.

Solar energy applications in Malaysia include solar PV, solar heating, and solar construction, all of which contribute significantly to solving the most recent energy problems in the world (SEP, 2011). Solar energy is classified as either active or passive. Furthermore, IEA predicts high long-term profit from the improvements that result in unlimited solar energy. Solar energy enhance energy safety through dependence on an original and unlimited resource, improves sustainability, reduces pollution, and lowers the price of crude oil (SEP, 2011). Table 1 lists the types of solar energy application and technology. As per this table, solar PV cells are the most popular global application.

The applications of solar energy in Malaysia are separated into two major categories: solar thermal and PV. The first Malaysian BIPV system has a capacity of 3.15 kWp and was installed in 2000 (Mekhilef et al. 2012). Figure 5 displays the worldwide cumulative installed capacity of

PV, which was 0.1 GW in 1992, 14 GW in 2008 (a significant increase), 22 GW in 2009, and over 37 GW by the end of 2010 (Purwandari et al. 2013).

Positive effects of solar energy (EGT 2013)

Reduced pollution Solar PV panels do not pollute the air.

Lack of GHG emission Solar panels do not release GHG into the atmosphere.

Noiselessness Solar panels operate silently because they do not contain moving parts.

Job creation Many jobs are created by solar power generation.

Decentralization of power Independent power generation is encouraged.

Infinite source of free energy Solar energy is completely free beyond the initial installation and the post-installation maintenance.

Off-grid application of solar energy Solar energy is used either on-grid or off-grid.

Negative effects of solar energy (EGT 2013)

Environmental pollutant Solar panels are constructed using available substances such as silicon tetrachloride which is a pollutant.

Heavy metal emission The manufacture of solar panels uses much energy, pollutes the environment, and emits dangerous metals and GHGs.

Inability to produce energy at night Solar systems cannot produce energy during the night.

Environment-dependent The applicability of solar energy depends completely on the environment; dense and foggy weather is not conducive to the production of solar power.

Low efficiency of solar panels The efficiency of solar panels is only roughly 22 %.

Requirement for a large area Large and open areas are required by PV-generated electricity.

Requirement for energy storage devices The technology has yet to reach its potential.

High initial cost The initial installation of a solar home system or building is costly.

Potentiality of wind energy

The development of wind power is influenced by the abundance of wind and environmental friendliness. A minimum of 83 countries commercially use over 200 GW of wind power (Liu et al. 2013); the wind-energy application types are listed in Table 2. Wind is converted into electrical energy by wind turbines; nonetheless, technologies that produce electricity from low-velocity winds are being developed. Wind turbines are used on 1–10 % of wind farms (Fthenakis and Kim 2009). Specifically, Denmark generated approximately 25 % of its electricity from wind in 2011 (WP 2013). Moreover, commercial wind energy industries are being established at an annual rate of roughly 30 %. Wind power is rapidly and increasingly installed globally, and the installed capacity rose to 2.8×10^5 MW (18.7 % increase) from 2.4×10^5 MW as of the 2011 that is shown in Fig. 6 (GWEC 2013). In China, the installed capacity of wind power is 7.5×10^4 MW. Comparatively, several countries have generated high levels of wind power (Nieves et al. 2011).

Table 2 Wind energy technology and application

S/N	Name of wind energy technology	Application	References
1	Mechanical power	A wind pump drains the land for agriculture and residences	Lindsay (2012)
2	Electrical power	A wind turbine is used to power lights	Hardy (2010)
3	Small/large and grid-unconnected	Remote areas without access to the grid	WPA (2013)
4	Small and grid-connected	Grid connections are utilized in remote and small communities	WPA (2013)
5	Large and grid-connected	1 MW-rated turbines are presently common 2 MW-wind turbines are still being tested	WPA (2013)

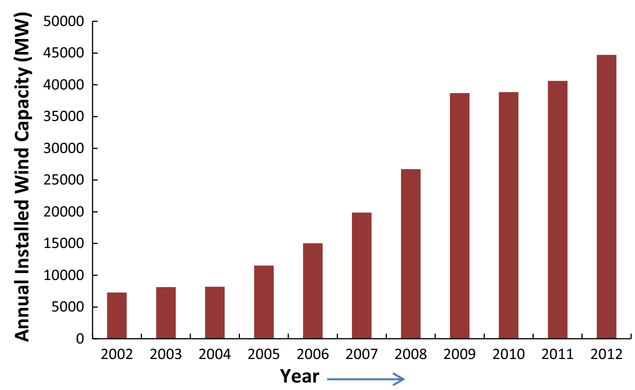

Fig. 6 Global annual installed wind capacity 2002–2012

Malaysia experiences two types of monsoon seasons. The northeast monsoon blows from November to March and originates from Middle Asia to the South China Sea. It then passes through Malaysia before proceeding to Australia. The southeast monsoon blows from May to September. It originates from Australia and moves across the

Sumatra Island to the Straits of Malacca (Mekhilef 2010). The energy from these monsoon winds is a potentially renewable source for successful rural electrification. The average wind speed in Malaysia is low; however, the northern wind can reach approximately 30 knots, which suitably produces electricity through a low-speed wind turbine. The study conducted successfully to generate electricity that is appropriate for the wind situation in Malaysia (Shafie et al. 2011). The northwest coastal areas in Sabah and Sarawak are potential environments in which wind energy can be converted to electrical energy given the wind strength of roughly 10 m/s or more. The wind speed is the highest from October to March; therefore, hybrid wind power systems can realistically complement the existing electrical supply during the monsoon seasons (Shafie et al. 2011). Table 2 lists the types of wind energy application and technology.

Tenaga Nasional estimates that Malaysia can produce 500—2 × 10^3 MW of wind-generated power. Some areas along the Malaysia–Thailand border record maximum wind speed of 15 m/s, which is suitable for the generation of wind power (Sung 2010).

Positive effects of wind energy (ADWP 2013)

Free The cost of electricity generation is lowered.

Environment friendly Fossil fuel is not burned.

Reduced global pollution No GHGs or other form of pollutants are emitted.

Small space requirement Wind turbines require smaller spaces than an average power station.

Accessibility by remote areas Electrification efforts are aided.

Strong business opportunity Wind power generation generates such opportunities.

Negative effects of wind energy (CEI 2013)

Power fluctuation The amount of power generated fluctuates with wind speed.

Noise pollution Wind turbines can be noisy.

Pollution The manufacture of wind turbines produces pollutants.

Size A large wind turbine should be constructed to generate an equally large amount of electricity.

Heavy equipment Wind turbines are problematic to transport.

Potentiality of hydro energy

Since the early twentieth century, the term hydro energy has been used in relation to modern improvements to hydropower generation. In 2010, approximately 16 % of global electrical power was generated by hydropower plants; this figure is expected to increase by 3.1 % every year over the next 25 years. Hydropower is generated in 150 countries, and the Asia–Pacific region produced 32 % of global hydropower in 2010 (WI 2014). The large amount of hydroelectricity produced by China in the same year served 17 % of its domestic electricity demand. Moreover, Norway generates 98–99 % of its electricity from hydropower sources (NEBP 2009).

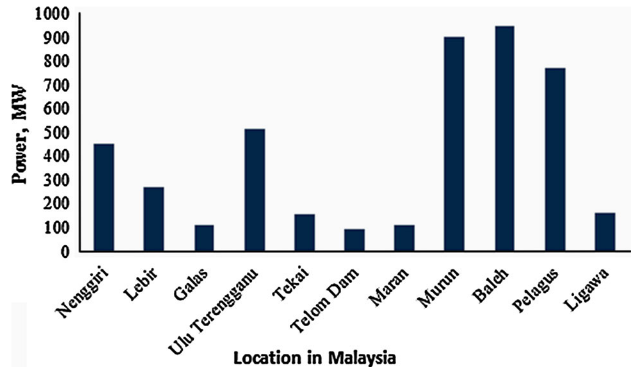

Fig. 7 Locations and installation capacities of Malaysian hydropower plants

Forty-two percent of Malaysia is composed of highlands, with a total area of 3.3 × 10^5 km^2 (Ahmad et al. 2011). The heaviest rainfall measures approximately 2,500 and 5,080 mm in West and East Malaysia, respectively, from September to December and from October to February. Hydropower is obtained from the energy derived from either high-head falling water or from a large volume of water. Thus, heavy rainfall and high water head generate much hydropower. Figure 7 presents the locations and corresponding capacities of Malaysian hydropower plants (Shafie et al. 2011).

The rural areas in Malaysia can use the micro hydropower system, which converts the energy obtained from rain water into electricity. These systems are small, cost-efficient, and easily controlled. The ideal criteria for them are met in many areas of Malaysia. Figure 8 depicts a micro hydropower system from a Malaysian project. Such projects may thrive because the communities they serve treat these undertakings as their own and make efforts to improve them. Their efforts are rewarded in the form of increased capacity and the availability of electricity (SSS, 2013). In July 2009, a total of 30.3 MW of micro hydro is under construction and the expected potential by 2020 is 490 MW (Ahmad et al. 2011).

The types of hydropower application and technology used depend on water volume and head. Table 3 presents the types of hydro energy application.

Fig. 8 Community-based hydro power installations in Sabah and Sarawak (SSS 2013)

Table 3 Hydro energy technology and applications

S/N	Name of hydro energy technology	Application	References
1	Large hydro	(1) Gorges Dam (22.5 GW) (2) Itaipu Dam (14 GW) (3) Guri Dam (10.2 GW)	WI (2014)
2	Small hydro	In 2008, its capacity increased to 85 GW (28 % increase) compared with that in 2005	WI (2014)
3	Micro hydro	Many systems generally produce up to 100 kW of power and are used in rural area electrification	MHS (2014)
4	Pico hydro	This technology is used by small, remote communities that require little power	Williamson et al. (2014)

The three hydropower systems operated by Tenaga Nasional Berhad in Peninsular Malaysia report a total installed production capacity of 1.9×10^3 MW. Several independent power generators also own and operate numerous small hydropower plants.

Positive effects of hydro energy (ADH 2014)

High reliability Hydro power plants are a reliable source of electricity.

Low power generation cost Hydro power plants reduce the cost of electricity significantly.

Low operation cost Hydroelectricity is a domestic energy source. Hydropower is highly efficient and entails very low cost in terms of operations and maintenance.

Reduced fossil fuel cost Hydro power is used instead of fossil fuels.

Reduced employment cost Hydro power plants do not require many employees.

Inexpensive hydroelectric stations Such stations are inexpensive to operate.

Alternative usage of the reservoir Large hydro powerplant dams can control floods.

Negative effects of hydro energy (ADH 2014)

Damage to the ecosystem and the loss of land Dams destroy bio-ecosystems.

Relocation of locals This step may be necessary.

Environmental effect Ecosystem damage contributes to climate change.

High initial cost The setup cost of hydroelectric power generation can be high.

Quality of river flow Hydro power plants can affect water flow and its quality.

Potentiality of biomass energy

Biomass is a prominent source of RE internationally. In developing countries, rural households consume the most of the biomass fuel (Halder et al. 2014). Most rural residents, along with a large portion of urban citizens, meet the increasing energy demand with biomass energy either directly or indirectly. Direct consumption involve cooking, space heating, and industrial processes, whereas indirect consumption includes the advanced processes of converting biomass into secondary energy (Hasanuzzaman et al. 2014). In 2010, the use of biomass in the power production increased significantly in a number of European countries, in the United States, in China, in India, and in some other developing countries. The estimated global biomass power capacity was 83 GW as of the end of 2012, which was 12 % higher than that in 2011. The global market of biomass manufacturing is expected to increase from USD 5.7×10^{11} to USD 6.9×10^{11} during the period of 2010–2015. The worldwide generation of electricity from biomass incineration has also gained momentum recently; the total electricity generated from biomass was approximately 3.5×10^8 MWh in 2012. This value represented a rate of increase of 5 % over that in 2011, which was estimated to be roughly 3.4×10^8 MWh (Halder et al., 2014).

Positive effects of biomass energy (BE 2014)

Lack of harmful emissions This type of energy does not emit harmful CO_2.

Abundance and renewability Biomass products are abundant and renewable.

Table 4 Potential of RE in Malaysia

RE	Potential (MW)
Hydropower	22,000
Mini-hydro	500
Biomass	1,300
Municipal solid waste	400
Solar PV	6,500
Wind	2,850

Table 5 Potential RE sources of four selected states

City	Annual available solar energy (kWh/kWp)	Annual available wind power (kW/m^2)	Annual available micro hydro power (kW)
Sabah	1,465.5	62.9	3,182 from 18 sites
Sarawak	1,380.2	91.7	6,317 from 22 sites
Kedah	1,509.1	21.3	496.7 from 5 sites
Perlis	1,441.4	22.6	No site

Reduced dependency Biomass energy reduces the dependency on fossil fuels as an alternate source of energy.

Reduced landfills Biomass energy prevents unnecessary expenses.

Negative effects of biomass energy (BE 2014)

Inefficiency Biomass energy is less efficient than fossil fuel energy.

Damage to the ecosystem The use of trees and tree products to generate power affects the eco-system.

Large land requirement The production of biomass requires much land.

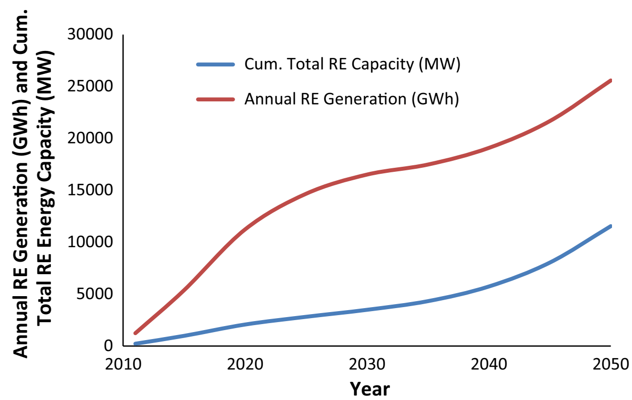

Fig. 9 SMART target for RE in Malaysia

RE in Malaysia

Availability of RE

Malaysia has numerous RE resources, including solar, wind, hydro, and biomass energy. However, they have not been applied, and are continuously being researched and developed (Borhanazad et al. 2013). The country generated significant results in relation to the application of such energy sources; nonetheless, the optimal use of RE has not been determined. Table 4 represents a brief summary of the potential use of RE for power generation in Malaysia (Oh et al. 2010). Permanent quests and studies focus on biomass as an alternative fuel (Ashnani et al. 2014). Table 5 summarizes the potential RE sources of four selected states (Borhanazad et al. 2013).

Energy policies

Fossil fuel prices increase with the maturity of technology; however, the cost of RE systems decreases (Mahapatra and Dasappa 2012). Climate change is a worldwide concern caused by GHG emission, which is in turn produced in electricity generation of electricity and by industries and vehicles (Garrison and Webber 2011). In 2011, Malaysia legislated the RE Act after initiating the development of RE (since 2000). The five-fuel policy adopts the principle that applies market forces to generate the intended outcomes of electricity production (SEDA 2011). In June 2010, the government implemented the National RE Policy and Action Plan to increase the supply of electricity from RE sources from 1 to 5.5 % by 2015 (Shafie et al. 2011).

Malaysia also pledged to reduce its carbon-emission intensity by up to 40 % (2005 levels) by the year 2020 at the 2009 United Nations seminar on climate change, which was held in Copenhagen (SEDA 2011). To ensure the effectiveness of the strategic RE thrusts and to accomplish the RE policy objectives, evaluation criteria must be developed and success indicators identified. A baseline must be established against which proof of improvement or progress can be measured. This baseline also identifies the data requirements for current and future assessments, as well as data collection issues. Therefore, it is necessary for most of the thrusts. Malaysia may be implemented baseline assessments for RE power generation, industry, research and development, public awareness, and skill levels. The SMART target (Fig. 9) is an important aspiration, but adequate allowance must be provided to achieve it. A

Table 6 Production cost of renewable power in Johor, Malaysia

RE	Maximum power output (kWh)	Total power production (kWh/year)	Energy cost ($ kWh)
PV panel	21.4	35,731	0.734
Wind turbine	0.42	159	1.054

tolerance of 10 % of the target is reasonable, and the target should also be reviewed periodically every three years (KeTTHA 2013).

According to the SMART target, CO_2 emission will be reduced by 16×10^6 *t* from 2011 to 2050 (Fig. 4). The first column of the Schedule of the RE Act 2011 presents renewable resources as frequent and non-depleting local resources or technology (SEDA 2011). The present focus of the Malaysian government is on increasing the number of effective RE policies (Hashim and Ho 2011). In fact, KeTTHA has already mapped out the RE resources in the country over the next 20 years (Fig. 9) (KeTTHA 2013). Renewable hybrid programs are also being implemented to accomplish the SMART target.

RE cost

A stand-alone PV system is mainly composed of solar energy sources. In Malaysia, the technological cost is highly subsidized (Borhanazad et al. 2013). Therefore, the prospect of solar energy use in electrification is high. Borhanazad et al. developed a suitable wind turbine for low wind speed to increase the wind energy potential of the region, to improve wind-energy power generation in remote areas, and to reduce production cost (Borhanazad et al. 2013). Mini- and micro hydro energy systems are also suitable for rural electrification in which most of the turbines require a static head of 10 m or more (Anyi et al. 2010). The rural areas in Malaysia are suited for small-scale biomass gasification generators ranging from 2 to 5 kW (Alauddin, 99). Haidar et al. also evaluated the optimal configuration for a system of renewable hybrid power generation based on the collected data and load (Haidar et al. 2011). The authors applied a similar load to a hybrid system that consists of a PV array and a wind–diesel generator. Furthermore, the feasibility of the use of renewable power was analyzed based on the production cost of solar-power and wind-power utilization. It was then compared with its annual yield. Table 6 shows the maximum power output, total annual power production, and energy cost for every kWh of energy obtained from the PV panel and the wind turbine (Haidar et al. 2011).

Electrification of rural areas with hybrid RE

Electricity directly improves human development index. In Bangladesh, this index is significantly higher in households with electricity than in those without. Thus, hybrid RE electrification is currently applied for sustainable development in remote areas. Renewable sources depend on the environment: solar energy depends on sunlight, wind energy depends on wind velocity, and micro hydro energy system depends on rainfall. Nonetheless, continuous sunlight, rainfall, or optimum wind velocity is impossible throughout the year. Therefore, hybrid RE is a feasible solution to this problem. The international energy demand will continue to increase by up to 33 % between 2010 and 2030 (Abdelaziz et al. 2011). However, the progress of electrification is gradual. According to IEA (2009), 1.3 billion people live without electricity, which represents 18 % of the global population. Thus, rural electrification is a huge challenge. Many areas in Malaysia are not linked to the electrical grid; therefore, some remote areas are fully reliant on local electricity supply sources, such as diesel genset (Bekele and Palm 2010). Moreover, several places reduce their diesel gensets because of the high costs of diesel and maintenance. As a result, rural/remote areas pay extra to enjoy fossil-fueled electricity supply, thereby mitigating the economic aids of electricity. In this case, RE is an optimistic solution to rural electrification. Nonetheless, RE depends on environmental conditions, and no single RE can meet specific electricity needs. Thus, a suitable arrangement should be developed for the utilization of RE from natural resources in electrical production. A hybrid of solar/wind/hydro energies may be ideal for rural electrification.

The electrification of rural/remote areas through grid connection is generally costly or is simply not planned. Therefore, the alternative electricity generation sources include solar panels, wind turbines, micro hydro turbines, and biomass energy. Figure 10 illustrates the plans of the Malaysian government to enhance RE generation. A review on hybrid schemes indicates that its annual reliable output is higher than that generated by either wind-only or PV-only schemes. Hybrid systems (consists of solar, wind, and hydropower energy) are mainly advantageous because of the enhanced consistency of energy supply. However, the energies generated by solar, wind, and hydro resources may differ, that is, a mismatch is observed at the period of load demand. Therefore, storage batteries and diesel generators should be prepared to ensure continuous power supply (Fig. 11) (Bekele and Palm 2010).

The daily hassle-free use of RE is facilitated by hybrid systems of PV, wind, hydro, and diesel genset.

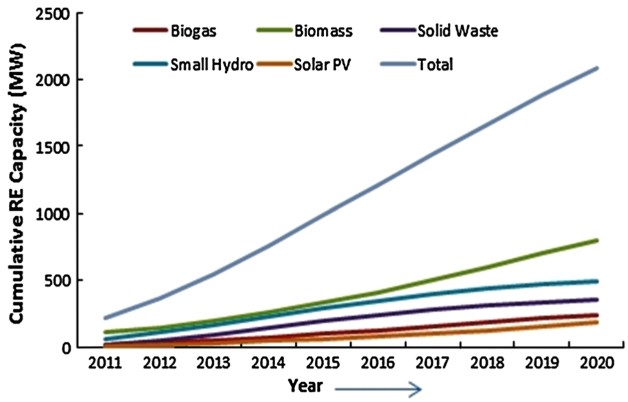

Fig. 10 Cumulative capacity for RE (MW) in Malaysia (KeTTHA 2013)

Drawbacks and solutions to the implementation of RE technology in Malaysia

Drawbacks

The implementation of RE technology for sustainable development is challenging. Despite the many benefits of RE resource utilization, Malaysia is limited by technological development, high RE costs, and energy security.

Financial limitations

The implementation of RE technology is primarily barred by high initial investment costs and the lack of suitable equipment. A sustainable market may reduce technological cost; however, this market cannot be generated when the technology is economically poor. Furthermore, the financial incentives for PV development are inadequate. This financial barrier can be reduced through a customized financial incentive program. The sales price of electricity also restrains the development of RE technology because it discourages many investors (Mekhilef 2010).

Lack of an agenda in the policy

The sustainable development policy lacks an appropriate agenda. These policies merely state the aims and copious approaches that can be applied by the government to develop green and sustainable technology (Kamaruzzaman et al. 2012).

Lack of resources

The supply of resources is uncertain because contributors are not committed to long-term agreements with RE project developers. For example, waste supply is dependent on the

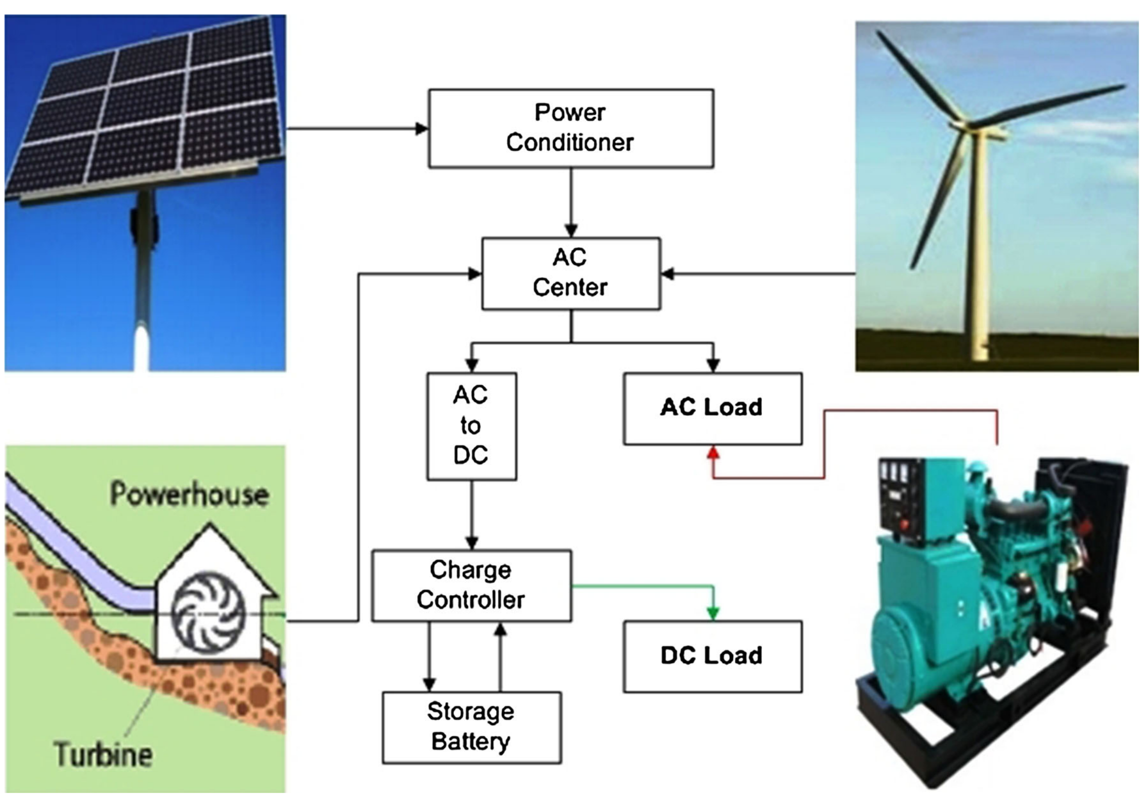

Fig. 11 Standard renewable hybrid system (GP 2013)

capacity and operation of mills; thus, the actual volume and quality of the wastes are inconsistent (Mekhilef 2010).

High import duties

High import duties are another barrier in Malaysia. The instruments used by the power sector are assigned import duties of up to 45 % and a sales tax of 10 %. Moreover, some of these instruments require an import license (Mekhilef 2010).

Sustainable development is also primarily limited by the lack of expertise, public interest, and awareness regarding environmental and energy issues (Kamaruzzaman et al. 2012).

Probable solutions to sustainable development

Policy

To implement RE technology, the government must pass acts and policies with sufficient incentives. The following can be subsidized: (1) the connection of RE technology to grid systems for large-scale development; (2) the integration of RE technology with fossil fuel-power generation systems; (3) small projects in remote areas; and (4) RE as a preferred component of power generation for residential purposes (Kamaruzzaman et al. 2012).

Funding from the private sector

Private sectors (developers and financial institutions) may enter the RE technology market as well. Such developers must be aware of environmental issues and energy security, and financial institutions may provide loans to these developers at low interest rates to establish RE technology. A "National RE technology fund" can be established and campaigned as an encouragement for residents develop technology for domestic purposes (Kamaruzzaman et al. 2012).

Tax relief and rebates

The provision of tax relief from the government can also encourage developers of RE technology, especially those in the solar power market. Additional rebates on electricity bill can also be an incentive for those who generate and consume power from renewable resources (Kamaruzzaman et al. 2012).

Finally, skilled manpower and expertise can be crucial in RE development. The scope of RE technology is wide and open for exploration and improvement. However, the lack of skilled manpower limits this endeavor. Therefore, higher education can offer related programs. Furthermore, technical schools and diploma programs in universities can develop the required expertise. Courses and workshops can also be organized for professionals (Kamaruzzaman et al. 2012).

Discussion

Hybrid renewable power is the most suitable option for rural/remote area electrification. Hybrid power systems are highly reliable, entail low-cost, and can generate power over the long term. Nonetheless, Malaysia continues to import a large amount of crude oil required for its energy supply; not only does this activity increase foreign-currency expenses, but the fossil fuel also pollute the environment. Many technologies have been developed at present to generate electricity from renewable sources. Although many of these technologies are unproven, the research on them and the potential enhancements are promising (Lee and Zhong 2014). Malaysia's SMART targets aim to reduce CO_2 by increasing the utilization of renewable sources and to lower the 2011 CO_2 emission levels by 16×10^6 *t* in 2050. These goals can be achieved through the optimal use of various RE resources and their hybrid technologies.

Conclusion

The literature indicates that solar, wind, and hydro energies are the main RE-based rural electrification options. The increased use of RE reduces dependence on fossil fuels and lowers GHG emission. Globally, electricity demand may increase by 35 % between 2010 and 2040, whereas the amount of electricity generated in Malaysia is expected to increase by only 5.3 % between 2005 and 2030. The CO_2 emitted by electricity generation constitutes 37 % of global CO_2 emission. To reduce the CO_2 emission of Malaysia by 7.1×10^6 *t*, the country aims to produce 10 % of its electricity through RE by 2020. Thus, hybrid RE resources are being considered in the electrification project of Malaysia's rural locations to meet the rising energy demands and to reduce GHG emission.

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