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Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia

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ABSTRACT

Currently, around 90% of Malaysia's electricity generation depends on fossil fuels. This reliance, in a long run, is not a secure option. However, renewable energy sources can contribute to a sustainable electricity generation system; but diversifying fuel supply chain is a complex process. Therefore, the aim of this paper is two folds. Firstly, various renewable resources potential are reviewed, and secondly an assessment model is developed for prioritizing renewable options. Four major resources, hydropower, solar, wind, biomass (including biogas and municipal solid waste) are considered. Their electricity generation potential, along with any likely shortcoming is also discussed. Moreover, using a multi-perspective approach based on analytic hierarchy process (AHP), an assessment model is developed. AHP model employs four main criteria, technical, economical, social and environmental aspects, and twelve sub-criteria. From the review it was found that renewable resources seem to have a sufficient potential to develop a sustainable electricity system. Furthermore, AHP model prioritize those resources, revealing that solar is the most favorable resource followed by biomass. Hydropower and wind however, are ranked third and fourth, respectively. The model also shows that each resource is inclined towards a particular criterion; solar towards economical, biomass towards social, hydropower towards technical, and wind towards environmental aspect. Besides reporting AHP model for the first time in Malaysian context, the assessment performed in this study, can serve decision makers to formulate long-term energy policy aiming for sustainability.

1. Introduction

Energy has become a crucial element for sustainable development and well being of any country in modern era. The total primary energy supply of Malaysia was 65,692 kilo-tonnes of oil equivalent in 2009 which rose to 72,951 kilo-tonnes of oil equivalent in 2010 [1]. Of the final usage of all primary energy, electricity had a share of 22% in 2010. Electricity demand in Malaysia has risen dramatically in recent years due to impressive economic growth and social development [2,3]. For the period 1998 to 2009 the economic growth (measured by GDP) had been growing at average rate of 6.6% while electricity consumption at 4.5% per year. Though the GDP growth rate is described as medium [4], Malaysia is one of the largest electricity consumers among the Association of Southeast Asian Nations member countries [2]. It is estimated that for the period 2004-2030 the GDP growth is going to be 4.6% [5] whereas, the peak demand for electricity is estimated to be 23,099 MW in 2020 [6]. It is expected that Malaysia would require 151 TWh by 2022 [7] whereas, by 2030 demand can grow up to 216 TWh [8]. It is anticipated that electricity demand could be higher owing to ambitious economic and social development goals set by the government. This put country's policy-makers in an overwhelming situation in ensuring a steady supply of electricity.

Seeing the 1973 oil crisis, Malaysian government capped oil and gas production following the National Depletion Policy of 1980. This policy aimed to reduce dependence on oil for electricity generation [9]. Later in 1981, Four-Fuel strategy introduced natural gas for electricity production [10]. Given the fact that fossil fuel reserves are limited, the Malaysia government introduced renewable resources under Five-Fuel Diversification Strategy of 2000 [11]. In spite of this policy, renewable capacity by 2011 was less than 1% of the total installed capacity [12]. Comparing this underachievement of Malaysia with the countries that are aiming for 100% renewable sources such as, Denmark [13] and Ireland [14], shows Malaysia's technology lock-in to fossil fuel based generation system.

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For a sustainable development of electricity production, it is utterly important to achieve fuel diversification [15]. Researchers have characterized electricity system as socio-technical and techno-institutional complex [16,17]. Thus any decision making in the system has become a complex process. The objective of this study therefore, is to review the potential of various renewable resources for electricity production in Malaysia, and using a multi-criteria approach to rank those resources in order of their merit. This ranking is believed to serve policy-makers in devising strategies for developing a sustainable generation system.

2. Malaysian electricity structure and intensity

Malaysia electricity industry has transformed from being a monopoly to a quasi competitive one. At present there are three main players; Tenaga Nasional Berhad, Sabah Electricity Sdn. Bhd, and Sarawak Electricity Supply Corp. These companies have their own generation capacities along with supply from various Independent Power Producers. Energy Commission or Suruhanjaya Tenaga (ST) acts as regulator, ensuring security of supply and safeguarding consumers' interests.

At present Malaysia's total installed capacity is 24,361 MW; the geographical distribution of which is given in Fig. 1. Peninsular Malaysia has got the largest share of 90% of the installed capacity, followed by Sarawak and Sabah at 5.5% and 4.8%, respectively. The reserves margin of the system stands around 43.7%; the long term objective of ST is to cut it to 20% level.

For the past 30 years, electricity consumption and economic growth has been growing exponentially, Fig. 2 summarizes this trend. This inclination is alarming for planners, especially in milieu of country's dependency on fossil fuels. In 2010, more than 90% of electricity generated was from coal and natural gas combined [11]. Despite the fact that there are sufficient natural gas reserves in Malaysia, their depletion is inevitable. At current consumption rate, reserves are estimated to last for 33-36 more years [18]. On the other hand, coal is already imported from Indonesia, Australia and South Africa [9].

In Fig. 3, the change in fuel-mix for the electricity production is shown. Natural gas is getting dominance along with coal, whereas, electricity production from oil is declining. In 1980, around 88% of electricity was generated from oil which plummeted to 2% in 2005. The share of renewable electricity has been minimal except for large hydropower, supplying only 7% of total demand [11]. Analyzing Figs. 2 and 3 in conjunction renders two key issues: substantial increase in future demand and dominance of fossil fuels over renewable ones. These two issues are sufficient to coerce Malaysia to enrich it fuel-mix for electricity production. To increase renewable capacity Malaysian government introduced feed-in tariff (FiT) scheme. This scheme intends to stimulate investments by providing financial incentives to renewable power producers. An independent organization called, Sustainable Energy Development Agency has been set up to manage the affairs of FiT scheme. Moreover, it is also an integral part of sustainable energy development strategies to replace fossil fuels by various renewable resources [19].

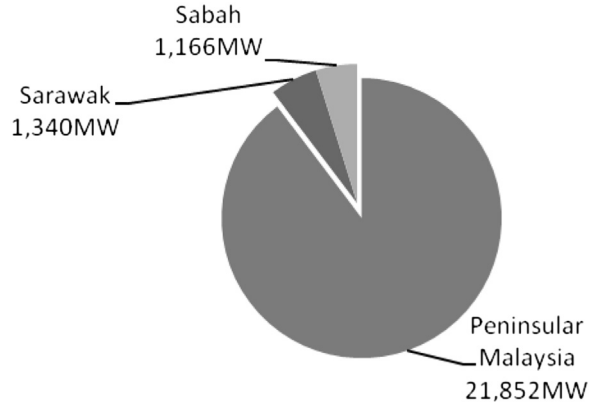

Fig. 1. Distribution of installed capacity in Malaysia.

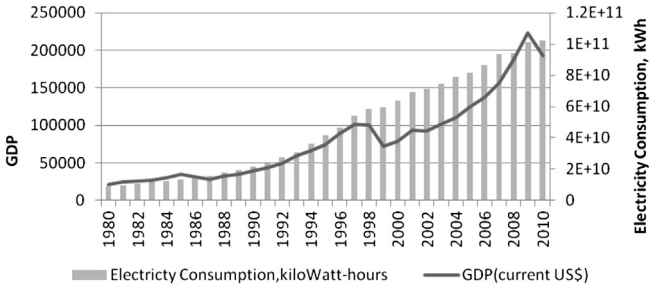

Fig. 2. Economic development and electricity consumption trend.

3. Potential of renewable energy sources

Following sub-sections provide an overview of renewable resource potential for electricity generation in Malaysia. Any associated drawbacks are also highlighted.

3.1. Hydropower

The potential of hydropower depends on the amount of available water and suitable terrain. Malaysia on average gets 3549 mm of rain annually [20]. There are about 189 named rivers in Malaysia having a total length of around 57,300 km. The origin of these rivers and streams is in the country's mountainous areas, which accounts for 41% of the total land area. Plentiful water and supporting terrain is favorable for hydropower projects. The Peninsular Malaysia hydropower potential seems to have exhausted [21]. However, East Malaysia potential is yet to be exploited fully. The estimated hydropower resources are 29,000 MW [22], whereas for mini-hydro it is 500 MW [6].

Despite having low per unit kWh cost, and apparently carbon neutral, the hydropower plants cause major social and environmental problems. These problems include displacement of local population, losing agriculturally productive land, soil erosion, and disturbance of echo-system. Moreover, hydroelectric plants require substantial land area for water reservoirs. On average, 75,000 ha of reservoir land area, and 14 trillion liters of water are required for the production of 1 billion kWh of electricity per year [23,24].

3.2. Wind power

Being an equatorial country, Malaysia lacks substantial wind speeds for any inland wind power plants. This can be verified from Fig. 4. However, Malaysia has got 29th longest coast line in the world, totaling about 4,675 km. This resource seems like to offer a considerable potential for developing wind power capacity.

According to wind map of Fig. 5, the inland annual average wind speed varies from 1.3 m/s to 2.7 m/s, whereas, on coast line it varies from 3.5 m/s to 4.5 m/s. This is regarded as low potential. Though wind power is the fasted growing technology in the world, yet its uptake is close to minimal in Malaysia. This low penetration can be attributed to lesser wind potential, and risk of tropical cyclones [27].