Renewable technology assessment for electricity production: a case of Malaysia

Salman Ahmad[1]*, Razman bin Mat Tahar[2]

[1,2]Faculty of Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, Gambang 26300, Malaysia

*Corresponding author email: salman_psh@yahoo.com

Abstract

Malaysia social and economic development has raised the country's demand for electricity. Historically, electricity demand has been met by power generation from fossil fuels. Uncertainty regarding fossil fuels, environmental constrains and security of supply risk stress on using renewable sources for electricity generation. The model takes a holistic perspective; social, economical, technological and environment, in developing as assessment model for various renewable technologies. Model simulation reveal that solar photovoltaic (PV) is the best option followed by biomass technology. Biogas and municipal solid waste (MSW) are assessed to be equally good, while small hydro seems to be least attractive option. The developed model is aimed to serve as a tool for future dialogue for better policy development.

Keywords: system dynamics, renewable electricity, feed-in tariff, Malaysia, technology assessment

1. INTRODUCTION

Malaysia, a South-East Asian country has experienced a strong economic and social growth. To fuel this growth, the country has relied on fossil fuel heavily for electricity generation (Akhwanzada and Tahar, 2012). The fuel mix since 1980 to 2010 period has been illustrated in Figure 1. The same trend has been carried forward in 2011. In 2011, non-renewable fuels in electricity supply chain account for around 86.8% of the fuel mix, whereas on the renewable side, only large hydropower has got a significant share of 10.5% in fuel fix (National Energy Balance (NEB), 2011). The fuel mix for Malaysia has been illustrated in Figure 2.

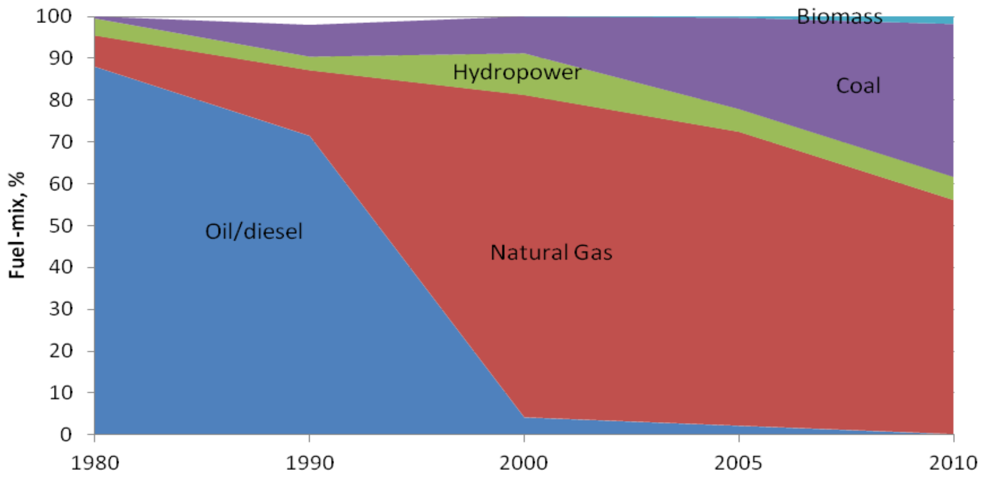

Figure 1. Historic fuel-mix for electricity generation (Oh 2012; Oh et al., 2010).

In 1990, the electricity demand was 19.932 TW h which rose to 107.33 TW h in 2011(NEB, 2011). This shows an increase of 8.02% per year. According to Ali el al. (2012), the electricity demand can be as high as 274 TW h by 2030. Likewise, the GDP of the country for the same time period shows an annual growth rate of 5.6%. Besides this, the country has targeted to attain the high income status by year 2020. To ensure security of supply there is a dire need to diversify the technology mix for electricity generation.

Security of supply, climate change, fossil fuel depletion, and availability and indigenous renewable resources has compelled the Malaysian government to diversify fuel mix for electricity generation. In this regard Malaysia has been pro-active on policy front. These policies have been discussed and summarised in, Hashim and Ho (2011) and Muhammad-Sukki et al. (2011). However, the contribution of renewable resources for electricity generation has been minimum (Maulud and Saidi, 2012). Being at an early stage of development five renewable technologies have been identified for electricity generation. They are: biomass, biogas, MSW, solar PV, and small hydro.

At current reserve to production ratio oil will last for 18-20 years, while natural gas production can y be sustained farther for 35-36 years (Oh and Chua, 2010; Shafie et al., 2011). On the other hand coal supply is maintained through imports (Muhammad-Sukki et al., 2011).

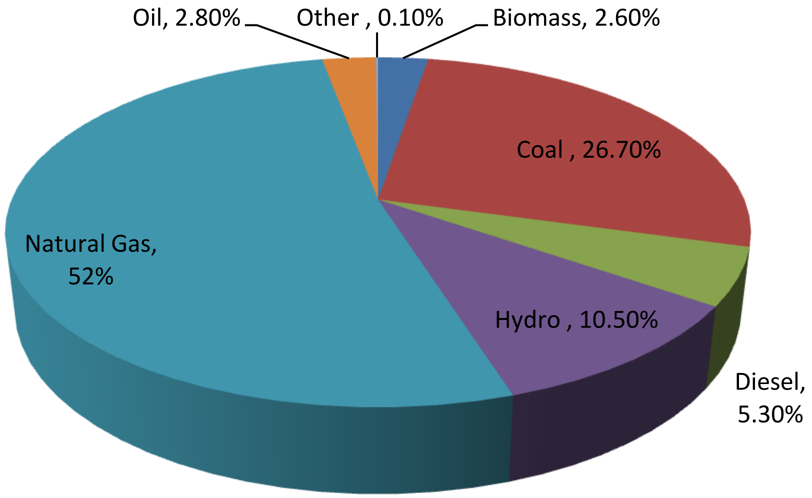

Figure 2: Fuel mix for electricity generation

The decision making in electricity sector has been termed as complex. It is due to inter-linkages of many factors, like, high capital requirement for development, delays in power plant construction, market uncertainty and last but not the least irreversibility of decision (Pereira and Saraiva, 2011; Olsina et al., 2006)

The objective of this paper is to present a quantitative system dynamics model which assesses the five renewable energy technologies in Malaysia. Besides this feed-in tariff (FIT) policy for Malaysia has been included to see its effect on renewable technology up-scaling. FiT has been included because of its usefulness in supporting renewable technologies around the globe (Muhammad-Sukki et al., 2014). Each technology is evaluated on four performance indices. The aim of the model is to provide an instrument for future communication, and dialogue on country's ability to focus on any single technology, or any combination of theirs.

This paper is structured as follows. Section 2 provides the literature review done to develop the model while section 3 presents the model conceptualisation. In section four results of model are presented. Finally section 5 summaries the conclusion of the study.

2. LITERATURE REVIEW

A number of studies have been done regarding the Malaysia' electricity sector. A number of modeling apparoched have been adopted. These include: descriptive(Umar et al.,2013; Murni et al.,2013; Ng et al.,2012; Ali et al.,2012; Maulud and Saidi,2012; Chua and Oh,2010 ; Oh et al.,2010; Sovacool and Drupady,2011); econometric (Gan et al. 2008;Tang and Tan,2013; Chandran et al., 2010); computational (Nor et al.,2014; Islam et al.,2011; Muis et al.,2010); linear algebra and higher order polynomials (Shafie et al., 2013; Johari et al., 2012; Mahlia, 2002; Saidur et al.,2007; Shekarchian et al., 2007); accounting(Muhammad-Sukki et al. 2012; Muhammad-Sukki et al. 2011; Seng et al.,2008; Koh and Lim, 2010). Apart from methodology none of the authors assessed the indigenous renewable resources for electricity generation in the country collectively from multi-perspective. Thus far, study by Ahmad and Tahar (2014a) takes a multi-perspective in evaluating various renewable resources for electricity generation in the country.

System dynamics approach has been extensively applied to issues in electric power industry around the world. The most recent work in system dynamics literature has been done by Aslani et al.(2014) looking into renewable energy development in USA from cost perspective; Aslani et al. (2014) assessing renewable energy development in Finland, and by Saysel and Hekimoglu (2013) by evaluating the potential of various renewable technologies related to carbon reduction in Turkish electricity supply chain. In a study by Hsu (2012) various subsidies policy for boosting solar PV in Taiwan has been evaluated. Further, biodiesel technology has been assessed by Musango et al. (2013) for South Africa.

3. MODEL CONCEPTUALISATION

The causal structure of the model has been developed following Ahmad and Tahar (2014b), Ford (2001), Qudrat-Ullah and Karakul (2007), and Rodilla et al. (2011). The model has been divided into nine sub-models. These sub-models are: construction; demand; electricity production; technology learning; land; social; environmental; feed-in tariff policy, and finally demand allocation. The interactions between these nine sub-models are assumed to generate the dynamics in the system.

The construction sub-model is shown in Figure 3. It is a typical supply line structure presented by Sterman(2000). The model considers the renewable capacity in three distinct stocks. The start rate is determined by the difference between the current capacity and targeted share of each capacity.

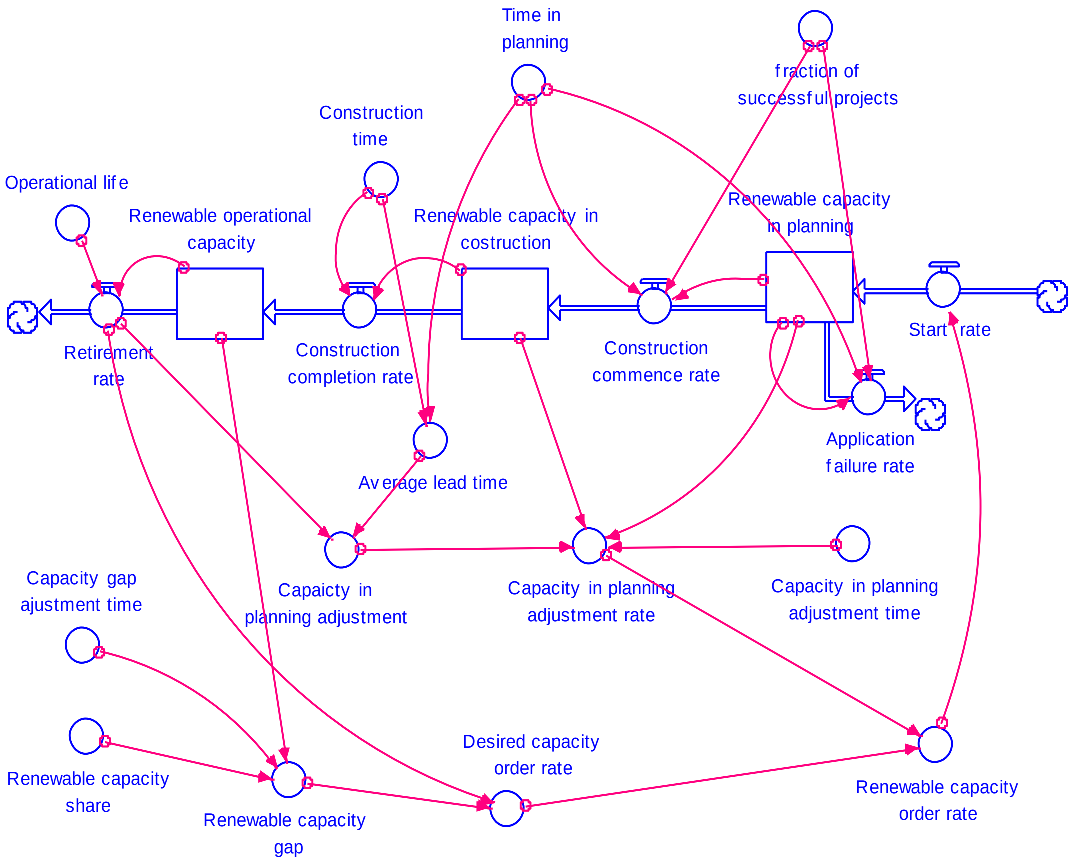

Figure 3: Construction Sub-Model

The electricity demand is taken as the peak demand because capacity extensions relate to peak demand as opposed to average demand. Two macro-economic indicators of population and GDP are used to model the peak demand. Equation 1 shows the relationship.

$$Electricity\ Demand\ = f(Population, GDP) \qquad (1)$$

In the electricity production sub-model , electric energy produced by each of renewable technology is considered. The mathematical equation governing the sub-model is given as:

$$Annual\ Electrocty\ Generated\ =\ Operational\ capacity * \text{ efficiency } *8760 \qquad (2)$$

The technology learning sub-model is concerned with technology cost reduction as a result of increase in renewable operational capacity. The structure of this sub-model is adopted following del Rio (2012). The technology cost reduction is based on learning-curve-approach is used. This approach endogenously determines the cost reduction as a function of total renewable operational capacity (Weiss et al., 2010). It is considered that by doubling the renewable operational capacity the adjusted operating cost of the technology decreases by a certain fraction.

Land is critical to renewable electricity infrastructure development. Therefore, land requirement is included in the model. A co-flow structure is used to control the dynamic of two land stocks in the model. The two land stocks are: *total allowable land* and *land required* for each of renewable technology. Both are in the units of Km^2. It is assumed that with capacity depreciation, the relinquished land is input *to total allowable land* stock. The dynamics of total allowable land is governed by Equation.3.

$$Total\ allowable\ land = \int (land\ reclaimed - land\ required\ )\ dt + Total\ allowabl\ land(0) \qquad (3)$$

In this sub-model jobs created, in units of person, by promoting renewable energy technologies are modeled. Two distinct categories are within this sub-model. The jobs created during the construction, and jobs created during the operation of renewable power generation system. The underlying structure of this sub-model is same as land, a co-flow to construction sub-model. The two stock dynamics are controlled by the Equation 4 and Equation 5.

$$\mathit{Opeational\ jobs} = \int (\mathit{Operation\ jobs\ created} - \mathit{operational\ jobs\ lost})\, dt\mathit{Operational\ Jobs}(0) \tag{4}$$

$$\mathit{Construction\ jobs} = \int \mathit{Construction\ jobs\ created} - \mathit{construction\ jobs\ lost}\ )\, dt + \mathit{Construction\ jobs}(0) \tag{5}$$

The sub-model consists of one stock variable, *total* CO_2 *avoided*, and one flow rate, *emissions avoidance rate*. Thus, the stock of total CO_2 avoided (in kg- CO_2) is increase by *emissions avoidance rate* in kg-CO2/year); *emissions avoidance rate* is a product of *emission factor* (kg-CO_2/kWh) and *annual renewable electricity generated* (in kWh/year). This is shown mathematically in Equation 6 and 7.

$$\mathit{Total\ \ emissions\ avoided} = \int (\mathit{Emission\ avoidance\ rate})\, dt + \mathit{Total\ \ emissions\ avoided}(0) \tag{6}$$

$$\mathit{Emission\ avoidance\ rate} = \mathit{emision\ factor} * \mathit{Annual\ Electrocty\ Generated} \tag{7}$$

This sub-model is unique in feed-in tariff modeling as compared to one used by Hsu(2012), and Saysel and Hekimoglue(2013). In this model, a year-wise feed-in tariff rate and feed-in tariff franchised capacity is model as oppose to aggregate capacity assumed by the mentioned studies. This is done by using two multipliers in the model. These two multipliers control the annual decrease of feed-in tariff rate along with determining the corresponding capacity. The first factor is controlled by *FiTStartMul*, and the later is controlled by *CCStartMul*. Figure 4 shows the structure of the said sub-model.

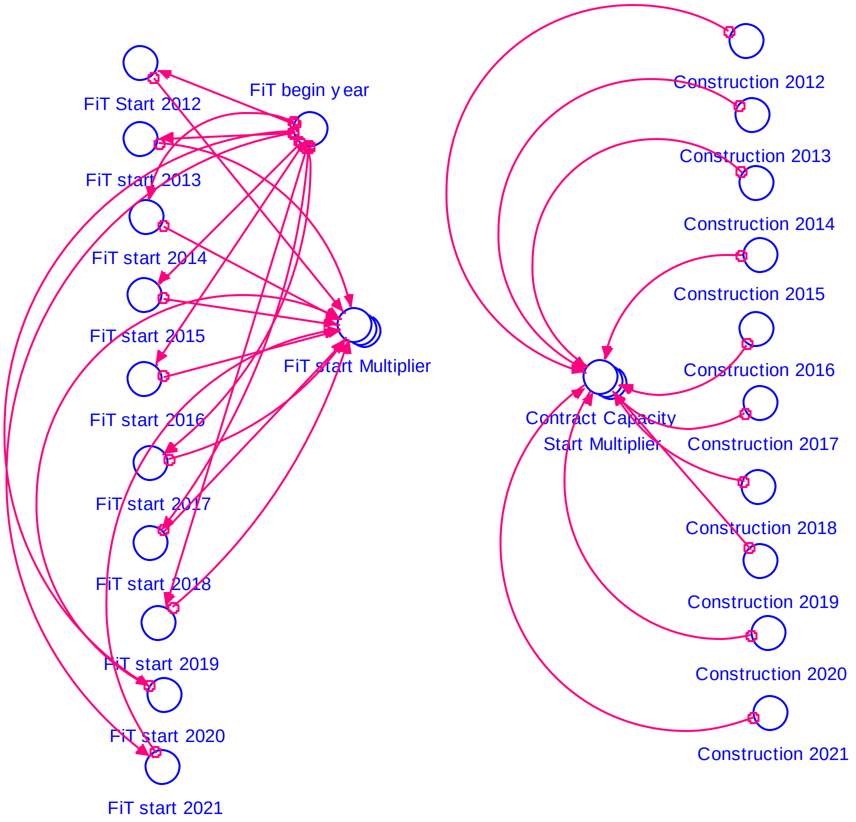

Figure 4: Feed-in Tariff policy contract management structure

Finally, the demand allocation model is use to set the capacity share that has to be met by each technology, annually. This sub-model deals with allocating share of peak demand on to five renewable technologies assessed in this study. Of the five technologies the one having the highest *relative willingness to invest* is directed to cater the higher share of demand. *Willingness to invest* is function of five non-linear effects calculated endogenously for each technology being modelled. These are: environmental effect, cost effect, social effect, land effect, and finally feed-in tariff effect. The portion of demand to be met by each source is assigned, share_i (in kW), where i ={Biomass, Biogass, MSW, solar PV and small hydro}. Mathematically, this is presented in Equation 8, where PED is the peak electricity demand.

$$\text{share}_i = PED * Relative\ willingness\ to\ invest_{\ i} \tag{8}$$

Relative willingness to invest is the ratio of an individual technology with *total willingness to invest*. Equation 9 and Equation 10 present the mathematical relationships of *relative willingness to invest* and *total willingness to invest*, respectively.

$$Relative\ willingness\ to\ invest_i = \frac{willingness\ to\ invest_i}{total\ willingness\ to\ invest} \quad (9)$$

$$total\ willingness\ to\ invest = \sum_i willingness\ to\ invest_i \quad (10)$$

4. RESULTS AND DISCUSSION

In this section model validation is discussed before presenting the simulation results. Ford (2000) states that a well-structured model will present the same general pattern. Therefore, validation process, as outlined by Quadrat-Ullah and Seong (2010) was followed. It was found that the developed model fulfills all the tests sufficiently.

Four performance indices are compared for each of technology. These indices are: renewable operational capacity; total feed-in tariff amount required; jobs created, and average annual cost reduction. The operational capacity of various renewable technologies is presented in Figure 5. For solar PV quite high level of capacity, around 4 GW, as compared to other technologies, is attained by 2019. Thereafter, the rate of increase in capacity slows down and capacity reached around 6GW in 2030. Thereafter, a decrease in solar PV capacity is witnessed which continues for next 7 years, till 2037. From 2038 onwards, solar PV capacity grows faster as compared to in previous years. In 2050, solar PV attains around 9.05GW of cumulative operational capacity. The initial high growth in PV capacity can be contributed high FiT rate which attracts investors to win a FiT contract. Later the growth in Solar PV capacity is due to cost reduction effect dominantly. Further, it can be seen that among the five technologies, solar PV and biomass show a sudden rise in capacity as compared to biogas, MSW and small hydro.

It can be seen from Figure 5 that small hydro technology has a high growth initially as compared to biogas and MSW but it is not maintained farther into future. Around 2026, decrease in small-hydro operational capacity can be seen. This decline continues till 2036. Analysis reveals that this decrease of capacity is due to the longer–lead time of the technology. Thus making it less attractive. The final renewable operational capacities are given in table 1.

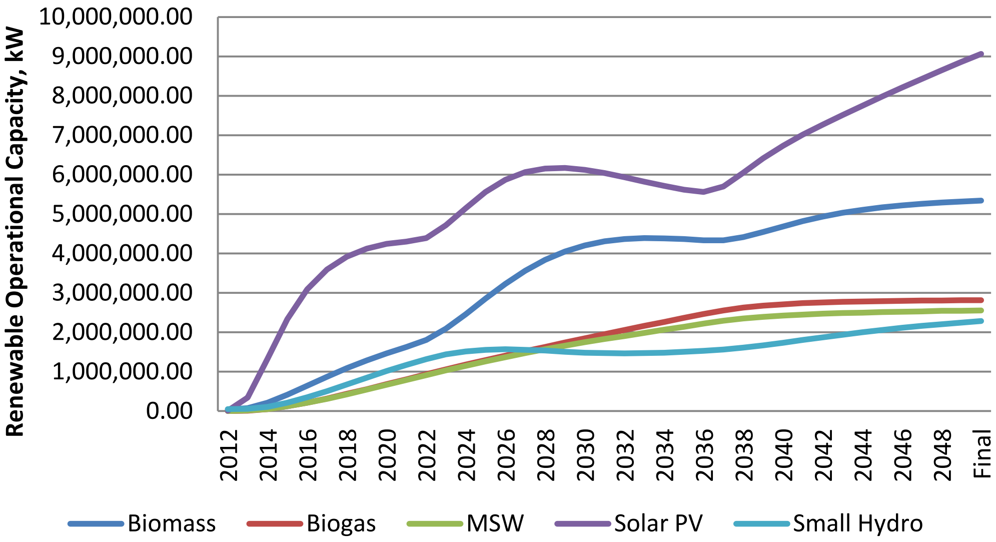

Figure 5: Operational capacities of various technologies by 2050

In Figure 6, the total feed-in tariff amount to be needed by each of the technology is presented. It can be seen that solar PV gets the most payments while MSW and biogas get the least. Interesting dynamics are exhibited by small hydro. The annual feed-in tariff support by small hydro grows slowly but cumulative amount required at the end of the simulation run is second to solar PV, though the final operation capacity of small hydro is the least. When this counter intuitive dynamics is analyzed it found that the high electricity production capability of small hydro is better than other technologies and no degression in feed-in tariff rate ad longer contract period favors this technology. By 2050 a total of 65.55billion Malaysia Rinngits(RM) will be required to paid in to feed-in tariff contract holders. This presents a challenging situation to handle. With current settings the government expects to earn 19.8billion RM by 2030. The comparison shows that feed-in tariff policy will be financially restrained. Table one summarizes the feed-in tariff amount required.

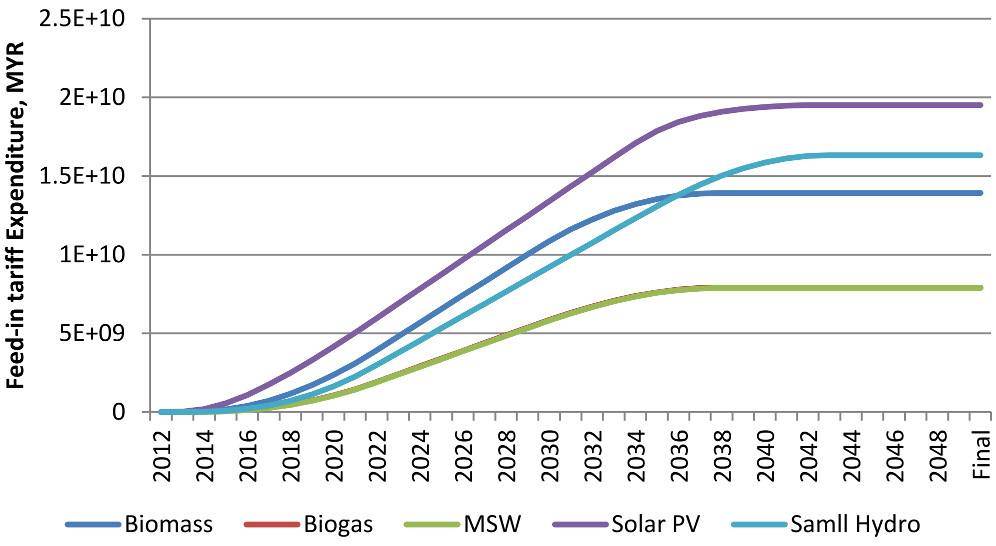

Figure 6: Feed-in Tariff policy expenditure

On the social side it is found that the solar PV generates the maximum number of jobs by 2050. Least number of jobs will be related to small hydro technology. The comparison of jobs in for all technologies is presented in Table 1.

Finally, in this study all five renewable technologies are assessed on possible cost reduction as a result of increasing cumulative renewable operational capacity. All five technologies reveal a similar trend, a decreasing trend. Focusing on individual technologies performance on adjusted operational cost reduction it is found that the most drastic cost reduction occurs in solar PV technology, while least reduction occurs for small hydro technology. Comparison of initial cost, and cost in year 2050 is show in Table 1. The highest average annual cost reduction over the simulation horizon occurs for solar PV (15.8%) while the least occurs of small hydro (3.2%). The reason for these dynamics can be attributed to learning effect occurring for solar PV while all other technologies are regarded as mature technologies.

	Biomass	**Biogas**	**MSW**	**Solar PV**	**Small Hydro**
Renewable operational capacity, MW	5,340	2, 814	2,555	9,058	2,281
Total FiT fund required, billion MYR	13.92	7.90	7.88	19.51	16.31
Jobs, person	13, 236	6982	6364	47,524	2480
Average annual cost reduction, %	3.5	5.0	4.3	15.8	3.2

Table 1. Output of various renewable technologies on three performance indices

Simulation results show that no one technology performs best on all four performance indices (except solar PV). This provides a challenge on final assessment of renewable technologies for electricity generation. To overcome this shortcoming, a ranking approach is adopted. By this approach all five technologies are ranked as to which one is the best. Any technology which scores minimum is ranked highest and other subsequently. The ranking of technologies is provided in Table 2.

As seen from Table 2, solar PV has the lowest score, followed by biomass. Next in the rank are biogas and MSW technology while small hydro is ranked the least.

	Biomass	**Biogas**	**MSW**	**Solar PV**	**Small Hydro**
Renewable operational capacity, MW	2	3	4	1	5
Total FiT fund required, billion MYR	3	4	5	1	2
Average annual cost reduction, %	4	2	3	1	5
Jobs, person	2	3	4	1	5
Total score	11	12	16	4	17
Rank	**2**	**3**	**4**	**1**	**5**

Table 2. Ranking of various renewable technologies

5. CONCLUSION

Many countries around the world have opted to diversify their power generation system by including renewable energy technologies. Since renewable technologies are minimum in in the electricity supply chain there is a need to assess them for future decision making. System dynamics approach is leveraged in this study to assess five renewable technologies in the country. This approach incorporates variable influences and feedbacks as opposed to other methodologies. The developed model incorporates multi-perspective in assessing a renewable technology. Analyses reveal that no one technology performs the best. However, overall solar PV seemed to be the best technology to be focused in Malaysia, followed by biomass. Though small hydro has one of the largest operation capacities in the country, analysis reveal that it might not be the most attractive one in future. On policy side it was found that feed-in tariff policy might face financial problem in long run.

Refrerences

[a]Ahmad, S. and Tahar, R. M. (2014). Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. Renewable Energy,Vol.63, pp.458-466.

[b]Ahmad, S., and Tahar, R.M. (2014). Using system dynamics to evaluate renewable electricity development in Malaysia. Kybernetes, 43(1), pp. 24-39.

Akhwanzada, S.A., and Tahar,R.M.(2012).Strategic Forecasting of Electricity Demand Using System Dynamics Approach. International Journal of Environmental Science and Development, 3,328-333, 2012.

Ali, R., Daut, I., and Taib, S. (2012). A review on existing and future energy sources for electrical power generation in Malaysia. Renewable and Sustainable Energy Reviews, 16(6), 4047-4055.

Aslani, A., Helo, P., and Naaranoja, M. (2014). Role of renewable energy policies in energy dependency in Finland: System dynamics approach. Applied Energy, 113, 758-765.

Aslani, A., and Wong, K.-F. V. (2014). Analysis of renewable energy development to power generation in the United States. Renewable Energy, 63,153-161.

Chandran, V. G. R., Sharma, S., and Madhavan, K. (2010). Electricity consumption–growth nexus: The case of Malaysia. Energy Policy, 38(1), 606-612.

del Río, P.(2012). The dynamic efficiency of feed-in tariffs: The impact of different design elements. Energy Policy, 41, 139-151.

Ford, A. (2001). Waiting for the boom: a simulation study of power plant construction in California. Energy Policy 29, 847–869.

Gan, P. Y., and Li, Z. (2008). An econometric study on long-term energy outlook and the implications of renewable energy utilization in Malaysia. Energy Policy, 36(2), 890-899.

Hashim, H., and Ho, W. S. (2011). Renewable energy policies and initiatives for a sustainable energy future in Malaysia. Renewable and Sustainable Energy Reviews, 15(9), 4780-4787.

Hsu, C.W.(2012). Using a system dynamics model to assess the effects of capital subsidies and feed-in tariffs on solar PV installations, Applied Energy,100, 205-217.

Islam, M. R., Saidur, R., and Rahim, N. A. (2011). Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function. Energy, 36(2), 985-992.

Koh, S. L., and Lim, Y. S. (2010). Meeting energy demand in a developing economy without damaging the environment—A case study in Sabah, Malaysia, from technical, environmental and economic perspectives. Energy Policy, 38(8), 4719-4728.

Johari, A., Ahmed, S. I., Hashim, H., Alkali, H., & Ramli, M. (2012). Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. Renewable and Sustainable Energy Reviews, 16(5), 2907-2912.

Maulud, A. L., and Saidi, H. (2012). The Malaysian Fifth Fuel Policy: Re-strategising the Malaysian Renewable Energy Initiatives. *Energy Policy, 48*, 88-92

Muhammad-Sukki et al. (2014). Feed in Tariff for Solar Photovoltaic: The Rise of Japan. Renewable Energy doi. 10.1016/j.renene.2014.03.012

Muhammad-Sukki, F., Munir, A.B., Ramirez-Iniguez, R., Abu-Bakar, S.H., Mohd Yasin, S.H., McMeekin, S.G.and Stewart, B.G. (2012). Solar photovoltaic in Malaysia: The way forward. Renewable and Sustainable Energy Reviews 16, 5232-5244.

Muhammad-Sukki, F., Ramirez-Iniguez, R., Abu-Bakar, S. H., McMeekin, S. G., & Stewart, B. G. (2011). An evaluation of the installation of solar photovoltaic in residential houses in Malaysia: Past, present, and future. Energy Policy, 39(12), 7975-7987.

Muis, Z.A., Hashim, H., Manan, Z.A., and Douglas, P.L. (2011). Effects of fossil fuel price fluctuations on electricity planning comprising renewable energy Asia-Pacific Journal of Chemical Engineering, 6(3), 552–562,

Murni, S., Whale, J., Urmee, T., Davis, J. K., and Harries, D. (2013). Learning from experience: A survey of existing micro-hydropower projects in Ba'Kelalan, Malaysia. Renewable Energy, 60, 88-97.

Musango, J. K., Brent, A. C., Amigun, B., Pretorius, L., and Müller, H. (2012). A system dynamics approach to technology sustainability assessment: The case of biodiesel developments in South Africa. Technovation, 32(11), 639-651

NEB. National Energy Balance 2011. Ministry of Energy, Water and Green Technology, Malaysia.

Ng, W.P.Q., Lam, H.L., Ng, F.Y., Kamal, M., Lim, J.H.E., 2012. Waste-to-wealth: green potential from palm biomass in Malaysia. Journal of Cleaner Production 34, 57-65.

Nor, K. M., Shaaban, M., and Abdul Rahman, H. (2014). Feasibility assessment of wind energy resources in Malaysia based on NWP models. Renewable Energy, 62, 147-154.

Oh, T.H.(2010) . Carbon capture and storage potential in coal-fired plant in Malaysia—A review. Renewable and Sustainable Energy Reviews 14, 2697-2709.

Oh, T.H. , Pang, S.Y. and Chua, S.C.(2010). Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth, Renew. Sust. Energ. Rev. 14, 1241-1252.

Olsina, F., Garcés, F, and Haubrich, H.J. (2006). Modeling long-term dynamics of electricity markets. Energy Policy 34, 1411-1433.

Pereira, A.J.C.and Saraiva, J.T. (2011). Generation expansion planning (GEP) – A long-term approach using system dynamics and genetic algorithms (GAs). Energy 36,5180-5199.

Qudrat-Ullah, H. and Karakul, M. (2007). Modelling for policy assessment in the electricity supply sector of Pakistan. International Journal of Energy Sector Management 1, 240-256.

Qudrat-Ullah, H., and Seong, B. S.2010.How to do structural validity of a system dynamics type simulation model: The case of an energy policy model. Energy Policy. 38: 2216-2224.

Rodilla, P., Batlle, C., Salazar, J. and Sánchez, J.J. (2011). Modeling generation expansion in the context of a security of supply mechanism based on long-term auctions. Application to the Colombian case. Energy Policy 39, 176-186.

Saysel, A. K. and Hekimoğlu, M. (2013). Exploring the options for carbon dioxide mitigation in Turkish electric power industry: System dynamics approach. Energy Policy. 60: 675-686.

Seng, L. Y., Lalchand, G., and Sow Lin, G. M. (2008). Economical, environmental and technical analysis of building integrated photovoltaic systems in Malaysia. Energy Policy, 36(6), 2130-2142.

Shafie, S.M., Mahlia, T.M.I.., Masjuki, H.H., and Andriyana A,C. 2011. Current Energy Usage and Sustainable Energy in Malaysia: A Review. Renew. Sustain. Energ. Rev., 2011, 15, 4370-4377.

Sovacool, B. K., and Drupady, I. M. (2011). Innovation in the Malaysian Waste-to-Energy Sector: Applications with Global Potential. The Electricity Journal, 24(5), 29-41.

Sterman, J.D. 2001. Business Dynamics, system thinking and modeling for a complex world. McGraw-Hill, New York.

Tang, C. F., and Tan, E. C. (2013). Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. Applied Energy, 104, 297-305.

Umar, M. S., Jennings, P., & Urmee, T. (2013). Strengthening the palm oil biomass Renewable Energy industry in Malaysia. Renewable Energy, 60, 107-115.

Weiss, M., Junginger, M., Patel, M. K., and Blok, K. (2010). A review of experience curve analyses for energy demand technologies. Technological Forecasting and Social Change, 77(3), 411-428.