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Diversified Sustainable Resource Availability by Optimizing Economic Environmental and Supply Risk factors in Malaysia's Power Generation Mix

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ABSTRACT

Population growth and economic development contribute to the rise in the demand for electricity. To meet the demand, electricity generation has been relying on fossil fuels. This practice has three major drawbacks: inevitable resource depletion, environmental concerns, and supply risk. Renewable fuels are touted to be the future of sustainable power generation. However, there is a need to assess and optimize the use of the available resource in an effective and efficient manner. In order to accomplish the desired objectives, this study adopted the multi-perspective approach for efficient utilization of resources, both in terms of cost and diversification, and also aimed to propose the optimum combination of technologies for electricity generation in Malaysia. In this regard, first, the potential of the resources was identified from the Malaysian prospective compliance with the five fuel energy action plan 2020. All the five fuels were examined in terms of economic, environmental and security parameters, and evaluated in the terms of cost to measure the total exposure in monetary units. For the economic analysis, the LCOE cost quantification method was used. Similarly, for the restriction of carbon emission, a carbon-tax policy was proposed and a novel technique was designed for the quantification of excessive cost of security in the electricity generation industry. This study applied the simulation mathematical modelling and the graphical evaluation approach to optimize the power generation mix in terms of cost and diversity index. Hence, this study will assist the policy-makers in making efficient long-term policies considering the impact of various factors on total generation cost while adopting the concept of diversification for an efficient and uninterrupted power generation process.

Keywords: Levelized Cost of Energy, Power Generation Mix Optimization, Energy Security, Carbon Tax
JEL Classifications: C23, Q43, Q54

1. INTRODUCTION

The importance of energy in the economic development of any country cannot be denied. The critical concern of policymakers worldwide is to meet the growing demand for energy, consequently providing energy security (Security of supply) and plummeting greenhouse gas emissions (Zahedi, 2010; Li et al., 2021). Prerequisites of human development and economic growth are attainment of clean, secure, affordable and reliable energy supplies. The World Energy Issues Monitor 2014 (World Energy Council, 2014; World Energy Outlook, 2020) added that the three main challenges trigger to today's energy leaders. Energy Equity, Energy Security and environmental Sustainability, named as Energy Trilemma.

Around the globe, in the list of issues Energy Security is at top (Cohen et al., 2011; Vivoda, 2009; Hedenus et al., 2010; Bang, 2009; Brown and Huntington, 2008; Turton and Barreto, 2006; Sutrisno et al., 2021; Axon and Darton, 2021). World Bank Report (2004) added they are several factors contributing to energy security issue. Prominent among them are fluctuation in energy markets, competition for energy resources and urge for economic development and poverty alleviation. Many governments have responded to this issue by formulating policies in order to improve the security of their energy supply. With the fact that energy security is significantly connected to other issues, such as environmental policy, affordable energy, climate change and many more, this has made many countries perceive energy security supply as their principal objective in the formulation of enery policy. The effects of climatic change and the need for a better quality of life have created a prime focus on affordable, reliable, and sustainable modern energy systems (Mukherjee and Sovacool, 2012; Akram et al., 2020; Sovacool et al., 2016). This research paper adopts the bottom-up approach, initiating with the broad spectrum of energy security and narrow it up to the particular objective (case study). Exclusively, three keys interconnected dimensions of security of energy levels were evaluated, (1) economic in the form of affordability, (2) environmental in the form of acceptability and (3) secure supplies for energy generation in terms of availability will be focused.

2. OVERVIEW OF MALAYSIA ENERGY SECTOR

Malaysia is an energy-dependent country (Chandran et al., 2010; Azis, 2021). The electricity demand in the country has risen extraordinarily. Energy consumption in Malaysia has increased to the level of 2.6 form 1.7 quadrillion Btu from 1998 to 2006. The use of electricity is also growing every year with an average of 2533 GW/year. According to (Bello et al., 2018; Haiges et al., 2017; Aqilah et al., 2021; Sibeperegasam et al., 2021) demand for electricity in Malaysia has risen from 38,820 GWh to 146,221 GWh from 1995 to 2015. It is further expected to increase by 30% in 2020 Malaysia Energy Statistics (2017). It is quite evident empirically that in Malaysia electricity usage has significant effect on economic growth (Chandran et al., 2010; Lean and Smyth, 2010a; 2010b; Tang, 2008; Tang and Tan, 2013; Yoo, 2006; Rahman et al., 2017; Etokakpan et al., 2020; Li and Solaymani, 2021).

According to Malaysia Energy Commission (National Energy Balance, 2013) hydrocarbons are contributing 88.4%, followed by hydropower with 11.4% of the share. On the other hand, renewable energy only adds 0.1% in the total power generation mix. World Bank Report, 2017 revealed Malaysia stood third in carbon dioxide emission in Southeast Asian region, followed by Indonesia and Thailand. In 2013, it was examined that the amount of carbon emission has increased to 236.5 metric tons compared to 56.6 metric tons in 1990. However, power sector alone is responsible for contributing 54.8% of total carbon emission (World Bank, 2017). Country's reservoirs for fossil fuels are depleting gradually. Oil reserve predictably last for 18-20 more years, natural gas 30-35 more years and coal will be imported for electricity generation (Oh et al., 2010; Chua and Oh, 2010; Hossain et al., 2018; Mah et al., 2019; Ghani et al., 2019). Gauged that in country situation has jeopardize the security and affordability of electricity. Therefore, people economic and social wellbeing are affected.

Renewable fuels for electricity generation were subsequently introduced in the 8th and 9th Malaysian plans. This national commitment to introducing green electricity has been reiterated in the 10th Malaysian plan for 2011 till 2015. However, till present, <1% has been achieved (EPU, 2015; Muis et al., 2011). The government plans to increase the renewable share to 5.5% of the fuel mix by 2015 (10th Malaysian Plan) (EPU, 2010). Therefore, there is a great need to assess the renewable technologies for electricity generation in Malaysia.

The Malaysians power generation mix is heavily dependent upon thermal resources. The dominant share is occupied by the natural gas; following gas is coal having 40% of the total share. Commutatively these two resources contribute more than 80% in the generation mix. Noticeably Malaysia has abundant natural gas, and oil reserves still a considerable part of generation capacity dependent upon imported fuel. A sudden disruption in energy imports may put the power sector on the verge of collapse. South Africa, Australia and Indonesia provide more than 90% of coal for Malaysians power generations. Saying this is not to be wrong that Malaysia's energy security is interlinked with its energy exporters.

Resource security risk is not only associated with the imported fuel but also profoundly depends upon indigenous resources like natural gas, oil and even renewable. It is essential to evaluate the risk exposure of domestic resources for stable and sustainable policymaking.

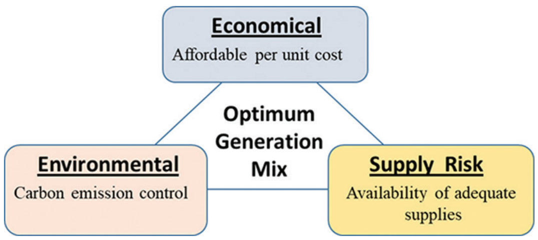
3. ENERGY SECURITY

Energy security has gained attention globally due to increase in demand and political instability. Environmental degradation, fluctuating oil prices, depleting reservoirs and unforeseen political events have encouraged policymakers intended to assess action plan for generation of sustainable energy. The objective is attainable with the help of policy modification and optimum utilization of available resources. The study incorporate three primary elements of energy in terms of cost to evaluate the total exposure. Theses primary elements are: integrated, affordability, acceptability and availability. Adequacy of these help to evaluate sustainability in economic growth, social stability and potential harm to environment. In this respect, energy experts around the globe are looking for effective tool to measure the impact of supply disruption in the process of energy generation. For high level of security additional cost will be incurred (Tufail et al., 2018b), however supply disruption has never been evaluated in monetary units.

A holistic approach is adopted in this study to assess the power generation portfolio of Malaysia. This approach is also known as sustainability approach. The study incorporates the interrelation between economic, environmental and technological aspects of each technology in the process of power generation. Apart from conventional approach of quantifying cost of power generation, the study mainly encompasses supplementary cost parameters that indirectly affect the power generation cost in form of carbon-tax penalty and excessive cost of reliable and secure resources of power generation.

Considering this a modified research framework is needed to be designed which reflects the important dimensions of energy security, quantification methods and tools and modification techniques with the appropriate optimization process. A conceptual framework of this study is illustrated in Figure 1 and detailed explanation is shown in Figure 2. This study formulates a novel approach which not only provides the in-depth cost analysis but also implies the concept of diversity to ensure the affordable, clean and secure generation process.

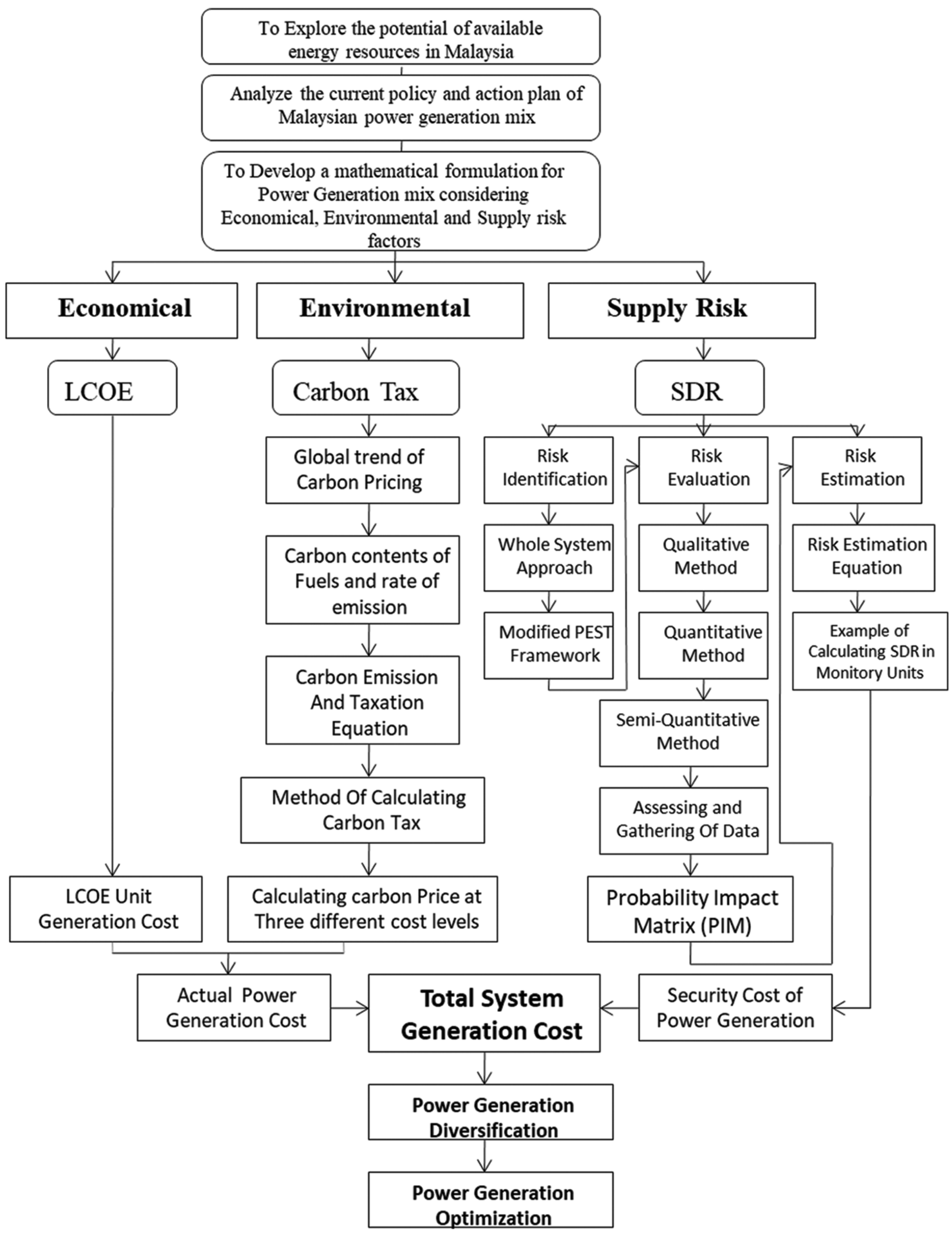
Figure 1: Integrated energy security dimensions contribute to the optimum generation mix



The designed framework follows the bottom to up approach initiates with the basic concept of energy security, focuses on the three critical, integrated dimensions, evaluated in the term of cost, compliance with principles of diversification and finally optimized and implemented on Malaysia's power generation portfolio. Figure 2 shows the step by step evaluation process and estimation methods of this study.

The key objective is to optimize the cost of electricity generation considering economic, environmental and security factors, using appropriate methodology. In order to estimate the least exposure, it is necessary to quantify all the functions/variables on a single

Figure 2: Research framework



platform, i.e. (regarding monetary units). It is obvious that 100% security of any system cannot be achieved, however, to attain the maximum level of security an excessive cost is required, which can be utilized as a compensator in the occurrence of unpredictable events. To identify, evaluate and estimate those events a systematic analysis and appropriate tools are required to measure the probability and impact on the system. In this regard, this study proposed a novel approach of quantifying supply risk indicators in the power generation process using Risk Impact Matrix.

To compliance with the 11th energy plan of Malaysia this study adopted five fuel policy of power generation. The aim is to propose an optimum solution for electricity generation by modifying existing available resources at an affordable cost. In this regard, a mathematical equation is formulated as a function of three cost variables affordability, acceptability, and availability of resources. However, affordability is directly related to the cost of electricity generation and can be calculated using world known method of LCOE (levelised cost of energy) which comprises parameters of costs (capital, fixed, variable, operation, maintenance, fuel), discount rate, plant efficiency, economic life, and capacity factor, but costing the environmental penalty and the excessive cost of security is the challenge to achieve.

The environmental costing process is divided into two steps. First the amount of carbon emission metric tons (MT) is to be measured in the electricity generation process using the value of carbon content in each fuel; secondly, a rate of carbon emission tax is proposed to restrict CO_2 emission in the process of generation. In the study, the carbon-tax is considered as the integral component of total electricity generation cost. The third process deals with the secure supplies of energy and to measure the impact of unavailability of supplies on the cost of power generation. As it has been already mentioned that higher level of security anchored extra cost on the system. To estimate the cost of security the risk analysis approach will be used in the form of a risk impact matrix. The process of quantification consists of three steps, Identification of risk, estimation of risk and evaluation of risk. The novel approach of quantification is proposed to quantify the probability and impact of unforeseen events in the form of monetary units, which combines with the total cost as a component of security cost of adequate supplies of energy. Once, the total cost has been identified the system will be examined on the scale of diversity to maximize the share of each generation technology at the optimum level at the lowest possible cost. To achieve the desired objectives an equation is formulated for the quantification of minimum total exposure. The objective function can be written as:

Objective Function

Min {Total Cost of Power Generation Mix}

Total Cost of Power Generation = Economic Cost + Environment Cost + Cost of Supply Risk

$$TC=\{LCOE+Carbon\ Tax+SDR\}\ Diversity\ (max) \quad (1)$$

3.1. LCOE Methodology in Electricity Generation

Potential of energy market can be gauged by conducting a techno-economical evaluation of various electricity generating technologies. Technology is not favourable if not cost effective. Economic evaluation of renewable technologies, biomass power generation is highly affected by the cost of electricity generation. The cost can be calculated by different methods, widely used among them is LCOE (Larson et al., 2014).

According to (IEA, 2010; NEA, 2010), LCOE considered as appropriate method to measure per unit generation cost of different technologies over their economic lifetime. On the basis of cost effectiveness it is graded as an efficient tool for ranking of power generating technologies (Branker et al., 2011; IEA, 2010; NEA, 2010). IRENA (2012 and 2013) also used LCOE method to calculate electricity generation cost of various renewable technologies around the globe.

$$LCOE=\frac{\sum_{t=1}^{N}\frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{N}\frac{e_t}{(1+r)^t}} \quad (2)$$

Where I_t is a Capital Investment in the Year t, M_t denotes Operation and Maintenance Cost in the Year t. Meanwhile F_t represents Fuel Cost in the Year t. r measures the Discount Rate, e_t indicates Total Energy Produced by the System and N is the designed Life of the Plant.

Nuclear Energy Agency (NEA), New Energy Externalities Development for Sustainability (NEEDS), European Sustainable Electricity (EUSUSTEL), Department of Energy and Climate Change (DECC), International Energy Agency (IEA), and Cost Assessments for Sustainable Energy Systems (CASES) all these gave the definition of LCOE Generation identical to the formula presented above in Equation 2 (Larson et al., 2014).

According to NREL (1995) the LCOE for every unit generated will become equal to the total life-cycle cost discounted back to foundation year. It is an amount required for the project in the way that cost becomes equal to revenue (including making a return of the capital invested) in the completion of the period. LCOE analyses were used for the comparison of different technologies using different scales to measure the investment and operating time. The result differs with respect to countries, available resources, adopted technology, capital investment, operation and maintenance costs, and the level of efficiency of the technology and the system (Tufail et al., 2019).

3.2. Carbon Emission and Taxation

Worldwide researches, policymakers are in process of reviewing policies for the reduction of Carbon Footprint. Previously studies targeted on transportation and Industrial sector for release of carbon emission. Specifically, power generation was not in focus, hence no standard tool as developed to measure carbon emission from power sector. The study particularly develops a simple equation for calculation of cost of carbon emission in process of power generation.

The cost of carbon (*Ci*) for generation of 1KWh of electricity is calculated as:

$$C_i = C_a C_b \sum n_x \quad (3)$$

Where C_a is a tons of carbon released during the generation of electricity, C_b denotes the cost of carbon released per metric ton. Meanwhile n represents the number of units generated and *x* indicates the type of fuel (Solar, Gas, Hydropower, Coal and Biomass).

Coal is considered as a most hazardous fuel amongst the family of fossil fuels and unfortunately dominating the power generation sector. On the other hand, hydropower and solar are the safest technologies with the minimum emission of carbon in the power generation process. Some sources of energy with their inherence to release carbon are presented in Table 1.

3.3. Supply Disruption Risk (SDR) in Power Generation Process

To secure supplies at an affordable cost is always remains the critical consideration of policymakers around the world. It has been acknowledged that the highest level of security includes excessive cost. On the other hand, the inadequate disruption supplies for generation process may result in the lesser unit to generate and engage constant interruption (load shedding) in electricity supply. Countries like Pakistan, India, Bangladesh, Nigeria and many more are facing electricity load shedding more than a decade, which ultimately results in low economic growth, less GDP and also increase frustration in daily lives.

In order to reduce the supply disruption risk, it is imperative to identify the disruptive factors and also to evaluate the cost to overcome those disruptions and to prepare for rainy days. This study evaluates a novel approach to identify, assess and estimate the probability and impact of supply disruption risk in the power generation process.

3.3.1. Identification of risk

Risk identification is foremost and perhaps most critical step in the process of risk management. Chapman and Ward (2003) conclude that identification of risk is challenging and crucial. Failure in identification of a particular risk will result in shift of a final goal and risk management cannot be implemented. In power generation risk associated with supply and energy extraction must be identified correctly. Such uncertainties cause losses in the production and leads to economic instabilities. Addressing risks in a power generation portfolio diminish enigmas and provide relentless supply of electricity to users.

Table 1: Various Fuel Types and Amount of Carbon Emission

Fuel	Capacity/Configuration/Fuel	(gCO_2e/KWh)
Coal	Various Generator Types	960-1050
Natural gas	Various Combined Cycle Turbines	443
Biomass	Short Rotation Forestry Reciprocating Engine	41
Solar PV	Polycrystalline Silicone	32
Solar thermal	80 MW, Parabolic Trough	13
Hydroelectric	300 KW, Run-of-river	13

Source: Sovacool (2008)

Several methods are used for risk identification, in power generation system dynamic nature of energy and innovative technologies make it more complicated to identify.

3.3.1.1. Whole system approach in risk

The concept of the whole system is based upon the interaction and behaviour of a system with its surrounding. A system is a combination of integrated variables which works together to achieve the desired objective (Ackoff, 1971). The ultimate objective of the whole system approach is to ensure smooth operation of the system and prepare itself for uncertain events in future. However, a system is exposed to two significant problems in itself. (1) Hard problem and (2) Soft problem. The hard issues of a system are usually well-defined and have a single preeminent solution. In comparison, soft problems are uncertain, poorly defined and not simple to quantify. To access these system problems services of industry experts are required to investigate the system and provide the best solution on the bases of their experience and knowledge.

3.3.1.2. Modified PEST framework

In order to identify the exposure risk to the energy system, a detailed review of the academic and grey literature has been conducted. The "PEST" analysis framework was used to identify the risk elements interact with energy supplies. The PEST acronym represents a political, economical, social and technology thematic area which guides the industry/organization to identify the intellectual risk in whole and to organize them according to the organizational objectives. However, in this study, the social content is ignored and replaced by the geopolitical barriers and climatic interference. These types of frameworks are highly recommended for strategic planning and provide a guideline to policy/decision makers (Luffman, 1996).

After drawing across the core energy literature and discussion being held with professional and academic colleagues, energy supply disruption five indicators have been identified. Their interaction with Malaysia's five fuel energy is shown in Table 2.

It is being noticed, presence of hydrocarbon interact with political interference and import disruptions. On the other hand, zero impact of these on renewable energy. Whereas, weather conditions significantly impact renewable energy while, hydrocarbons are less reactive under season variations.

The study estimate risk in terms of percentage. Rating assigned to likelihood (Probability) multiplied by the impact (Seveity) for each individual fuel in the generation portfolio. Equation formed for total risk evaluation is average sum of five indicators. As shown below:

Total supply disruption Risk in power generation = [Geological Risk + Geopolitical Risk + Economical Risk + Technical Risk + Climatic Risk]

Table 2: Identification of Key factors influence energy supply security using modified PEST analysis

Types of Risk	Reasons	Coal	Gas	Biomass	Hydro	Solar
Geological Risk	Resource Depletion/Shortage	✓	✓	✓	X	X
Geopolitical Risk	Political instability (War, Terrorism) High import dependence	✓	✓	X	X	X
Economic Risk	Lack of investment in the extraction of resources	✓	✓	✓	✓	✓
Technical Risk	Plant equipment malfunctioning/Failure	✓	✓	✓	✓	✓
Climatic Risk	Extreme weather conditions Intermittency Risk	X	X	X	✓	✓

$$Risk = Probability \times Impact \quad (5)$$

$$Supply\ disruption\ risk\ for\ x\ fuel = SDR_x = (P_{Gx}I_{Gx} + P_{Lx}I_{Lx} + P_{Ex}I_{Ex} + P_{Tx}I_{Tx} + P_{Cx}I_{Cx}) / Y \quad (6)$$

Where *P* is a likelihood and *I* is the Impact of risk. Meanwhile *X* is the type of generation fuel, i.e. (Coal, Gas, Hydro, Solar, Biomass), *G* denotes Geological risk, *E* Economic Risk, *L* geopolitical risk, *T* technological risk, and *C* climatic risk. Whereas *Y* represents the total no of risk in the system.

The above equation will use to evaluate the probable loss of generation units. Policymakers should consider the cost of risk for secured power generation portfolio as the part of the total generation cost at the time of planning. Consider a system having a SDR value of 60% means it should include the excessive cost of 60% to the actual cost for example.

Referring to the equation (4)

$$Actual\ Cost = LCOE + Carbon\ Emission\ Tax \quad (1)$$

$$Excessive\ cost\ of\ security = SDR = 60\%\ of\ Actual\ Cost \quad (8)$$

Referring to the main equation section (1)

$$Total\ Cost = LCOE + Carbon\ Emission\ Tax + SDR \quad (9)$$

3.4. Diversity Evaluation Indice

In the event of protection against risk and its mitigation the remedy works is diversification of resource, transportation and energy supplies. In the energy literature generally energy diversity metric is derived from two main elements: business and ecology. Commonly used diversity indices are Herfindahl-Hirschman Index and Shannon-Wiener Index (Hippel et al., 2011; Jansen and Seebregts, 2010; Kruyt et al., 2009). In this study, we use HHI for diversity evaluation.

3.4.1. Herfindahl- Hirschmann Index (HHI)

In the quantification of diversity in a portfolio diversity score may not be simple. It is measure as degree of diversification in a portfolio. Commonly known method for measurement is Herfindahl- Hirschmann. HH Index estimate concentration of portfolio by using aggregate data.

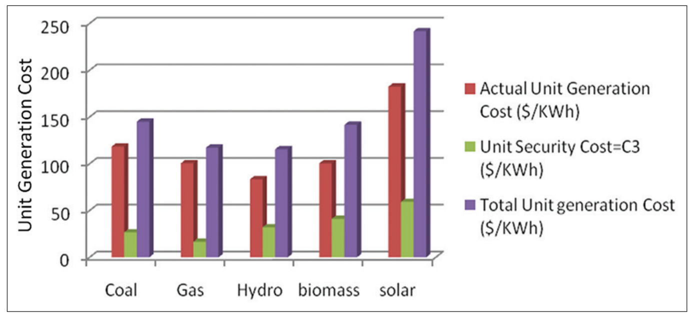
HHI is extensively used in power generation industry to assess the impact of mergers and acquisition of regional electricity market concentration (Tufail et al., 2018a). In the measurement of fuel diversity, HH Index is calculated as sum of squares of market share of each resource. It is shown as:

$$HHI = \sum_{i=1}^{N} C_i^2 \quad (10)$$

In formula, *Ci* is market share of i*th* resources, expressed in percentage. *N* is total categories of resources. We, consider *P* power generation portfolio comprising of 5 different generation technologies, C*i* where *i* ranging from 1 to 5. HHI measure the value of diversification of five different generation technologies.

$$HHI = C_1^2 + C_2^2 + C_3^2 + C_4^2 + C_5^2 = \sum_{i=1}^{5} C_i^2 \quad (11)$$

Figure 3: Comparison of actual cost, security cost, and total system cost



4. RESULTS

Referring to equation 1 the total cost of power generation can be calculated by summing the economic, environment and ssecurity cost. Table 3 shows the total electricity generation cost of Malaysia's power generation mix.

Table 3 shows estimated total generation cost of Malaysia's power generation mix. The most numbers of unit generated by natural gas, which considered as the safest fuel for electricity generation which is responsible for heavy amounts of carbon emission. However, hydropower is the cheapest form of technology for electricity generation, but occupying <10% of total shares in the generation mix. On the other hand, biomass and solar are completely ignored, having a share of <1% is Malaysia's power generation mix. Table 3 shows the combination of total cost in terms of actual and excessive cost of security. However, the comparison of unit generation cost is shown in Figure 3.

Figure 4: Optimum portfolio comparison in terms of Cost and Diversity

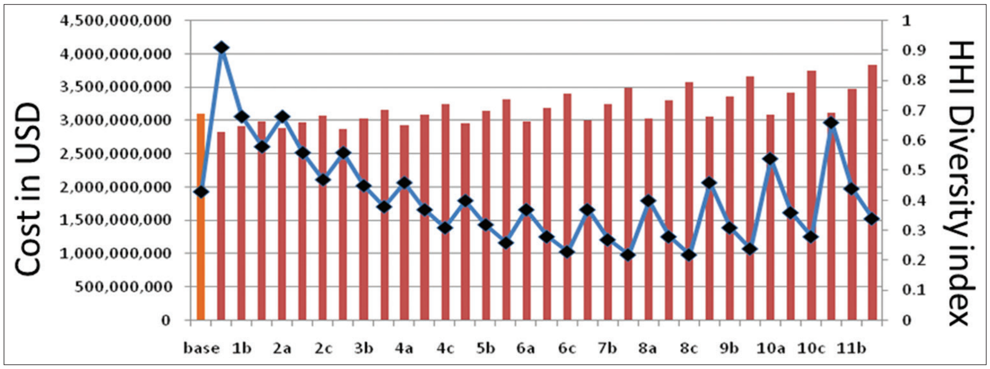


Table 3: Total Cost of Malaysia's Power Generation Mix

Sno	Fuel Type	Units Installed Capacity (MW)	Economic Cost (EC)/year	Carbon Tax (CT)/year	Actual Cost AC=EC+CT	Security Cost (SC)/year	Total Cost TC=AC+SC
1	Coal	9,257	9,601,212,288,000	1,629,935,520	9,602,842,223,520	2,160,272,764,800	11,763,114,988,320
2	Gas	12,278	10,820,061,168,000	952,939,780	10,821,014,107,780	1,796,130,153,888	12,617,144,261,668
3	Hydro	2,046	1,496,567,160,000	4,659,960	1,496,571,819,960	576,178,356,600	2,072,750,176,560
6	biomass	62	54,583,560,000	445,360	54,584,005,360	22,379,259,600	76,963,264,960
5	solar	145	231,811,500,000	558,880	231,812,058,880	75,338,737,500	307,150,796,380
	Total Units	23,788 MW	22,204,235,676,000	2,588,539,500	22,206,824,215,500	4,039,034,191,094	26,837,123,487,888

4.1. Optimum Power Generation Portfolios

After quantifying the three key indicators of energy security in terms of monetary units the Primary purpose of the study is to evaluate optimum power generation portfolio of Malaysia's electricity generation mix. The process of optimization is carried out by using excel spreadsheet solver optimization tool. In order to achieve the lowest cost power generation mix with the maximum level of diversity the five fuels of Malaysia's power mix were divided into two segments (1) Conventional power generation technologies and (2) Non-Conventional power generation (renewable) technologies as shown in Table 4. The study proposed eleven portfolios for optimization subsequently increasing and decreasing by the rate of 10% share of each fuel. Each and every portfolio were analysed by three different scenarios, i.e. minimum units of generation by each generation technology should be >10%, 20%, and 30% respectively as shown in Table 5, however optimum portfolios are represented in Figure 4.

From Figure 4 it can be concluded that the portfolio 7C and 8C are the maximum diversified portfolio having diversity index 0.22 followed by 6C with the value of 0.23; however portfolio 1A and 3A are cheapest in terms of monitory value. In order to quantify the optimum portfolio in terms of cost and diversity this study oppose a techniques of base line graphical evaluation method (BLGEM). The BLGEM is a novel approach used in this study to find the single optimum portfolio for Malaysia power generation mix satisfying the condition of minimum possible cost at the maximum level of diversity as shown in the equation.

$$\text{Optimal Portfolio} = [\text{Min } \{\text{Total Cost of Power Generation Mix}\}] \text{ Diversity Index}_{\text{Min}} \quad (12)$$

To identify the optimum generation mix the entire eleven quantified portfolios with three different scenarios has been

Table 4: Conditions for evaluation of optimum portfolio for Malaysia power generation mix

Portfolio Conditional table for Optimization of Power Generation Mix				
Conventional Power Generation		Non-Conventional Power Generation		
Coal	Gas	Hydro	Solar	Biomass
100-0%			0-100%	
Scenario 1	At least 10% of the units should be generated by each technology			
Scenario 2	At least 20% of the units should be generated by each technology			
Scenario 3	At least 30% of the units should be generated by each technology			

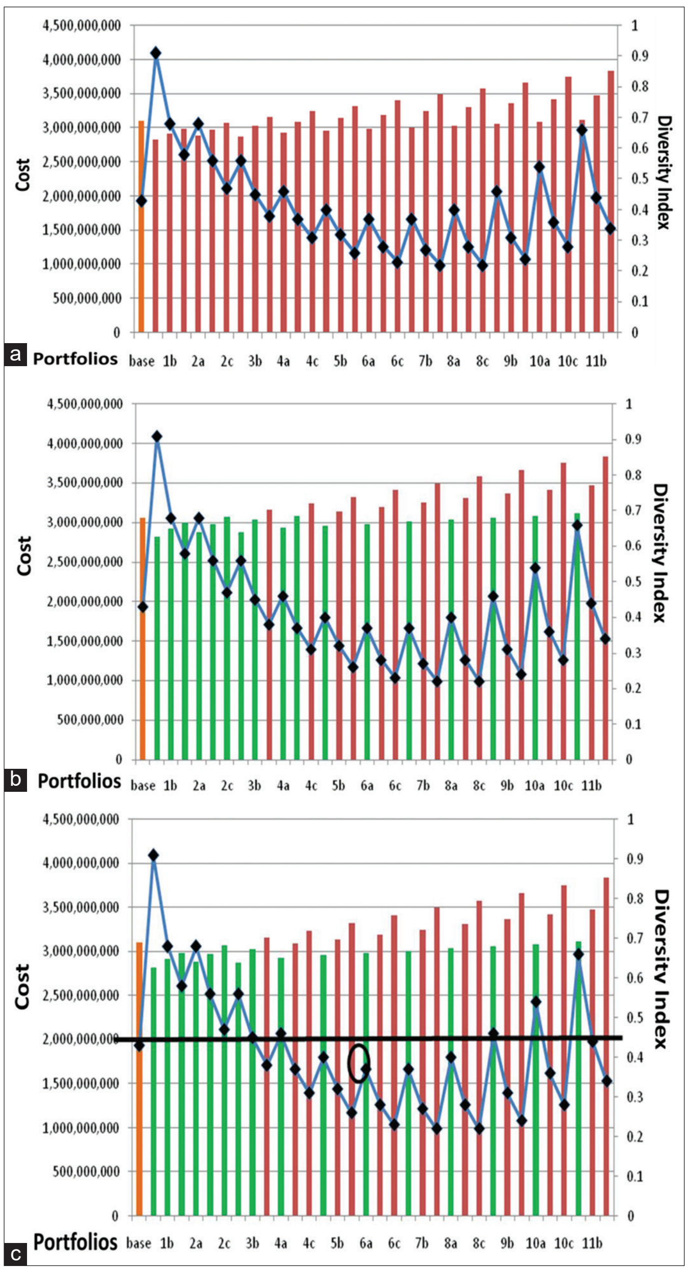
plotted on the graph (Figure 4). It has been observed that the cost has the inverse relationship with the value of diversification. The cost will increase with the decrease in diversity index. From the other perspective, we can say that cost is directly proportional to the level of diversification. The more diversified the portfolio, more the cost, and vice versa. Here the evaluation method has been carried out in two simple steps. The current values of the Malaysian power generation mix are considered as the base value (scenario) and compared with the other entire portfolio in terms of cost and diversity index. The portfolio having maximum diversity at lower cost in comparison to base scenario will consider as the optimum portfolio of Malaysia power generation mix.

Step 1: In first step cost of the entire identified portfolio compared with the base cost. The cost lower than the base cost placed in the consideration set and has shown with green color on the graph, however, the high-cost values in red were ignored disregarding the diversity index shown in Figure 5b.

Table 5: Comparison of the Optimum portfolio with Base Scenario

S No	Fuel Type	Cost of unit generation (KWh)	Base Scenario			Optimum Portfolio		
			Units Capacity (KW)	Total Cost of generation	Diversity Index	Units Capacity (KW)	Total Cost of generation	Diversity Index
1	Coal	145.06	9,257,000	1,342,818,032	0.43	1,188,000	172,330,974	0.37
2	Gas	117.31	12,278,000	1,440,311,335		10,705,000	1,255,785,375	
3	Hydro	115.65	2,046,000	236,615,307		9,517,000	1,100,619,688	
6	biomass	141.71	62,000	8,785,760		1,188,000	168,346,497	
5	solar	241.81	145,000	35,062,875		1,188,000	287,273,763	
	Total Units		23,788,000	3,063,593,309		23,788,000	2,984,356,297	

Figure 5: (a) Graphical evaluation of optimum power generation mix using baseline scenario. (b) Step 1 identification of lower cost values in comparison to base scenario (consideration set). (c) Step 2: Identifying optimum portfolio in terms of maximum diversity



Step 2: In step two considered portfolio with lower cost were examined in terms of diversity index. The portfolio has the highest level of diversification with a lower value of diversity index is considered as the optimal portfolio. The identification is carried out by drawing a reference line from base diversity index value as shown in Figures 4 and 5c.

Table 6: Top 10 optimum portfolios for Malaysia power generation mix

S No.	Portfolios	Power Generation Cost	Diversity Index
1	Portfolio 6a	2,984,356,297	0.37
2	Portfolio 7a	3,010,030,141	0.37
3	Portfolio 4b	3,088,082,114	0.37
4	Portfolio 5a	2,958,682,453	0.4
5	Portfolio 8a	3,035,703,986	0.4
6	Portfolio 3b	3,032,783,984	0.45
7	Portfolio 4a	2,933,008,608	0.46
8	Portfolio 9a	3,061,377,830	0.46
9	Portfolio 2c	3,073,015,168	0.47
10	Portfolio 10a	3,087,051,674	0.54

From the above Figure 5a, it can be observed that the portfolio 6A has the highest level of diversification with the value of the lowest diversification index, i.e. (HHI = 3.7) at a lower cost than the base scenario. The comparison in terms of cost, a number of units generated and the diversity index is shown in Table 5 below.

In comparison to other values, it has been observed that portfolio 4B and 7A also have the same value of diversity index, i.e. (HHI = 3.7) but higher in cost to the base scenario. Among the thirty-three optimum portfolios, top ten portfolios have been selected and ranked with respect to the lowest cost at the maximum level of the possible diversity index. The identification of top ten optimum portfolios was carried out using the baseline graph evaluation method.

From the Table 6, it can be concluded that portfolio 6A is the optimum portfolio having lower generation cost and better value of diversity index. The generation cost of the portfolio has reduced from 3,063,593,309 to 2,984,356,297, however, diversity index has improved with the value of 0.37 in comparison to 0.43 of base scenario. Portfolio 7A and 4B secured second and third positions at the same level of diversity index but slightly increased generation cost.

5. CONCLUSION

Globalization, economic growth, industrialization and increasing population have increased the demand of energy more than ever before. There is a need for sustainable power generation mix to incorporate concept of energy security in long run. In the context of energy sustainability, security, affordability, acceptability and the diversification of fuel supplies and technology, the study has been set out to explore the optimum combination of five technologies for electricity generation in Malaysia. The level of cost has been examined on the scale of affordability, acceptability and the excessive cost of security compliance with the concept of diversity to formulate an optimum combination of power generation mix. To scrutinize the technologies on a single platform a multi-perspective approach was adopted followed by the hybrid technique of optimization.

The multi prospective includes economic, environmental and security aspects of each technology in the generation portfolio on the other hand optimization process was conducted to achieve the optimum level of cost at the maximum possible level of diversity. On the basis of energy security dimensions ten optimum portfolios have been identified with minimum cost and maximum diversification. The process of diversification has been performed through HHI index and further purified using novel technique of base line graphical optimization method. This research will not only help in achieving energy security in long run but also help in economic stability and environmental sustainability.

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