SUSTAINABLE RESOURCE AVAILABILITY BY OPTIMIZING ECONOMIC AND ENVIRONMENTAL FACTORS IN MALAYSIA'S POWER GENERATION MIX

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By

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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: energy security, levelized cost of energy (LCOE), carbon-tax, excessive cost of security, power generation mix optimization.

ABSTRAK

Pertambahan populasi dan pembangunan ekonomi menyumbang kepada peningkatan keperluan bekalan tenaga elektrik. Bagi memenuhi keperluan tersebut, tenaga elektrik dijana dengan menggunakan sumber bahan api fosil. Kaedah berkenaan mempunyai tiga kelemahan utama iaitu pengurangan sumber, kebimbangan alam sekitar, dan risiko bekalan. Bahan api yang boleh diperbaharui dikategorikan sebagai sumber jana kuasa yang mampan. Walau bagaimanapun, terdapat keperluan untuk menilai dan mengoptimumkan penggunaan sumber yang sedia ada dengan cara yang lebih berkesan dan cekap. Untuk mencapai matlamat tersebut, kajian ini menggunakan pendekatan pelbagai perspektif bagi memastikan penggunaan sumber yang cekap, sama ada dari segi kos dan kepelbagaian, serta bertujuan untuk mencadangkan gabungan teknologi yang optimum dalam penjanaan tenaga elektrik di Malaysia. Dalam hal ini, sumber yang berpotensi telah dikenal pasti berlandaskan kepada pematuhan prospektif Malaysia dengan pelan tindakan lima tenaga bahan api 2020. Kelima-lima bahan api telah diselidik dari segi ekonomi, alam sekitar dan parameter keselamatan, serta dinilai dari segi kos untuk mengukur jumlah bebanan dalam bentuk kewangan. Untuk analisis ekonomi, kaedah pengkuantitian kos LCOE digunakan. Begitu juga sekatan terhadap pelepasan karbon, dasar cukai karbon telah dicadangkan dan teknik baharu direka untuk pengkuantitian kos keselamatan yang berlebihan dalam industri penjanaan elektrik. Kajian ini menggunakan model matematik simulasi dan pendekatan penilaian grafik bagi mengoptimumkan campuran penjanaan kuasa dari segi kos dan indeks kepelbagaian. Oleh itu, dapatan kajian ini dapat membantu penggubal dasar dalam merangka dasar jangka panjang yang cekap dengan mengambil kira faktor-faktor yang mempengaruhi jumlah kos penjanaan semasa mengamalkan konsep kepelbagaian untuk proses penjanaan kuasa yang efisien dan konsisten.

Kata kunci: Keselamatan Tenaga, Kos Tahap Tenaga (LCOE), cukai karbon, kos keselamatan yang berlebihan, pengoptimuman campuran penjanaan kuasa.

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LIST OF ABBREVIATIONS

LCOE	Levelized Cost of Energy
SDR	Supply Disruption Risk
MW	Mega Watt
KWH	Kilo Watt Hour
IEA	International Energy Association
NEB	National Energy Balance
GDP	Gross Domestic Product
BP	British Petroleum
BBl	Barrel of Oil
IPCC	Intergovernmental Panel on Climate Change
TWH	Tera Watt Hours
GHG	Greenhouse Gas
ASEAN	Association of Southeast Asian Nations
OECD	Organization for Economic Cooperation and Development
GWH	Giga Watt Hour
LNG	Liquid natural Gas
PIM	Probability Impact matrix
HHI	Herfindahl-Hirschmann index

CHAPTER ONE
INTRODUCTION

1.1 Background of Study

In modern society, the importance of electricity is paramount. Electricity is essential and is largely linked to several facets of life because power is the lifeblood of human activities in the modern world. According to Gilbert (2005), the tremendous advancement in the modernization of technology is a contributor to the raised demand for energy in 21st century besides the rapid increase in the world population. IEA (2015) reveals the facts that about 17 trillion watts of energy are being used worldwide. It has been foreseen by the experts that the further requirement of 30 trillion watts would be needed by 2030 due to the rapid rise in global population and brisk economic growth (Timmons, Harris and Roach, 2014).

Figure 1.1 illustrates that in 2013 the most of the energy generated (approximately 87%) was comprised of fossil fuels like oil, coal, and gas. In the 20th century, fossil fuels were given preferences for power generation due to their comparatively lower prices (BP Statistical Review 2014). Regrettably, it is a well-known fact that human health is severely affected by the catastrophic climatic changes caused by fossil fuels (Holgate, 1999), global warming (Letcher, 2009) and their reservoirs are gradually depleting (Simmons, 2005). The utilization of fossil fuels for electricity generation has been exposed to two major challenges: (1) finite resources and (2) environmental degradation. Energy experts have predicted that naturally available fossil fuel reservoirs are depleting continuously and will expect to remain one more century (Sovacool and Watts, 2009). The second challenge points towards the catastrophic emission of carbon (CO_2), nitrogen (NO_2) and sulfur (SO_2) emits during utilization of fossil fuels in electricity generation process. However, Hook and Tang (2013) believe that these emissions are the major contributor to global climate change. Keeping this in mind policymakers is working consistently for updating their proposed action plans by engaging renewable energy sources for electricity generation. This diversification will achieve reliability and sustainability in production as well as combat climate change. The push toward a sustainable and cleaner environment is resulting in new pressure on the power generation industry.

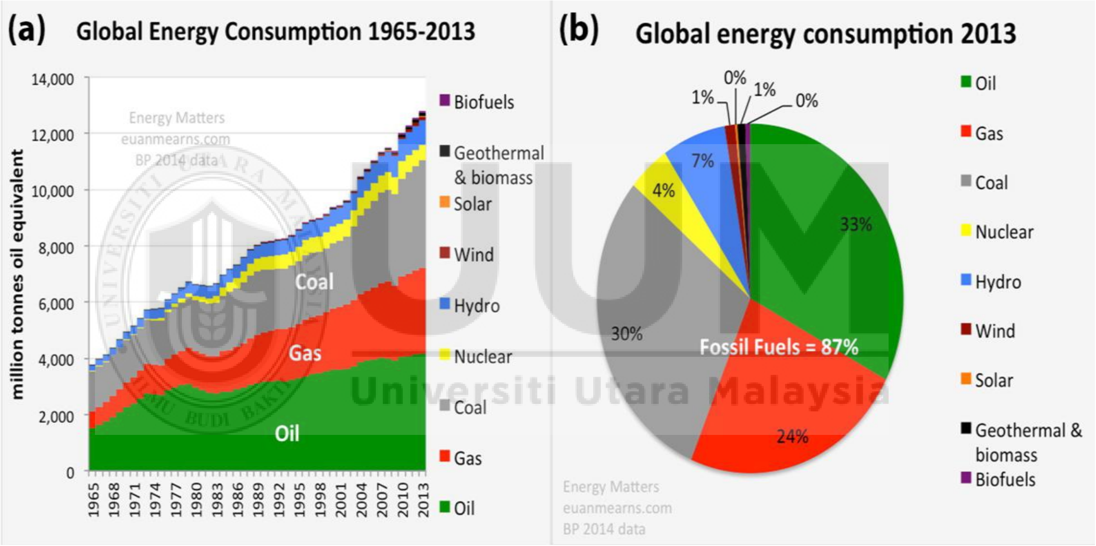


Figure 1.1.
(a) Worlds energy utilization and growth (1965-2013) (b) Global primary energy mix
Source: B.P., (2014)

Due to the dominance of fossil fuels in power generation sector makes the industry one of the major contributor of carbon dioxide today. However, there are numerous climate change initiatives in various stages of development and implementation that will rapidly impact the future course of the industry. The ineffective adaptation of such policies which includes effective and efficient utilization of renewable resources will not only influence the sustainable economic development but also creates savior impact on global warming. It is not an option to change the entire generation mix overnight, but the diversified optimization of available resources is the best solution to reduce the greenhouse gas emission effect. Achieving the highest level of economic growth is desirable, but it would not be at the cost of environmental degradation instead we need to enhance sustainable development.

Industrialization, economic growth and rapid increase in population emerges the need for energy security more than ever before. With the rising global concern for energy security, the increasingly unstable supply of fossil fuels, and the massive energy demand of developing countries, urgent policy responses to national energy security are required. However, few attempts have been made to define energy security and measure the cost of energy security. This study classifies energy security into economic security, climate change mitigation impact and risk of resource supplies used for electricity generation in Malaysia, such as coal, natural gas, hydropower, biomass and solar which are the contributor of power generation mix. A comparison of these generation technologies has been made in terms of economic cost, environmental cost and the impact of the supply shortage of power generation. The supply shortage impact will transform into the financial loss, and total exposure of all generation techniques will be evaluated. Finally, an optimal mix will be identified at least cost exposure and recommended to policymakers for implementation.

To maintain a secure, reliable and affordable supply of electricity along with the lower level of risk, policymakers have to update their policies and intended action plans continuously. This situation mainly owes to uncertainties surrounding electricity sector. The sources of difficulties in the sector are delays in infrastructure construction, choice and advancement in technology, resource limitation, price and demand fluctuations, pollution and environmental concerns and, last but not the least, regulatory and political issues (Olsina et al., 2006). Energy planning has been classified as a complex issue due to its interaction with other sectors of the society (Höök and Tang, 2013; Qudrat-Ullah, 2013). The attributes of energy policy may include policy implications of energy supply and use from their economic, social, planning and environmental aspects, incentives to investment and other public policy techniques (Andrews & Jelley 2013). While the policies related to energy can cover a variety of sources such as renewable, nuclear and fossil fuels, the subject can be studied at different levels, namely regional, national, state, industry, business, and corporate. The depleting reservoirs and high supply interruption risk have motivated policymakers, economist, politicians, and scientist to engage secure alternative with lower potential risk. For instance, fossil fuels are not harvestable in all countries and even not stable in producing countries. Furthermore, continuous fluctuation in oil prices, the unstable political situation of producing countries along with an increase in transportation and other variable costs make utilization of fossil fuels more unreliable. On the other hand, the environmental, technological, and political dangers of nuclear energy illustrate the utilization necessity from other reliable resources.

1.2 Problem Statement

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). The primary challenge that underlies the global economic growth and human development is a fundamental requirement of reliable, affordable, clean and secure energy supplies. The World Energy Issues Monitor 2014 (World Energy Council, 2014) discusses the challenges faced by today's energy leaders. The three main challenges energy security, energy equity and environmental sustainability are referred to as the "energy trilemma".

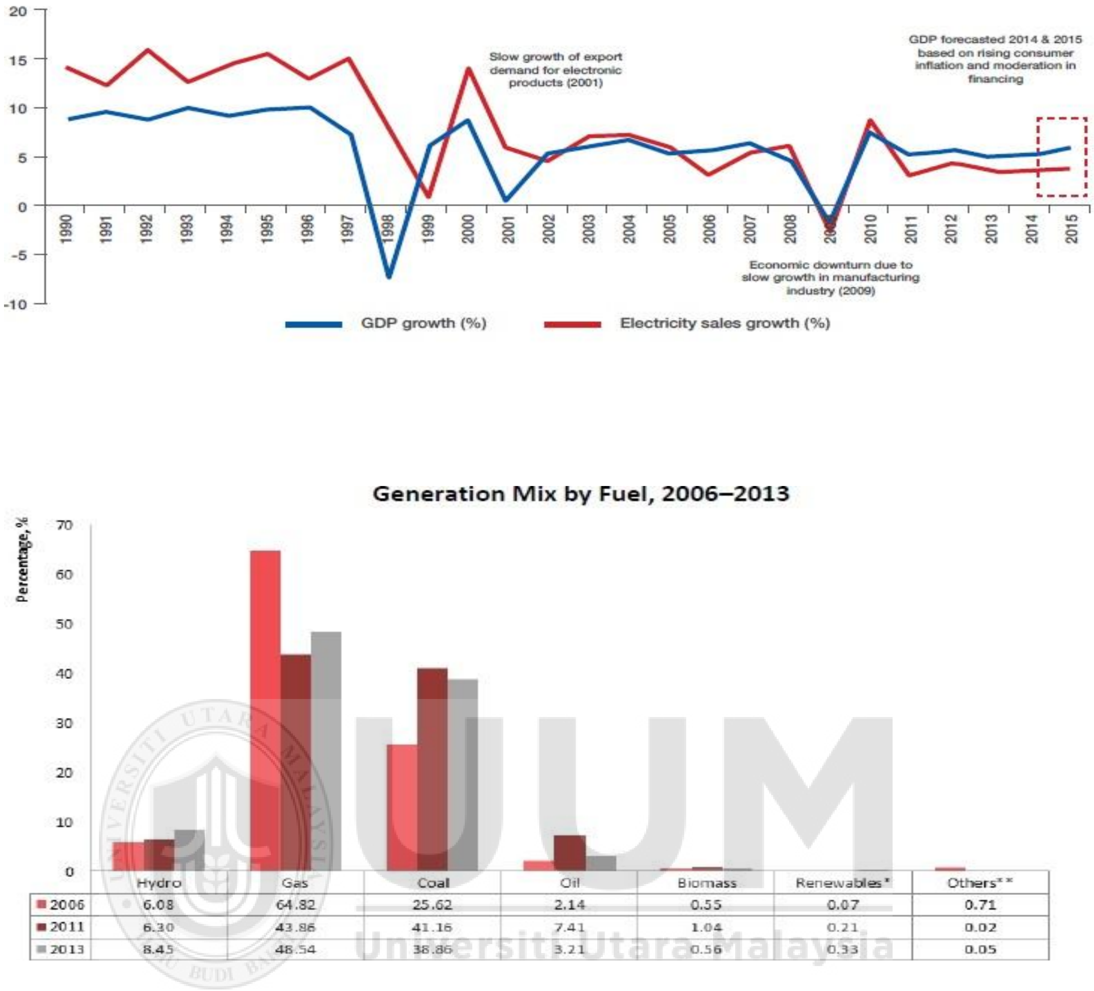
Energy security ranks as a top issue in many countries around the world (Cohen, Joutz & Loungani, 2011; Vivoda, 2009; Hedenus, Azar & Johansson, 2010; Bang, 2009; Brown & Huntington, 2008; Turton & Barreto, 2006). Several factors have been identified by World Bank (2005) that contributes to this issue, such as the volatility in world energy markets, the growing competition for energy resources, and the need for economic development and poverty reduction. 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 strongly related to other problems, such as affordable energy, climate change, environmental policy and many more, this has made many countries perceive security of energy supply as their principal objective in their energy policy formulation.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 & Sovacool, 2012).

This thesis will adopt 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.

1.2.1 Overview of Malaysia Energy Sector

Malaysia is an energy-dependent country (Chandran et al., 2010). The electricity demand in the country has risen extraordinarily, from 1998 to 2006 the primary energy consumption in Malaysia has been increased from 1.7 to 2.6 quadrillion Btu. The use of electricity is also growing every year with an average of 2,533 GW per year. Since 1995 to 2015 the demand for electricity has been increased from 38,820 GWh to 146,221 GWh and is expected to increase 30 % more by 2020 (MES, 2017). Empirical evidence has shown that the electricity consumption has a significant impact on the economic growth of Malaysia (Chandran et al., 2010; Lean and Smyth, 2010a, 2010b; Tang, 2008; Tang and Tan, 2013; Yoo, 2006). The relationship between economic growth and electricity consumption is shown in figure 1.2(a). The increasing trend in energy consumption the government of Malaysia needs to update their policies continuously to ensure the reliability and security of supply in the long term. Concerted efforts are consistently being undertaken to ensure the sustainability of energy resources, both renewable and non-renewable energies. The first and the foremost measure is the affordable energy supply, secondly to find the mix of energy resources which is diverse, affordable, reliable and environmentally friendly.

The historic consumption trend can be seen in figure 1.2(b). To meet the increasing demand investments in fossil fuel based generation capacity had been made, neglecting renewable technologies (Lau et al. 2009). This inclination resulted in fossil fuels based technologies dominating the generation capacity.



	Hydro	Gas	Coal	Oil	Biomass	Renewables*	Others**
🟥 2006	6.08	64.82	25.62	2.14	0.55	0.07	0.71
🟥 2011	6.30	43.86	41.16	7.41	1.04	0.21	0.02
▨ 2013	8.45	48.54	38.86	3.21	0.56	0.33	0.05

Figure 1.2.
(a) Malaysia GDP vs Electricity sales (1990-2015) (b) Malaysia electricity generation fuel mix (2006-2013)
Source: NEB, (2013)

According to Malaysia Energy Commission (NEB, 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. Malaysia is also third largest carbon dioxide (CO_2) emitted in Southeast Asia followed by Indonesia and Thailand (WB, 2017). In 2013, It was examined that the amount of carbon emission has increased to 236.5 matric tons compared to 56.6 matric tons in 1990. However, power sector alone is responsible for contributing 54.8% of total carbon emission (WB, 2017). Malaysia fossil fuel reservoirs are gradually depleting. It is estimated that Malaysia’s oil reserve will last 18 to 20 more years, natural gas 30 to 35 more years and coal are imported for electricity generation (Oh et al., 2010; Chua and Oh, 2010). In the long term, this situation will result in jeopardizing the security and affordability of electricity in the country. Hence, the social and economic well-being of the people will also be 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, less than 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, 2011). 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 percent 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.

1.2.2 Economic Analysis (AFFORDABILITY)

Affordability has always been a key consideration of policymakers, although it is directly influenced by the other external factors considerably demand and resource availability. A reduction in supply allows prices to rise and demand to fall, while an upward shift in demand raises rates and, hence, supply. The most of the energy generated approximately 80% was comprised of fossil fuels like oil, coal, and Gas. In the 20th century, fossil fuels were given preferences for power generation due to their comparatively lower prices (BP Statistical Review 2014). After the 1970 oil crisis, the use of fossil fuel becomes unreliable and massive fluctuation in oil prices has been observed. Recently oil prices fell from a peak of 115 US $ per barrel (US$/bbl) in June 2014 to less than 50 US$/bbl in January 2015 (IEA, 2015).This was a break with several years of prices lowering in a narrow band around US 100 $/bbl. It was also against widely held expectations. According to the resent forecast by the International Energy Agency the steadier prices will increase for many years to come and will expect to reach once (again to 112- 116 US$/bbl by 2020 (IEA, 2015; WEC, 2015).

While oil price shocks are always dramatically when they occur, massive and unexpected swing in oil prices is not new, from 1970 to 2016 the fluctuation in oil prices has been observed between 5 to 115 US$/bbl. (Klevnas et al., 2015). The impact of lower fossil fuel prices hurt producers, but eventually beneficial for consumers. In simple words it can be said that oil price volatility hurts the economy, one consequence of these combined effects is that a reduction in oil prices does not benefit the economy as much as price increase pains it (Mork, 1989).

Conclusively, dependence on fossil fuel energy has a volatile penalty. Measures to reduce this dependence can help prevent economic harm. Options include reducing the energy intensity of the economy, improving energy efficiency and last but not least maximizing the share of non-fossil energy (Renewable).

1.2.3 Environmental Impact (ACCEPTABLITY)

It is now acknowledged that the projected increase in atmospheric concentrations of Climate-related greenhouse gases (GHGs) would change the scale of seasonal variations in temperatures in many parts of the world (IPCC, 2007, 2011), which is expected to increase the danger facing human civilization in years to come. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) gives the best estimate of increases in global temperatures over the next century, which ranged from 1.8 to 4.0 and even to 8.0 ^{0}C. Although this seems like a small change, it is much more rapid than any changes that have occurred in the past 10,000 years (Nordhaus, 2007). US Environmental Protection Agency (EPA) has also admitted that atmospheric concentration of GHG has tremendously increased in the last fifty years from 312 ppm 1950 to 401 ppm 2015 (EPA, 2016) which is responsible to raise global temperature, sea level, patterns of rainfall, plants growth and productivity, intensity of storms, marine life and chemistry of the oceans (Marron et al., 2015).

The consumption of fossil fuel as an energy resource in a population is one of the vast challenges to global environmental sustainability and economic stability.

Greenhouse gases “GHG” and chemicals that evolved during the combustion of fossil fuels are the biggest threat to human health. However, Fossil fuel burning is responsible for contributing 67% of the entire emission globally (Fernando &Hor, 2017). A significant reduction in utilization of fossil fuel is the only option to restrict the changing global temperature below 2^0C (IPCC, 2014). Among the GHG CO_2 is the most abundant gas produced by human activities (IPCC, 2005) released as a by-product in the combustion process of fossil fuels, namely coal, natural gas, and petroleum products (Thollander et al., 2007). Following the natural phenomena partial amount of CO_2 has been absorbed by the oceans, but as emission increased, the consequential edification of those oceans leads to the climate change and global warming (Cubasch et al., 2013).

Today, the worldwide population is using about 17 trillion watts of power which is accountable to release 32,190 mmt of CO_2 in the atmosphere (IEA, 2015). Coal burning was responsible for 43% of the total emissions (Glikson, 2013). Electricity generation (and heating) currently contribute approximately 25% of global anthropogenic greenhouse gas emissions, the primary driver of observed climate change (Zhu, Liu, and Wang, 2010). Indeed, as much as a third of oil, half of gas and over four-fifths of coal reserves must be left unburnt for global warming to stay below 2 degrees Celsius (McGlade and Ekins, 2015). However, in US power plant is the most substantial standalone source of GHG emission which contributes approximately 29% of total US carbon emission (Contreras et al., 2016). Similarly, in Malaysia over 55% of emission is due to the electricity generation industry (World Bank, 2017). The great challenges of Malaysia power sector are the sustainability, security, and reliability of energy supply, which is a mix of non-renewable and renewable energy for long-term development. Today, the world is more circumspect, and renewable energy has been put in the limelight in upgrading the efficiency of the existing power resources. Numerous sound energy policies and significant measures have been formulated to prepare the country for its transition to being a developed nation on a sustainable basis (Chong and Lam, 2013). Various efforts were undertaken to embark on the utilization of renewable energy resources, biomass, biogas, solar, nuclear, hydro-power and municipal waste for energy generation. In tandem with the government's initiatives, some renewable energy policies, strategies, and program were launched and enforced to ensure the reliance on the energy supply (Hossein and Wahid, 2012).

More than ever before, there is an emerging global consensus that the unsustainable use of conventional energy sources is detrimental to the natural environment and now poses a major health risk for both human and non-humans (Mokheseng, 2010). Donohue and Cogdell (2006) argued that government, private sectors, and the scientific community have been united on a single platform to seek such alternative energy sources which can be developed an adopted to decrease the consumption of fossil fuels and simultaneously reduced GHG emissions. To deal with the impacts of greenhouse gases emissions, primarily carbon dioxide, some countries have introduced an efficient economic measure—a carbon tax—in order to save energy and reduce carbon dioxide emissions (Lin and Li, 2011). There is a growing consensus among policy-makers – that has long been accepted among economists – that putting a price on GHG pollution is the most effective means of reducing our carbon footprint (see for example, Stern,2007; Krupnick et al., 2010; OECD, 2011; Aldy and Stavins,2012; Mankiw, 2013; IMF, 2014; Parryetal., 2014). Sustainable policy implementation has now become an essential task for economic and social development with a rapid mode of action in power generation system.

1.2.4 Secure supplies of Resources (AVAILABILITY)

Fossil fuel reservoirs are gradually depleting. It has been anticipated that rapidly decreasing reservoirs of oil will remain available for 200 more years, coal 164 years and natural gas 65 years approximately. Not only fossil fuels, but the non-renewable nuclear resource will last for only 70 more years (Sovacool and Watts, 2009). A more prudent estimate shows a grimmer picture of coal, oil, and gas lasting for 107, 35 and 37 years, respectively (Shaifee and Topal, 2009). The importance of oil can never be ignored in modern life, but its depleting reservoirs, environmental concerns and energy security emerge the needs of alternative sources which reduced the dependency from oil in an efficient way.

As it has already been mentioned earlier that almost 80% of primary energy depends upon fossil fuels and its adequate availability is very sensitive to modern society. A medium-term disruption in energy supplies can drag the whole world into economic crisis. It has been noticed that the political instability has always influenced the security of energy supplies. Unfortunately, most of the fossil fuel reservoirs are located in the countries that have been prone to political upheaval, or in the countries that have had fossil fuel production disruption because of political events. Several major oil price shocks have observed at the same time as supply disruptions triggered by the political events, conspicuously the Arab oil embargo in 1973, the Iranian revolution, The Iraq-Iran war in the 1990’s, and the Persian Gulf war 1990. More recently, disruptions to supply from political events have occurred in Nigeria, Iran, Iraq, Venezuela, and Libya. Considering the history of oil supply disruption caused by political events, policymakers continuously assess the possibility of future disruptions. In addition, the size, duration, availability of stocks and the ability of other producers for the diversification of supplies are also under consideration.

Despite the political interference, weather also plays a significant role in the supply of fossil fuels and renewable energy. In 2005, hurricanes in the Gulf of Mexico region shutdown oil productions and many petroleum refineries which ultimately results in high oil prices. Disruption in supplies always creates a high impact on prices. Considering the case of Malaysia cancellation, delay or default in coal imports may eventually raise the production cost as local market with high price remains the only option (Ibrahim, 2013).

Similarly, renewable energy sources are also under the influence of weather conditions and are not always available, cloudy days reduce the electricity generated from solar installation; without wind minimize electricity from wind farms, and droughts reduce the water availability for hydropower. Every resource is exposed to the specific type of supply risk. Therefore, there is a need to optimize all the resources for least cost at minimum presented risk through diversification. Diversification in the primary energy mix and global power generation resources is the key consideration of policymakers around the world

1.3 Research Questions

The research questions of this study are as follows:

1. How to develop a sustainable energy mix model?
2. How can decision-makers optimize the power generation mix?
3. How can a novel sustainable approach be tested in a real environment?
4. What type of method can be used for validation of the approach?

1.4 Research Objectives

The objectives of the research are;

1. To develop a mathematical formulation of energy mix model by considering the economic, environmental and supply risk factors.
2. To develop a new approach which allows for the optimizing decision- making in the selection of energy mix portfolio based on total exposure.
3. Testing the developed approach in the industry by taking Malaysia as a case study; and
4. To validate the developed approach using diversity index.

The primary goal of this study is to evaluate an optimum portfolio of generation mix with minimum exposure for electricity generation in Malaysia. Besides this, it is also aimed that the study will provide insights for policy-makers and energy-advisors; both at the governmental and private levels regarding each technology. The study attempts to fill in the gap in the area of the energy mix for electricity generation.

1.5 Scope of Study

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 primary focus of this study is to illustrate the development of a new tool to measure the energy security, which is based on the principle of sustainability, pragmatism and applicability. The traditional approach to electricity generation planning has been the least-cost methodology, which is based on calculating the levelised costs of electricity generation, expressed in $/MWh, for different alternative production technologies and after comparing those costs, choosing the lowest cost options (Zhu and Fan, 2010). The LCOE costing method is not sufficient from policy prospective however it is beneficial from private investment point of view. This study develops a novel approach which quantifies the cost of generation in terms of affordability, acceptability and availability of supplies for electricity generation process. For economic analysis LCOE cost quantification method was used, similarly for the restriction of carbon emission a carbon-tax policy has been proposed finally for the efficient combination of technologies a risk minimization approach has been adopted which first identifies the risk, evaluate it and impact is estimated in the terms of the monetary unit to calculate the total cost exposure of the system.

The proposed novel approach can be further modified and include other cost related parameters to make the tool more realistic. LCOE, a carbon-tax and supply disruption risk is represented in the terms of cost to identify the total exposure of power generation in terms of monetary units and to plan the critical measures accordingly.

Firstly the research identifies the generation cost of individual technologies along with the amount of carbon released during per unit generation. The carbon-tax will also assume to motivate the investors to invest in sustainable power generation resources. The level of supply risk will identify with each technology, a mathematical formulation of these risks and cost of generation technologies were developed and quantified in monetary form. Lastly, the study selected the most appropriate approach for optimizing the risk and the costs in the power generation mix by developing an algorithm solution to solve this optimization problem.

Transmission and distribution system is considered as an essential component in power generation and always interrelated with each other. It is excluded on the premise that the government of Malaysia mandates distribution companies to provide grid access to power producers. The reason for not including these aspects is due to the need to provide a specific focus; evaluation of diversified power generation from multi-perspectives. Though these aspects are also important for any electricity system, they are more suitable for engineering oriented studies.

1.6 Significance of Study

The finding of this study will rebind to the benefits of the society, considering that energy plays a vital role in sustainable development today. The increasing demand of energy justifies the more effective and efficient development of a tool for secure energy supplies and uninterrupted power generation process. By achieving the objective of this study, a novel technique is to ensure the affordability of electricity considering the minimum impact on the environment and risk of supply disruptions. It will provide the insight to the policymakers to update their action plans accordingly to the conditions. At the top of that, this study supports the body of knowledge in the several fields. These are discussed further subsequently.

(a) Body of Knowledge

The primary objective of the study is to provide the affordable energy (electricity) to the consumers for the sustainable growth without harming the environment. The adequate supplies of energy are essential for the uninterrupted generation of electricity. This study will contribute to the well being of society by providing the uninterrupted supplies at an affordable cost. The study also contributes to the field of optimization area. In addition, it will also contribute in the field of risk identification and evaluation of energy supplies. Since this study focuses on the development of the risk technique based on the availability of supplies at an affordable cost, thus the techniques and the practice that influence the generation process which focuses on the disruption of supplies for electricity generation will be revealed. The optimization process will help the decision makers to select the best option while considering the least dependence on imports and maximizing the use of indigenous available resources to reduce the external risk factors.

(b) Study Contribution

The research presents a technique for determining the optimum energy generation mix at affordable cost considering and minimizing the environmental harm. It also intends to reduce the supply-oriented risk for the production of electricity. The findings of the study may be useful to government and organizations that are interested in reduced cost, carbon emission and the exposed level of supply risk by the means of diversification at the optimum level for power generation. The data and analysis will contribute to the pool of knowledge in the study area and it will help in shaping energy and environment policies as regards resource use and environmental conservation. This newly developed approach may be useful for the other countries around the globe to optimize their energy mix for sustainable economic growth.

1.7 Thesis Organisation

This thesis consists of five chapters. The contents of each chapter are given below.

Chapter One (INTRODUCTION) provides a brief introduction to the background and problem statement for the studies followed by research questions and objectives. It also discussed the scope and significance of studies.

Chapter Two (LITERATURE REVIEW) this chapter starts with the global perspective of the energy mix, following the energy crisis around the world and energy resources. After making a background of the global situation, it focuses on the broad terminology of energy security definition, indicators and dimensions are discussed. Finally, the current situation of Malaysia's power generation mixes, along with the potential of available resources and intended energy action plans are reviewed briefly.

Chapter Three (METHODOLOGY) in this chapter framework of studies was discussed along with the research design, an integrated research framework is also proposed, it also discusses briefly regarding data collection method and technique used in this thesis. Finally, data analysis models, equations, and process are discussed in details.

Chapter Four (RESULTS AND DISCUSSIONS) this chapter provides the results of analytical processes which includes LCOE, carbon emission and taxation, supply disruption risk, and analysis, measurement of diversity index and finally proposed an optimum portfolio for Malaysia's electricity generation mix.

Chapter Five (CONCLUSION) this chapter concludes the thesis by providing the summary of the study, research findings, and contribution followed by recommendation of future studies.

CHAPTER TWO
REVIEW OF THE LITERATURE

2.1 Global Energy Mix

Today, the world is faced with an unprecedented uncertainty in the energy sector. The fundamental challenge that underlies the global economic growth and human development is a basic requirement for reliable, affordable, clean and secure energy supplies. The World Energy Issues Monitor 2014 (World Energy Council, 2014) has discussed the challenges faced by today's energy leaders. The three main challenges of energy security, energy equity, and environmental sustainability are referred to as the "energy trilemma". The primary hurdle of economic development faced by the elected governments and policymakers is creating a framework that simultaneously delivers a secure, affordable and environmentally sustainable energy system. So, they have to make daunting and critical decisions in developing energy sources and expand the infrastructure for the delivery of energy from the source to the consumer. The global energy system mainly consists of fossil fuels. Coal, oil, and gas are the three major fossil fuel sources categorized as non-renewable energy sources. The fossil fuels exist in the form of heavy materials, the transportation and storage of raw material are easier than other power generation resources, and this is the main reason that fossil fuels occupied a supreme position in fuel resources since the industrial revolution. Energy harness from fossil fuels are extremely concentrated so highly convenient and advantageous and have been the primary and important booster for industrialization, economic stability and modern globalization (Mcdaid, 2009). The argument of Haw and Hughes (2007) reveals that the fossil fuels had been the dominated core source of energy since ancient times. The highly consumed predominated energy sources are those that are accessible and convenient to consume.

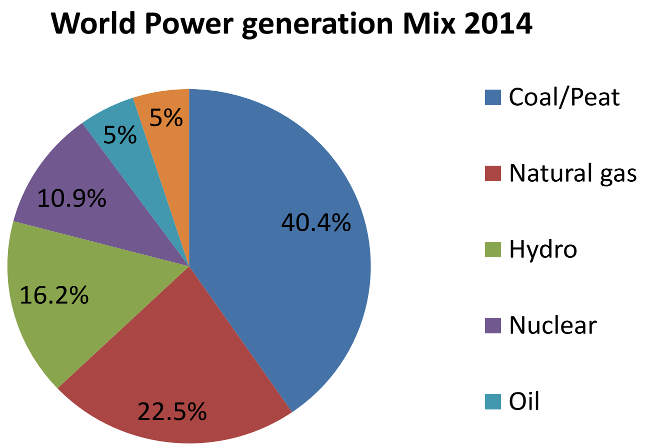


Figure 1.1: Electricity generation by fuel, 2014

Source: Redesigned from IEA (2014)

Figure 2.1.
World fuel mix for electricity production in 2014
Source: IEA, (2015)

Figure 2.1 shows the global power generation mix for year 2014. The predominant source across the world for recent global electricity production is coal, contributing a considerable share of 40.4 percent. Gas followed by coal is 22.5 percent, hydro 16.2 percent, nuclear 10.9 percent, oil 5 percent and other renewable occupies 5 percent share in the global power generation mix. Commutatively fossil fuel contributes 67 percent of electricity generation worldwide. The global demand for electricity is on the rise. In 2001, electricity generation was 15,640.7 TWh, which grew to 21,365.8 TWh in 2011 (BP, 2011), whereas the world primary energy consumption 7,095,887kt and 12,715,769kt were recorded in 1980 and 2014, respectively with an average increase of 9,368,874.16 kt and 176.38 percent during this period (Baffes and Cosic, 2014). Depleting reservoirs become a primary concern of policymakers. An adequate supply of energy is the prime objective around the globe. According to energy experts, coal, oil, and gas lasting for 107, 35 and 37 years, respectively (Shaifee and Topal, 2009).

The second concern regards to harmful emissions, like COx, NOx, and SOx from using fossil fuels for electricity generation. These emissions are also believed to be contributing to global climate change (Höök and Tang, 2013). Therefore, one of the top priorities of countries around the world is to divert their energy mix from nonrenewable to renewable energy sources. This diversification will help to achieve sustainability in a generation as well as combat climate change. Two crucial transformations in electricity sector have been witnessed: deregulation and governmental support for electricity production from renewable technologies (Alagappan et al., 2011).

The first transformation is instigated to break the monopoly of government-owned power generation companies, and to allow private enterprises to set up their power plants. By introducing competition in the industry, large-centralized power generation of small-distributed one is aimed. This change is believed to bring efficiency in the sector. Deregulation of electricity industry has been carried out by various countries around the world, e.g. Australia, Brazil, California (USA), New Zealand, Ontario (Canada), Colombia, Malaysia, Pakistan, and the UK. Though not an exhaustive list, it shows the popularity of deregulation among developed and developing countries, alike. However, there are doubts about deregulation.

These doubts can be attributed to the unique socio-political status of particular countries (Ochoa, 2007). On the other hand, support for renewable technologies for electricity generation is arising from necessity as a result depletion of fossil fuels. This situation has given impetus to energy planners and decision makers to search for ways to bring alternative fuels into electricity-generating supply chain fuels. There are three major concerns over the use of fossil fuels for electricity generation: finite resources, environmental degradation, and supply disruptions.

2.2 Energy Crisis around the World

In global agenda, energy occupies the forefront position. It is the core of the different leading issues of development, global security, environmental safeguard and accomplishing the millennium development goal (MDG) (UN, 2010). Energy is essential in enabling enterprise development, utilizing locally available resources and creating jobs (Flavin & Aeck, 2005). Furthermore, energy is critical for facilitating the development, manufacture, and distribution of drugs. Lastly, energy boosts agricultural production by enabling irrigation and reducing post-harvest losses through better preservation methods (Flavin & Aeck, 2005). Despite the importance that energy plays in development its demand has not been met as a result of continuing growth of the world's population. The exerting demand for energy is becoming an ever more critical challenge for the world's energy leaders (World Energy Council [WEC], 2015).

It has been predicted that the world's energy demand will be raised almost three folds by the end of this century (Donohue & Cogdell, 2006), keeping the primary energy needs of the world to uninterruptedly growing. The IEA supposed no significant changes in the policies till the 2010 calculating growth rate of 1.4% per year till 2035 (IEA, 2013). Global energy utilization is expected to grow by 56% in between the year 2010 to 2040 from 524 quadrillions Btu to 820 quadrillions Btu.

OECD countries are the main contributors to this development as a robust economic growth necessitate the energy growth (EIA, 2013).

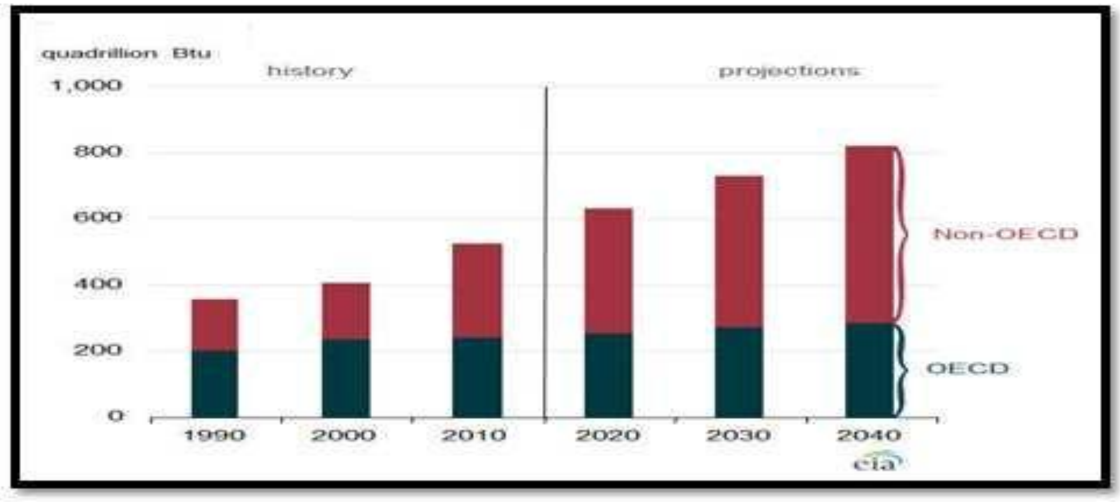


Figure 2.2
World total energy consumption, 1990-2040
Source: IEA, (2015)

Figure 2.2 shows the trend of global energy consumption from year 1990 to year 2040. Rapid economic development has enhanced the demand for electricity in Asian countries, especially those who have a quick spurt of economic growth (WEC, 2012). Since 1993 in crude oil production China occupies the 5th greatest position in the world, but still fails to meet its demand.

Energy demand is not the only feature which plays a role in the vulnerability in the energy security. The inflation in the energy sector in the last decade is also responsible for its vulnerability. It shows that China has not only to face the provision of energy, the policymakers of the country also has to deal with the tremendous challenges of heavy pollution dreadfully, keeping energy prices constant, atmospheric conditions, the inadequacy of water and energy (Jian, 2011)

EIA (2013) reports that India is following China, USA, Russia in 2011 enjoys the 4th uppermost position in energy consumption in the world ranking. Its escalating demand is due to the rapid and progressive economic development and innovation over the past decades. Meanwhile, India’s per capita energy utilization is 1/3 of the world’s average energy consumption, which is expected to rise to 2.8% by 2040. Achieving the highest level of economic growth is desirable, but it would not be at the cost of environmental degradation instead it is required to enhance sustainable development. The consequences of global warming and the need for the healthier environment have drawn attention towards reliable, sustainable and affordable modern energy system. However clean and affordable energy always remains the primary objective of sustainable energy policies (Mukherjee & Sovacool, 2012). On average, from 1980 to 2014, there is a vast increase in energy consumption was recorded, but the sources of energy production differ by regions and income levels. Evidently, significant sources of energy come from conventional and non-renewable sources like coal, oil and natural gas is also called fossil fuels. The trends in fossil fuel consumption during 1980 to 2015 are presented in Table 2.1. The facts show that coal consumption is ranked first among all fossil fuels during 1980 – 2015, followed by natural gas and oil consumption. However, recent facts are different from the average of 1980 – 2015. For example, in year 2015 oil continues to be the world’s leading source of energy production, coal ranked second, and natural gas remains on third position.

Table 2.1
World Fossil Fuels Energy Consumption (%) 1980-2015

1980-2015		2015	
Coal	30.4	Oil	32.47
Natural Gas	28.7	Coal	30.05
Oil	17.0	Natural Gas	23.72

Source: IEA, (2015)

In this context, it will not be an exaggeration to the nation that Greenhouse Gas (GHG) emission due to fossil fuels consumption is the leading cause of global warming and GHG result primary from the combustion of fossil fuels. According to Olivier, Janssens-Maenhout, and Peters (2012), fossil fuels combustion accounts for about 90 percent of total global CO_2 emission. Consequently, there is a need to allocate alternative sources for energy production such as renewable energy generation.

The energy that comes from various sources such as biomass, wood, tide, wave, solar and wind is commonly known as renewable energy. The renewable energy is environmentally friendly, safe and unlimited as compared to fossil fuel energy. Consequently, a rapid increase in the world demand and consumption of renewable energy has been recorded. According to IEA (2014), renewable energy generation shows continuous increasing trends; it has increased 18 percent, 21 percent and 22 percent in 2007, 2012 and 2014, respectively.

Malaysia is also one of the countries which are highly dependent upon the non-renewable energy sources (Ong, Mahlia, Masjuki, 2011). The depleting reservoirs and global price variations have brought a significant concern for economic policymakers. It is noteworthy that Malaysia has a growing economy and it has been observed that an average energy annual growth rate was 6.6 percent in 1980 to 2010. Meanwhile, the fact that cannot be denied is that energy has given its large share in achieving Malaysians developmental goal. Malaysia has been blessed with enormous renewable energy potential amongst the Association of South East Asian Nations (ASEAN).

The consumption of fossil fuel as an energy resource in a population is one of the enormous challenges of global environmental sustainability and economic stability. ”Greenhouse gas” and chemicals that evolved during the combustion of fossil fuels are also responsible for many health issues. Donohue and Cogdell (2006) argued that government, private sectors, and the scientific community have been united on a single platform to seek such alternative energy sources which can be developed and adapted to decrease the consumption of fossil fuels and simultaneously reduced GHG emissions. The non-sustainable use of fossil fuel and traditional biomass emerges a need of engaging new renewable resources like biogas, solar and wind for sustainable power generation (Amigun et al., 2012) Renewable energy has the potential to play a significant role in durable, affordable and reliable power generation in Malaysia. Hence the increasing supplies of electricity from renewable resources will not only reduce the price stability risk but also help to mitigate climate change (UNEP, 2011). Biogas which is produced from renewable sources can play an essential role in meeting both energy and environmental problems (Kabir, Yegbemy & Bauer, 2013).

2.3 Global Energy Resources

There are two types of energy resources available (Open energy Information, 2013)

1. Renewable
2. Non-Renewable

All kinds of energy resources can be changed into the other form of useful energy including electricity, thermal or heat. The known energy resources around the globe are renewable energy (Hydro, solar, wind, biomass Geothermal), fossil fuels (Coal, oil, natural gas) and nuclear energy (Open energy information, 2013). Figure 2.3 shows the extraction and processing of energy resources. The existence and the handling of energy resources are specific to their Geopolitical location. Technical expertise is required in the mining and transformation of the resources to be supplied to the buyer depending upon their energy requirements (Novan, 2011).

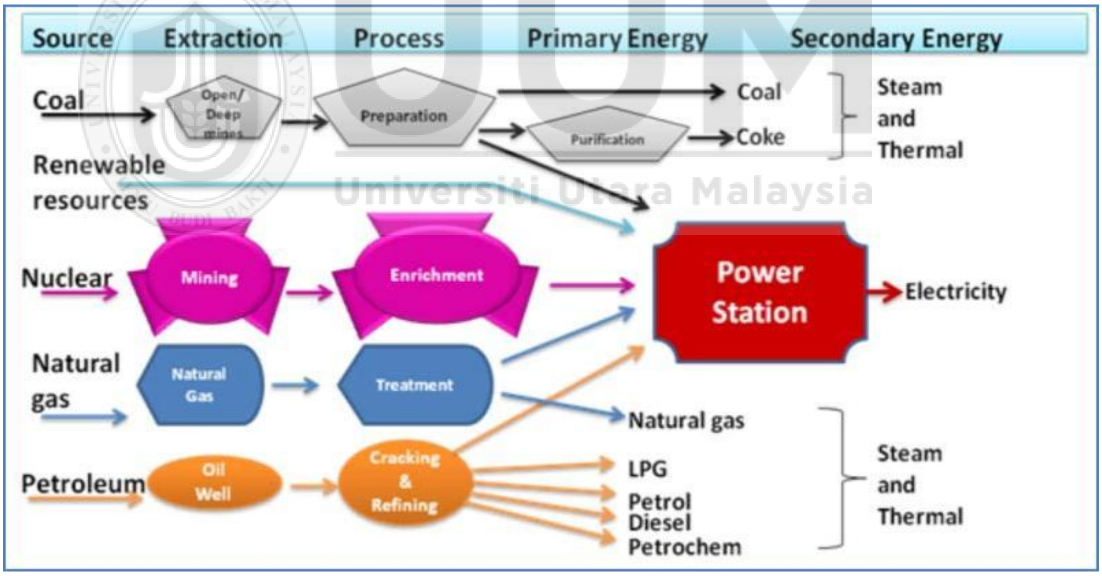


Figure 2.3.
Energy sources and End-users
Source: Nuvan, (2011)

The investors around the world show a keen interest in low carbon technologies because of fossil fuel and nuclear-associated environmental risk (Sun et al., 2012). It may be remembered that the utilization of non-renewable energy resources through unnatural process liberates the greenhouse gases GHG, CO_2, CH_4, NO_2, Hydrofluorocarbon, perfluorocarbon and Sulpher hexafluoride recognized as GHG gases are liberated after consumption of fossil fuels (IPPC, 2007).

GHG's are standardized as CO_2 per their polluting potential, and they differ from each GHG (Urge-Vorsatz and Herrero, 2012). An uncased release of GHG has raised their concentration in the atmosphere which is a significant threat to the environment. The risk in the atmospheric concentration of CO_2 had been observed by a curve called Keeling curve which shows the CO_2 emission in Manna Loa Hawaii. In 1950 CO_2 curved value found was 315 parts/million by volume which has increased to 392 ppmv in July 2011 (World Bank, 2012; Grubb et al., 1999; Keeling et al., 2008).

The hazardous effect of GHG's to the environment can also be elaborated by the statement given by the intergovernmental panel on climate change that the average of $2^{o}C$ will increase the global temperature to $3^{o}C$ that will change the weather pattern in the world (IPCC, 2007). The coastal cities of London, Miami, Hong Kong, New York are more under the threat of floods because of temperature differences that have caused rapid melting of glassier and snow pacts (Stern, 2007). According to IPPC increased in CO_2 concentration in the atmosphere has produced ocean acidification by dissolving which ultimately reduced 15% to 40% fish stock that cannot live in the acidic ocean. There are also some issues related to the geographical such as in the tropics temperature variation has increased vector-borne diseases and cold-related diseases in high altitudes (IPCC, 2007a). It is also noteworthy that climate changes due to temperature variations have severely affected the agriculture sector, fields show a tremendous decline in the outturn that leads to famine subsequently malnutrition in a tropical region (Stern, 2007). A large number of people have moved to different places because of the temperature variations which lead to increased hatred amongst them (IPPC, 2007b). According to stern (2007), 20% loss of GNP estimated nearly 5500 billion Euros, which resulted due to global warming.

It has been widely acknowledged by researchers (Kaygusuz, 2012; Thavasi and Ramakrishna, 2009a; Thiam, 2011; UNEP et al., 2013) energy can be produced by renewable resources by utilizing low carbon technologies like wind, tide wave, rainfall, and sunlight and geothermal heat. The UN program has shown that every energy resources has its own financial and environmental value so that the choice of renewable resources depends upon the community requirement, the extraction and processing a resource should be with a budget of a community and the end use technology (UNEP et al., 2013).

Renewable resources exist in the dynamic state of nature (UNEP et al., 2013). They don’t release carbon during production process, so they are named as clean fuels (UNEP et al., 2013). The energy resources for renewable energy technology is free of cost (priceless) but specific to the resource location. Though the energy resource for renewable energy technology is free and peculiar to the resource location, the immature technology to transform the fuel resource to electricity makes it expensive to run (Chow et al., 2003).

2.4 Energy Security

The terminology of energy security is not very new. It always plays a vital role alongside with energy supply and demand, but it never got the attention indeed. In the beginning, energy was only available to the industrial sector and some of the wealthy households. The requirement of energy was increased when it becomes available to some growing societies. Today, it is thankless life without electricity, hot water in every house, not having any transport for daily mobility. The demand for energy is growing every corner of the world with the increase in population and changing lifestyles. But what is energy security. Is it just a balance between demand and supply of energy. Or it is something more? Some researchers tried to find this answer in the past.

Energy services and energy security both are interrelated to each other, they are essential to support well-functioning of the society. It is critical to evaluate the secure supplies (Sovacool and Brown, 2010). Generally; security is often portrayed as less reliance on imported energy, especially oil (Bohringer & Keller, 2011).

Several authors have defined the term “Energy Security”, but it’s still unclear. The concept of security of supply or in the short term “Energy Security”, seems to be blurred and unclear (Loschel et al., 2010), There is no common interpretation of energy security (Checchi, Behrens & Egenhofer, 2009). Its concept is still elusive (Kruyt et al., 2009; Mitchell, 2002) or it may illustrate as “slippery” and “polysemic” (Chester, 2010), considering its tendency to integrate multiple dimensions at the same time. In comparison with other energy policy objectives, there is no thumb rule to measure energy security (DBERR, 2007). Instead, there are a variety of dizzying fragmented and contradictory interpretations of security of energy in policy and scholarly literature (Cherp & Jewell, 2014).

In this research, it is more useful to start with the general definition of energy security, to narrow it down to its indicators. Energy security is considered as the umbrella term for many different policy objectives (Winzer, 2011). The bunch of definitions gives way to sarcasm.

The lack of universal acceptance of definition may include.

How different stakeholder values different parameters. Example (energy intensity, decentralization of supply) (Mansoon et al., 2014; Tziogas & Georgidas, 2015); it includes the origin of stakeholders are net importers or resource-rich. The country depends upon the state involvement or market solutions. The difference in policies and priorities is developed and developing nations also involves the differences in the scientific background of the researcher (engineer, economist, scientist etc.) (Mansoon et al., 2014).

In fact, energy security is the combination of many diverse attributes. Therefore, there is a need to assess it from systematic perspective and consider all the attributes in the account (Gracceva & Zeniewski, 2014). Energy security is the combination of interactive and interdependencies of a highly complex system, whose attributes are not completely defined by the understanding of its components (Gracceva & Zeniewski, 2014).

The lack of clarity concludes that scientific and public debates are hampered due to missing practical definition of energy security. Lack of definition points out towards the absence of indicators for energy security. It is a problem that cannot be adequately measured and difficult to improve (Bohringer & Keller, 2011).

Some of the recent explicit definitions of energy security are:

According to Sovacool (2014), energy security is to equitably provide available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users.”

IEA’s most cited definition, defines energy security as the uninterrupted physical availability at affordable prices, while also considering environmental concerns. (IEA, 2016).

Some views energy security as a specific supply-side phenomenon. Long-term energy security (supply) is a surrogate for the certainty level at which the population in a considered area has uninterrupted access to fuel and carrier used for fuel transportation in the absence of underexposure to supply side market power over the period of 10 years or more (Jasen & Seebregets, 2010). While from the prospective economic security of supply can be defined as the availability of demanded energy volumes at a reasonable price (Le Coq & paltseva, 2009). Yergin establishes the energy security from the cultural and political aspects. The purpose of energy security is to assure adequate, reliable supply of energy at a reasonable price and in the way that does not risk dominant national values and agendas (Yergin, 1988).

2.4.1 Classification of Definition of Energy Security

Ecofys (2009) divides energy security definition into two categories:

1. Economic principles
2. Policy-oriented

A standard definition of energy security would be the loss of economic welfare occurring due to the change in the price of physical disruption of energy; while from a policy point of view these definitions point out requirements called dimensions of energy security. It focuses on the accessibility and affordability of energy. Another aspect may also include availability and acceptability.

Luft (2011) differentiates two dimensions as, an economic dimension covers price volatility and affordability; a physical dimension may also refer to as available, reliable, and accessible supply of energy. These dimensions are correlated with each other. Physically resource scarcity or disruption in supply may affect the price. Volatile and low rates may result in a reduction of investment in infrastructure and production equipment (Mansson et al., 2014).

Winzer (2012) reviewed 36 definitions of energy security. All of them include the risk of continuous supply or supply disruption. He distinguishes three groups of authors, authors who focus on the constant supply of commodities. This concept is fundamental to all other definitions of energy security. Authors who introduce additional subjective severity filters to differentiate between the reliable and unreliable level of continuity, Extra filters involve, the scarcity of energy towards price above a certain level, while the price volatility below that level is not relevant (Winzer, 2012). According to IEA (2014), Energy security is defined in term of the physical availability of supplies to fulfill demand at a given price. The speed, size, and suspension in increasing cost being beyond a certain level. Energy security is impaired when supplies are low or interrupted in some areas to the extent that causes an automatic, significant and sustainable increase in prevailing prices (Mabro, 2008).

2.4.2 Evaluation of Energy Security

Energy security is such a mysterious concept to define and measure; It is not clear-cut and straightforward to identify to whom it benefits (cost) are more relevant. The energy security policy literature is quite sparse, and three significant questions are ignored (Labanderia & Manzana, 2012). The first question relates to the evaluation of the cost and benefits of energy security. It should not be a conclusion in itself, or in the broad-spectrum argument for energy policy intervention, but relatively a concept that allows societies to protect their welfare in proper and in the defined and balanced way (Labanderia & Manzana, 2012). The second question referrer to discover an operational definition of energy security. While the last question points out the ignored interaction any synergies between policies of energy security and other policies like (climate change, renewable energy resources, energy efficiencies etc.).

In the long term security of energy, traditional approaches like economic modeling approach provide in-depth knowledge of the supply of one or more of the exhaustible fuels like coal, natural gas, and oil (Jasen & Seebergts, 2010).

Winzer (2012) argues that the security of energy should be separated from other policy objectives, for example, relates to the sustainability and economic efficiency, and also defines the term as a continuous supply of energy for its relative demand. Thus narrowing the concept of energy security, the economic definition of energy security is more appropriate and comprehensive for academic research and planning perspective, but the accounting welfare losses are a difficult task (Ecofys, 2009). The volatility of price and availability not only impacts the society’s energy-related activities but may also affect the economy as a whole (Levefre, 2010). This leads towards the uncertainty of the energy security assessment. An overall effort to measure welfare impact associated with the insecurity of energy typically depends upon stylized models (Ecofys, 2009).

Economic definitions of energy security do not indicate welfare losses. Usually, the uncertainties of extreme weathers, the concentration of fossil fuel resources, combined with the sensitivity of the political climate of exporting countries (Levefre, 2010).

Researchers involved in the quantitative analysis of security externalities cannot ignore subjective propositions beyond the realm of positivist science (Jasen & seebregts, 2010). The identified dimensions in the policy-oriented definitions are not adequately defined. It is upon the expert elicitation as to what constitutes an appropriate level for each, for example (when is energy deemed adequately affordable or accessible) (Ecofys, 2009). Many definitions have highlighted the perspective and dimensions, but none of them defines a threshold, for example, it is not properly defining that up to what extent price volatility becomes a threat for security (Mansson et al., 2014). For the qualitative description this may be suitable, but in the case of quantitative assessment, it becomes a problem (Ecofys, 2009). The advantage of involving additional subjective severity filter is to differentiate between the secure and unsecured level of continuity is that additional criteria filter out smaller discontinuities that are not crucial for the security of a country. The other filter of subjective severity makes the concept of security more inaccurate and complicated to measure (Winzer, 2011).

When sustainability involves as a component of energy security, it makes its concept much broader but also difficult to evaluate and sometimes even makes it operational. (Winzer, 2011).

2.4.3 Conventional 4A's of Energy Security

The classic definitions of energy security, more focus on the availability and affordability of energy (Deese, 1979; Yergin, 1989). The four ”A”s framework of energy security presented by the Asia Pacific Energy Research Council (APERC) was the modified form of world energy council's three sustainability objectives (The 3As). The three sustainability objectives consist of Accessibility, Availability, and Acceptability. However, APERC added 4th A as Affordability (APERC, 2007). The report was not able to justify its contents from previous research neither from empirical analysis or logical reasoning (Cherp & Jewel, 2014). Later the terminology of 4 A's are further elaborate and extended to the meaningful form regarding “Availability” to assure the uninterrupted physical availability of supplies. Accessibility” the available resources are also accessible, “Affordability” must be cheap and affordable and “Acceptably” should not harm the environment (APERC, 2007; Kruyt et al., 2009; Hughes & Shupe, 2010; Sovacool & Mukerjee, 2011; IEA 2011). Chester (2010) also addresses the 4A's framework; his study includes (Availability, Affordability, Adequacy, and sustainability).

The integrated concept of energy security in te form of 4A's is represented in figure 2.4. Cherp and Jewell (2014) criticize Conventional 4A's framework in several different ways.

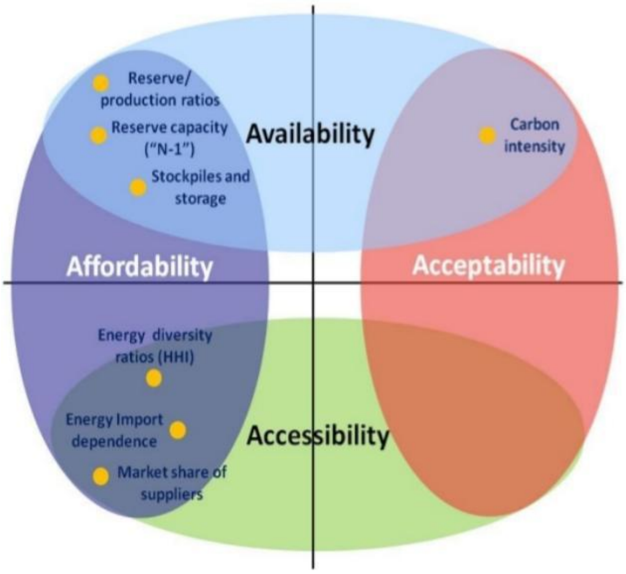


Figure 2.4.
4A 's of Energy security
Source: Kruyt, (2009)

The first legacy of four A's framework is, it's not proper to define for whom energy should be acceptable and affordable. Affordability can be defined in different perspectives. From a consumer's point of view, it may be profitable (APERC, 2007). From the consumer side, it may be the low price of energy (Kruyt et al., 2009; Hughes. 2012), while the government may consider it as the intensity of subsidy or export/import stability (Sharifuddin, 2013). But, acceptability and environmental concerns have given equal weight by APERC (2007). The conventional four A's fails to portray a complete picture of environmental concern; its acceptability varies with the state of the actors, acceptability level is different between the local population industries, states and environmental NGO's. It is unclear about the social norms, type of energy system and linkage between them. The classic definition of energy security focuses on the self-evidence and implicit linkage between national values an (independent oil and territorial integrity) and actual energy system (supplies of oil). The concept of energy security extends beyond the domain of oil to other energy sectors, and replace the conventional geographical values with economic welfare, also domestic political and domestic stability.

The Conventional 4A's Framework also does not include the concept of "risk and reliance". Winzer (2012) addresses the risk of availability in his research. He describes "natural source of risk" with "availability" and "human source of risk" with accessibility", while economic activities are associated with "affordability" and finally "acceptability" highlights the environmental cancers.

2.4.4 Modern Perception of Energy Security

The trend has changed from "dimension" of energy security to the "attributes" (characteristics), while the system should be capable enough to manage or act against risk (threats or adverse events). Modern conceptual expansion defines energy security as a "low vulnerability of essential energy system" (Jewell et al., 2014).

As stated earlier, the energy system is complex which interacts with technical and nontechnical elements in which energy security has dynamic behavior (Cotella et al., 2014).An energy supply chain system consists of industrial and commercial behavior that involves in supplying of energy and energy-related inventory and services, to eventually provide energy services (Blum & legey, 2012). A secure supply chain system plays an essential role in providing quality energy-related services. The supply chain system may be complex and include many steps, for example (extraction, transportation, conversion, transmission, distribution and final consumption). The system may extend beyond national borders (Mansson et al., 2014).

The essential energy systems are resources, infrastructure and their uses which may altogether sustain significant social operations. They can be represented by sectoral or geographical limitations (cherp & Jewell, 2011; 2013). Differentiating between the energy system permit improved measurement (metrics) as well as improved targeting of energy security policies (Jewell, 2014).

According to Luft and Korin (2009), the definition of energy security depends upon the need of the countries and the situation of vulnerability of energy supply in the region. They further argued that the distinction between the two primary energy consumption sectors, transport, and electricity, in essential to explain the particular energy situation. Most vulnerable countries are those whose needs are heavily dependent upon energy imports in both sectors. The only dependence on resource import in power generation provides at least a chance for diversification. The electricity generation fuel mix consists of coal, oil, natural gas, renewable and nuclear power, among these resources, coal is dominant in the generation sector while oil in the transportation. Diversification is one of the essential dimensions of energy security. With the help of diversification in suppliers and resources, the risk of disruption of energy supply can be reduced.

2.4.5 Energy Security and its Contents

According to Yergins (2006), that the current energy system is based upon the concept of the industrialized nation on energy crisis of 1973. At that time, energy importing countries had realized that how much they are dependent upon oil imports and exporting states are using it as a political weapon against them. Due to that reason, IEA was established to provide a platform for industrialized countries against the disruption of energy supplies. Another reason is to create a strategic stockpile for energy conversion and also for emergency sharing of energy supplies. He argued that the following principle must be adopted for the smooth supply of energy in the long term.

2.4.5.1 Energy Diversification

Diversification is the first and most important principle of energy security in the long run. From a consumer perspective, diversification can be divided into two components.

- Diversification of energy resources
- Diversification of energy suppliers.

For example, more than 80 percent power generation fuel of Malaysia consists of coal, natural gas, It is easier for a country to react in case of disruption of energy supplies if the generation mix designed in such a manner that it can provide other energy resources in a short period to fulfil the demand of citizens, or in the worst scenario can provide supplies to the production industry. Nations who depend upon only one source of energy cannot take advantage of this opportunity. Diversification in energy suppliers is considered as the second alternative. Today Malaysia is more than 50% dependent upon imported coal, disruption in coal supplies can cause a significant impact on the economy. As a consequence, Malaysia has great incentives to enlarge the diversification of suppliers.

2.4.5.2 Resilience

While making a strategy for energy security every country needs to put a buffer in its energy policy. It may include reserved supplies of machinery, strategic reserves, enough storage conveniences along the supply chain and the stockpiling of important parts of electricity generation and transmission equipment but not only limited to these.

Resilience is a critical task to accomplish since it includes too many different perspectives, for example, sudden disruption due to natural disaster, terrorist attack, political instability, etc. It is challenging to secure the complete supply chain process without knowing the occurrence of a disaster, the rise of possible terrorist attack against energy based target has been the already present threat to energy security (Yergin, 2006). The uncertainty of such event is the greatest challenge for energy resilience. To reduce uncertainty to some extent, it is necessary to have beside reactive and preventive instrument of resilience. For example, time and place of terrorist attacks can be known through intelligence securities, and required instruments and action plan can be used to prevent attacks.

2.4.5.3 Information

Information is most important and critical aspect of energy security principles. It helps in reducing the risk associated with the investment. Adequate sharing of information between producer and consumer results in the equilibrium of market price. Sufficient information helps in the secure supply chain management, from a technological point of view, it contributes to the exploration of untapped energy resources, such as deep sea drilling. A platform for sharing information should exist and operational like (IEA and OECD) and also share information with its members. Exchange of information between member countries makes a win-win situation for both.

2.4.5.3 Trade

The world is a global village no country can be self-sustaining. Trade is essential at international level for the growth of GDP and its associated variable for the wealth of a society (Yergin, 2006). Without sufficient amounts of energy resource demand of society can never be fulfilled. According to Luft and Korin (2009), (transportation) energy makes the world to go beyond the borders. Consequently, it is important for the countries to admit that they will depend upon other nations for the need of energy either as a supplier or as a consumer with regards to unstable supply and prices or as a nation that is rich in energy resources. But it still needs foreign technology and expertise for the extraction and purification of energy resources. To some extent, all of the world is connected and depended on each other.

2.4.6 Energy Security and Globalization

Global energy market divided into two groups. IEA and OPEC; OECD and non-OECD; producer and consumers, they all have to be recognized (Yergin, 2006). As mentioned earlier that the demand for energy is increasing around the globe while in OECD countries demand will not increase by a large extent, But countries like China, India, and Pakistan are held liable for the considerable portion of overall energy demand. It would be irrational to reject that these countries will control the largest share of the energy market in the future.

Due to the rising threat of terrorism security of resources and supply chain becomes an essential part of energy security (Yergin, 2006). According to Kalicki and Goldwyn (2005), for the strength of US energy suppliers and their vulnerability to acts of terrorism are significant factors of US energy security and national security.

Luft and Korin acknowledged terrorism as a huge threat to the security of energy, most importantly in the power generation sector. Also highlighted by Koknar, he mentioned electricity grid stations, oil and gas extraction infrastructure as highly vulnerable (Luft and Korin, 2009; Koknar, 2009).Disrupting the supply chain system by destroying the electricity grid, might have created a vital loss for the economy as a whole.

Fossil fuel resources are depleted because of high rising demand, and the probability of energy is becoming the main reason for high future conflicts. It does not mean that the war in the future will be only about energy, but it may also happen for energy resources.

2.4.7 Linkage between Energy Security and Sustainability

The study of sustainability is a relation between economic development climatic conditions and social impartiality and the term "Sustainable development" is the ability of a system that fulfills the needs and requirements of a society and its economy and without causing the harm to the environment (Rogers et al., 2008).In 1987 the definition was given by the world commission on environment and development "Development that can fulfill the requirement of the present generation without affecting the capability of foresee generation to meet there own needs".

Like energy security, sustainability has also got no any universal boundary and its technique the concept can absorb any execution intervention, action plan to accomplish its particular goals and requirements of each region (Hopwood et al., 2005). Sustainable development can also impact on the socioeconomic status of developing countries by increasing the per capita income, living standards and hence decreasing the imbalance inequity and inconsistency in the society. It has been argued that electricity generation and its provision to remote and countryside should be increased and on the other hand, the electricity crisis and pollution caused by its production must be minimized to keep the environment clean and standard of living up (UN energy, 2007). According to Sovacool and Brown (2012), the high energy price can impact directly on the socioeconomic status of a population considerably the low-income people who have to suffer more because of its high price as commodities and services get expensive too. Energy services and economic growth are covalently bound (IEA, OECD, 2010; Valentine, 2010). The energy growth can be a component or a technique of sustainable development which is characterized by rising the income with the utilization of natural resources (Rogers et al., 2008). In this scenario, the relation between the energy security and sustainable development is obvious when an energy system is enhanced to get stability, and this is the preference of energy security (Jewel, 2013). The affordability of new and advanced energy services is also required to reduce poverty, a great lifestyle and limit the utilization of energy resources. An energy system is considered as a multidimensional, critical system in which it deals with environmental, social and economic aspects which are the major components of energy security. According to Indriyanto et al. (2010) in the sustainable development priority should be given to short and medium-term objectives rather than long-term goals. Sovacool and Brown (2010) discussing energy policy define sustainability as a decreased released of hazardous gases such that they should not saturate the environment there must be a balance between extraction of conventional resources and utilization and maturation of nonconventional fuels. Economic and social components of energy security are mostly defined in term of affordable services and their access (Indriyanto et al., 2010). IEA and OECD (2010) have argued that energy policies when are described in developing countries for short-term objectives often ignored environmental disturbance. The policymakers can use modern technologies and frameworks that enable to break the relationship between intensity and financial development and decrease climatic humiliation (UN energy, 2007). It is also noteworthy that the role of the nonconventional resource is being changed due to the lack of fossil fuels, unstable oil prices and hazards to the environment (Valentine, 2011; Jewell, 2013). The benefit of fossil fuel due to its low price over the different resources and technologies is being argued (Valentine, 2011). The renewable energy program has the opportunity to enhance energy security by decreasing reliance on foreign oils and diversifying energy supplies for electricity generation. Meanwhile, these programs can help in decreasing climatic variation and enhance financial growth, since many renewable energy technologies can be implemented in small or medium-scale and decentralized systems (Turkenburg et al., 2012).

2.4.8 Dimensions of Energy Security

The concern of energy security began mostly on securing access to oil and other fossil fuels. However, the old energy security rationales which were focused mainly on oil and natural availability are becoming less salient due to diverse energy markets and the transformation and use of energy (Vivoda, 2010). In addition to the transformation of the energy security definition, many new dimensions of energy security have begun to surface. Several factors such as rising energy costs, volatility of energy prices, uncertainties about available imports of energy, and concern about climate change and air pollution (IEA, 2007; Umbach, 2010; Chalvatzis & Hooper, 2009) have altered the dimensions of energy security. Therefore, a workable framework of energy security dimensions needs to be more comprehensive to analyze a holistic perspective of energy security. This is important to yield greater understanding about energy security in a broader sense for both energy exporters and importers (Vivoda, 2010).

Several institutes and researchers are working to develop new dimensions of energy security. For example, Asia Pacific Energy Research Centre has defined four aspects of energy security – availability of resources, accessibility of resources, environmental acceptability, and affordability (APERC, 2007). Von Hippel et al. (2009) have further expanded the work by APERC to several other dimensions. They included energy supply, economic, technological, environmental, social, cultural and military security in energy security dimensions. Another work based on APERC dimensions can be traced to Sovacool and Brown (2010). They defined energy security in term of availability, affordability, energy and economic efficiency, and environmental. This work then has been further modified by Sovacool and Mukherjee (2011) their modification of energy security dimensions included availability, affordability, technological development and efficiency, environmental and social sustainability, and regulation and governance as shown in table 2.2.

Table 2.2
Dimensions of energy security

Dimension	Components
Availability of Energy Supply	• Sufficient supplies of energy • Reliable energy system and energy mix of the system • Using domestically available energy sources • The dependency on imported energy supply • Diversification of energy sources and suppliers • Prudent reserve to production ratios
Affordability of Energy Services	• Affordable and stable energy services prices • Accessible and equitability to all population
Technology Development and Efficiency	• Promoting innovation and research into the energy system • Resilience and adaptive capacity • Sufficient investment and employment • Promoting energy efficient among consumers
Environmental and Social Sustainability	• Mitigation efforts for controlling pollutions and climate change • The balance of energy spending budget for consumers
Governance of Regulations, Policies, and International Cooperation	• Clear energy regulations and policies • A stable and transparent regulations and policies • A Participant from authorities in making regulations and policies • Promoting educating public • Commitment toward international cooperation

2.4.9 Indicators of Energy Security

Energy security indicators are used to measure the dimensions of energy security. The main perspective of indicators is to stabilize the energy security from unforeseen events, provide in-depth risk exposure to policy makers (Tonjes & de Jong, 2007) and secure system from supplier monopoly of increasing prices. Sovacool and Mukherjee (2011) divide indicators of energy security into two components (1) simple indicators and (2) complex indicators. Simple indicators are used to quantify physical and financial values whereas complex indicators deal with the measurement of diversity in the system. Energy diversity is an important element that needs to be considered while formulating the energy policy for a country. The Energy system is considered to be more secure if it is highly diversified.

2.4.10 Diversification in Power Generation System

The diversity of fuel supply and resources for energy has received increasing attention globally in recent years as a result of rising energy prices and increasing recognition of risks of supply disruptions and price volatility in world fuel markets. The concept of diversification revolves around the famous proverb “Do not put all the eggs in one basket”. According to Yergin (2006), the strength of energy security depends upon the policy of diversification used in the system. Diversity is the state or quality of being varied or different (Farlex, 2013). Diversification applies to an energy system and considered as the key to system’s energy security (Yergin, 2005). Hughes has illustrated the different views of diversification: one such view is the use of a similar form of energy to meet the demands of the energy service with different suppliers, signalling the replacement of a less secure source of energy with the one that is more secure. Such as, after the 1970 oil crisis The U.S. government decreased oil trade from Asian counties by substituting from Canada, Nigeria, Mexico and Venezuela (Hughes, 2009). In some conditions, introducing or changing new infrastructure that permits alternative energy sources - replacing existing ones - is regarded as a form of diversification and applied to electrical generation. One such example occurred in the late 1970s when increasing costs of oil contributed to the first oil shock of the 1970s, the world-wide change of energy source takes place from oil to coal and nuclear for electrical generation (Hughes, 2009).

Stirling defines diversity in a different context which includes economics, society, culture, science, innovation, and technology factors (Stirling, 2010). The dependence on a variety of symbiotically disparate suppliers and their energy supplies is known as energy diversity and is seen as an essential component of energy security (Andy Stirling, 2010). The unpredictable threat and risk that can significantly impact on the security of a system can be reduced by engaging the concept of diversity and enhance the overall security of the system (Stirling, 1998). Stirling characterizes the concept of diversity in energy system into three general properties; Variety: "The different numbers of available alternatives that can be used in diversification" and it can also be defined as available options or portfolio of energy resources. Balance: "It is a proportion of distributed energies among the system". It relates to the evenness or relative abundance of the different energy sources. Disparity: "The manner and degree in which energy options may be distinguished" (Stirling, 2010).

Taiwan energy policy can be quoted as a good example as the used complex structure of security indicators, which resulted in the reduction of energy reliance on foreign trade along with the improvement in the diversity of supplies. (Chuang, Ming, hwong 2013). Concerning the short-term security, Mexico current generation mix is the good example (Haruichi, 2012). Similarly, the UK power generation mix can be quoted as an excellent example of suppliers in power generation mix which not only enhance the long-term security of power generation system but also influence on low-carbon objectives (Grubb, Butler, & Twomey, 2006). In Germany, the significant utilization of renewable energy resources for power generation will not only impact on long-term energy security but also enhance the efficiency of the system regarding affordability and availability of resources (Lehr, 2009). And, the development of a novel linear diversity constraint for the production scheduling in microgrids, to maintain diversity in the generation of electricity from multiple resources (Naraharisetti, Karimi, Anand, & Lee, 2011).

Energy diversity is an important element that needs to be considered while formulating the energy policy for a country. A key element of diversity includes dependence on available indigenous energy resources. Governments, while formulating energy policy give preference to the indigenous resources over imported fuels. There are examples related to energy policy followed by the UK that relied heavily on domestic coal for power generation and France reliance on nuclear energy. In Malaysia, there are quite a few available options for energy diversity, including coal, natural gas, hydro and renewable energy resources. There is an emerging need for a good policy for utilization of available resources at an optimum level.

According to Chevalier (2006), the elements of security of energy supply are categorized in four main elements: a reliable supply of energy (diversification of energy sources and suppliers), reliable means of transportation used for supplies, the reliable distribution system of supplies, and finally affordability for consumers.

Researchers and policymakers have defined different measures to determine energy security in the form of indicators. These indicators help to provide in-depth knowledge of unforeseen events to formulate effective and efficient policies. The detailed analysis of indigenous available resources, government interference of low and high fuel prices and short/long energy importing/exporting policies are the three main factors to evaluate the countries energy security levels. (IAEA, 2005; IEA, 2004; Hippel et al., 2011; APERC, 2007; Jansen and Seebregts, 2010; Kruyt 2009; Looschel et al., 2010).

Among the other energy security measures diversification in energy supplies, resources and technology are one of the major components of secure energy policies that have been reviewed in this dissertation. The basic idea for diversification in indicators originated from the finance theory of portfolio analysis. The essence of the theory is the risk of the system can be reduced by considering different (diversified) portfolio of supplies (Dybvig & Ross, 2004). The “diversification of energy supplies” indicators deals with the impotence of divergence in the form of wealth and equitability of resources. The “net import dependency” indicator reflects the impact of both diversification and imports on energy supply security (USAID, 2008).

2.4.11 Energy Policy and Diversification Strategy

According to Andrew and jelly (2013), the main objective of energy-related studies is to provide the in-depth analysis of issues related to the utilization and development of energy which includes energy supply chain parameters (generation, distribution, and consumption). Concerning the attributes, besides economic parameters, an efficient energy policy may also include social and environmental parameters along with investment incentives, subsidiary policy and other sustainability techniques. While the option related to electricity generation policies covers a variety of sources like nuclear, renewable and traditional fossil-fuels, the subject can be studied at different levels such as business, corporate, industry, regional, state and national.

The restriction on the consumption of conventional energy resources has encouraged policymakers, economist, politicians, and scientists to consider any other natural resources as a substitute for lower levels of possible risk. For example, conventional resources are not extractable in all countries and even not stable in producing countries. Meanwhile, fluctuating oil prices and other cost-related issues which includes transportation distribution and logistics costs make the utilization of fossil fuel more unreliable. Similarly, on the other hand, the issues related to the technology, environment and political dangers of nuclear power generation illustrates the adaption of other sustainable energy resources.

Diversification is one of the important aspects of energy security studies. Concerning energy security, Ganova (2007) divide the diversification into three different levels; diversification of energy suppliers; diversification of energy resources and; and diversification in transportation routes. Among the three measures diversification in energy resources and supplies are the most critical to evaluate the level of security of supplies and energy dependency in a country. High dependency on imported fuels with few numbers of suppliers increased the risk of supply disruption. The major supply security-related issues involve political instability and over-reliance on few numbers of suppliers. Furthermore, the dominancy of one fuel in energy mix (fossil fuel) will not only increase the supply disruption treat but also influence on affordability and environmental risk factors. Diversification in energy supplies means a portfolio of indigenous and imported energy resources that should be adopted in a country or a region to reduce the disruption risk related to energy supplies and over dependency on imported fuels. Yergin (2006) argued that the diversification of energy resources will help to reduce the occurrence of disruption in electricity generation process.

Malaysia’s Power generation mix is highly dependent upon thermal resources. A gas having the leading share of approximately 50 percent following gas is coal with 26 percent share. Although hydro is making good progress, other renewable energy resources have a share of less than 1%. A proper diversification fuel strategy required for long-term sustainable growth of the economy. According to Kettha (2014), heavy dependence and overutilization of depleting gas reserves create extra pressure on coal imports, which is already concentrated. Diversification in coal supplies and generation mix engaging renewable technologies is one of the key challenges of Malaysia’s energy policymakers (Kettha, 2014).

2.5 Overview of Malaysia Power Generation Sector

Malaysia, like other countries around the world, strongly depends on non-renewable energy sources (Ong, Mahlia, & Masjuki, 2011), which has increased economic policymakers concern over the reserves of these resources and their global price fluctuations. Countries like the United States, China and India depends heavily on coal which contributes around 40%, 64%, and 59% respectively in their energy mix illustrates the significance of coal in power generation infrastructure (IEA, 2015). Figure 2.5 represents the comparison of six different countries in terms of their power generation mix.

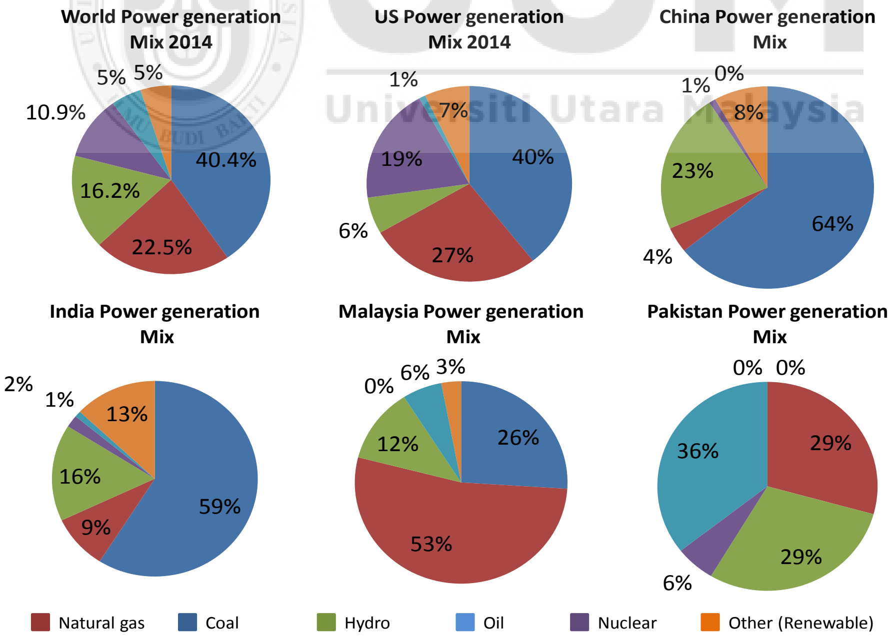


Figure 2.5.
Comparisons of the different power generation mix
Source: IEA (2016)

2.5.1 Demographic conditions of Malaysia.

Malaysia is located in Southeast Asia near the equator with coordinates of 2° 30′ N and 112° 30′ E, and a total area of 329,750 Km^2. It is divided into two parts by the South China Sea; named as Peninsular Malaysia bordering the south of Thailand, and East Malaysia bordering northern Singapore and the Indonesian islands. Its climate is hot and humid (tropical) throughout the year with an average rainfall of 250 cm a year, and an average temperature of 27 °C (BLC, 2017). These typical subtropical climatic conditions of Malaysia closely affect the indoor environmental comfort conditions in buildings.

2.5.2 Brief Overview of the Electricity Sector in Malaysia

Energy is considered to be the critical factor for the development of economic, social and sustainable elements in a country. The rapid development of infrastructure and economic growth is continuously impacting on the growing demand for energy in Malaysia. The rising energy demand is influenced by the demographic changes (which involve factors of urbanization and economic growth), population growth and per capita income. However, the rise in final energy consumption is recorded by the rate of 7.5% in 2012 which is expected to increase in the range of 6% to 8% in the subsequent year (NEB, 2014)

Since inception, Malaysia has witnessed a remarkable economic growth accompanied by a corresponding growth in the electricity demand especially within the manufacturing and industrial sectors (Sayed and Bodger, 2009). In recent years, the sector has assumed even a more pivotal role in ensuring that the country’s vision 2020 aspiration of becoming a ‘high-income nation’ is actualized. The increment of

1,728% has been observed in energy demand from 1978 to 2014 with the values of 604 Ktoe to 111,042 Ktoe respectively (Malaysia Energy Information Hub MEIH), (NEB, 2014).

The electricity supply industry in Malaysia is mostly monopolistic with regionalized vertical integration of the generation, transmission, and distribution of electric power. At present, there are three main players; Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn. Bhd (SESB) and Sarawak Electricity Supply Corp (SESCO), each covering the region of the Peninsula Malaysia, Sarawak, and Sabah respectively (The only exception to this is the NUR Power Sdn Bhd an independent power utility (220 MW) company that is licensed to generate, distribute, and sell electricity to tenants at the Kulim Hi-Tech Park in Kulim, Kedah, for 30 years (1998-2028). These companies have their generation capacities along with supply from various Independent Power Producers. Energy Commission or Suruhanjaya Tenaga (ST) acts as a regulator, ensuring the security of supply and safeguarding consumers' interests.

In 1998, Sabah electric supply limited became a subsidiary of Tenaga Nasional Berhad. Across the country, private participation takes the form of Independent Power Producers (IPPs) generating and supplying electricity to the utility companies to transmit to consumers. The national utility companies play an important role as the sole off-takers for the generating capacity and electrical energy produced by the IPPs.

2.5.3 Malaysia Electricity Generation mix

More than 80% of electricity in Malaysia is generated through fossil-fuels (natural gas and coal) which is continued to expand rapidly over the years. Total installed capacity at present stands at around 29 Gigawatt (GW), among which most of the power generation stations are situated in the densely industrial and densely populated Peninsular Malaysia. Meanwhile, the states of Sabah and Sarawak which are located in the Borneo archipelago are mostly powered up by hydropower due to their favorable geographical terrains. A few of these thermal power generation plants are based on co-fuel generation technology, which can run on two different fuel hence this advancement allow greater flexibility for plant operation at an optimal level. Malaysia's total installed power generation capacity by the end of 2010 was 24,361 MW (NEB, 2010); the geographical distribution of which is given in Figure 2.6. 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 reserve margin of the system stands around 43.7%; the long-term objective of Suruhanjaya Tenaga (ST) is to cut it to 20% level; thus reducing unused electricity generation capacity resulting in operational cost savings. The national grid serves all the urban population, while 98% of the rural population has access to electricity network (Bakhtyar et al., 2013)

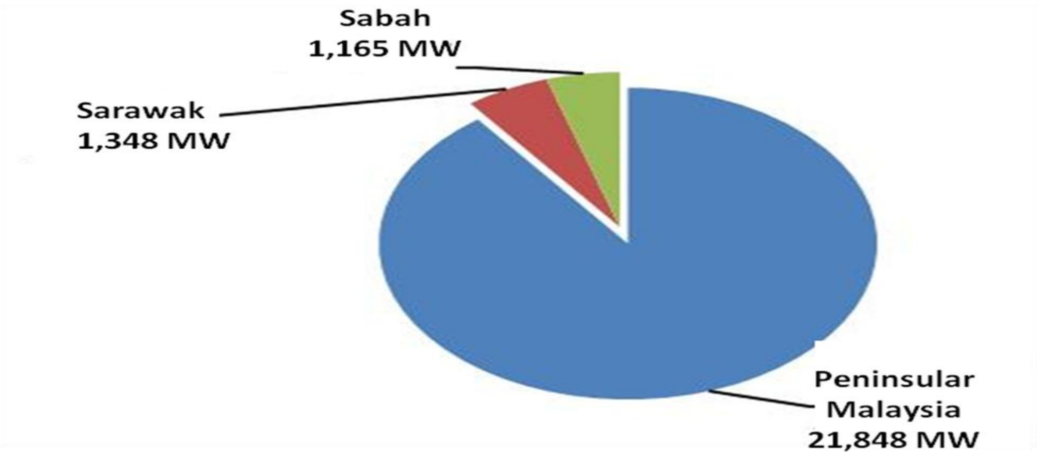


Figure 2.6.
Distribution of installed capacity in Malaysia)
Source: NEB, (2010)

A drastic change in primary energy supply has been observed during the year 2010 to 2014 with the incremental value of 9.27% from 76,809 Ktoe to 92,487 Ktoe respectively. The final energy demand has also been increased by the rate of 11.45% from 41,476 Ktoe to 52,209 Ktoe in the same fiscal year (NEB, 2010; NEB, 2014). Malaysia's total power generation capacity was also increased from 24,361 MW in 2010 to almost 30 GW in 2014. The value of total power generation has been increased by 15.36% from 108,175 GWh to 147,489 GWh during 2010 to 2014. Meanwhile, the electricity consumption has also raised by 10.19% from 104,521 GWh to 128,330 GWh by the end of the year 2014. (NEB, 2010; NEB, 2014). Figure 2.7 shows the disparity in installed power generation capacity from 2010 and 2014.

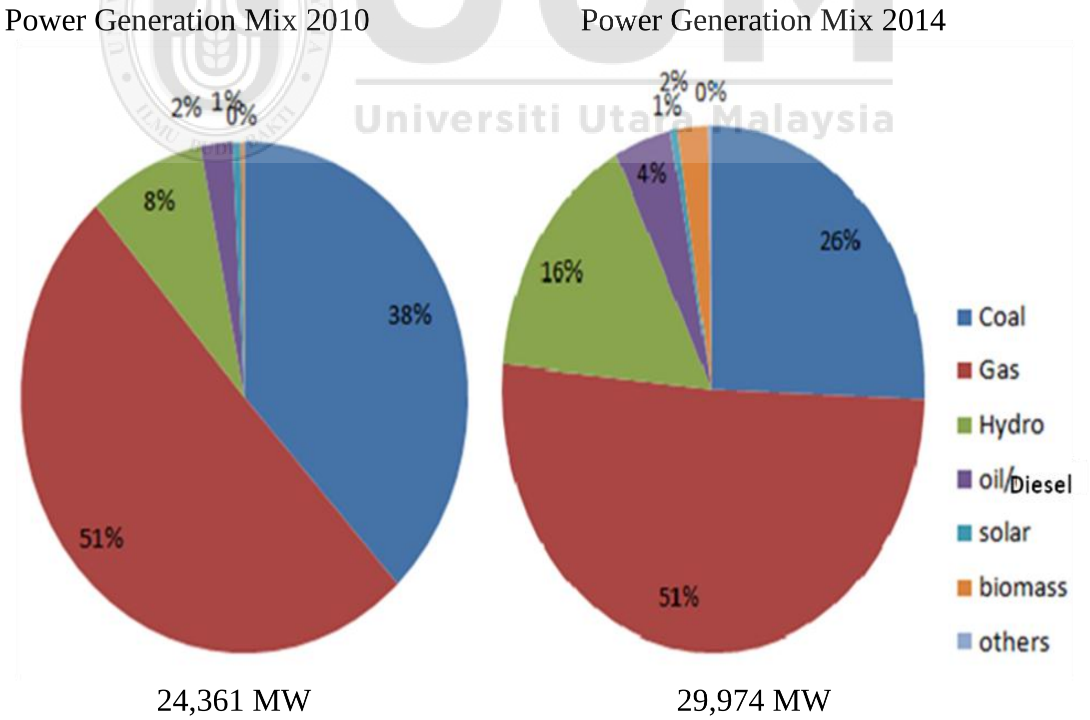


Figure 2.7
Electricity installed capacity comparison of 2010 and 2014.
Source: National Energy Balance (NEB, 2010; NEB, 2014).

It can be concluded from the above figure 2.7 that the 2014 power generation mix has been comparatively diversified as compared to the year 2010 that is 91% fossil fuel, renewable 0.2% and hydro 8%. This scenario leads Malaysia towards sustainable and environment-friendly future of buildings. Since, it has almost reduced its dependency on fossil fuel by 10%, besides almost doubled its hydroelectric and solar resources and added the use of biomass and biogas as renewable resources.

Since 1990, a tremendous growth in the gross domestic product (GDP) and electricity consumption has been observed; Figure 2.8 summarizes this trend. This inclination is alarming for planners, especially in the milieu of country’s dependency on fossil fuels. In 2010, almost 90% of electricity was accumulated to generate from coal and natural gas (Chua and Oh, 2010). Despite the fact that there are sufficient natural gas reserves in Malaysia, their depletion is inevitable. It has been anticipated that the gas reserves were remains for 30-33 more years with current consumption rate (WEC, 2010). Meanwhile, coal is already imported from South Africa, Australia, and Indonesia (Rahman Mohamed and Lee, 2006; Muhammad-Sukki et al., 2012).

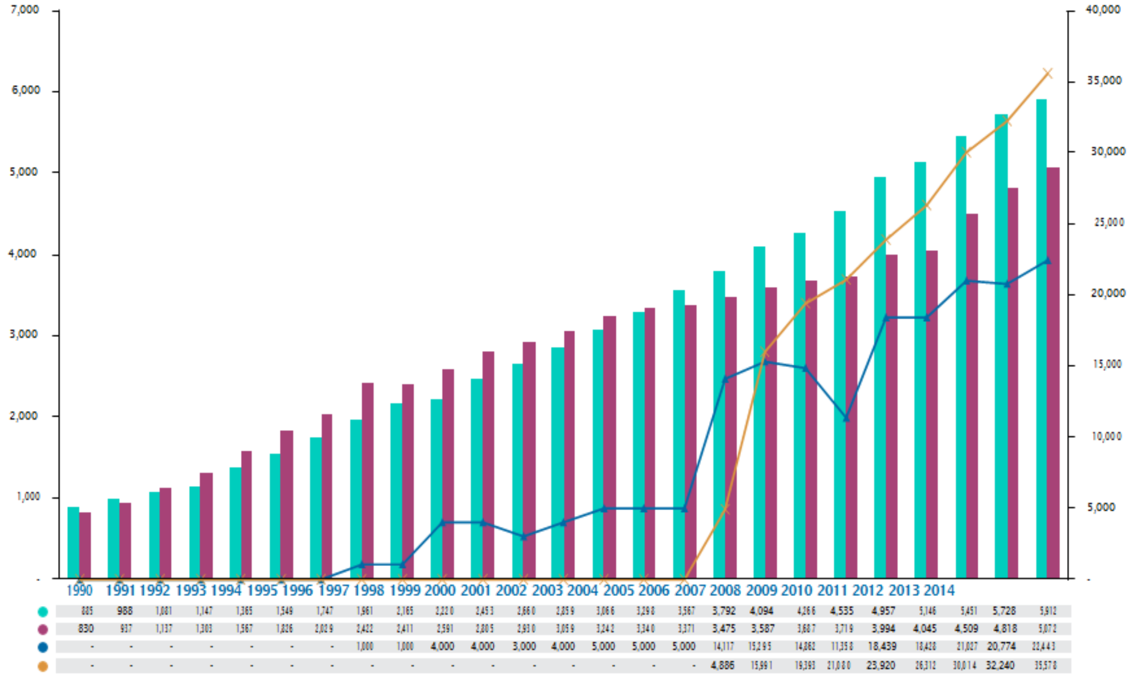


Figure 2.8
Economic development and electricity consumption trend
Source: National Energy Balance (NEB, 2014)

Being a developing country, Malaysia is constantly trying on its toes to meet with the increasing energy requirement in a country, while improving the dynamic energy growth in a cost-efficient manner. By the end of the year 2010, the reported population of Malaysia was approximately 23 million with a study growth rate of 1.8 Percent annually. With the current incremental rate, it is predicted to reach 33.4 and 37.4 million by 2020 and 2030 respectively. However, the urbanization and rising industrialization are the key driving factors (Ali, Duat and Taib, 2012).In comparison to the social civilization and population development, the final energy consumption is growing at a meteoric rate. It has been highlighted by the central intelligence agency in worlds Factbook (Chua and Oh, 2010) that the total energy consumption in Malaysia was incremented by the rate of 5.6 percent per annum during 2000-2005, 6.3 percent 2005-2010, and 9.7 percent between 2010-2014 (NEB, 2014). The total energy demand for the year 2014 is shared by various sectors - such as transport 47% followed by industry with 25% of the share. Meanwhile commercial and residential sectors contribute 14%. On the other hand, the share of agriculture and non-energy sector is 2% and 12% respectively, as depicted in figure 2.9.

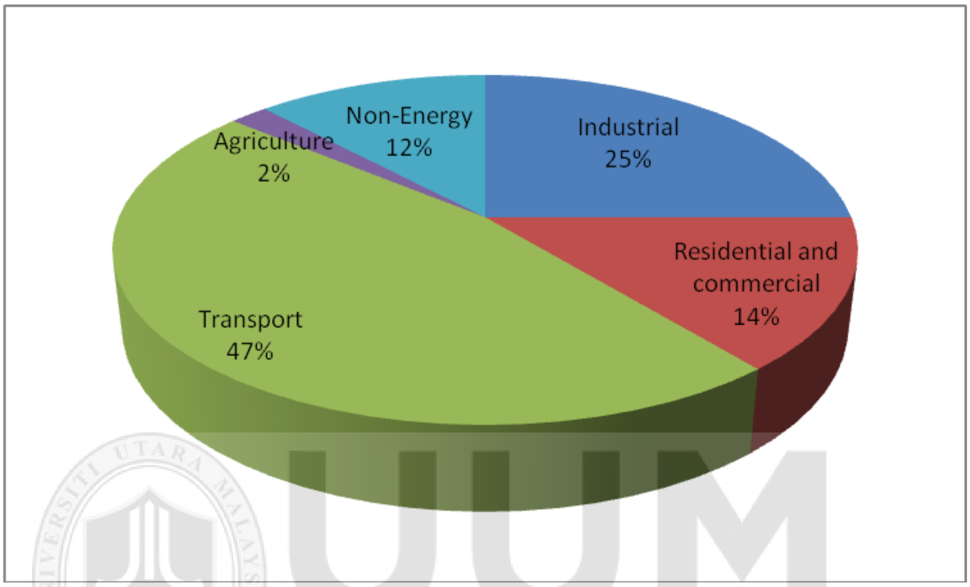


Figure 2.9
Sectorial wise final energy consumption of Malaysia
Source: (NEB, 2014)

On the policy front, as an aftermath of the 1973 world oil crisis, the Malaysian Government capped oil and gas production in National Depletion Policy of 1980. This policy aimed to reduce dependence on oil for electricity generation (Rahman Mohamed and Lee, 2006). Later in 1981, Four-Fuel strategy introduced natural gas for electricity production (Jafar et al., 2008). Given the fact that fossil fuel reserves are limited, the Malaysia government introduced renewable technologies under Five-Fuel Diversification Strategy of 2000 (Chua and Oh, 2010). In spite of this policy, renewable capacity by 2011 was less than 1% of the total installed capacity (Muis et al., 2011). Comparing this underachievement of Malaysia with the countries that are aiming for 100% renewable sources such as, Denmark (Lund and Mathiesen, 2009) and Ireland (Connolly et al., 2011), shows Malaysia's technology lock-in to fossil fuel-based generation system. Compliance with the five fuel diversification policy for electricity generation this study considered the 2010 power generation mix as a base scenario consisting of Natural gas, coal, hydropower, Solar Power PV, and biomass for the future energy generation portfolio. The share of oil and other generation technologies has been ignored which accountable contributes 573 MW of electricity in national grid and total generation capacity is reduced to 23,788MW from 24,361MW. Table 2.3 shows the detailed share of each fuel type for power generation portfolio.

Table 2.3
Malaysia Electricity generation mix.

Sno.	Fuel Type	Units Installed Capacity	The percentage share of generation type
1	Coal	9257	38.90%
2	Gas	12278	51.60%
3	Hydro	2046	8.60%
5	Solar	145	0.60%
6	Biomass	62	0.26%
	Actual Total Units	**23,788 MW**	100%

2.5.4 Crude Oil

The contribution of oil in Malaysia's energy mix was once as high as 90% (in 1980) but after the international oil crisis in 1973 and 1979; its share has declined significantly by as early as 1981. This scenario also prompted the Government of Malaysia to implement a fuel diversification strategy prevent over-dependence on oil (Economic Planning Unit, 2012). As of 2010, Malaysia has proven oil reserves of

5.8 billion barrels of which more than 60% are located in East Malaysia (Sabah and Sarawak) (BP Statistics, 2011; and Economic Planning Unit, 2012).

Malaysia has significantly improved the refining industry in last 20 years, and finally able to fulfill the domestic requirement of petroleum products for a country. Malaysia has ranked as 24 in global oil resources having almost 4 billion barrels of oil reservoirs of oil products (EIA, 2013). According to several studies (Haidar et al., 2011; and Ong et al., 2011) based on a production rate of about 650,000 barrels per day and the ratio between reserve and production, the proven oil reserves are expected to exhaust over next 14 to 21 years. Malaysia has recently launched five new oil operational power plants with various generation capacities from 398MW to 180 MW. The power plant of Gelugor in Penang has the highest generation capacity of 398MW, while The Sandakan electricity generation corporation, Melawa plant of Sabah, Tawau power station and Star electricity generation plant own generation capacity of 180 MW respectively. As the world has been recently facing the beginning of depletion of fossil fuels with the world's oil production being nearly flat for the last five years (BP Statistics, 2011), Malaysia is also experiencing this phenomenon. The production of crude oil has been flat since 1996 and decreasing a little since 2008 as shown in Figure 2.10 indicating that the country could be at peak oil. The country's oil consumption, however, has been increasing from 57 Tbd in 1970 to 556 Tbd in 2010 as shown in Figure 2.10 an 2.11 (BP Statistics, 2011; and Economic Planning Unit, 2012).

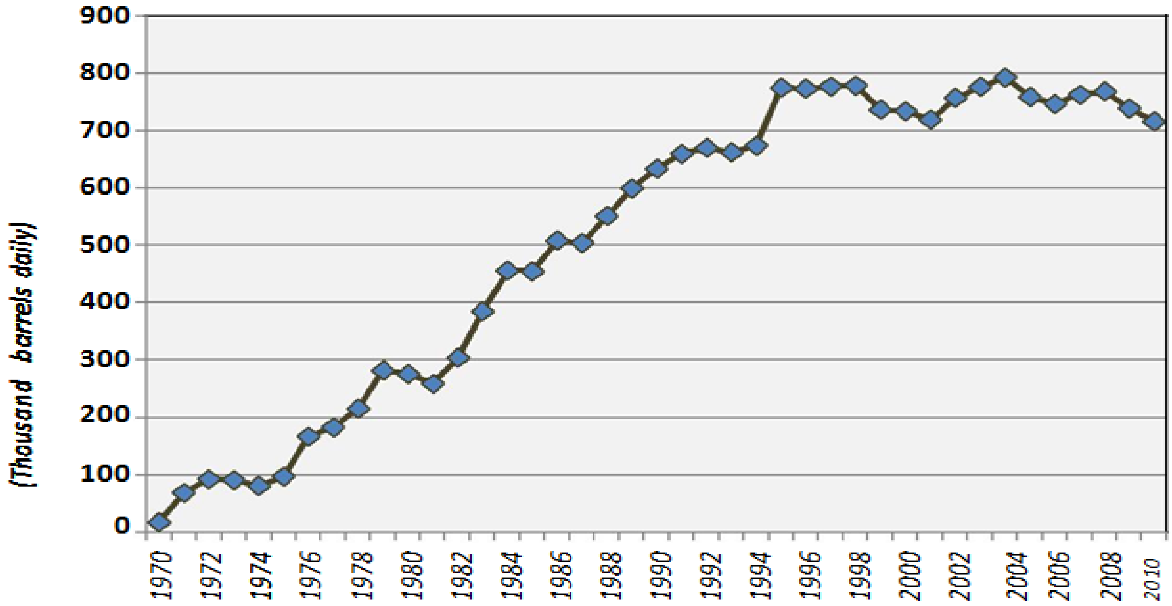


Figure 2.10

Malaysia's oil Production, 1970- 2010

Source: Derived from the BP Statistical review of the world energy 2011

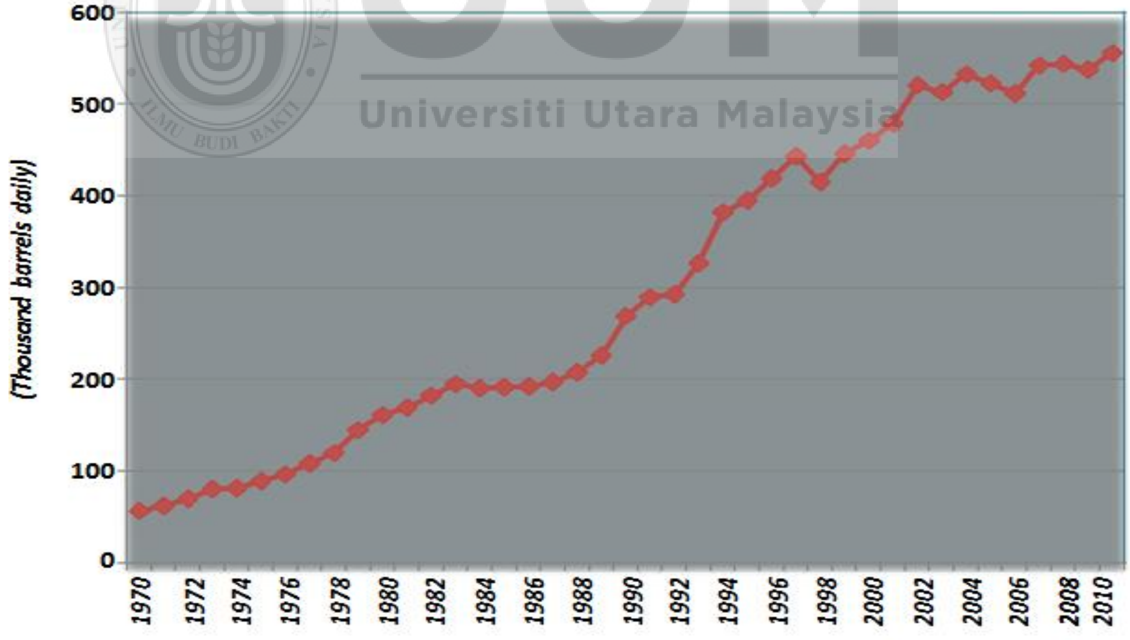


Figure 2.11

Malaysia's oil Consumption, 1970- 2010

Source: Derived from BP Statistical review of the world energy 2011

2.5.5 Coal

Being the cheapest and most abundantly available fossil fuel, coal plays a major role in the energy mix strategy. During the period 1995-2000, total coal reserves in Malaysia increased from 974 million tonnes in 1995 to 1,050 million tonnes in 2000. However, coal production has been decreasingly slowly because most of the new deposits are hard to get coal located in the interior areas (Sarawak and Sabah), which lack transportation infrastructure, and therefore are currently uneconomic to be fully exploited (Economic Planning Unit, 2012). The major coal fields are located in Sabah and Sarawak with a small portion in Peninsular Malaysia. Sarawak is the richest state with respect to coal reservoirs containing 80% of total share followed by Sabah with almost 18.5% of capacity. However, the rest of Peninsular Malaysia including (Perlis, Selangor, and Perak) only contains 1.5% of entire reservoirs (Thaddeus, 2002).

Nevertheless, the use of coal as an energy source in electricity generation is one of the GoM plans for security and reliability of energy supply (Economic Planning Unit, 2012). According to the BP Statistical Energy Survey in 2011 (BP Statistics, 2011), Malaysia had consumed of 3.4 million tonnes oil equivalent of coal, accounting 0.1% of the world total in 2010. Also, in 2011, coal was the second largest contributor (41.9%) to the country's generation mix of electricity (Economic Planning Unit, 2012). Moreover, currently, Malaysia is actively promoting coal as a fuel of choice for power generation to free up more of the natural gas for export. Currently, in Malaysia, there are six main power plants are operation on coal among which four are located in peninsular with the generation capacity of 8215 MW. However, only 220 MW of electricity is generated in Sarawak with two coal-fired power stations. Although indigenous coal reservoirs are sufficient enough to fulfill the need of coal-fired power stations, still (84%) of coal is imported from Indonesia , Australia (11%), and South Africa (5%) (Thaddeus, 2002).

The annual coal production of Malaysia has been significantly increased from 65,000 tons (1990) to 383 tons (2010). Together with the imported coal, it contributes more than 30% of total power generation. However, it has been anticipated that in the long term the demand for coal will be increased due to the fluctuating prices of oil in the international market (Mohamed & Lee 2006; Jaffar 2009).In 2008, the total energy demand from coal was 30% or 14,200-MW, and it is expected to increase to 42% or 17,600-MW in 2013 (TNB, 2008).

Currently, the coal reserves in Malaysia are approximately 1938 million tonnes having the reserves-to-production ratio of 285 years. 1n 1998 the national mineral policy was launched with the theme of promoting the utilization and extraction of indigenous coal reservoirs. The policy was aimed to provide the incentives for the private sector to encourage the development of coal resources with the utilizing innovative technology in extraction and production activities. The most promising progress was expected in the extraction and mining sector which involves large and expensive inventory (Moggie and keynote, 2002). Recently two licenses of 1000GW of coal-fired plant units have been awarded to Suruhanjaya Tenaga (ST) at Tanjung bin and Manjung, however, more licenses will be awarded in the near future by considering the fluctuating prices of oil in international market. Although energy from coal seems to play the vital role in future the environmental consequences of greenhouse emission can never be ignored. Since Malaysia has committed to reducing its emission to 45% by the end for 2030, it is necessary to restrict the utilization of coal and to engage the clean-coal technology in existing generation system with the help of electrostatic precipitators and flue gas desulfurization. However, the installments of gas cleaning technology would significantly enhance the capital costs of the current power generating plants (Mohamed and Lee, 2006).

2.5.6 Natural Gas

Among the fossil fuels, natural gas is considered to be the most valuable commodity in global energy market (Malik and Sukhera, 2012). Globally the consumption of natural gas has risen dramatically due to its affordability, lower environmental harm, convenient to use, and sufficient available reservoirs. After the commencement of exploration in 1983, natural gas has become the main contributor to Malaysia energy mix by replacing oil (Oh et al., 2010). The natural gas reserves of Malaysia have been amounted to 83 trillion standard cubic feet (tcf) by 2010 with the reserve-to-production ratio of 38.2 years (U.S. Energy Information Administration (2012). Till 2010, Malaysia was the 10th largest holder of natural gas reserves in the world. The offshore Sabah and Sarawak contain 64% of entire shares however Peninsular contain 35 percent only. Table 2.4 shows the detailed picture of natural reservoirs of Malaysia.

Table 2.4
Natural gas Reserves of Malaysia

Natural Gas Reserves of Malaysia

Region	Reserves [Billion Standard Cubic Meter (BSCM)]		
	Associated	Non-Associated	Total
Peninsular Malaysia	264.05	726.3	990.4
Sabah	106.6	267.7	374.3
Sarawak	94.3	1325.2	1419.3
Total	464.9	2319.2	2784.1

Source: Samsudina, (2016)

It has been anticipated that the natural gas reservoirs of Malaysia will remain only 40 more years. On the other hand, the installed capacity of a gas-fired power plant is approximately 15.4 GW until 2013.Many studies claim that the natural gas reserves in Malaysia will last less than 40 years. For instance, according to one study by Malaysian academician (Haidar et al., 2011; and Oh et al., 2010) the natural gas reserves in Malaysia are estimated to last for another 33 to 36 years. Furthermore, according to research by The Association for the Study of Peak Oil and Gas (ASPO), Malaysia is not expected to be net natural gas importer until 38 years' time (Association for the Study of Peak Oil and Gas, 2009).

2.5.7 Potential of Renewable Energy Technologies

The energy that comes from various sources such as biomass, wood, tide, wave, solar and wind is commonly known as renewable energy. The renewable energy is environmentally friendly, safe and unlimited as compared to fossil fuel energy. Consequently, a rapid increase in the world demand and consumption of renewable energy has been recorded. According to IEA (2014), renewable energy generation shows continuous increasing trends; it has increased 18 percent, 21 percent and 22 percent in 2007, 2012 and 2014, respectively.

Among the members of the Association of Southeast Asian Nations (ASEAN), Malaysia is a country that gifted with abundant renewable energy potential. A comparison, renewable energy potential between Malaysia and other ASEAN countries is presented in Table 2.5. It shows that Malaysian ranked first, Vietnam second, Thailand third, Indonesia fourth and Singapore remained in fifth in ASEAN countries.

The primary domestic renewable sources comprise of palm oil, biomass wastage, hydropower, solar power, solid waste, landfill gas, wind energy. Amongst the available indigenous resources, hydropower is applicable for both small and large-scale, solar photovoltaic (PV) can a choice for small-scale application and at the household level. In biomass, sector marked advancement and development have been achieved, which has proved its significant cost effectiveness too, peculiarly on a large scale, in industries (Malek and Malaysia, 2010). It is worthwhile to acknowledge that Malaysia enjoys the highest renewable electricity potential in comparison to the share of the ASEAN countries (Olz and barefoot, 2010).

Table 2.5
Renewable energy potential

Name of country	**Potential of renewable energy per capita**
Malaysia	4.74
Vietnam	2.19
Thailand	1.84
Indonesia	1.56
Singapore	0.74

Source: Olz and Beerepot, (2010)

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

2.5.7.1 Hydropower

The potential of hydropower depends on the amount of available water and suitable terrain. 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 the country's mountainous areas, which accounts for 41% of the total land area. Plentiful water and the supporting terrain are favorable for hydropower projects. The Peninsular Malaysia hydropower potential seems to have exhausted (Hussein and Raman, 2010). However, East Malaysia potential is yet to be exploited fully. The estimated hydropower technology's potential is 29,000MW (Lidula et al., 2007), whereas for mini-hydro it is 500MW (Oh et al., 2010).

Currently, hydropower is assumed to be the only renewable resource that can be implemented on a large scale for electricity generation in Malaysia at cheapest per unit generation cost. Out of 16 major hydropower stations, the majority of them are located in Perak, where six major hydropower stations have been built to generate electricity. Table 2.6 illustrates the installed capacity of hydropower stations in Malaysia (Mohammad et al., 2006). Despite having the lowest per unit KWh cost and least environmental harm still hydropower plant considered to be unfavorable for electricity generation in some countries because of social and environmental problems. These problems include low agricultural productivity, relocation of local populations, soil erosion, and disturbance of ecosystems. Moreover, a substantial area of land is required for water storage on a large scale of hydropower plan. An estimated amount of 14 trillion liters of water and 74.000 hectares of the land reservoir are required to generate 1 billion kWh of electricity per year (Gleick and Adams, 2000; Schilling, and Esmundo, 2009).

Table 2.6
Installed Capacity of Major HydroPower Stations in Malaysia

Installed capacity of Major Hydro Power Stations in Malaysia		
Power station	**Installed Capacity (MW)**	**Total (MW)**
Terengganu		
Stesen Janakuasa Sultan Mahmud Kenyir	4 x 100	400
Perak		
Stesen Janakuasa Temenggor	4x 87	348
Stesen Janakuasa Bersia	3 x 24	72
Stesen Janakuasa Kenering	3 x 40	120
Chenderoh	3 x 10.7 + 1 x 8.4	40.5
Sg. Piah Hulu	2 x 7.3	14.6
Sg. Piah Hilir	2 x 27	54
Pahang		
Stesen Janakuasa Sultan Yussuf	4 x 25	100
Stesen Janakuasa Sultan Idris II	3 x 50	150
Cameron Highland Scheme		11.9
Kelantan		
Pergau	4 x 150	600
Kenerong Upper	2 x 6	12
Kenerong Lower	2 x 4	8
Sabah		
Teno Pangi	3 x 22.0	66
Sarawak		
Batang Ai		108
Bakun	4 x 27.0	1,800.00
	Total	3,905 MW

Source: Samsudina, (2016)

2.5.7.2 Wind Power

As it is in the equatorial region, the blowing of wind in Malaysia is not sufficient enough to support any inland power plant to operate at maximum efficiency as shown in figure 2.12. However, Fortunately Malaysia is blessed with 29th longest coastline in the world estimated about 4,670 Kilometres. The available resource is sufficient enough to support consistent medium to large scale power generation through a wind turbine.

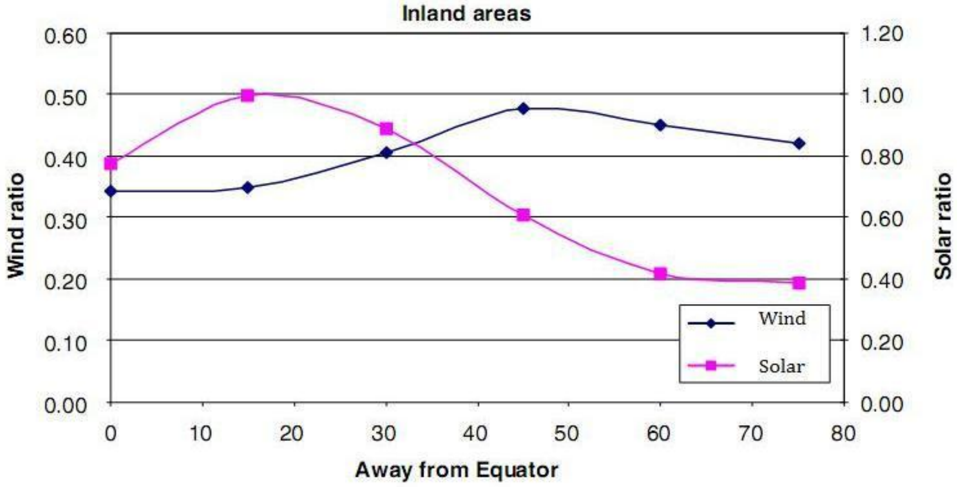


Figure 2.12
Wind and Solar potential as a function of distance from the equator
Source: Asif and Muneer, (2009)

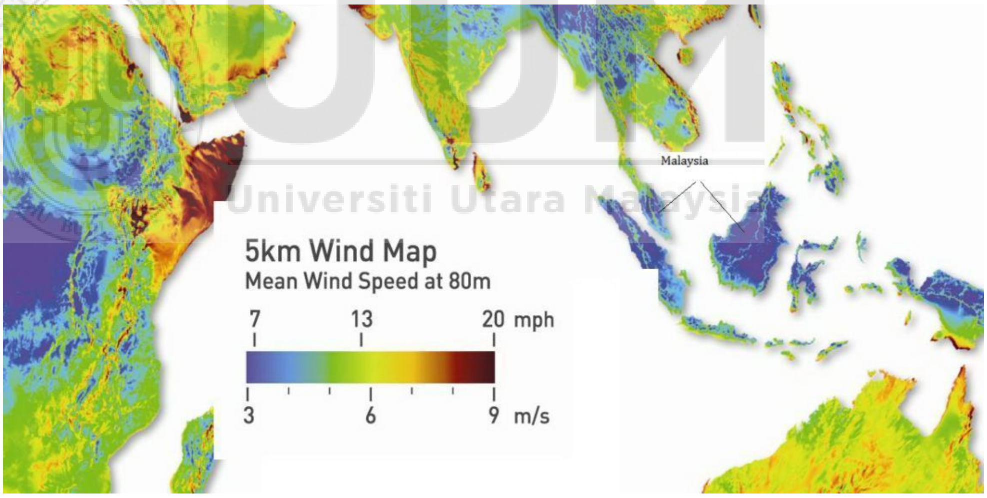


Figure 2.13
World Wind Map
Source: www.3tier.com

Referring to the wind blowing map shown in figure 2.13 the available speed of wind blowing fluctuates between 1.2 meters per second to 2.8 meters per second in comparison to this coastal region blowing speed fluctuates between 3.4 meters per second to 4.6 meters per second which are considered as the low available potential. The onshore and offshore wind turbines are the rapidly growing technology around the world, but still, its adoption is close to zero in Malaysia energy mix. However, around 0.16 MW of off-grid wind power generation plant can be found in the country (Bakhtyar et al., 2013). This low penetration can be attributed to lesser wind potential, and risk of tropical cyclones (Islam et al., 2011). Referring to the environmental consequences wind turbines are also responsible for interfering of electromagnetic signals in the large vicinity of installation, flight-divergence of migrating birds, a huge noise of rotating blades and most of all tarnishing of the landscape (Schilling and Esmundo, 2009).

2.5.7.3 Solar Power

Solar energy has the great potential to solve global warming issues and considered to be the promising source of renewable energy. Fortunately, Malaysia is located on 110 to 120 degree east longitude and about 1 to 7 degree north latitude which considered to be the which considered to be the world second largest radiation region (Mansor and Muhamad, 2014; Mekhilef et al., 2012).

Malaysia on average receives daily solar irradiation of 4.21–5.56 kWh/m2 (Kamaruzzaman et al., 2012), with around 12 hours of daily sunlight (Mekhilef et al., 2012). Figure 2.14 illustrates the solar potential of Malaysia. From figure 2.14 it can be observed that Peninsular Malaysia has the higher solar potential concerning East Malaysia (Sabah Sarawak). Johar Bahru, Melaka, Kuala Lumpur, Kota Kinabalu, Kuching, Penang, Kota Bharu and Kuantan are considered to be optimal for solar electricity generation containing the capacity of 1,150 KWh/KWp to 1,500 KWh/KWp (Chua and Oh, 2012). However, in East Malaysia, Sabah and Sarawak have the comparatively low radiation potential varies from 16-25 MJ/m^2/day and 12-15 MJ/m^2/day respectively. According to Oh (2010), the solar potential of Malaysia for electricity generation is approximately four times more than the global fossil-fuel reservoirs.

Solar electricity generation is considered to be the safest for the environment and does not produce any air pollution. However, it requires a large area of land for electricity generation. Approximately two-thirds of Malaysia’s land vicinity is sheltered with tropical forests. Thus, the best way to harness solar energy is to use rooftop photovoltaic cell (PV) at commercial and residential level. In last few years a drastic decrease in PV cell prices has been observed in the global market, but still, the installed capacity is quite low.

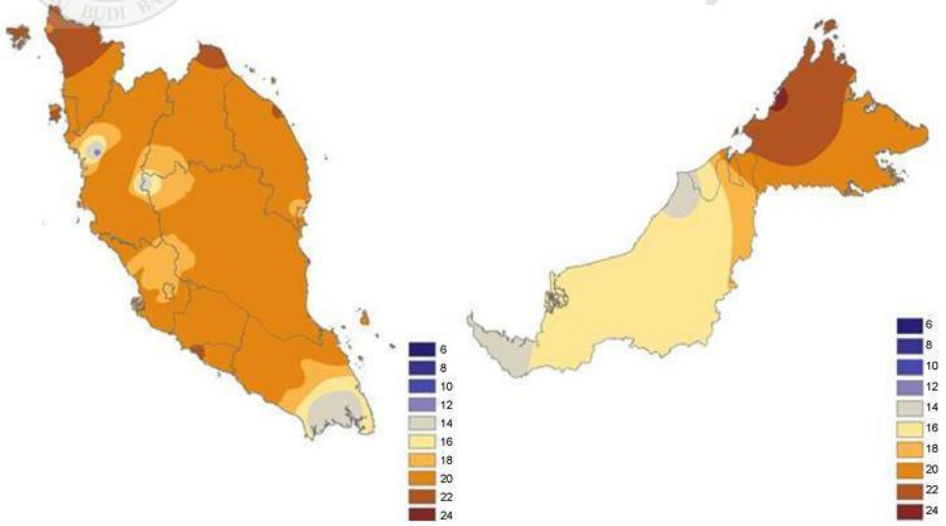


Figure 2.14
Solar map of peninsular and east Malaysia, MJ/m^2/day
Source: Meteorological Department of Malaysia

2.5.7.4 Biomass

Biomass is the mass of combustible material of any organic origin which can be extracted from plants, or process waste and can be used for electricity generation. Globally the use of biomass for electricity generation has risen extraordinarily. From last fifty years, Malaysia is amongst the largest producer and exporter of palm oil. Usually, palm oil is cultivated for its oil, but the by-product like empty fruit bunch (EFB) and the shell has a high potential for generating electricity. Under five-fuel energy diversification policy, Government of Malaysia has identified the use of biomass as a potential source of generating electricity. Having almost 380 palm oil production companies distributed all over, Malaysia has a potential of generating 2400 MW of electricity by biowaste (Muzlina, 2005).

At present, Malaysia is the second largest producer of palm oil, in the world, after Indonesia (Sulaiman et al., 2011). Of the total land area (32.9 million ha) of Malaysia, 14.9% is used for agricultural activities in which oil palm has got a share of 34.16% (Ong et al., 2011). In 1920, there was 400 ha of oil palm plantation, which rose to 4.06 million ha in 2009, it is estimated to expand to 5.2 million ha in 2020 (Shafie et al., 2011). 1 hectare of oil palm plantation produces 50-70 tonnes of waste. This waste can be used for electricity production. The annual energy potential is estimated to be around 800GWh (Bazmi et al., 2011), whereas the capacity potential is 1,300 MW (Oh et al., 2010). This potential can further be enhanced by including other agricultural refuse like biogases, rice-husk and forest residue. The estimated power generation potential of biomass can thus reach, 29,000 MW (Lidula et al., 2007).

Besides several advantages, there are also some reservations about using palm biomass for generation of electricity. Alternative usage of empty fruit bunch (in fertilizers and cement industry), GHG emission high water and land requirement are the amount the few disadvantages of biomass electricity generation (Schilling and Esmundo, 2009). Worst of all combustion of biomass release carbon monoxide, nitrogen oxide and particulates. The estimated potential of various renewable technologies for electricity generation in Malaysia is summarized in Figure 2.15.

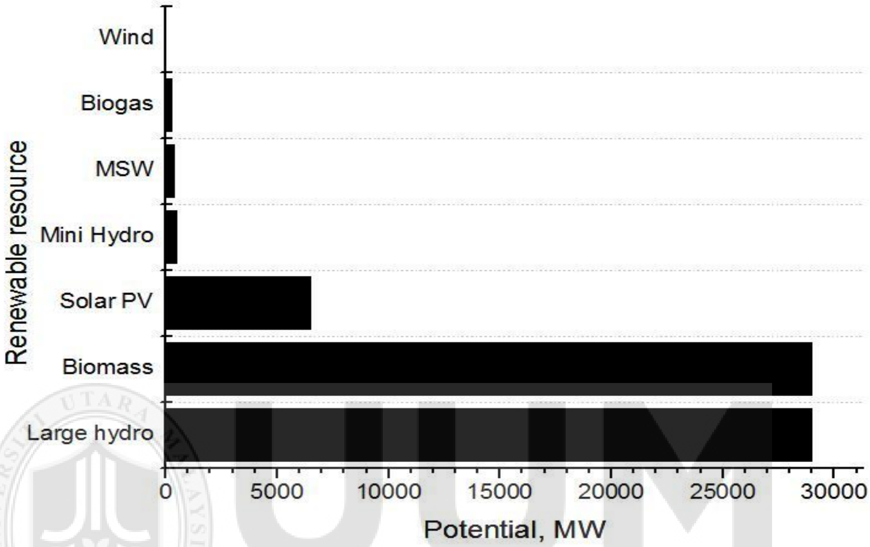


Figure 2.15
Estimated potential of renewable electricity sources in Malaysia

The renewable technologies potential review indicates that there is sufficient resource potential in the country to produce electricity.

2.6 Malaysia Fuel Policies

Since 1980, the Malaysian energy sector has been guided by the four-fuel diversification strategy. The policy was formulated against the aftermath of two global oil crisis and the effect of prices in quantum leaps of 1973 and 1979, at that instance of time Malaysia energy sector was heavily dependent upon single generation source, oil. The policy was designed to protect the probable oil crisis and to shift the burden on globally stable commodity (coal) and locally available natural resources like (natural gas and Hydropower). At that time there were a large amount of indigenously untapped gas and hydropower reserves. However coal was considered as a stable and abundant commodity globally, and the trade of coal was conducted in the form of long-term contracts to control the price fluctuation. Due to the impact of this policy, Malaysia has significantly tipped the stability in the fuel mix for power generation from a high 90% dependence on oil in 1980 to less than 64% in the year 1997. Meanwhile the coal and natural gas has adopted as a replicable fuel with the share of 30% and 5% respectively in the total power generation mix.

Malaysia has launched the efficient five-fuel diversification in policy in its 8th national action plan (2001-2005), in which government has set the target of engaging at least 5% of energy from the sustainable renewable energy resources by the end of the year 2005. Unfortunately, the policy was ended up by just reaching 0.3 of the set target by the year 2005 (Muhammad-Sukki, Ramirez-Iniguez, Abu-Bakar, McMeekin, & Stewart, 2011). The target was again set in 9th national action plan (2005-2010) with more rapid implementation to enrolled 5% share of renewable energy in the national energy mix.

During 8th and 9th action plan, Malaysia has taken several measures for promoting the use of renewable energy on both domestic and commercial levels as an alternative fuel source. In this process, approximately 900 million US dollars were invested in the exploration and production of indigenous renewable energy resources (Olz&Beerpoot, 2010). Until now the set target of 5% renewable adaptation in generation mix under 8th and 9th national action plan was not achieved, and nonetheless, only 8% of the target has been reached (Maulud & Saidi, 2012). Even though the target for Peninsular Malaysia is 300MW, and that for Sabah and Sarawak is 50MW, only 56.7 MW of energy in Malaysia is produced from renewable energy sources (Hashim & Ho, 2011). It indicates that even after ten years of adopting renewable energy policy still the share of renewable energy sources in Malaysia's power generation mix is less than 1% (EPU, 2010).

However, realizing the importance of renewable energy a sustainable development always remains the major objective of Malaysian energy policies. In this regard, the 10th national action plan (2011-2015) Government of Malaysia aimed to generate 985 MW of electricity from renewable energy resources which are approximately 5.5% share of total power generation mix (on the data we did not know yet either Malaysian government successful to achieve this goal or not). Concurrently, the National Renewable Energy Policy was also launched in 2010, and it set a target of 11% of the total energy from renewable sources (2080 MW) by 2020. Comparing this underachievement of Malaysia with the countries that are aiming for 100% renewable sources such as, Denmark (Lund and Mathiesen, 2009) and Ireland (Connolly et al., 2011), shows Malaysia's technology lock-in to fossil fuel-based generation system. Figure 2.16 summarises the main energy-related policies in the country.

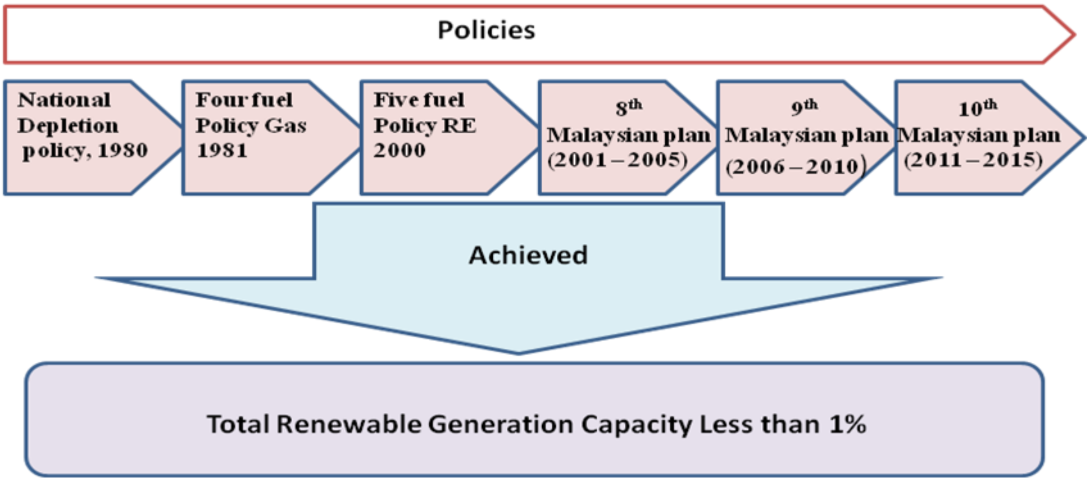


Figure 2.16
Policy development and achievement towards renewable power

Table 2.7 summarizes the chronological development of the country's energy policies from the 7MP until 10MP (1996-2015) (EPU, 2010; EPU, 2015).

Table 2.7
Malaysian key emphasis for energy development (7NP-10NP)

Malaysia plan	**Key Emphasis**
Seventh Malaysia Plan (1996–2000)	Emphasis on sustainable development and of depletable resources and the diversification of energy resources.
	Ensuring adequacy of generating efficiency as well as expanding and upgrading the transmission and distribution infrastructures.
	Encouraged the use of new and alternative energy sources as well as proficient deployment of energy.
Eighth Malaysia Plan (2001–2005)	Emphasis on the sustainable development of energy resources, both non-renewable and renewable. The energy mix includes five fuels: oil, gas, coal, hydro, and RE.
	Intensive efforts on ensuring sufficiency, quality and security of energy supply.
	Greater emphasis on energy efficiency (EE): encourage efficient utilisation of gas and RE as well as provide adequate electricity generating capacity.
	Supports the development of industries in production of energy-related products and services.
	Highlights in promoting RE and EE: incentives for EE, incentives for the use of RE resources, and incentives to maintain quality of power supply.
Ninth Malaysia Plan (2006–2010)	Emphasis on strengthening initiatives for EE particularly in transportation, commercial and industrial sectors, and in government buildings.
	Encourage better use of RE by diversifying fuel sources.
	Intensify efforts to further reduce the dependency on petroleum provides for more to integrate alternative fuels.
	Incentives in promoting RE and EE are further enhanced.
Tenth Malaysia Plan (2011–2015)	Short term goals vested in National Green Technology Policy:
	Increased public awareness and commitment for the adoption and application of green technology through advocacy programmes.
	Widespread availability and recognition of green technology in terms of products, appliances, equipment, and systems in the local market through standards, rating and labeling programmes.
	Increased foreign and domestic direct investment in green technology manufacturing and services sector.
	Expansion of local research institutes and institutions of higher learning to expand. research, development and innovation activities on green technology towards. commercialization through appropriate mechanisms.
	Launching new RE act and FiT mechanism

Source: Derived From the Malaysian Plan-Economic Planning Unit (EPU, 2012a)

2.7 Carbon Emission in Power Generation System

The focus to achieve the clean environment put new pressure on electricity generation industry. The numerous thermal power generation plants that operate today make the sector one of the largest CO_2 emitter. There are many climate change initiatives in various stages of development and implementation that will strongly influence the future course of the industry. The failure to accept and implement those policies will seriously impact on the environment and human health-related issues and ultimately make economic development unsustainable. An intergovernmental panel on climate change (IPCC) has conducted a detailed investigation on catastrophic consequences of climate changes and hence have suggested introducing environmental friendly strategies in their development plans. After the publication of Sterns (2007) report on global warming, many countries have implemented carbon reduction policies by maximizing the share of renewable resources in their energy portfolio. Besides that several countries have committed to carbon emission using efficient and innovative production technologies. The burning of fossil fuel is the major contributor to carbon content in the atmosphere. The amount of global CO_2 emissions in 2011 from fossil fuel combustion was 34.8 billiontonnes.Coal burning was responsible for 43% of the total emissions (Glikson, 2011). Electricity generation (and heating) currently contribute approximately 25% of global anthropogenic greenhouse gas emissions, the main driver of observed climate change (Zhu, Liu, and Wang, 2010). Indeed, as much as a third of oil, half of gas and over four-fifths of coal reserves must be left unburnt for global warming to stay below 2 degrees Celsius (McGlade and Ekins, 2015).

It is not possible to imagine the development of economic activities of countries without the use of energy. There is a consensus that energy is needed for the economic growth and development of countries. In the same way, if countries can produce and use cleaner electricity, the world economic development will be more sustainable (Ayres and Vourdouris, 2014; Yildirm, Sukrouglu, and Aslan, 2014).

Considering the catastrophic climate change and uncertainty related to long-term projection many studies proposed to engage the measure for mitigation through direct induction of transition policies rather relying on qualitative measures (Rosen and Guenther, 2015; Van den Bergh et al., 2011).

This is especially so when the expected utility derived from decision making under uncertainty may offer little realistic solutions to address climate damage (Heal and Millner, 2014; Kunreuther et al., 2013). Although long-term quantitative projections are often characterized by information problems, there is evidence to show that the world is experiencing a major series of geophysical changes that is unprecedented (Byatt et al., 2006; Carter et al., 2006; Nordhaus, 2007, 2008; Pizer, 1999; Tol, 2003; Weitzman, 2007). The recent report from IPCC (2011) indicates that the global mean surface temperature would rise sharply in the next century and beyond if existing patterns of human activity are left unchecked. Worldwide the atmospheric concentrations and emissions are rising, and there are signs of rapidly increasing average surface temperatures in recent decades (IPCC, 2007; Nordhaus, 2008; Ozdogan, 2011; Stern, 2007).

The scientific community has become increasingly concerned with how to deal with the recent upheavals associated with atmospheric concentrations, temperature increases and emissions rather than on disputes and disagreements with scientific facts (Nordhaus, 2007; Stern, 2007). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) gives the best estimate of increases in global temperatures over the next century, which ranged from 1.8 to 4.0 8^0C. Although this seems like a small change, it is much more rapid than any changes that have occurred in the past 10,000 years (Nordhaus, 2007). Thus, it is obvious and acknowledged by the scientific community that temperatures would increase over the coming century up to 3.0–4.0 8^0C, which is certain to raise people’s vulnerability to climatic catastrophes (Carter et al., 2006; IPCC, 2007; Nordhaus, 2007; Weitzman, 2007). The direct vulnerability impact of temperature increases and global warming related climate change include the degradation of natural resources, damage to infrastructure and environment, health hazards facing humans, and destruction of the global economy. Also, there will be indirect damages, which are expected to be dangerous as well (Al- Amin and Leal Filho, 2014). Recent projections of climate change and global warming recognize the importance of environmental quality and sustainable economic development, which has prompted efforts to establish a balance between environmental quality and economic development.

Global warming refers to the observed century-scale rise in the average temperature of the earth's climate system and its related effects. In recent years, the impact of global warming has drawn more and more global attention (IPPC, 2014). Increasing concentrations of greenhouse gases were causing most of the global warming. In the IPCC's recently released fifth assessment synthesis report, it once again stressed the following:

Currently, measures should be taken to encourage significant emission reductions over the next several decades to achieve the temperature target at the end of the 21st century, which limits the temperature rise to less than 2°C relative to preindustrial levels (Pachauri et al., 2014). To deal with the impacts of greenhouse gases emissions, especially carbon dioxide, some countries have introduced an efficient economic measure—a carbon tax—in order to save energy and reduce carbon dioxide emissions (Lin and Li, 2011) There is a growing consensus among policy-makers – that has long been accepted among economists – that putting a price on GHG pollution is the most effective means of reducing our carbon footprint (see for example, Stern,2007; Krupnick et al.,2010; OECD, 2011; Aldy and Stavins, 2012; Adopting this mechanism as a policy is expected to be an effective tool reducing the GHG emissions due to fossil fuels (Kaygusuz, 2009; Baranzini et al., 2000). Carbon-tax is an excise duty tax which is regulated according to the carbon content of fossil fuels (Baranzini et al., 2000; Zhang and Baranzini, 2004). The Netherlands, Denmark, and Sweden have been collecting carbon taxes for more than 10 years. China has also listed such a scheme in its national development program and would begin to collect the carbon tax as early as the13th five-year plan period (2016–2020) (Liu et al., 2015). A carbon tax has been taken as a cost-effective scheme to reduce GHG emissions in some countries. As a typical example, British Columbia (B.C.) implemented the carbon tax on July 1, 2008, at a rate of $10 per ton of CO_2. In July 2014, the B.C. carbon tax was increased to $25 per ton of CO_2 (Carbon Tax Center, 2015).

Table 2.8
The list of countries along with the carbon tax rate are discussed in detailed.

Country	Year Adopted	Overview Coverage	Tax Rate
Chile	2014	Chile’s carbon tax is part of legislation enacted in 2014. The country is to start with measuring of carbon dioxide emissions from thermal power plants in 2017 and begins the tax on CO2 emissions from the power sector in 2018.	USD5 per tCO2e (2018)

Costa Rica	1997	Costa Rica enacted a tax on carbon pollution, set at 3.5 percent of the market value of fossil fuels. The revenue generated by the tax goes toward the Payment for Environmental Services (PSA) program, which offers incentives to property owners to practice sustainable development and forest conservation.	3.5% tax on hydrocarbon fossil fuels
Denmark	1992	The Danish carbon tax covers all consumption of fossil fuels (natural gas, oil, and coal), with partial exemption and refund provisions for sectors covered by the EU ETS, energy-intensive processes, exported goods, fuels in refineries and many transport-related activities. Fuels used for electricity production are also not taxed by the carbon tax, but instead a tax on electricity production applies.	USD31 per tCO2e (2014)
Finland	1990	National 1990 While originally based only on carbon content, Finland's carbon tax was subsequently changed to a combination carbon/energy tax. It initially covered only heat and electricity production but was later expanded to cover transportation and heating fuels	EUR35 per tCO2e (2013)
France	2014	In December 2013 the French parliament approved a domestic consumption tax on energy products based on the content of CO2 on fossil fuel consumption not covered by the EU ETS. A carbon tax was introduced from April 1, 2014 on the use of gas, heavy fuel oil, and coal,	€14.5/tCO2 in 2015 and €22/tCO2 in 2016. transport fuels and heating oil. EUR7 per tCO2e (2014)
Iceland	2010	All importers and importers of liquid fossil fuels (gas and diesel oils, petrol, aircraft and jet fuels and fuel oils) are liable for the carbon tax regardless of whether it is for retail or personal use. A carbon tax for liquid fossil fuels is paid to the treasury, with (since 2011) the rates reflecting a carbon price equivalent to 75 percent of the current price in the EU ETS scheme	USD10 per tCO2e (2014)
Ireland	2010	The carbon tax is limited to those sectors outside of the EU ETS, as well as excluding most emissions from farming. Instead, the tax applies to petrol, heavy oil, auto-diesel, kerosene, liquid petroleum gas (LPG), fuel oil, natural gas, coal and peat, as well as aviation gasoline.	EUR 20 per tCO2e (2013)
Japan	2012	Japan's Tax for Climate Change Mitigation covers the use of all fossil fuels such as oil, natural gas, and coal, depending on their CO_2 emissions. In particular, by using a CO_2 emission factor for each sector, the tax rate per unit quantity is set so that each tax burden is equal to US$2/tCO2 (as of April 2014).	USD2 per tCO_2e (2014)
Mexico	2012	Mexico's carbon tax covers fossil fuel sales and imports by manufacturers, producers, and importers. It is not a tax on the full carbon content of fuels, but rather on the additional amount of emissions that would be generated if the fossil fuel were used instead of natural gas. Natural gas therefore is not subject to the carbon tax, though it could be in the future. The tax rate is capped at 3% of the sales price of the fuel. Companies liable to pay the tax may choose to pay the carbon tax with credits from CDM projects developed in Mexico, equivalent to the value of the credits at the time of paying the tax.	Mex$ 10 -50 per tCO_2e (2014)* * Depending on fuel type

Norway	1991	About 55 percent of Norway's CO2 emissions are effectively taxed. Emissions not covered by a carbon tax are included in the country's ETS, which was linked to the European ETS in 2008.	USD 4-69 per tCO_2e (2014)* *Depending on fossil fuel type and usage
South Africa	2016	In May 2013 the South African government published a policy paper for public comment on introduction of a carbon tax.The paper proposes a fuel input tax based on the carbon content of the fuel. It was agreed that emissions factors and/or procedures are available to quantify CO2-eq emissions with a relatively high level of accuracy for different processes and sectors.The carbon-tax will cover all direct GHG emissions from both fuel combustion as well as non energy industrial process emissions and is expected to start in January 2016.	R120/tCO_2 (Proposed tax rate for 2016)* *Tax is proposed to increase by 10% per year until end-2019
Sweden	1991	1991 Sweden's carbon tax was predominantly introduced as part of energy sector reform, with the major taxed sectors including natural gas, gasoline, coal, light and heavy fuel oil, liquefied petroleum gas (LPG), and home heating oil. Over the years carbon tax exemptions have increased for installations under the EU ETS, with the most recent increase in exemption starting from 2014 for district heating plants participating in the EU ETS.	USD168 per tCO_2e (2014)
Switzerland	2008	Switzerland's carbon tax covers all fossil fuels, unless they are used for energy. Swiss companies can be exempt from the tax if they participate in the country's ETS.	USD 68 per tCO_2e (2014)
United Kingdom	2013	The U.K.'s carbon price floor (CPF) is a tax on fossil fuels used to generate electricity. It came into effect in April 2013 and changed the previously existing Climate Change Levy (CCL) regime, by applying carbon price support (CPS) rates of CCL to gas, solid fuels, and liquefied petroleum gas (LPG) used in electricity generation.	USD15.75 per tCO_2e (2014)
Australia	2012	Australia's carbon tax also imposed climate-equivalent fees on methane, nitrous oxide and per fluorocarbons from aluminium smelting, and was collected from roughly 500 of the nation's biggest emitters These included electricity generation, stationary energy producers, mining, business transport, waste and industrial processes	\$23 per ton (metric ton), equated to \$19.60 per U.S. ton of CO_2
Newzeland	2005	The tax would have been revenue-neutral, with proceeds used to reduce other taxes (Hodgson 2005). However, a new government determined that the carbon tax would not cut emissions enough to justify the costs, and the tax was abandoned (Myer 2005). [CTC addendum: In Sept. 2007 the government unveiled a proposed emission cap-and-trade scheme intended to cover all carbon emissions.	carbon tax equivalent to \$10.67 (of U.S.)
United States	2007	the United States' first tax on carbon emissions from electricity According to the City of Boulder, the tax is costing the average household about \$1.33 per month, with households that use renewable energy receiving an offsetting discount. The city expected the tax to generate about \$1 million annually until its expiration in 2012, with the revenues used to fund Boulder's climate action plan to further reduce energy use and to comply with the Kyoto Protocol (Kelley 2006)	approximately \$7 per ton of carbon

Canada Quebec	2007	Canada’s second largest province began collecting a carbon tax on “hydrocarbons” (petroleum, natural gas and coal) on Oct. 1, 2007. Though the tax rate is quite small, the tax nevertheless made Quebec the first North American state or province to charge a carbon tax.	Petroleum tax rate just 3.1 cents (U.S.) per gallon of gasoline and 3.6 cents for diesel.
South Korea	2008	A carbon tax is imposed on emissions of greenhouse gases including carbon dioxide. The direct taxation system is now applied	tax rate of 31,828 won (25 Euros) per ton of CO_2
India	2010	India's total coal production is estimated to reach 571.87 million tons in the year ending March 2010 and is expected to import around 100 million tons. The carbon tax expects to raise 25 billion rupees ($535 million) for the financial year 2010–2011	100 rupees per ton ($1.60/t at $60.5 conversion)

Table 2.8 shows the different rates of carbon-taxes implemented by the countries in the world. Sweden has implemented the higest rate of tax on per matric ton of emission i.e. 128 US$, followed by finland and danmark with 35 and 31 euro per matric ton of carbon emission.

2.8 Technique of Risk Evaluation

In an evaluation of energy supplies that involves efficiency and sustainability, systems and operations are becoming more complex, and thus, this makes intuitive risk management decisions more difficult and less reliable. Consideration of diverse risks that may be important to various stakeholders requires a process that is holistic and systematic. A process that can help develop just the right information about risk on how and when to apply risk analysis is very much needed.

Risk-based decision making is a process that is frequently used to deal with issues or unwanted outcomes with uncertainties in management choices. This approach helps decision makers with systematic and orderly structure information in order to formulate policy options, decisions and assess various distributional impacts and implications. Due to this ability, risk assessment has emerged as one of the tools to help manage technical, financial, and even issues, such as energy supply availability in the international market.

As in many cases dealing with uncertainties, a deeper analysis of the subject usually gives the researcher a deeper appreciation of the complexity of the problem and leads to a holistic approach to risk analysis. If examined holistically, complexity can arise from two avenues. Firstly, uncertainties affect at the personal, corporate, governmental, and social scales. Uncertainties also play a part in the planning, development, design, operation, and management phases of any undertaking. Uncertainties can affect the decision-making process regardless of the number of parties involved, the constraints imposed economically or environmentally, the socio-political influences, the scientific and technological limits, and even the influences of stakeholders. Secondly, risk-based decision making is complex because it is cross-disciplinary (Haimes, 1998). One may have to immerse oneself in probability, statistics, economic issues, regulatory issues, and optimization to fully appreciate a problem using the risk assessment approach.

2.8.1 Definition of Risk

Risk can be defined in various ways, according to the application and situational context. Commonly, people refer to risk as the future harm that is affected by certain sources or action taken in their everyday life. In a more formal and academic sense, the risk is defined as a measure of probability and severity of adverse effects (Lowrance, 1976). Risk has also been defined as “the extent to which there is uncertainty about whether potentially significant and disappointing outcomes of decisions will be realized” (Sitkin & Poblo, 1992). Meanwhile, according to Zsidisin (2003), risk can be categorized into three dimensions which are outcome uncertainty, outcome expectation, and outcome potential. In general, three aspects are identified as important when analyzing the risk: the action or the sources causing the risk, the outcomes of the risk, and the impact measurement to adverse or mitigates outcomes. So, risk can be concluded to be related to the probability of future outcomes caused by certain actions or sources and the measurement of impact from these outcomes. Ballard (1992) proposed a formula for the quantification of risk which can be written as:

Risk = Frequency x Consequences.

According to Rowe (1977), risk involves two major components (a) the existence of a possible unwanted consequence or loss and (b) uncertainty about the occurrence of that consequence which can be expressed in the form of a probability of occurrence. These components are equal to the two components mentioned above by Lowrance (1976). Also, the risk is defined here as the potential for realization of unwanted, negative consequences of an event. The causative event may be a single event, a combination of events or a continuing process and the result may affect individuals, groups of people, society, and its institutions or they may affect physical and biological systems. Theoretically, risk does not occur under conditions of certainty. If a catastrophic event is known with certainty, then benefit and cost may be traded before the event to reduce the impact to an acceptable level.

2.8.2 Risk Assesment Technique and Process

Two stages of risk assessment: risk estimation and risk evaluation had been identified by Otway (1973). Risk estimation may be thought of as the identification of a decision and subsequent estimation of the magnitude of associated risks. Risk evaluation is the complex process of anticipating the societal response to risks. However a third stage, risk identification was added by Kates (1978) at the beginning of the process. This approach seems to make considerable sense for three reasons, which are:

1. Risk identification involves reduction of descriptive uncertainty.the tasks in this area can include research on the components that affect risk, screening or filtering to reduce components of interest, monitoring these components and diagnosis.
2. Risk evaluation involves reduction of measurement uncertainty by process of deduction, revelation, intuition, and extrapolation based on the previous risk identification tasks.
3. Risk estimation involves risk aversive action which can result in risk reduction or risk acceptance. In this stage, the cost-benefit analysis can be done to determine the best course of action to manage risk.

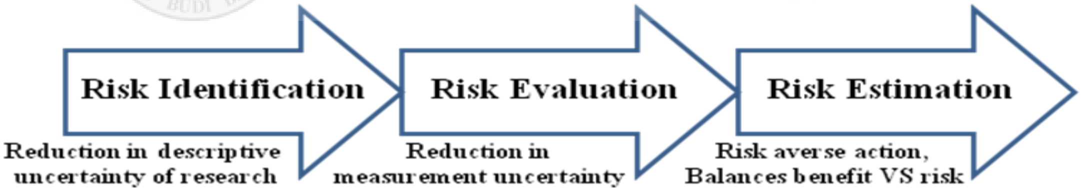


Figure 2.17
Stages of risk assessment

Based on the above, this thesis will use the three stages of risk assessment described to solve the engineering problems which are illustrated in figure 2.17.

2.8.3 Risk Evaluation Technique Compartive Studies

Electricity generation planning is associated with the affordability, environmental concerns and secure and reliable supplies of energy simultaneously considering the factors of increasing population and rising energy demand. The strategy of future investment and feasibility of optimal expansion is deeply depends upon the secure and consistent supplies of energy to electricity generation sector. The traditional approach to electricity generation planning has been the least-cost methodology, which is based on calculating the levelised costs of electricity generation, expressed in $/MWh, for different alternative production technologies and, after comparing those costs, choosing the lowest cost options (Zhu and Fan, 2010). The LCOE costing method is not sufficient from policy prospective however it is beneficial from private investment point of view. The LCOE only gives the cost of generation based on capital investment and fuel parameters; however, it will not consider other environmental and social acceptance parameters. From the policy prospective it is necessary to consider the catastrophic environmental impact of power generation and security of supplies. Beside conventional generation technologies there are different alternatives available for power generation e.g. (Solar, wind and biomass). Considering the issue of depleting reservoirs, environmental concern and risk associated with the fossil fuels, academicians and policy-makers continuously engage new methodologies from the optimization of power generation with multiple prospective (Awerbuch and Berger, 2003).

Considering the impact of two factors (cost and Risk) several authors have proposed the use modern portfolio theory (MPT) which has its roots in optimization of financial assets portfolios in 1952 by Markowitz (Awerbuch and Berger, 2003; Damodaran, 2001). Number of studies has tested the potential this approach in selection of optimum portfolios in terms of cost and risk especially considering the renewable technologies (Amesano et al., 2012; Losekaan at al., 2013). The one major drawback of using Modern portfolio theory is that it quantifies the cost and risk in different frame of reference. The cost is measured in monetary units however risk is measured in terms of variance. Therefore to evaluate the total exposure of portfolio is not possible. Considering the multiple dimensions of energy security on a single platform is one of the major contributions of this study.

2.9 Summary of Literatures Review

This chapter provided a comprehensive review of previous studies related to the investigation topic- sustainable resource availability by optimizing economic and environmental factors in Malaysia's power generation mix, and methodologies used for assessment. The main purpose of reviewing the literature was to find the background information on the topic and find the gaps in previous researches.

This study fills the research gap by following aspects:

1. This study analyse the global electricity generation trend and the crisis faced by the modern power generation industry.

2. The study discussed in detail the concept of energy security from multi prospective approach and compares the past and modern security definitions, trends and attributes.

3. The study intends to evaluate the total cost exposure in terms of affordability, acceptability and availability of secure supplies to electricity generation industry in this regard it discusses the challenges .and importance of diversification in generation portfolio.

4. Study discusses the power generation mix, potential of available resources and the policies and action plan for future power generation expansion in Malaysia.

5. Finally, study discusses the analysis method, approaches and technique to quantify the optimum combination of technologies for electricity generation portfolio.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

A methodology is a description of the techniques used to achieve the objectives of the study. The methodology is also referred to as a sequential process or a framework used to attain the desired objectives. The research study carried out here is based on Design-Science (DS) research. According to March and Smith (1995), Design-Science is an application of existing knowledge to build an innovative, practical, and valuable artefact (e.g. framework, model, procedure, algorithm, etc.) that assists in carrying out some specific tasks. The ultimate objective of this research is proposing the optimum generation mix for electricity generation in Malaysia. To achieve the objectives, this chapter introduced different models, methods, and techniques to evaluate the optimum combination of generation technologies. This chapter therefore also describes how the work in this research project fits within Design-Science and how Design-Science Research Methodology (DSRM) is used to accomplish our goals.

The first section of the chapter represents the research framework which illustrates the step by step evaluation process of this research. In the second section, the designed framework is integrated with research design under the design science research methodological framework. Following the framework, data collection method and technique will be discuss. Finally, analysis techniques will be discuss in details which involves the formulation of the equation, data evaluation and diagnosis tools and selection of appropriate methods for optimization.

3.2 Research Framework

The rising global demand for energy and political instability has raised the issue of energy security more than ever before. Depleting reservoirs, environmental degradation, fluctuating oil prices and unforeseen political events have encouraged policymakers intended to review action plans for sustainable energy generation with the help of policy modification and optimum utilization of available resources. This study will incorporate three key integrated energy dimensions in terms of cost to evaluate the total exposure. Affordability, acceptability, and availability of adequate supply are the factors to evaluate for sustainable economic growth, potential environmental harm, and social stability. Energy experts and policymakers around the globe are looking for the effective tool to measure the impact of supply disruption in the energy generation process. High level of security incurred an extra cost (National Economic Research Associates (NERA), 2002); however, opportunity loss due to supply disruption has never been evaluated regarding the monetary unit.

A holistic approach is adopted in this study to assess the power generation portfolio of Malaysia. This approach is also known as sustainability approach (Bassi, 2009). The study incorporates the interrelation between economic, environmental and technological aspects of each technology in the power generation process. Besides the traditional approach of quantifying power generation cost, this study encompasses other cost parameters which indirectly affect the cost of generation in the form of carbon-tax penalty and the excessive cost of secure and reliable power generation resources.

In this regard, 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 3.1, and detailed explanation is shown in figure 3.2. 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.

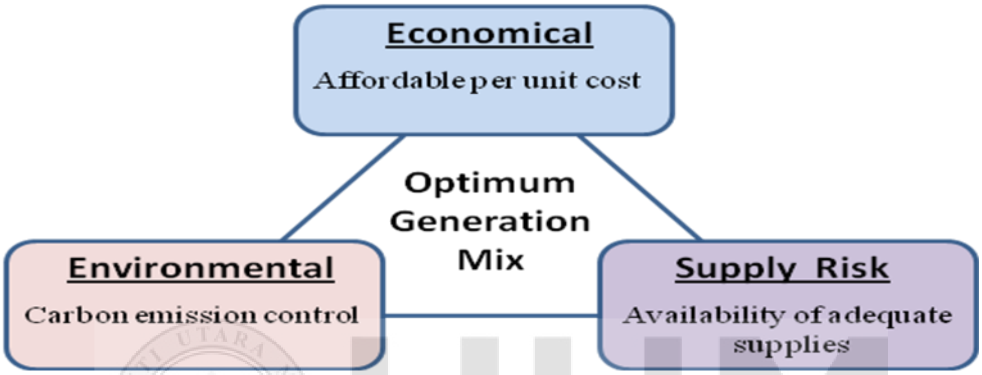


Figure 3.1
Integrated energy security dimensions contribute to the optimum generation mix

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 3.2 shows the step by step evaluation process and estimation methods of this study.

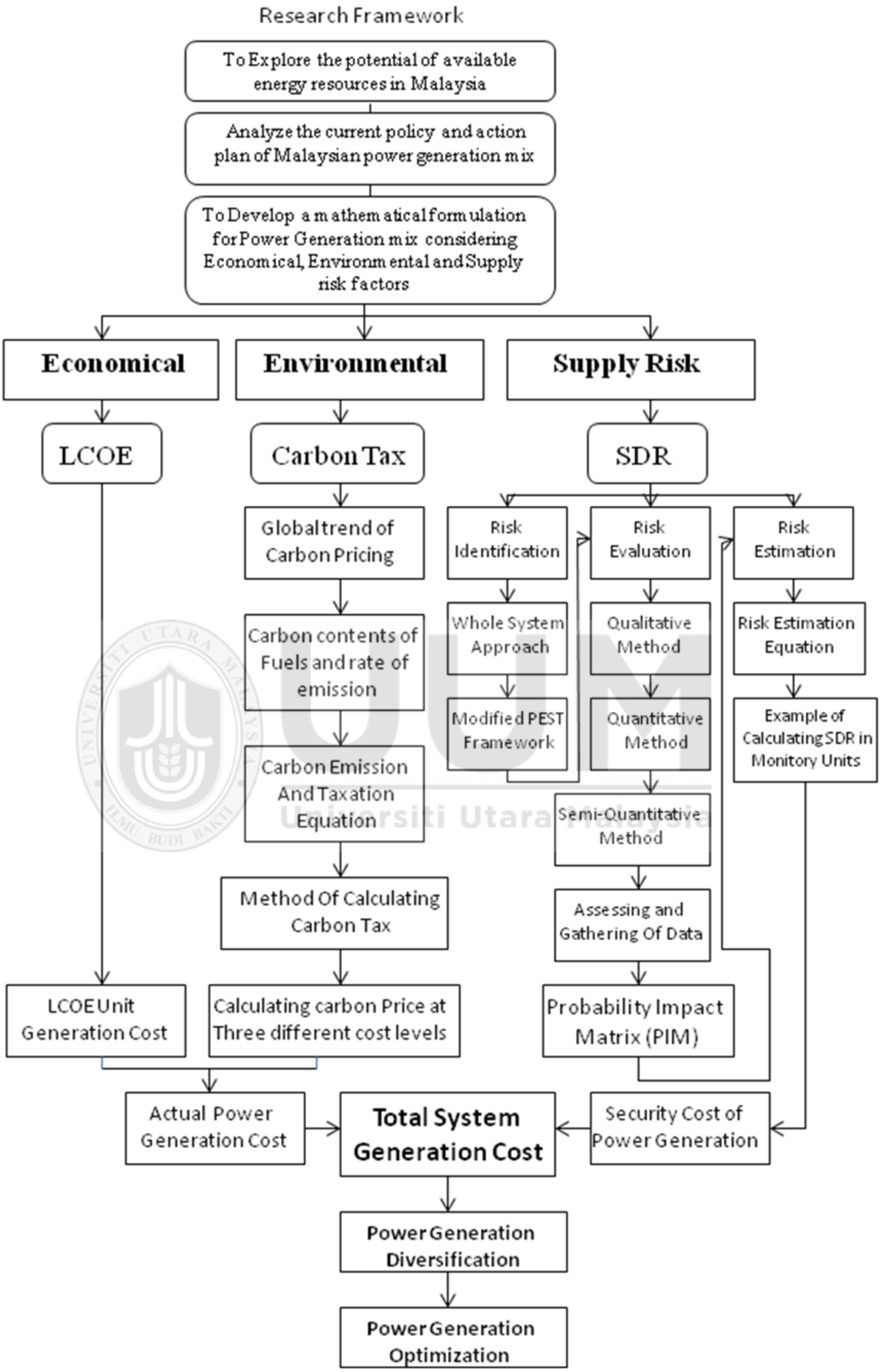


Figure 3.2

Research framework

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 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.

The study initiates with the evaluation of potential resources of electricity generation in Malaysia followed by the 11th Malaysian energy action plan considering five fuel policy for 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 will be 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 involves parameters of capital cost, fixed and variable cost, operation and maintenance cost, fuel cost, 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 generation process. In this 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 quantify the total cost of electricity generation the equation is formulated consisting of LCOE for the calculation of economic cost, carbon-tax as a parameter of environmental cost and the excessive cost of security as a compensator of occurrence astonishing events in the power generation process also called the excessive cost of security.

To achieve the desired objectives an equation is formulated for the quantification of minimum total exposure. The Malaysian power generation mix will be considered as the case study. Initially, this methodology will implement five fuels, i.e. coal, gas, hydropower, biomass, and solar and maybe extend to other forms of technologies. 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

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

3.3 Research Design

The Research is defined as the systematic investigation of materials and sources in order to establish facts and reach new conclusions (Soanes and Stevenson, 2008). All activities within a research project as well as its scope are defined by the research design (Morrow and Brown 1994; Yin 2003). The research design is the sequence of steps within a research project that comprises the discussion of the initial research problem to the final conclusion. However, a research design is more than just a guideline of how to proceed in the course of a project. The research design is meant to ensure that the results of the investigation fit into the initial research questions. The main issues which are addressed in the context of the research design are: (1) what philosophical assumptions are appropriate to study the research questions, (2) what research methods fit to the philosophical assumptions and allow for answering the research questions, as well as (3) what research process is required to come to rigorous and relevant research results.

Design science research (DSR) approach is chosen in this research for discovering and identifying opportunities and problems relevant to the power generation industry and for directly inventing new improved conceptual means to address those problems.

3.3.1 Definition of Design Science Research

DSR is an innovative research process implemented to solve real-world problem and, with the intention to make a contribution to the theory of the discipline in which it is applied (Lukka, 2003). However, March and Smith (1995) expend the concept to the exploration of alternative solutions to solve problems and to enhance the stages of problem-solving process and serve human purposes. In addition, Saunders et al. (2009) looked at it as a tool that seeks to explore the valid knowledge specifically used to solve the problems of an organization. The main objective of DSR is to formulate new scientific concepts which support the proposed design of professionals and to focus on its knowledge orientation.

DSR is a research procedure for producing innovative construction intended to solve problems faced in the real world and, by that means, to make a contribution to the theory of the discipline in which it is applied (Lukka, 2003). In addition, March and Smith (1995) looked at it as a way that seeks to explore new solution alternatives to solve problems, to explain this exploratory process and to improve the problem-solving process and serve human purposes. Saunders et al. (2009) explained that from the design science perspective, the main purpose of academic management research is to develop valid knowledge to support organizational problem-solving in the field. A design-science is not concerned with the action itself but depends upon the information used in designing solutions followed by designed-based action

(Aken, 2004).

The first and the most important characteristic of the design science research process is that it is motivated by the problem-solving and the second unique attribute is the prospective nature of the outcome of a research program. According to Lukka (2003), the productive research approach consists of following attributes.

1. It is stressed on real-world problems and are relevant and can be solved in better way.
2. The constructive designs have an innovative approach to solve real-world problems.
3. The design must have a valid approach and can be implemented in the real time interval.
4. The design must reduce the gap between researchers and practitioners to share the empirical findings.
5. It must reflect the compatibility to prior theoretical knowledge, and
6. And the design has the ability to compliance the empirical findings back into theory.

Simon (1996), discriminate the natural science process and the design science (science of artificial) process as "*A natural science is a body of knowledge about some class of things – objects or phenomena – in the world (nature or society) that describes and explains how they behave and interact with each other. A science of the artificial, on the other hand, is a body of knowledge about artificial (man-made) objects and phenomena designed to meet certain desired goals".*

In the context of above definition, March and Smith (2005) further simplify the concept by idealizing that the information evaluated by the natural scientist provides an opportunity to design scientist to exploit in their attempts to develop technology and provides substantive tests of the claims of natural science research (March and Smith, 1995). Simulation techniques, new mathematical algorithm, technical studies, information system and clinical medicine provide a few of theoretical examples of research in DSR (Lukka, 2003, Kasanen et al., 1993).

3.3.2 Research Philosophy

Prior to proceeding with this section, it is important to understand the difference between two confusing terminologies of "Research Methodology" and "Research Approach" (Also known as research paradigm or perspective of research i.e. the research philosophy adopted). Liavari et al. (1998) define this as a well-defined sequence of elementary operations, which permits the achievement of certain outcomes if executed correctly" whereas the approach is a set of "fundamental concepts and principles" of research. The author argued that the approach is the set of instructions that may serve as the template during the whole research process. Following an object-oriented analogy, an approach is a class of methodologies and a methodology is a concrete instance of such a class. It is not possible to develop any system without bringing to the development task a set of implicit and explicit assumptions (Hirschheim, Klein, & Lytinen, 1995).

Design science is fundamentally a problem-solving paradigm in information science research. This brings together two important components: a design process and evaluation of design elements (Collins, Joseph, & Bielaczyc, 2004). A design process mainly focuses on a sequence of activities that constructs an innovative product (the design artifact). The evaluation of the design artifact then offers feedback information which assists in improving both the quality of the product and the design process (Hevner, March, Park, & Ram, 2004). This build-and-evaluate loop is iterated a number of times until the final design artifact is completed (Markus, Majchrzak, & Gasser, 2002). The research described in this thesis falls under the category of design science. In this particular Design-Science research within the IS domain, these approaches go from ontological to epistemological positions as well as to an axiological stance.

Design science focuses on the development of artifacts to solve the problem or to study a particular problem. It is at the interface of social and technological aspects. Because of the focus on the power generation system which involves economic and social factors, this research focuses on the development of an optimum system which involves social factors (in terms of environmental degradation) economical factors (in terms of affordability) and also the technological advancement for smooth and efficient power generation process. In this research, the approach is developed to integrate the socioeconomic-technological challenge and primarily adopt socio-technologist/ develop-mentalist stance. With respect to the basic belief phelospical prospective can be catagarised into three main facrors, ontology,epistemology and axiology. Thesse three factors can further classified into two major phelospical approaches, positivist and interpretive. In comparison the DSR methodology adopt socio-technologistic stance. Comparison of phelospical assumtions is illustrated in table 3.1.

Table 3.1
Philosophical assumptions of three research perspective

Basic Belief	Positivist	Interpretive	DSR
Ontology	A single reality, Knowledge, Probabilistic	Multiple realities, socially constructed	Multiple, contextually situated alternative world state socio-technically enabled
Epistemology	Objective; dispassionate, Detached and Observer of truth	Subjective (i.e., values and knowledge emerge from the researcher-participant and interaction	Knowing through making: objectively constrained construction with a context Iterative circumscription reveals the meaning
Axiology: what is value	Truth: Universal and beautiful; prediction	Understanding: situated and description	Control; creation; progress (i.e., improvement); understanding

Source: Vaishnavi and Kuechler, (2007)

3.3.3 Research Methodology

Before Proceeding with this section, it is essential to discriminate between two interrelated terminologies; method and methodology. There is a huge possibility to use these terms interchangeably in academic literature, indeed to use one when the other is more appropriate. Blailie (1993) defines that the research methods are the procedures or techniques used in collecting and analyzing of data specifically associated with a hypothesis or research questions. For example structured interviews, formal and informal group communication and free-flowing discussions along with questionnaires, fieldwork, and observation of human behavior and activities, However, the methodology is the technique of analysis of proceeding research. It includes the adaptation of theories that support the central research idea. Thus, it is an investigation plan which moves from underlying philosophical assumptions to research design (i.e. research process) as well as data collection. It is obvious that scope of the methodology is far much broader than the methods.

Therefore an umbrella of research methodology covers the combination of tools, techniques, and methods that are essential to research within a research domain (Nunamaker et al., 1990-91).

A common taxonomy of research methods involves division into quantitative research and qualitative research. Sometimes this classification is confused with the debate afore-addressed, i.e. with the discussion of the underlying epistemology of research (Guba& Lincoln, 1994). Moreover, according to Myers and Avison (2002), the word ‘qualitative’ is not a synonym for ‘interpretative’. These categories are in fact orthogonal to each other. A new category of research method, formally suggested by Gregg et al. (2001) and Purao (2002) is the developmental/design research method (DSR). Vaishnavi and Kuechler, (2004, 2011) proposed the design science research framework which consist of five steps of evaluation process. The first step is the awareness of problem which deals with the explaination of objectives. The second step proposed the framework and new suggestion to deal with the exsisting problems. The third step develops the artifacts in the form of mathematical model or expression for analysis. After seting the boundries in terms of srtifacts an appropriate method of analysis will proposed for the evaluation of desired objectives. And finally the conclusion is presented with new solution of exsisting problem.

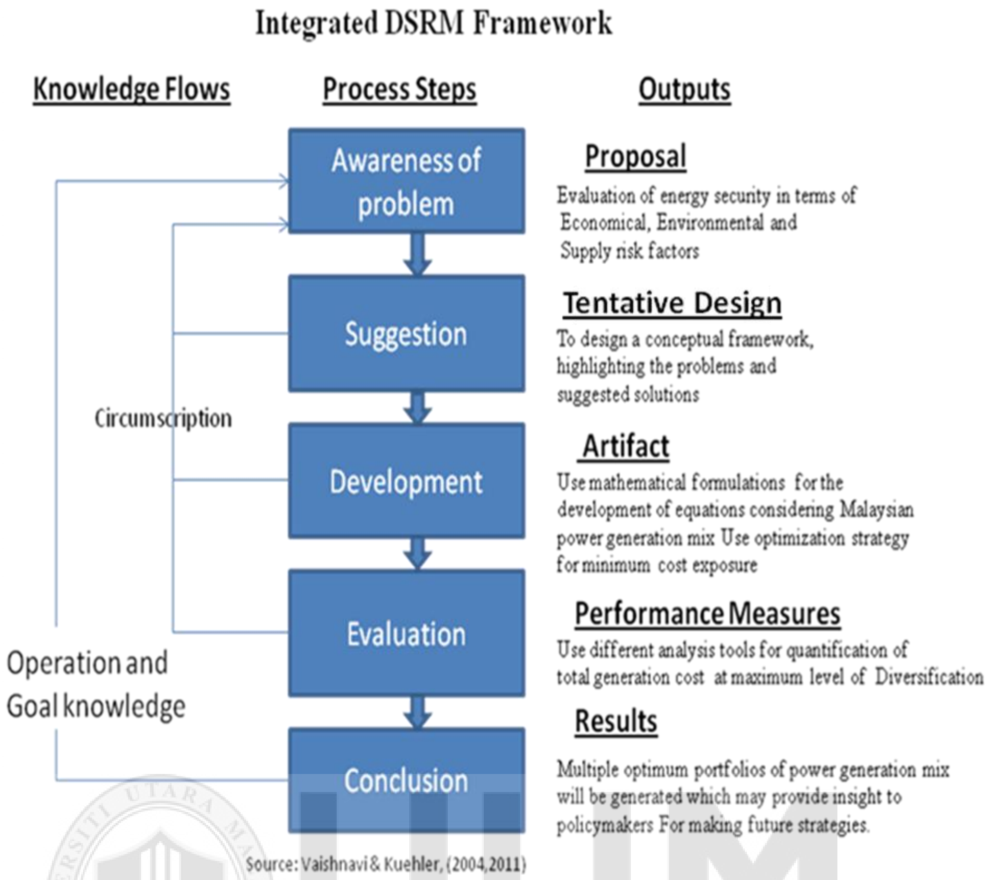


Figure 3.3
Integrated design science research process and framework
Source: Vaishnavi and Kuechler, (2004; 2011)

3.4 Data Collection

After defining the research problems and setting up the desired objectives, the next phase is to collect the relevant data. Collection of precise and accurate data is the essential component of advanced manufacturing analysis, such as studies adopting complex engineering and mathematical tools, e.g. (simulation, modeling and optimization techniques). If the relevant processing data is not accessible, the project timeliness may be affected, and the quality of results will also endure. When multiple analysis tools used a standard set of data, it can be used from a different perspective to achieve advance combinations of the result. Data collection is a specialized and lengthy process, and need appropriate planning failure to do so will lead towards the excessive time and cost. However, most simulation practitioners have argued that sometimes the collection and processing of input data occupies extremely long time, typically more than a third of entire project time (Liyanage & Perera 1998). It is therefore recommended that the data collection process should be well-planned; result oriented and focused on relevant information's that will guide to accomplish the common objectives of the study (Harrington & Tumy, 2000). The number of data that need to be gathered is strongly dependent upon the project/report objectives and credibility of the respondent.

Primary and secondary data are the two types' which falls within the scope of statistics and can be used as a part of research method. Primary data can be defined as the information collected from sources like interviews, survey or questionnaires with a particular intention on a specific subject by the researcher himself. Unlike collected primary data, data gathered from references who addressed another research question are known as secondary data. Secondary data has the advantage over primary data that it requires less time and capital to obtain. Already available data can be analyzed immediately. Hence, it is very convenient to include accessible and appropriate data and use it for new purposes. Moreover, re-analyzed secondary data can contribute to new perspectives and broader understanding of the subject. (Blumberg et al. 2011).

Historic secondary data is the primary source of data for this study. There are some reasons for using this approach as it reflects the positives of other studies within the power generation sector stated in the literature review. There are three key reasons: • Accuracy • Use of real-life data • A large pool of data historical recorded data from electricity generation companies

For this research, secondary data is obtained from public documents, official websites, brochures, official statistical reports published by generation and distribution companies like Malaysians Energy Action Plans, National Energy Ballance Reports, Tenaga Nasional Berhad (TNB), Sabah Electricity Sdn. Bhd (SESB), and Sarawak Electricity Supply Corp (SESCO), Malaysia's Energy Planning unit, Ministry of Energy Green Technology and Water, Ministry of Plantation Industries and Commodities of Malaysia, Department of Sustainable Socioeconomic Development also includes international agencies published data including International energy association IEA, world bank energy published reports, OECD, LAZADS, B.P. STATISTICS, WEC, IPCC, etc.

Designing an integrated and efficient power generation mix is a complex process and includes multiple steps of analysis. This section begins with the estimation of unit generation cost by using a levelized cost method which includes elements of fixed and variable cost, operational cost, discount rate and other factors which directly impacts on the cost of per unit generation. The next method of analysis based on the environmental harm caused due to the emission of harmful gases during the conventional generation process. However, the third method involves a risk management process to minimize the disruption of continues supplies of energy. Methods of optimization and diversification will also discuss in this section.

3.5.1 LCOE Methodology in Electricity Generation

The potential of the energy market can be assessed by conducting a techno-economical evaluation of different electricity generating technologies. Technology cannot be considered as favorable until unless it is not cost effective. As stated by Larsson (2014), the economic evaluation of renewable technologies (biomass) based power generation is hugely influenced by the cost of generating electricity. Electricity generation cost can be calculated by several methods, among which LCOE is widely used (Larsson, 2014).

Efficiency and performance of any power generation plant can be measured by different economic factors, among them priority will be given to capital investment, fixed and variable cost also called operation and maintenance cost, and fuel cost.

According to IEA and NEA, LCOE considered as a suitable method to measure per unit generation cost of different technologies over their economic lifetime (IEA, 2010; NEA, 2010). It can also be used as an efficient tool for the ranking of power generation technologies on the basis of cost-effectiveness (Branker, 2011; IEA, 2010; NEA, 2010). IRENA (2012 & 2013) also used LCOE method to calculate electricity generation cost of various renewable technologies around the globe.

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

Where

I_t	Capital Investment in the year t
M_t	Operation and maintenance cost in the year t
F_t	Fuel cost in the year t
r	Discount rate in the year t
e_t	Total energy produced by the system in the year t
N	Life of the plant

International Energy Agency (IEA), Nuclear Energy Agency (NEA), Department of Energy and Climate Change (DECC), Cost Assessments for Sustainable Energy Systems (CASES), New Energy Externalities Development for Sustainability (NEEDS) and European Sustainable Electricity (EUSUSTEL) all of these organizations used definitions of levelized costs of energy generation identical the formula as presented in Equation 2 (Larsson, 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 (Harnandez-moro and Martinez Duartz, 2013)

3.5.1.1 Capital Cost

Capital costs are fixed, one-time expenses incurred on the purchase of land, building, construction, and equipment used in the production of goods or the rendering of services. In simple words, it is the cost needed to bring a project or a plant to a commercially operable status. Whether a particular cost is a capital or not depends on many factors such as accounting, tax laws, and materiality. While considering the power projects, it can be considered as a cost which includes the cost of site preparation, construction, and manufacturing, commissioning and financing a power plant. Building a large-scale electricity generation project takes thousands of workers, huge amounts of steel and concrete, thousands of components, and several systems to provide electricity, cooling, ventilation, information, control, and communication. To compare different power generation technologies, the capital costs must be expressed regarding the generating capacity of the plant (for example as dollars per kilowatt). Capital costs may be calculated with the financing costs included or excluded. If financing costs are included, then the capital costs change in proportion to the length of time it takes to build and commission the plant and with the interest rate or mode of financing employed. It is normally termed the 'investment cost'. If the financing costs are excluded from the calculation, the capital costs are called the 'overnight cost', because it imagines that the plant appeared fully built overnight. Table 3.2 shows the expected levelized cost use for the establishment of each type of power generation plant.

Table 3.2
Technology and cost per unit comparison

Cost $/MW	**Coal**	**Gas**		**Biomass**	**Hydro Power**	**Solar**	
		IGCC	**GCC**			**PV**	**Thermal**
Capital Cost	3,000-8,400	4,000-9,800	1,000-1,300	3,000-4,000	3,500-4,000	1,500-1,750	10,000-10,300

Source: Lazard estimates, (2015); IEA, (2015)

3.5.1.2 Operation and Maintenance Cost

The operation and maintenance (O&M) cost of any plant or equipment is the cost encored on daily operations and routine maintenance activities. Each component of the system has a different lifetime, and maintenance activities were planned according to the designed life cycle. The operation and maintenance cost of any equipment is the total sum of O&M of each component in a system. In case of power generation plant, the maintenance cost of the plant is based on hourly value while when it comes to the grid, it will measure on an annual basis. The O&M cost varies widely among different power generation systems, but it considers an integral of any power plants business case. While policymaking, the every technology was examined for the routine operation and maintenance cost values and ranked which technology is cheapest to run and maintain. The electricity generation system has both fixed and variable cost factors, but the proportion of both values varies dramatically with respect to generation technology. For example, in thermal power generation plant, the one-time fixed the cost of installation is lower than the nuclear reactor, but the variable fuel cost is higher and also unstable. Even with the current low cost of natural gas, fuel costs for generating electricity via natural gas and coal are higher than for nuclear. On the other hand, the natural gas cost is little higher than coal while ignoring the environmental concerns.

Hydropower generation system is similar to nuclear having higher fixed cost values than other generating technologies, but once it becomes operational requires less maintenance and last much longer approximately 50 years. Thus, it is a general perception that hydropower has no fuel cost. However, each state has a water usage fees which ultimately becomes a fuel cost for hydropower plant. Although the amount gathered in the form of fuel cost eventually included in the stated general revenue, solar and wind are the emerging power generation technologies. The power generation cost structure is primarily fixed and reflects the one-time installation/commission cost with a minimal annual maintenance allowance. However, the fuel cost for wind and solar power generation technologies is zero.

The different generation cost structure of each technology finally reflects in selling price of electricity. Whether the electricity is generated from coal, gas nuclear or renewable, the cost of operation and maintenance plays an important role in a power plant’s business case. A piece of the investment puzzle along with capital expenditure and fuel costs that must be balanced against the life-cycle profitability, output efficiency, and availability. The operation and maintenance cost are also responsible for routine preventative and corrective maintenance activities, engineering labour costs, asset and site management, maintaining health and safety issues, and a host of other routine operations. O&M costs are allocated as variable and fixed costs.

Variable operating costs are directly proportional to the number of electricity units generated usually measured on KWh and considered as incremental costs. They may be calculated in $/kWh.

Fixed operating costs are unaffected by the number of electricity units generated. It is usually measured in hours of operation per year and expressed in $/year or $/hour.

However, a perfect measure of fixed and variable cost is a complex process and not easy to compute. Several cost items have both values as a single commodity. Considering the example of a co-fired gas turbine that’s is known by the number of operating hours should be placed in a variable section of maintenance cost. The fixed cost is unaffected by the number of electricity units generated. However, the variable cost varies with the number of units generated and consumed.

- The fixed component of cost represents the one-time investment used in establishing the system.

- The variable component of cost represents the routine operation and maintenance activities and fuel cost.

O&M cost varies with respect to the technology adopted for electricity generation, and the O&M burden often plays a varying role in the basic cost analysis of different power plants. Sometimes a high maintenance cost benefits in long-term and vice versa. Here in this study, the study presents the average operational and maintenance cost of five power generation technologies following with the main objective of the study compliance with the five fuel policy of Malaysian national action plan.

The basis for this analysis is data taken from the International Energy Agency's (IEA) World Energy Investment Outlook 2014 and Lazard’s levelized cost of energy analysis 9.0., which includes raw information on average yearly O&M costs in the power industry, both currently and in the future. The IEA's future cost predictions are based on its so-called New Policies Scenario (NPS), which incorporates countries' announced policy commitments and plans in its projections. Current costs are taken from 2012 data, with projections given for 2020 and 2035.

3.5.1.3 Fuel Cost

After 1970 oil crisis fuel prices are becoming unpredictable. The major concentration of policymakers around the world is to give critical importance to fuel prices. Although it has been considered that the coal and gas are the cheapest sources to produce electricity, their fluctuated unpredictable price makes them unreliable for future dependence.

The assumptions on fuel prices are an important factor for the generation cost of some power generating technologies (e.g. Gas-fired power stations) is heavily fuel dependent. Most power generating technologies except renewable (excluding biomass-fuelled power plants) use some kind of fuel to generate electricity. IEA & NEA (2010) assume fuel prices to be constant in time. Hard coal and natural gas figures are based on average OECD import prices. For the purpose of this study fuel prices and associated supply risk has given the highest priority as they can dramatically change the whole generation of the fuel based power plant. Despite thermal energy resources, availability of renewable energy resources is also important to examine which will be discussed later in another section. Table 3.3 shows the operation and maintenance cost associated with each technology along with the fuel price.

Table 3.3
Fixed/ Variable and fuel cost

Cost $/MW	**Coal**	**Gas**		**Biomass**	**Hydro Power**	**Solar**	
		IGCC	**GCC**			**PV**	**Thermal**
Fixed O&M	40-80	62-73	6.2-5.5	95	15	10-13	80-115
Variable O&M Cost	5-8	7- 8.5	2-3.5	15	6	-	-
Fuel cost	1.96	0.6-1.4	3.45	1-2	-	-	-

Source: Lazard estimates, (2015); IEA, (2015)

3.5.1.4 Discount Rate

The value of money has historically declined with the passage of time. The purchasing power of currency has reduced today with respect to 20 years ago; this financial term is known as inflation. There are numerous economic factors that cause inflation; one of them is the perception that the money in hand today is more valuable than one to be received in future (Thumann and Dunning, 2008). In order to examine energy system advantages and costs that occur at different intervals of time, all financial components should be transformed into a common time basis; this transformation is known as discounting. This investment may be for an energy system or a potential alternative investment used as a comparison.

The variations in the value of discount rate are market specific, but in some common factors that influence in determining the discount rate are:

- Rate higher than a U.S. Treasury Bond
- The anticipated rate of inflation
- The rate of interest that balances costs and benefits (savings and/or revenues)
- The rate of financing available
- The rate of return on alternative investment with similar risk

The option of selecting the value of discount rate specifically depends upon the scenario which is being analysed. A low discount rate is considered to be more beneficial for the project with long-deferred advantages. Meanwhile, high discount rate leads towards the quick paybacks. The discount rate should reflect the opportunity cost of the capital to be invested.

3.5.1.5 Other Important Cost Parameters

Some other important factors for calculating LCOE are plant efficiency, economic lifetime, heat emission rate and plant capacity.

Plant Efficiency affects the total fuel cost. A lower electrical efficiency leads to more fuel being spent per unit of electricity produced. The total thermal efficiency of a CHP station is also very important as it affects the amount of heat being produced in the power plant. Something that needs considering when looking at the reported efficiency figures is if they are reported by using lower heating values (LHV) or by using higher heating values (HHV). HHV assumes that the water is in a liquid state (and thereby containing the energy of vaporization) after the combustion. LHV assumes water in the gaseous state. As the efficiency is calculated by taking the ratio of energy output to energy input, the reported efficiency will be higher by using LHV as the input on a LHV basis is smaller than when using HHV. The difference between the two values is not that high for coal power plants, but quite significant for gas-fired power plants (about 10% difference) (National Petroleum Council, 2007).

Economic facility life is the period during which the power plant is assumed to be useful to the owner. It can be different from the actual technical life of the power plant (the time period that it is physically possible to operate the installation).

Combined heat and power plants produce both electrical energy and heat. The costs borne by a CHP plant could, therefore, be imputed to both the produced electrical energy and to the produced heat. Singling out the cost shares is however difficult as electricity and heat are common products that are produced at the same time. The accepted methodology is, therefore, to calculate the electricity generation cost by subtracting an assumed value of the heat that is produced, which is called *heat credits*. The heat credits vary widely from study to study and the assumptions have a big impact on the generation cost result.

The capacity factor is an easy theoretical way of describing the output of a power plant by assuming that all production occurs at rated power during a certain period of time. It is defined as the ratio of the actual energy produced to its theoretical maximum. It is essential to make a good assumption regarding the capacity factor since it is directly correlated to the annual electricity production of the power station in question. Table 3.4 illustrates the values of other factors which effects on power generation process.

Table 3.4
Other key factor effects on generation cost

Technology	**Coal**	**Gas**			**Hydro**	**Solar**	
Cost $/MW		**IGCC**	**GCC**	**Biomass**		**PV**	**Thermal**
Capacity Factor	93	75	40-70	85	54	23-32	52-85
Heat Rate	8,750-12,000	8,000-11,700	6,700-6,900	14,500	9,516	-	-
Facility life	40	40	20	25	30	30	35
Facility Capacity	600	580	550	35	500	30	10
Construction time	60-66	57-64	36	36	36	12	36

Source: Lazard estimates, (2015); IEA, (2015)

3.5.1.6 Unit Cost of Power Generation Using LCOE

LCOE is the widely used method of calculation energy unit generation cost over its lifetime. The International Energy Association (IEA), LAZARD and many other different energy organizations are using this method for the calculation of per unit generation cost of different generation technologies. This method includes all the significant factors which directly contribute to generation cost. However, the limitation of this calculation is it did not include the cost of external factors which directly impacts on the generation process. Considering this fact, the additional cost of these elements should be included in the quantification of unit generation cost. The key factors, including in this formula are capital Investment or initial financial investment, Fixed and variable operation and maintenance cost, variable fuel cost, discount rate, plant operational life, capacity, efficiency and numbers of total unit generated by the plant. Considering the factors explained in chapter 3 following unit generation cost has been calculated identically using LCOE formula with the discount rate of 10% per year. These values are calculated in USD international accepted monetary unit shown in the table below.

Table 3.5
Unit power generation cost

	The range for Total System LCOE ($/KWh)		
Plant Type	**Min**	**Avg**	**Max**
Conventional Coal	108.7	118.4	138.5
Conventional Combined Cycle	86.84	100.6	112.2
Hydroelectric	69.3	83.5	107.2
Biomass	90	100.5	117.4
Solar PV/Thermal	136.1	182.5	287.9

Source: (IEA, 2015)

Table 3.5 is based on the five fuels policy of Malaysia's power generation action plan 2020. The table is formulated based on the values published by internation energy associate in 2015. It can be concluded that hydropower is the cheapest form of electricity in terms of economic factors followed by the biomass and natural gas. However, due to the rapid advancement of technology, there are different efficient and effective generation method has been introduced in last ten years. In coal generation, the most common generation technology is a conventional method. A conventional coal-fired power plant produces electricity from the burning of coal and air in a steam generator, where it heats water to produce high pressure and high-temperature steam. The steam flows through a series of steam turbines, which spin an electrical generator to produce electricity. Some other methods include advanced coal and advanced coal CSS technology, which reduces the amount of carbon emission during coal burning process. The cost mentioned in above table is the average generation cost of all these three technologies. Similarly, the cost of natural gas consists of various technologies used in the natural gas-fired plant including conventional combine and advanced combine cycle power plant, conventional and advanced combustion turbine and advanced gas carbon captured (GCC) plant technologies. Figure 3.4 shows the unit price compasrison of five different types of power generation plantsin graphical form.

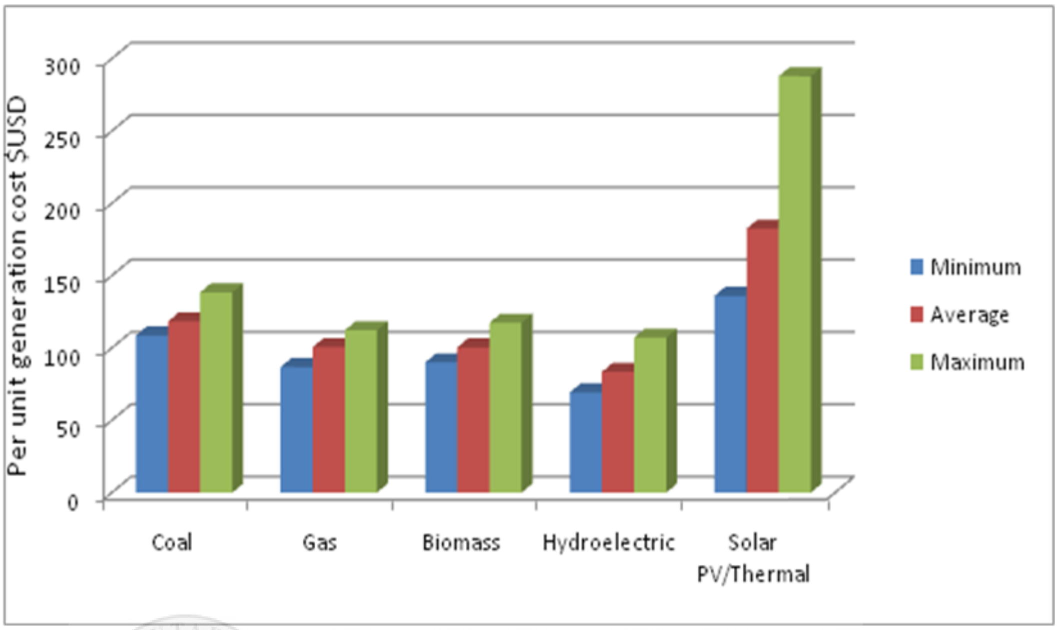


Figure 3.4
Unit power generation cost comparison

3.5.2 Carbon Tax

As defined in section 2.7 the numerous fossil-fired power plants that operate today make the industry one of the largest human-made carbon dioxide emitters. To deal with the impacts of green house gases emissions - mainly carbon dioxide - some countries have introduced an efficient economic measure—a carbon tax—in order to save energy and reduce carbon dioxide emissions (Lin and Li, 2011) There is a growing consensus among policy-makers – that has long been accepted among economists – that putting a price on GHG pollution is the most effective means of reducing our carbon footprint (see for example, Stern, 2007; Krupnick et al., 2010; OECD, 2011; Aldy and Stavins, 2012; Mankiw, 2013; IMF, 2014; Parryetal.,2014).

3.5.2.1 Global Trend of Carbon Pricing

Adopting this mechanism as a policy is expected to be an effective tool, reducing the GHG emissions due to fossil fuels (Kaygusuz, 2009; Baranzini et al., 2000). The carbon tax is an excise duty tax which is regulated according to the carbon content of fossil fuels (Baranzini et al., 2000; Zhang and Baranzini, 2004). The Netherlands, Denmark, and Sweden have been collecting carbon taxes for more than ten years. China has also listed such a scheme in its national development program and would begin to collect the carbon tax as early as the 13th five-year plan period (2016–2020) (Liu et al., 2015). A carbon tax has been taken as a cost-effective scheme to reduce GHG emissions in some countries. As a typical example, British Columbia (B.C.) implemented the carbon tax on July 1, 2008, at a rate of $10 per metric ton of CO_2. In July 2014, the B.C. carbon tax was increased to $25 per metric ton of CO_2 (Carbon Tax Center, 2015).

Recently in Europe, two of the coal-fired plant has been shut down due to the carbon taxation. The latest blow is the closure of Britain’s biggest power station, at Ferrybridge in West Yorkshire, shuts down seven years earlier than its expected time. The plant can generate 2,000 MW of electricity and half of the plant stopped operating in 2014 because of not been updated to meet strict new European Union emission rate. British carbon prices is among the highest in the developed countries. Today the price of power station across the EU is just 5.30 pounds per tons of carbon dioxide emitted, but British coal plant pays 23.38 pounds per tons emitted (Tony, 2015).Similarly, in order to meet the green goal Scotland power plant of 2,400 MW capacity was shut down after 50 years of successful operation (Andrew, 2015). Excluding Japan, the China, India and the rest of the Asian countries are not paying carbon emission taxes. Malaysia is planning to become a developed country by 2020, and it is a huge concern of policymakers to bring sustainability in the electric sector. Recently in Associate Professor DR. Budy Resosudarms of Australian National University (ANU) said that Malaysia and Indonesia are heavily dependent upon the thermal resources for electricity generation. The study conducted by him proposed to implement a carbon tax on heavy industries, i.e. start from the minimal amount of $10 per ton of carbon emission (Saiful, 2014).

It was mentioned in 2011, TNB and IPP generated 45,160.000 KWh of electricity from their combined 7,000 MW of coal power station and emitted 40.6 million tons of carbon dioxide in the process (Assuming that every MWh emits 0.9 tons of CO_2). Imposing a carbon tax of RM 72 per ton of emission using an Australian benchmark of AUD 23/ tones, the government would collect RM 2.85 billion annually to fund renewable energy projects (Cheng, 2014). However, in 6th national energy forums hosted by the energy commission, the Ministry of Environment, Green Technology and Water raised the question for the carbon-tax in Malaysia. It is expected that the tax may be implemented after the extension of MRT line 1 extension project (Hafidz, 2015). As per the recommendation of Dr.Budy for this study the carbon tax will be considered as $ 10/ ton of carbon emission.

3.5.2.2 Carbon Emission and Taxation

Researchers and policymakers around the globe are continually reviewing their policies to reduce the carbon footprint. Most of the studies in the past focused on the transportation and industrial sector. However, particularly power generation sector does not focus in many studies, and there is no standard tool to calculate carbon emission only for power generation process. This thesis develop a simple equation to calculate the cost of carbon emission in the power generation process.

The carbon price for the generation of 1 KWh of electricity can be calculated as:

$$C_i = C_a C_b \sum n_x \qquad \textbf{(3)}$$

Where

C_i Cost of carbon released during the generation of electricity

C_a Tons of carbon released by x type of technology in KWh

C_b Price of per metric ton of carbon released.

n Number of units generated

x Type of fuel (Coal, gas, Hydropower, Biomass, Solar)

3.5.2.3 Carbon Contents of Fuel and their Rate of Emission

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 energy sources along with their inherence to release carbon are as shown in table 3.6.

Table 3.6
Different 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	80MW, parabolic trough	13
Hydroelectric	300 kW, run-of-river	13

Source: Sovacool, (2008)

3.5.2.4 Example of Calculating Carbon Tax

Let consider a coal power generation plant having a generation capacity of 10 MW with the plant capacity of 80%. The total number of unit generated per year can be calculated as.

n = Power Generation (MWh) = Installed Capacity (MW) x Plant capacity (%) x Plant Operational time in a Year.

$$n = 10 \times 1000 \times 0.8 \times 8760$$

$$\boldsymbol{n = 70{,}080{,}000 \text{ KWh}}$$

Referring to the table 3.6 Sovacool (2008) have suggested the estimated values of carbon emission released in per kilowatt of electricity generation.

$$C_a = (960+1050)/2 = 1005\ (\text{gCO}_2\text{e/KWh})\ \text{OR}\ \mathbf{1.005 \times 10^{-3}\ (TonCO_2e/KWh)}$$

$$\boldsymbol{C_b = 10\$ \text{ per metric tons}}$$

Substituting all the three values in equation 3

$$Ci = 1.005 \times 10^{-3}\ (\text{TonCO2e/KWh})(\mathbf{70{,}080{,}000}\ \text{KWh})(\$10)$$

$$\boldsymbol{C_i = 704{,}304\ \$}$$

It has concluded that 10 MW capacity of coal power generation plant will release 70,430.4 (TonCO$_2$e) which impose a penalty of a carbon tax with the amount of **704,304** $/year.

3.5.2.5 Calculating Carbon Pricing Using Three Different Cost Levels

After knowing the consequences of carbon emission in the atmosphere, many countries around the globe have already implemented a carbon tax to restrict the footprint in the future. The carbon-Tax will imply on the units of metric tons of carbon emission into the atmosphere. The taxation rate varies from 5$ to 40$ per metric tons of emission. The table 3.7 shows the five fuels with the number of units generated in MW. The carbon content of each fuel is shown in grams of carbon released in per KWh of electricity generated. The table below shows the price of a carbon tax for per Mega watt-hour of electricity generation for five different fuels at three different cost levels.

Table 3.7
Estimated per unit carbon tax at three different cost levels

SNo	Fuel Type	(gCO2e /KWh)	Unit Carbon Tax @10$ /MWh	Unit Carbon Tax @20$ /MWh	Unit Carbon Tax @30$ /MWh
1	Coal	1005	10.05	20.10	30.15
2	Gas	443	4.43	8.73	13.16
3	Hydro	13	0.13	0.26	0.39
4	biomass	41	0.41	0.82	1.23
5	solar	22	0.22	0.44	0.66

3.5.2.6 Actual Cost of Power Generation

Referring to section 3.5.1, LCOE is the widely used method to calculate the per unit cost of power generation. However, the limitation of LCOE is it does not include the cost of carbon-tax or penalty of carbon emission in power generation process. For the convenience of this study, the levelized cost of energy generation LCOE and the cost of Carbon-Tax are combining together to calculate the actual cost of power generation process. The equation can be written as:

$$\textit{Actual Cost} = \textit{LCOE} + \textit{Carbon Emission Tax} \qquad (4)$$

3.5.3 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.

3.5.3.1 Risk Identification

Identifying risks is the first and perhaps the most critical step in the risk management process. Chapman and Ward (2003) conclude that risk identification is both crucial and challenging, If there is a failure to identify any particular risk, then the other steps in the risk management cannot be implemented for that risk and resultant in the shift of a final goal. In the power generation system exposed risk associated with energy extraction, supply and generation must be identified correctly. These uncertain events may cause a loss in the production and leads to economic instability. Addressing these risks in a generation portfolio will reduce the ambiguity and provides sustainable supplies of electricity to end users.

Many methods can be used for risk identification, but in power generation system dynamic nature of energy and innovative technologies makes it complicated to identify.

3.5.3.1.1 Whole System Approach in Risk

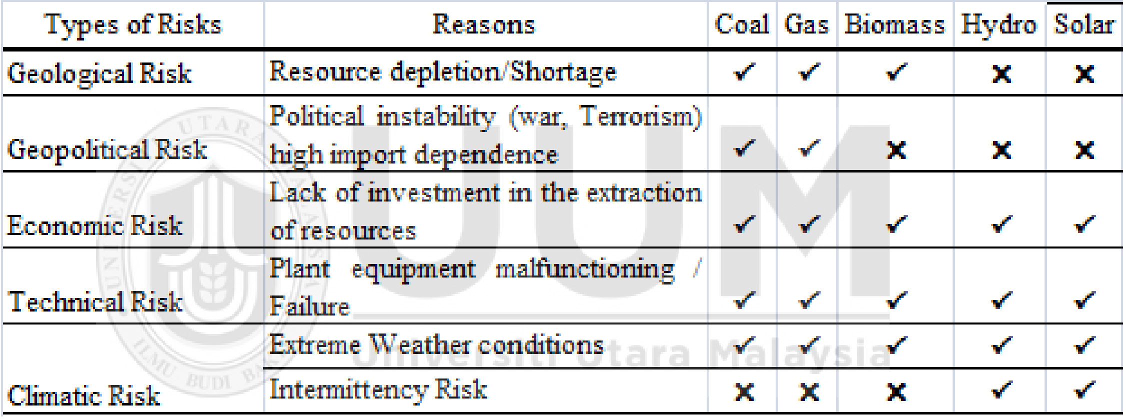
The concept of the whole system is based upon the interaction and behaviour of a system with its surrounding. A system is a combination of integrated variables which works together to achieve the desired objective (Ackoff, 1971). The ultimate objective of the whole system approach is to ensure smooth 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.

3.5.3.1.2 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 et al., 1996).

Drawing across the core Energy literature and discussion with professional and academic colleague's five indicators of energy supply disruption has been identified, and their interaction with Malaysia's five fuel energy is shown in table 3.8.

Table 3.8
Identification of Key factors influence energy supply security using modified PEST analysis



Types of Risks	Reasons	Coal	Gas	Biomass	Hydro	Solar
Geological Risk	Resource depletion/Shortage	✓	✓	✓	✗	✗
Geopolitical Risk	Political instability (war, Terrorism) high import dependence	✓	✓	✗	✗	✗
Economic Risk	Lack of investment in the extraction of resources	✓	✓	✓	✓	✓
Technical Risk	Plant equipment malfunctioning / Failure	✓	✓	✓	✓	✓
Climatic Risk	Extreme Weather conditions	✓	✓	✓	✓	✓
	Intermittency Risk	✗	✗	✗	✓	✓

It has been observed that hydrocarbons highly interact with import disruptions and political interference while on another hand, renewable energy has zero impact of these on its availability. Similarly, renewable energy is highly sensitive to extreme weather conditions and seasonal variations on other hand hydrocarbons have very low effect of seasonal toughness.

3.5.3.2 Risk Evaluation

Once risks have been identified, the next logical step in risk management is the evaluation. There are mainly three types of risk evaluation methods used in risk analysis, qualitative, semi-quantitative or quantitative (IEC/ISO, 2009). A risk evaluation will finally decide the risk consequences and provide a basis for introducing countermeasures.

3.5.3.2.1 Qualitative Approach

The qualitative analyses are used to describe the risk in words or scales. It is usually based on personal experiences, expert's opinion, and focused groups and sometimes on previous survey records. Initially, the data are gathered from interview sessions or survey conducting within the organisation and then it will use to examine the threats, weakness, and control parameters of the organisation to evaluate the real exposure of the risk. In the complex structure of modern world evaluation of risk by quantitative measures are not much effective to simulate entire possibilities. Thus the utilization of qualitative measures might help to achieve the objective more effectively. Mostly the qualitative method is preferred when the analyst do not have sufficient historical data or records to perform complex quantitative mathematical simulations to risk model (Karabacak&Sogukpinara, 2005). The qualitative analysis used the past trend and marked the possibility of occurrence of Likert-scale in the form of low, moderate and high levels without analysing the elaborate figures of organization's operational data. While one of the limitations of qualitative analysis is that it lacks the support of figures. It primarily depends upon the subjective judgment, for example, biases of analyzer's opinion or experience and cannot offer very objective decisions.

3.5.3.2.2 Quantitative Approach

The quantitative research method uses mathematical and simulation techniques for the transformation of risk information into measurable value. It supports the risk analysis result with quantitative value and standard so that the objectives result (compared to the qualitative method) is more dependable and easy to accept and understand. However, the analyzation process is very complicated and time-consuming. There are numerous modern methods and statistical tools to gather the required information to quantify the quantitative value of risks. Meanwhile, it is necessary to maintain the quality, accuracy and integrity of data used for analysis. Therefore it is quite impossible to calculate the entire process of risk assessment, but to achieve the optimum level is always desirable.

3.5.3.2.3 Semi-Quantitative Approach

Semi-quantitative risk evaluation method provides an intermediary value between the numerical evaluation of quantitative risk approach and the textual estimation of qualitative risk assessment, by quantifying risks in the form of a score. Semi-quantitative risk analysis approach is used when the objective is to optimize the allocation of available resources simultaneously minimizing the impact of risk on the system. The one of the major advantages of this approach is to provide a large scale of data assessment without using complex, expensive and time-consuming mathematical models used in the quantitative analysis (WHO, 2009). The Semi-quantitative approach of risk analysis uses numerical rating scales to characterize risks consequence and probability, and then make the overall risk assessment using simple mathematical formulas (Karabacak&Sogukpinara, 2005). In this approach researcher, can enjoys the accuracy of quantitative measures with the convenience of qualitative analysis.

Once risks are identified, rate each risk on two dimensions on a scale of low, medium, and high. Some levels of risk can vary from 3 to 10 or more in a semi-quantitative approach. The first dimension is the probability of that risk occurring.

The second dimension would be the potential for adverse impact if the risk were to become an issue. Evaluating the risk impact can be an individual effort, and best estimates using expert judgment must be employed in these instances.

3.5.3.2.4 Assessing and Gathering of Data

Expert interviews were conducted with representatives from the energy industry to identify the relevant risks that might apply to the five fuel policy of the Malaysia electricity system and then ranked for the likelihood of occurrence and severity of the impact. They all had exceptional skills and knowledge of various sorts regarding power generation and its use, e.g. electricity generating and distribution companies, design, engineering, consultants, consumer groups, civil servants, academic researchers (both energy analysts and electrical power engineers), and environmental (generally pro-renewable) campaigning groups. In that sense, they were 'expert' stakeholders. It was envisaged that this would help to provide a balanced overview of electricity sector risks from differing but informed perspectives. A questionnaire was developed to provide a risk ranking and to help guide expert interviews (Annexure). Rating risk levels were done using a 5-point 'Likert' scale. The scale measured riskiness, varying from 1 (low risk) to 5 (high risk). Experts were then asked to assess the level of risk individually for each fuel in the generation mix. However, this study is based on the five fuel policy of Malaysia energy mix where every fuel was examined to the identified risk in the portfolio. This was accomplished by asking the experts the question, 'What level of risk do [e.g. Geopolitical Issues] pose on the supplies of resources for power generation?' Experts provided a score of riskiness, using the above-described risk scale, and qualified their assessment with a rationale, which was recorded and analysed to estimate the impact on generation mix. The scoring guideline for the evaluation of potential risk is shown in table 3.9.

Table 3.9
Risk scoring criteria

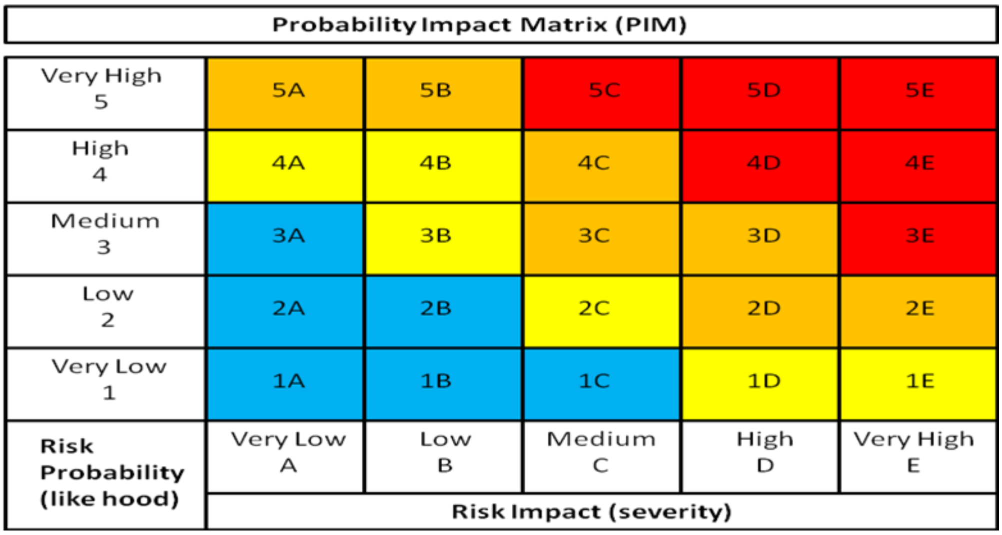
Rating the frequency of Risk		Score	Rating the Severity of Risk	Score
Very low	May or not occur in 50 years	1	Delay in supplies	A
Low	Once or twice in 50 years	2	Only local short disruption in supplies	B
Medium	Up to about once in 10 years	3	Widespread regional disruption to supplies	C
High	At least twice in 5 years	4	Long-term regional level disruption	D
Very high	Once or more than once in one year	5	Widespread national level disruption	E

3.5.3.2.4 Method of Quantifying Risk Probability and Impact Using PIM

The scores provided by the experts will be used to calculate the associated risks in using a Probability Impact matrix (PIM). Risks could then be ranked from highest to lowest, according to these scores. Likelihood and severity of threats were assumed to have equal weight – but scaling could be applied if one element was found to be more significant than the other. Here, a five-point scale was employed. Thus, the scores of 5, 4, 3, 2, and 1 were used to represent “Very High” (VH), ‘High’ (H), ‘Medium’ (M), ‘Low’ (L) and ‘Very Low’ (VL) likelihood and A,B,C,D and E for the severity of the risk, respectively. The likelihood and severity of risks were then evaluated using a five-by-five matrix illustrated schematically in table 3.10 (PIM).

Table 3.10

Risk evaluation matrix

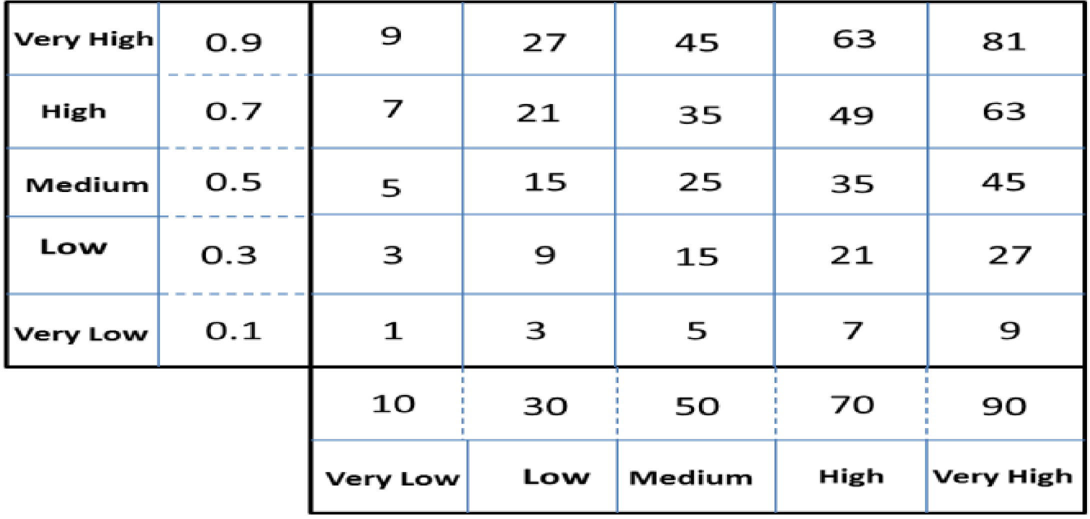


Probability Impact Matrix (PIM)					
Very High 5	5A	5B	5C	5D	5E
High 4	4A	4B	4C	4D	4E
Medium 3	3A	3B	3C	3D	3E
Low 2	2A	2B	2C	2D	2E
Very Low 1	1A	1B	1C	1D	1E
Risk Probability (like hood)	Very Low A	Low B	Medium C	High D	Very High E
	Risk Impact (severity)				

The probability of producing threats are assessed on a scale from 0.1 to 1 (0.1 – low, 0.5 - Average, 1.0 - high), and the impact on a scale from 10 to 100 (10 - low, 50 - medium, 100- high).As illustrated in Table 3.11, the risk is the combined effect of probability and impact. Probability lies in the range of 0 to 1. However, impact lies between the values of 1 to 100.

Table 3.11

Risk probability impact weightage matrix



Very High	0.9	9	27	45	63	81
High	0.7	7	21	35	49	63
Medium	0.5	5	15	25	35	45
Low	0.3	3	9	15	21	27
Very Low	0.1	1	3	5	7	9
		10	30	50	70	90
		Very Low	**Low**	**Medium**	**High**	**Very High**

An evaluated risk can be prioritized concerning the associated risk score. Immediate action is not always necessary; however, addressing the risk can be useful in long-term strategic planning. A risk assessment table is formulated with the combination of probability impact matrix (PIM) and the relative weighted average score. Four levels of assessment are shown in table 3.12 with respect to necessary action required.

Table 3.12
Risk assessment criteria index

Risk Assessment Index	Criteria	Risk Score
3E,4D,4E,5C,5D,5E	Immediate Action required	45 - 81
2D,2E,3C,3D,4B,4C,5B	Unacceptable, short term planning required	21 - 35
1D,1E,2B,2C,3B,4A,5A	Unacceptable, long term planning required	7 - 15
E	Acceptable, temporary no action required	1 - 5

3.5.3.3 Risk Estimation

Once the risk has been identified and evaluated the third and the most important step is to estimate the risk. In power generation system the estimation of risk can be evaluated by quantifying the financial loss caused due to insufficient resources or unavailability of supplies. By above-identified risk exposure to power generation system, impact and probability of occurrence of every type of risk will be evaluated by the expert's score’s using designed risk and impact matrix. Each risk will be examined individually according to its intensity. Let’s assume a five fuel generation portfolio consisting of coal, gas, hydropower, biomass and solar energy as primary fuels. Each generation type had a different generation cost and exposed to a different level of risk. The supplies of coal are more sensitive to geopolitical risk on another hand it has zero impact on solar energy, similarly solar is highly reactive to intermittency risk which is less effective on natural gas. Each fuel has a different value of perceived risk and different level of sensitivity.

3.5.3.3.1 Development of Equation for Risk Estimation in Power Generation Mix

In this study, the estimation of risk will be evaluated in percentage by multiplying the rating assigned for the likelihood (Probability) and the impact (Severity) for each fuel individually in generation portfolio. The total risk will be the weighted average sum of all five identified risk as shown in the equation below.

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

$$Risk = Probability \times Impact \tag{5}$$

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

Where

P = Risk Probability (like hood)
I = Risk Impact (severity)
X = Type of generation fuel, i.e. (Coal, Gas, Hydro, Solar, Biomass)
G = Geological Risk
L = Geopolitical Risk
E = Economical risk
T = Technological risk
C = Climatic Risk
Y = No. of risks

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 percent 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

Excessive cost of security = SDR = 60% of Actual Cost

Referring to the main equation section (1)

Total Cost = LCOE + Carbon Emission Tax + SDR

3.5.3.3.2 Example of Calculation SDR in terms of Monetary Units

Consider the same example of section 3.5.2.4, a coal power generation plant having a generation capacity of 10 MW with the plant capacity of 80%. The total number of unit generated per year can be calculated as.

n = Power Generation (MWh) = Installed Capacity (MW) x Plant capacity (%) x Plant Operational time in a Year.

n = 10 x 1000 x 0.8 x 8760

***n* = 70,080,000 KWh**

The total generation cost can be calculated as :

Total generation Cost = (number of units generated) x ***(Per Unit generation cost)*** **(8)**

In case of coal generation power plant estimated unit cost as per International energy association is 108 USD/KWh (refer to table 3.5).

Therefore

Total Generation Cost = (70,080,000 x 108)

Total Generation Cost = 7,568,640,000 $

However, the experts have predicted that the coal system is exposed to 60% of supply disruption risk per year. In that case, the system may have a probability to generate 60% lesser units. The excessive cost should be added to the overall generation cost to make the system reliable in the occurrence of any supply disruption factor.

The secured system cost can be calculated as:

Secured Power Generation Cost = (Total Generation Cost) + {(SDR (Total Generation Cost)}. **(9)**

By substituting the values we get

Secured Power Generation Cost = (7,433,856,000) + (60/100 x 7,433,856,000)

= (7,433,856,000) + (4,460,313,600)

Secured Power Generation Cost = 11,894,169,600 USD or 169.72 USD/KWh.

3.5.4 Diversity Evaluation Indices

Diversification of energy supplies, resources and transportation is a significant, and sometimes the only option of risk mitigation and protection against large losses in case of event risks. Energy diversity metrics often cited in the energy literature generally are derived from two fields: ecology and business. The two most common methods of diversity indices are Herfindahl-Hirschman Index and Shannon-Wiener Index (Hippel et al., 2011; Jansen & Seebregts, 2010; Kruyt et al., 2009). In this study, we use HHI for diversity evaluation.

3.5.4.1 Herfindahl- Hirschmann Index (HHI)

The quantification of diversification, a diversity score, in a portfolio may not be straightforward. The diversity score is defined as a measure of the degree of diversification for a given portfolio. One commonly used method of measuring the degree of diversification is the Herfindahl-Hirschman. HHI is a detailed study to estimate the portfolio concentration using aggregate data.

It has been extensively used in the power generation industry to evaluate the impact of mergers and acquisitions of regional electricity market concentration. In the perspective of fuel diversity measurement, the HHI is calculated as the sum of the squares of the market share of each resource category, as shown in the following formula:

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

Where,

Ci is the market share for the *i*th resource, expressed as a percentage of the total.

N is the number of resource categories in total.

Let consider a power generation portfolio *P* consisting of 5 different generation technologies C_i where i=1 to 5.The value of diversification across five different generation technologies can be measured using HHI,

Where;

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

If there is only one supplier the index is 1, if there are five suppliers of the same size the index is 0.2. If there is one dominant supplier with 90% of the market and only one other supplier with 10%, then the index is 0.82. A lower index means greater diversification of supply. The reciprocal (1/H) of the Herfindahl index can be viewed as the number of equivalent suppliers. Figure 3.5 shows that a system having two evenly distributed sources contains the value of diversification 0.5 and it decreases with the increase in a number of sources, at 10 equal sources the value would be 0.1.

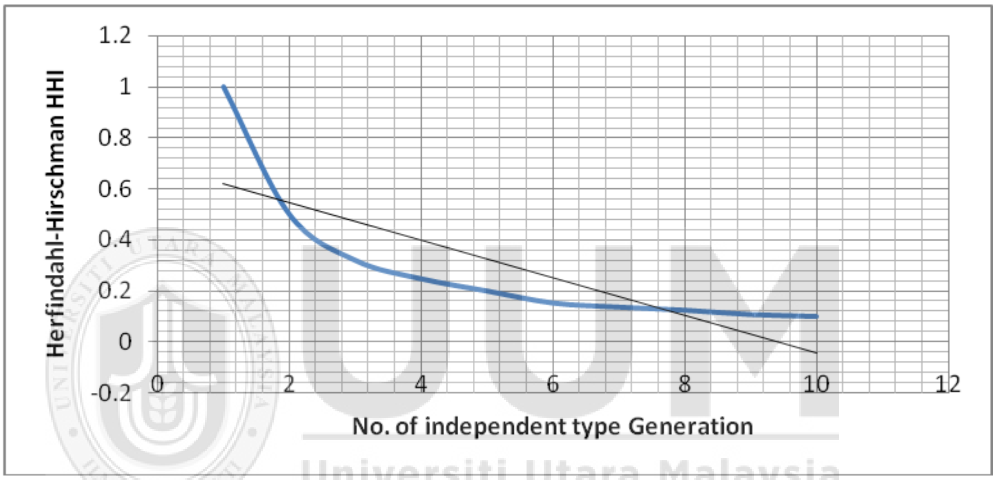


Figure 3.5
Herfindahl-Hirschmann index (HHI) evaluation

3.5.5 Optimization Using Excel Spread Sheet (SOLVER)

Due to increasing demand and limited resources, sustainability becomes an essential component of energy-related studies. Notably, in the field of energy consumption and generation, methods are selected that contributes to producing energy efficiently. To enable economic and ecological feasible projects, optimization methods are considered as a key element for planning, optimizing and forecasting sustainable system. One of the main objectives of this research is to maximize the energy generation mix in terms of economic and environmental factors considering the lowest level of supply disruption risk. To achieve the desired objective, an appropriate tool is needed to be selected.

The process of optimization can be defined as a mathematical model consists of an objective function and a set of constraints in the form of a system of equations or inequalities. The true meaning of optimization is to find the best answerer for a particular problem. Such as, a problem associated with cost will require the best cost to be as less as possible; on other hand problem associated with profit will need a maximum value as the best solution. In short, optimum is the word which can be used to express the meaning of best and the process involved to find the best solution to a problem is known as the process of optimization (Antoniou and Lu, 2007).

Optimization models are usually used in almost all the areas of decision making, including engineering design, financial optimization portfolio selection. It can be used in a focused and structured process for optimization problem formulation, design of optimal strategy, and quality control tool that involves validation, verification and post solution of activities.

An optimization model consists of following components. The first step is to define the decision variables. They are usually represented by symbols (X1, X2, X3,…, Xn). These variables are the unknown values which combine to form an optimum combination. In case of power generation portfolio X1, X2 can be represented as the no of units generated by the individual type of generation technology. The second step is to formulate the objective function in mathematical form. The objective may be related to maximize the profit or to minimize the risk. In case of power generation, the objective of this study is to minimize the total power generation cost.

The final step is to define the constraints which are expressed in the form of inequalities and apply the limitations on decision variables.

Let consider a power generation system generating 100MW of electricity consist of three generation technologies (coal, gas, and hydropower) having different unit generation cost shown in table 3.13. The objective is to find the minimum cost at certain condition. At least 10% electricity should be generated by each fuel.

Table 3.13
Example of optimization

Generation Type	No. of units Generated	Unit Generation cost	Total Cost
Coal	X1	118	118X1
Gas	X2	100	100X2
Hydro Power	X3	83	83X3
	100 MW		Z

Creating a linear programming model to represent the problem:

Decision Variables are X1, X2, and X3. Where;

X1= Number of electricity units generated by coal

X2= Number of electricity units generated by gas

X3= Number of electricity units generated by Hydropower

Objective function to minimize the total generation cost “Z”.

Objective Function

Z=Min {Total Cost of Power generation Mix}

Z = *min* {LCOE + Carbon Tax + SDR}

$$Z = Min\{\frac{\sum_{t=1}^{N}\frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{N}\frac{e_t}{(1+r)^t}} + C_a C_b \sum n_x + (P_{Gx} I_{Gx} + P_{Lx} I_{Lx} + P_{Ex} I_{Ex} + P_{Tx} I_{Tx} + P_{Cx} I_{Cx})/Y\}$$

(12)

Constraints are:

$X = X1 + X2 + X3 = 100$ MW

$X1, X2, X3 \geq X/10$

After defining the decision variable, objective function and constraints all the three values were analyzed using spread sheet data analysis tool “solver” which is an add-on feather of Microsoft excel used for linear and non-liner data optimization problem.

CHAPTER FOUR
(RESULTS AND DISCUSSION)

4.1 Introduction

Quantifying the cost of power generation is a complex process integrating financial, technical and environmental variables. It has various internal and external factors which impact directly or indirectly on generation process and results in generation loss. As discussed in literature review previous studies were focused on the evaluation of cost and risk individually, this study acuumulate the cost and risk on a single plateform i.e. (monitary units) to quantify the total exposure. However, this study believes in the optimization of the power generation mix through diversification, including three vital integrated variables of energy security which are Affordability, Acceptability, and Availability of secure supplies. The previous chapter discussed the relationship between these variables in specific, but there interaction and impact of the system is still needed to be measured.

The first section of this chapter illustrates the real cost of unit generation of five different fuels, which includes the factors of capital investment, fixed and variable operation and maintenance cost, fuel cost (for conventional energy resources) discount rate, the life of the plant and total unit generated by the plant (life cycle). The second section evaluates the cost of carbon emitted during the generation process considering different values of carbon tax per metric ton emission. The third section quantifies the risk associated with the supplies of energy and will quantify the impact of disruption on power generation process. However, it has been observed in the past that these types of disruption results in an increase of fuel prices which ultimately affect the entire generation process and long-term disruptions may also result in a generation shortfall which directly contributes in economic losses. Evaluating these factors is the core contribution of this study. After assessing security cost, a commutative cost table formulated which shows the total value as a function of actual and excessive security cost of Malaysia power generation mix.

In the fourth section, the HHI diversity index is used to evaluate the level of diversification in the current generation mix. The fifth section of this chapter deals with the optimization of portfolio considering the factor of diversification with minimum cost exposure using HHI diversity index. Diversification is the key element of system security reliance on single fuel may have volatile penalty evaluated. An integrated add-on solver tool was used for the optimization of five fuels as per Malaysia's energy policy.

4.2 Quantifying Cost of Malaysian Power Generation Mix Using LCOE

Referring to section 3.5.1 it has been acknowledged that LCOE is the widely using method of calculating per unit economic cost of power generation. Using the identical (Equation 2) table 4.1 shows the total power generation cost of Malaysia's power generation mix as per Malaysian fuel energy policy.

Table 4.1
Estimated Cost of Malaysia's Power generation mix

Sno.	Fuel Type	Units Installed Capacity (MW)	Avg. Unit Generation Cost	$/year
1	Coal	9257	118.4	9,601,212,288,000
2	Gas	12278	100.6	10,820,061,168,000
3	Hydro	2046	83.5	1,496,567,160,000
6	Biomass	62	100.5	54,583,560,000
5	Solar	145	182.5	231,811,500,000
	Total Units	**23,788 MW**		**22,204,235,676,000**

Table 4.1 is based on the five fuels policy of Malaysia's power generation action plan 2020. However, due to the rapid advancement of technology, there are different efficient and effective generation method has been introduced in last 10 years. In coal generation, the most common generation technology is a conventional method. A conventional coal-fired power plant produces electricity from the burning of coal and air in a steam generator, where it heats water to produce high pressure and high-temperature steam. The steam flows through a series of steam turbines, which spin an electrical generator to produce electricity. Some other methods include advanced coal and advanced coal CSS technology, which reduces the amount of carbon emission during the coal burning process. The cost mentioned in above table is the average generation cost of all these three technologies. Similarly, the cost of natural gas consists of various technologies used in the natural gas-fired plant, including conventional combine and advanced combined cycle power plant, conventional and advanced combustion turbine and advanced gas carbon captured (GCC) plant technologies.

From the above results, it can be concluded that hydropower is the cheapest source of generating electricity followed by biomass and natural gas.

4.3 Carbon Emission and Taxation of Malaysia's Power Generation Mix

The power generation sector is responsible to contribute 25 percent of shares in total carbon emission. Coal and gas contain the highest amount of carbon contents and release carbon dioxide during the burning process. The total estimated amount of carbon released in Malaysia's power generation process is shown in table 4.2 below.

Table 4.2

Total Amount of carbon Emission in Power Generation Process

SNo.	Fuel Type	Units Installed Capacity (MW)	(gCO2e/KWh)	Carbon Emission MT/KWh
1	Coal	9257	1005	81,496,776
2	Gas	12278	443	47,646,989
3	Hydro	2046	13	232,998
6	Biomass	62	41	22,268
5	Solar	145	22	27,944
	Total Units	**23,788 MW**		**129,426,975**

Malaysia’s power generation sector is responsible to contribute 129 million metric tonnes of carbon emission per year. Implementing carbon tax may divert the attention of policymaker to reduce the share of fossil fuel and to increase the investment in the renewable energy sector for sustainable power generation process.

Malaysia’s current generation mix consists of two conventional and three renewable resources, however, more than 85 percent of generation shared is occupied by conventional resources. The current share of renewable (solar and biomass) is less than 1 percent. According to 11th Malaysia, energy action plan at least 5 percent of electricity should be generated through solar and biomass for sustainability. On the other side increasing environmental concern increases pressure for policymakers on the immediate reduction in conventional generation resources and induced policy of carbon taxation on carbon emission. France, Denmark, Ireland, Iceland, Japan, Mexico and even South Africa have already implemented a carbon tax on carbon emission. Australia has taken 27$ USD on per metric ton of carbon emission. Table 4.3 shows the estimated amount of carbon emission during Malaysia power generation process with the measurement of impact in terms of monetary units with three different costs in the tax ranges from 10, 20 and 30 $ USD per metric ton of carbon emission.

Table 4.3
Estimated Cost of carbon Tax for Malaysia's Power generation mix.

Sno.	Fuel Type	Units Capacity (MW)	(gCO_2e/KWh)	10 $	20$	30$
1	Coal	9257	1005	814,967,760	1,629,935,520	2,444,903,280
2	Gas	12278	443	476,469,890	952,939,780	1,429,409,670
3	Hydro	2046	13	2,329,980	4,659,960	6,989,940
6	Biomass	62	41	222,680	445,360	668,040
5	Solar	145	22	279,440	558,880	838,320
	Total Units	**23,788 MW**		1,294,269,750	2,588,539,500	3,882,809,250

Figure 4.1 shows the graphical comparison of cost at three different taxation rates for per metric ton of carbon emission during the power generation process. It shows that approximately 3,882,809,250 USD per year should be paid on account of carbon emission in the power generation process at the rate of 30$ per metric ton. Although the amount seems to be very low with respect to its consequences to the environment and human health still a good initiative to restrict the investment in conventional power generation technologies. In future, this amount can be increased for the safe and sustainable environment for our future.

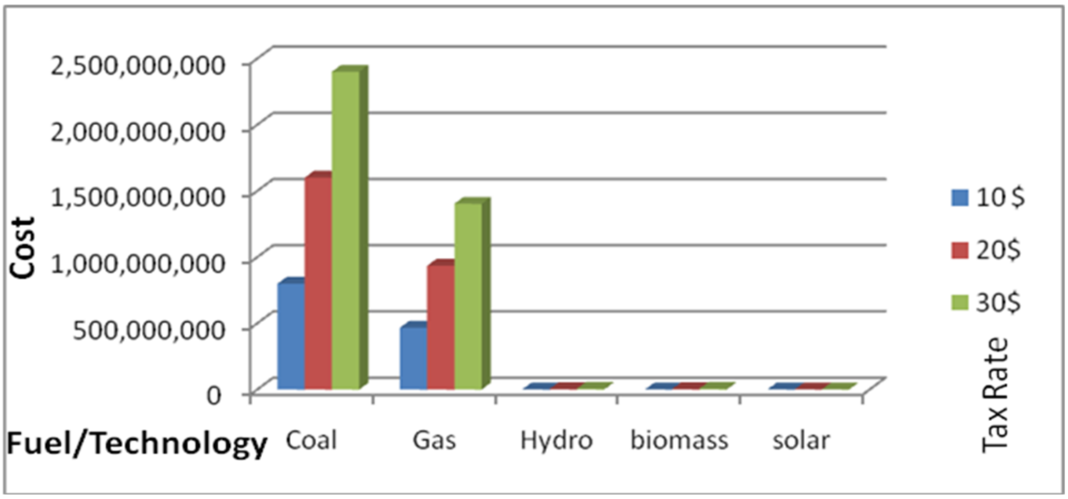


Figure 4.1
Comparison of carbon Emission in terms of Monitory Units.

4.4 Actual Cost of Power Generation

The actual cost of power generation system is highly dependent upon the initial investment, operation, and maintenance cost and variable fuel cost which can be calculated using LCOE. However, the carbon-tax is now also considered as an internal component of the measurement of generation cost in monetary unit. These two costs combine together and known as the actual cost of power generation shown in table 4.4.

Table 4.4
Estimated Actual Per unit Generation Cost

SNo.	Fuel Type	Units Capacity (MW)	(gCO$_2$e/ KWh)	Economic Cost $/MWh (EC)	Carbon Tax @ 20$ / MWh (CT)	Actual Cost AC=EC+CT ($/KWh)
1	Coal	9257	1005	118400	20.09	118,420.09
2	Gas	12278	443	100600	8.85	100,608.85
3	Hydro	2046	13	83500	0.25	83,500.25
6	Biomass	62	41	100500	0.82	100,500.82
5	Solar	145	22	182500	0.43	182,500.43

It can be concluded from the above table that the economic cost is far away higher than the environmental cost. This may be one of the reasons that investors still prefer the electricity generated through conventional methods because of easy availability of supply and lower technology cost. The above result shows that the hydropower generation is still leading with the minimum generation cost followed by biomass and natural gas. Unfortunately, the share of hydropower in Malaysia’s generation mix is less than 10% which is similar to global power generation mix.

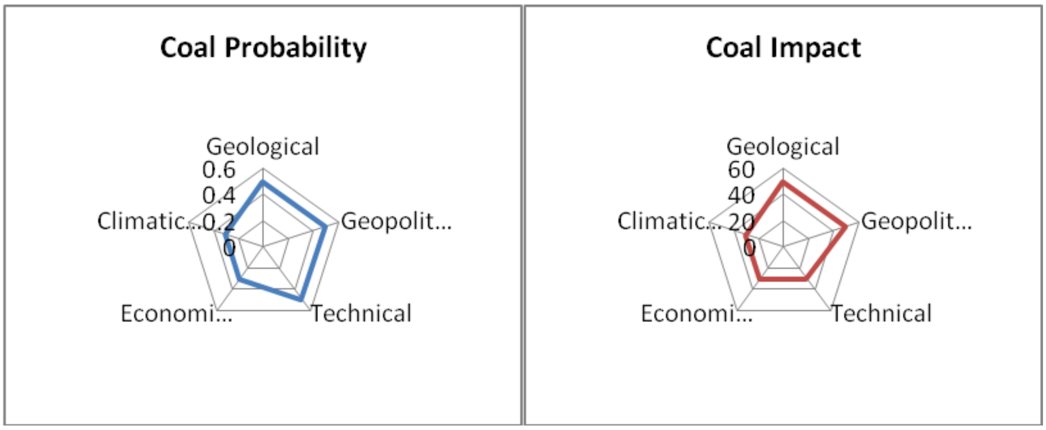
4.5 Quantification of Supply Disruption Risk

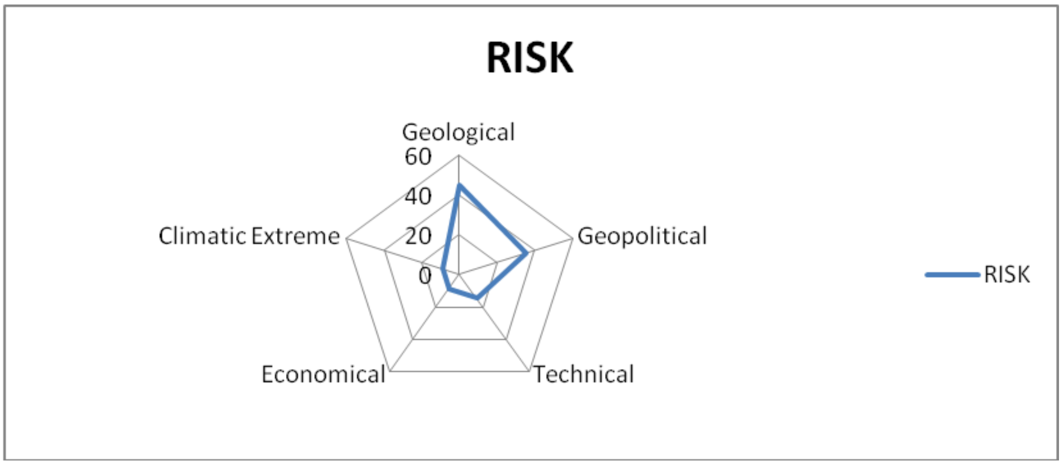
Secure and reliable supplies of resources are essential for the uninterrupted generation of electricity. In order to quantify the supply disruption risk, an expert opinion of an event in power generation taken in the form of probability of occurrence and expected impact of that event on power generation industry. Refereeing to Section 3.5.3 the experts have analyzed the energy system and based on their knowledge and experience section 4.5 shoes the scores of probability and impact of the risk in power generation system.

4.5.1 Coal

Coal supplies are highly dependent on offshore trade in most of the countries around the world. Experts have predicted that that war, terrorism, and internal political instability may create an adverse impact on coal supplies. Similarly, it has been acknowledged that the coal reservoirs are gradually depleting and will last for 107 to 164 years. Coal supplies are sensitive to geological, geopolitical, technical, economical and extreme climate conditions; however, it remains unreactive to climate intermittency. The probability of occurrence and the impact has been rated by the experts in the spider web chart shown in table 4.5.

Table 4.5
Coal Probability Impact Graph



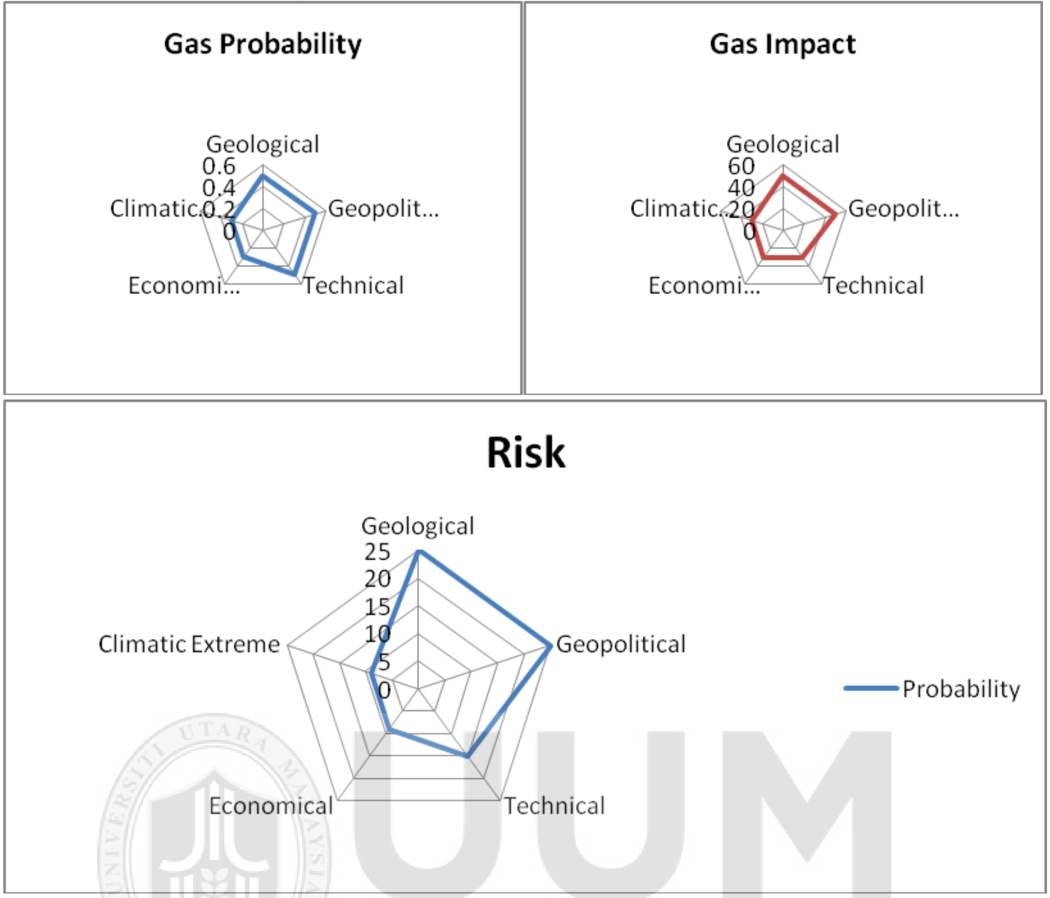


From the table 4.5, it can be observed that the coal supplies are highly sensitive to the geological event which deals with the extraction of resources. However, geopolitical events also affect adversely on the entire generation process. On the other hand, the probability of technical malfunctioning is higher, but they are temporary and create a low impact on the entire generation process. Extreme climatic conditions always remain uncontrollable and always create a moderate impact on the occurrence.

4.5.2 Natural Gas

Malaysia has considered as the one of the largest exporter of natural gas in the world that is why natural gas occupied the majority of shares in Malaysia power generation mix. However, depleting reservoirs are the major threat to maintaining the consistent supplies of gas. Government policies, extreme weather conditions, and economic stability are the key factors of secure natural gas supplies. Technical plant malfunction always remains the threat of generation systems. However, its impact is low and for a short interval of time. The rate of probability and impact is shown in table 4.6.

Table 4.6
Natural Gas Probability Impact Graph

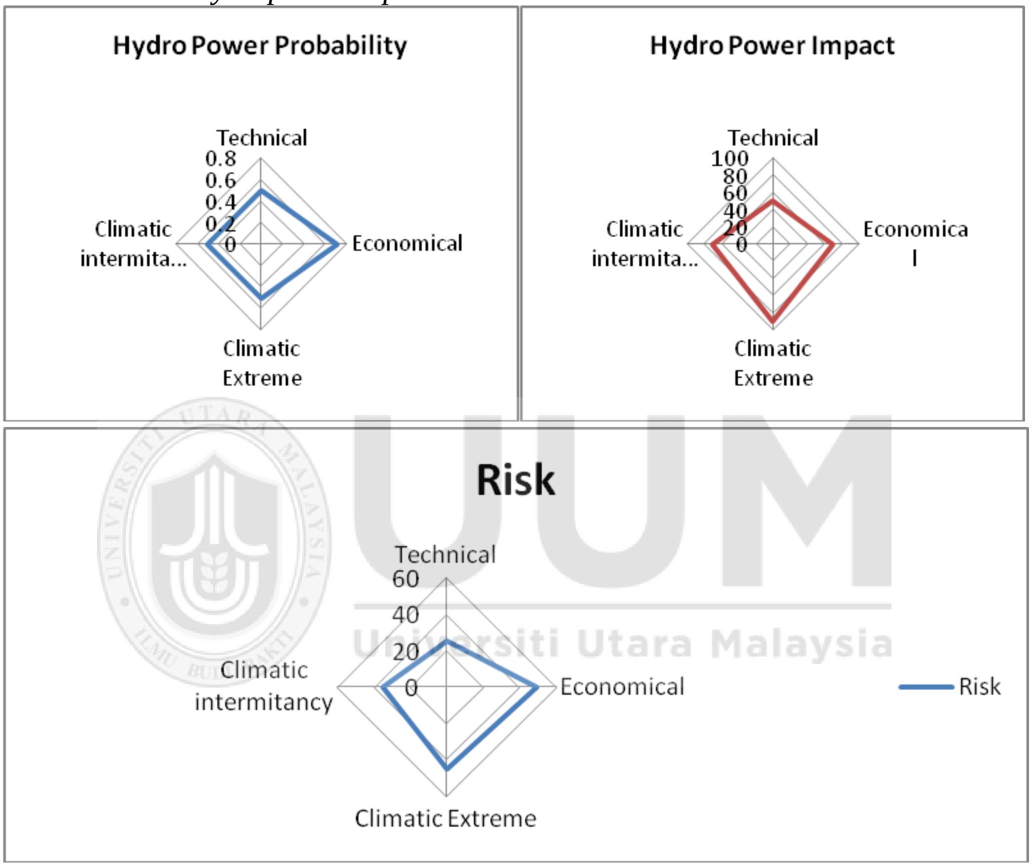


From the scores in table 4.6, it can be concluded that similarly coal the gas supplies are also highly reactive to geopolitical and geological events. However, it has a moderate probability of the low impact of the technical issue. In continuation of this, they are least impacted by extreme weather conditions and low investment economical issues.

4.5.3 HydroPower

Hydropower system is considered as the most reliable and cheapest power generation source. However, there are also some factors which directly impact the generation process. The most frequent is the seasonal variation which results in the droughts. Research has not shown any impact of depleting water reservoirs which keeps it unaffected with geopolitical barriers; however, in some countries, it has been affected by the political interference like India, Pakistan, and China. Building dams on the waterfront will impact the water supplies for other countries.

Table 4.7
Coal Probability Impact Graph

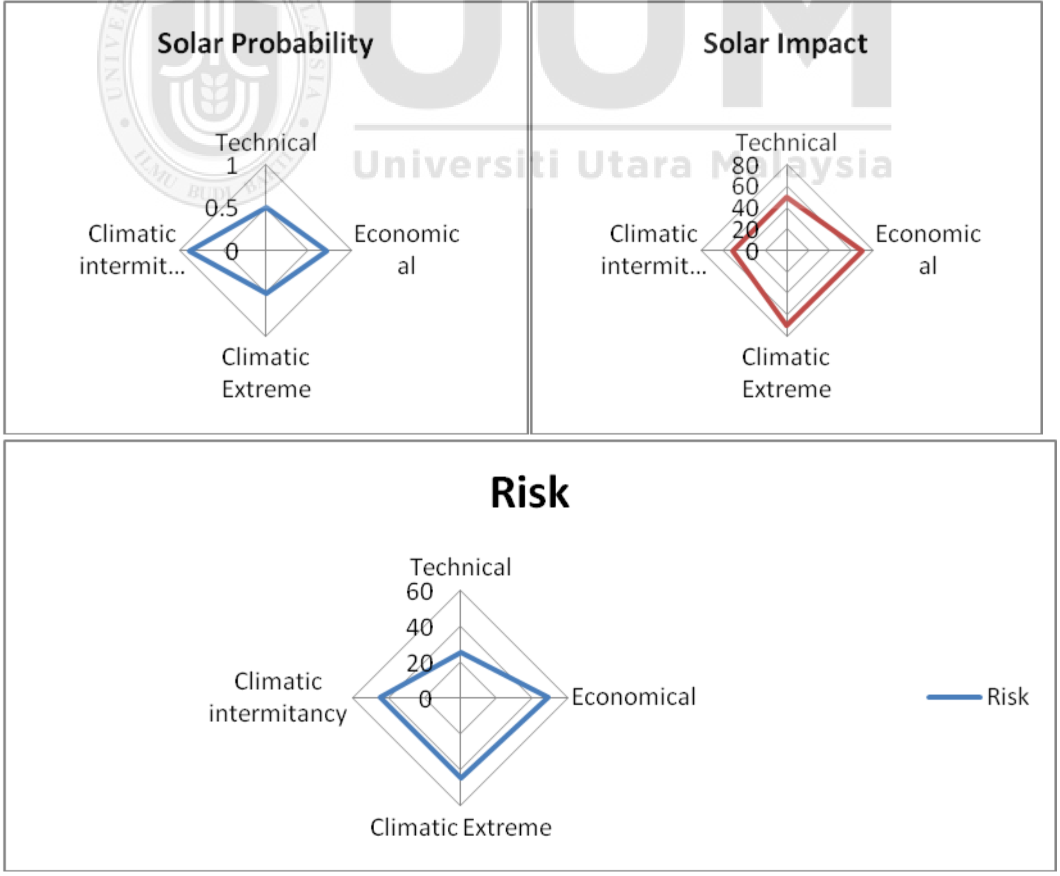


From the scores in table 4.7, it can be evaluated that extreme weather conditions create the worst impact on the hydropower generation system followed by the economical investment issue as hydro plant involve a high amount of capital investment. On the other hand, climatic intermittency and unpredictable technical issues create a moderate low impact on the generation process. The hydropower generation process remains ineffective of geological and geopolitical events.

4.5.4 Solar Power

Solar power energy is the most emerging forms of technology around the world. It is environmentally friendly, endless and free of fuel cost. However, the major barrier to adopting solar for power generation system is intermittency loss. The supply of sunlight is not consistent and unpredictable. The initial investment, technical complexity, and extreme weather conditions are also the barriers to adopting solar technology for reliable power generation. However, maximizing the share of solar with other technologies will defiantly effective for secured and reliable generation portfolio. The exposed probability of supply disruption and its possible impact is shown in table 4.8.

Table 4.8
Solar Power Probability Impact Graph

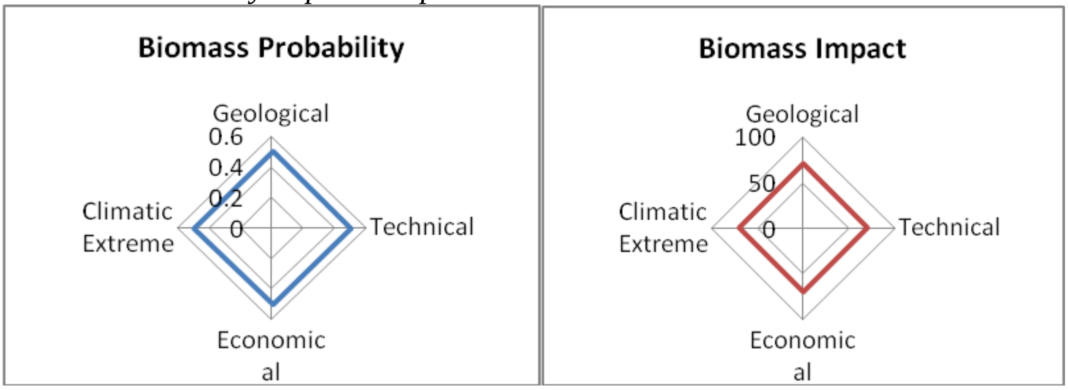


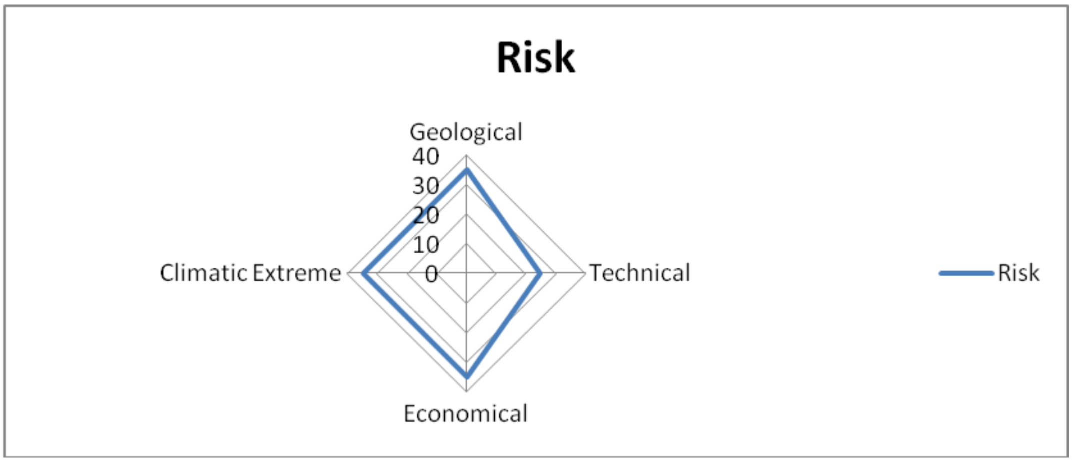
Nowaday’s solar is one of the most emerging technologies of power generation consider as the safest in terms of environmental hazards. On the other hand, solar generation is still the expensive option for electricity generation and occupied less than 3% share in the global generation mix. Solar generation of electricity is highly sensitive to climatic intermittency losses and extreme weather conditions, however, they have a moderate to low impact of technical malfunctioning and economical investment issues because of the low scale of generation.

4.5.5 Biomass

Biomass considered as the most secure forms of fuel for electricity generation, but only available for the indigenous generation system. The supplies of biomass remain unaffected by geopolitical barriers because of self-dependence. However, maintaining stock for a high level of generation is still not manageable. The use of biomass is increasing globally with great extent. It will be beneficial for reducing the stress from other generation technologies as a supporting source of power generation. Supplies barriers with their probability and impact are rated in table 4.9..

Table 4.9
Biomass Probability Impact Graph Biomass





The biomass is considered one of the lowest electricity generation resources among the five generation fuels and stands at the second position in terms of economic cost, but on the other hand, it is difficult to generate large amounts of electricity using biofuel because of the sensitivity of fuel supplies. Biofuels supplies are highly impacted by climatically conditions along with the moderate probability of technical issues related to extraction and generation.

4.6 Risk Scoring Using Risk Impact Matrix (RIM)

The given values by the experts in the form of probability and impact were substituted in table 3.11 and evaluated in the form of percentage which is presented in table 4.10.

Table 4.10
Experts Risk Scores

Fuel	Geopolitical	Geological	Technical	Economical	Climatic	
					Extreme Weather	Intermittency
Coal	35	45	15	9	9	x
Natural Gas	25	25	15	9	9	x
Hydro Power	x	x	25	49	45	35
Solar Power	x	x	25	49	45	45
Biomass	x	35	25	35	35	x

The above table shows the values of risk given by the experts on basis of their experience and expertise. Refereeing to section 3.5.3 the severity of scores can be classified into four stages, namely Extreme, High, Moderate and Low-risk levels represented by Red, Orange, Yellow and Blue colors.

It can be observed from the given score that coal is highly sensitive to geopolitical risk event and have the minor impact of economic and climatic risk factors. On the other hand hydro and biomass are highly reactive to economic factors and extreme weather conditions. Meanwhile, biomass remains unaffected by geopolitical and geological events.

4.7 Risk Quantification in Terms of Monetary Units

The ultimate objective of this tool is to quantify the risk in terms of monetary units. Table 4.10 shows the transformed values of risk in the form of a percentage. Each fuel/technology is examined for six different risk dimensions. Equation (5) is used for the quantification of the commutative value of these dimensions and represented as a product of probability and impact in the form of percentage in table 4.11.

Table 4.11
Total Supply Disruption Risk Score in Percentage

SNo.	**Fuel Type**	**Units Installed Capacity (MW)**	**Score of SDR (%)**
1	Coal	9,257	22.5
2	Gas	12,278	16.6
3	Hydro Power	2,046	38.5
6	Biomass	62	41
5	Solar Power	145	32.5
	Total Units	**23,788 MW**	

The Supply disruption risk is further processed and evaluated in the form of monetary units which is actually a proportion of entire cost shown in table 4.12.

Table 4.12
Estimated Security Cost of Malaysia's Power Generation Mix

S No.	Fuel Type	Units Installed Capacity (MW)	SDR (%)	Security Cost (SC) $
1	Coal	9,257	22.5	2,160,272,764,800
2	Gas	12,278	16.6	1,796,130,153,888
3	Hydro	2,046	38.5	576,178,356,600
4	Biomass	62	41	22,379,259,600
5	Solar	145	32.5	75,338,737,500
	Total Units	**23,788 MW**		**4,630,299,272,388**

Table 4.12 shows the total amount of security cost which should be considered during the generation of electricity from any of the above technology. The security cost is the component of unpredicted events which may occur during the generation process already identified and discussed in section 3.5.3 From the table 4.11 it can be concluded that Biomass is the riskiest technology for the generation of electricity followed by hydropower. However gas is the most secured electricity generation technology among the five fuels of Malaysia power generation portfolio.

4.8 Evaluation of Total Power generation Cost of Malaysia's Power Generation Mix

Referring to main equation section 3.1 the total cost of power generation can be calculated by summing the economic, environment and security cost. Table 4.13 shows the total electricity generation cost of Malaysia's power generation mix.

Table 4.13
Total Cost of Malaysia's Power Generation Mix

Total Cost of Malaysia's Power Generation Mix

S no	**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**

Table 4.13 shows the 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 less than 10 percent of total shares in the generation mix. On the other hand, biomass and solar are completely ignored, having a share of less than 1 percent is Malaysia's power generation mix.

Table 4.13 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 4.2.

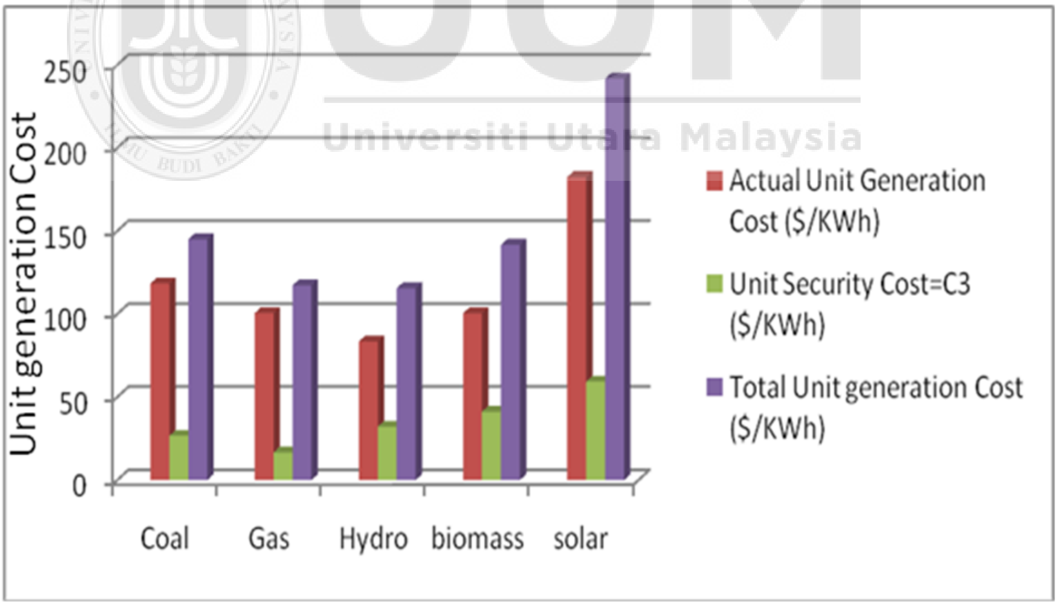


Figure 4.2
Comparison of Actual Cost, Security Cost, and Total System Cost

4.9 Quantifying Level of Diversity Using HHI

Referring to the section 3.5.4 HHI diversity index is used to measure the level of diversity in Malaysia power generation mix. As it has already been mentioned that the index values vary from 1 to 0 (minimum to maximum) the lower the value of index the higher the level of diversification and vice versa

Table 4.14
Calculating unit generation cost and level of diversity of Malaysia Power Generation Mix

S No.	Fuel	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of Generation/hour	Diversity Index
1	**Coal**	9,257,000	145.06	1,342,818,032	**0.43**
2	**Gas**	12,278,000	117.31	1,440,311,335	
3	**Hydro**	2,046,000	115.65	236,615,307	
6	**Biomass**	62,000	141.71	8,785,760	
5	**Solar**	145,000	241.81	35,062,875	
	Total Units	**23,788,000**		**3,063,593,309**	

The table 4.14 shows the total generation cost and the value of diversity index of Malaysian power generation mix. The above table is used as the base scenario and will compare to other portfolios as a reference case.

4.10 Ranking of Individual Power Generation Technologies in Terms of Economic, Environmental and Security Cost

Since the beginning, this study is focused on the optimization of the power generation mix containing five different generation technologies. In table 4.13 the total cost of generation is calculated which reflects the results shown in table 4.14. It has been concluded that Natural gas is considered as the most secured fuel for the power generation with the least level of disruption in supplies, however, the economic cost of natural gas is a bit higher then Hydropower and biomass because of the environmental factor. Hydropower is the cheapest source of generating electricity followed by biomass. Table 4.15 shows the ranking of each technology in terms of economic, environmental and security cost factors.

Table 4.15
Ranking Technologies in Terms of Lowest Cost for Malaysia's Generation Mix

S no	Fuel Type	Economic Cost	Environmental Cost	Security Cost
1	**Coal**	4th	5th	2nd
2	**Gas**	3rd	4th	1st
3	**Hydro**	1st	1st	4th
4	**Biomass**	2nd	3rd	5th
5	**Solar**	5th	2nd	3rd

4.11 Optimum Power Generation Portfolios

After quantifying the three key indicators of energy security in terms of monetary units the last objective of this study is to evaluate the optimum power generation portfolio of Malaysia's electricity generation mix. Referring to section 3.5.5 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. The study proposed eleven portfolios for optimization subsequently increasing and decreasing by the rate of 10% share of each fuel. Each and every portfolio will be analyzed by three different scenarios, i.e. minimum units of generation by each generation technology should be greater than 10%, 20%, and 30% respectively as shown in table 4.16.

Table 4.16
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.			

Furthermore, all the portfolios are examined and compared in terms of a number of units generated, the total cost of electricity generation and the level of diversification measure through HHI diversity index.

4.11.1 Optimum Power Generation Portfolio 1A

(Conventional 100%, Non-Conventional 0%)

Scenario 1: (At least 10% electricity should be generated by each technology)

Portfolio 1 is considered as the purest conventional power generation portfolio in which 100% of electricity is generated through Coal and Gas power plants. Gas is the cheapest generation technology among hydrocarbons. As per the condition in scenario at least 10 percent of the segmental share must be generated by each fuel in the segment. Table 4.17 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.17

Scenario 1 Optimum portfolio 1A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation/hr	Diversity Index
1	Coal	1,189,000	145.06	172,476,033	0.91
2	Gas	22,599,000	117.31	2,651,050,322	
3	Hydro	-	115.65	0	
6	Biomass	-	141.71	0	
5	Solar	-	241.81	0	
	Total Units	23,788,000		2,823,526,355	

Table 4.17 illustrates that the above portfolio consists of two power generation resources only. The portfolio is heavily dependent upon the natural gas, which is the cheapest form of electricity generation among hydrocarbons. Approximately 90% of electricity has been generated by gas, which is about 22,599,000 Kilo Watts of units. This portfolio is the cheapest portfolio with the highest value of diversity index, which means the higher the value of diversity index lower the level of diversification among resources and vice versa. The diversity index has been reduced with respect to the base scenario i.e (0.43 to 0.91). The system with this value of diversification is considered as the least stable system and highly reactive to unforeseen events.

4.11.2 Optimum Power Generation Portfolio 1B

(Conventional 100%, Non-Conventional 0%)

Scenario 2: (At least 20% electricity should be generated by each technology)

The second scenario of portfolio 1 is restricted to the condition of at least 20% of electricity must be generated by each fuel in the segment. However, portfolio 1 is the pure conventional portfolio and has 0% of renewable fuel. Table 4.18 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.18
Scenario 1 Optimum portfolio 1b

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation/hr	Diversity Index
1	Coal	4,758,000	145.06	690,194,253	0.68
2	Gas	19,030,000	117.31	2,232,376,991	
3	Hydro	-	115.65		
6	biomass	-	141.71		
5	solar	-	241.81		
	Total Units	**23,788,000**		**2,922,571,244**	

Table 4.18 is highly dominated by natural gas which occupies the 80 percent share of the entire generation portfolio, i.e. 19,030,000 numbers of units have been generated by the gas out of 23788000 KW of electricity. As the above portfolio is a pure conventional portfolio and has a zero contribution of renewable energy resources. On the other hand, coal generates 4758000 KW of electricity. In comparison to the base scenario, the total cost of generation has been reduced 2,922,571,244 from 3,063,593,309. In terms of diversification, the diversity index has increased (0.43 to 0.68) which reduced the stability against supply disruption in the portfolio.

4.11.3 Optimum Power Generation Portfolio 1C

(Conventional 100%, Non-Conventional 0%)

Scenario 3: (At least 30% electricity should be generated by each technology)

As the portfolio 1 is a pure conventional portfolio the condition of generation has been restricted to 70 to 30 segmental ratio. However, non-conventional fuel contributes ‘0‘percent share in the segment. In the third scenario of portfolio 1C, the percent share of coal has been increased from 20% to 30%. Table 4.19 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.19
Scenario 1 Optimum portfolio 1C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation/hr	Diversity Index
1	Coal	7,136,000	145.06	1,035,146,319	0.58
2	Gas	16,652,000	117.31	1,953,417,849	
3	Hydro	-	115.65		
6	biomass	-	141.71		
5	solar	-	241.81		
	Total Units	**23,788,000**		**2,988,564,168**	

In comparison to the base scenario (Malaysia’s current power generation mix), the above table shows that the total cost of generation has been reduced from 3,063,593,309 per day to 2,988,564,168 per day. However, in comparison with the scenario 1 and of the same portfolio the slight increase in the generation cost can be observed. The contribution of gas and coal is 70-30 which means gas generates 16,652,000 units and coal contributes 7,136,000 units of electricity in the portfolio. Finally, the diversity index has been increased as compared to the base case but more diversified in comparison to other two scenarios i.e. (0.43 to 0.58).

4.11.4 Optimum Power Generation Portfolio 2A

(Conventional 90%, Non-Conventional 10%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 2A is consisting of 90% conventional power generation resources i.e (coal and gas) and only 10% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.20 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.20
Scenario 1 Optimum portfolio 2A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	2,140,000	145.06	310,427,848	0.67
2	Gas	19,269,000	117.31	2,260,413,675	
3	Hydro	1,905,000	115.65	220,308,974	
6	biomass	236,000	141.71	33,442,570	
5	solar	236,000	241.81	57,067,852	
	Total Units	**23,788,000**		2,881,660,919	

Table 4.20 shows that the highest no of units is generated through gas following by coal. Out of 23,788,000 KW of electricity 19,269,000 KW of electricity is generated through gas, which is the 81 percent share of total electricity generated in the portfolio. However, among renewable resources hydropower is the cheapest form of electricity generation and contributed 1,905,000 KW of electricity in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 236,000 KW of electricity. In comparison to the base scenario (Malaysia’s current power generation mix), the above table shows that the total cost of generation has been reduced from 3,063,593,309 per day to 2,881,660,919 per

day. Finally, in comparison to the base scenario diversity index has increased from 0.43 to 0.67 which shows the low level of fuel diversification in the portfolio.

4.11.5 Optimum Power Generation Portfolio 2B

(Conventional 90%, Non-Conventional 10%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 2 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.21 concurrently fulfilling the applied conditions.

Table 4.21
Scenario 1 Optimum portfolio 2B

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation/hr	Diversity Index
1	Coal	4,282,000	145.06	621,145,815	0.56
2	Gas	17,126,000	117.31	2,009,021,984	
3	Hydro	1,426,000	115.65	164,913,699	
6	biomass	475,000	141.71	67,310,258	
5	solar	475,000	241.81	114,861,143	
	Total Units	**23,788,000**		2,977,252,899	

In comparison to the base scenario (Malaysia's current power generation mix), the above table shows that the total cost of generation has been reduced from 3,063,593,309 per day to 2,977,252,899 per day. The table 4.21 the highest no of electricity units has been generated by the gas, i.e. 17,126,000 which is 72 percent of total electricity generated in the portfolio. However, the coal acquires the second position with 4,282,000 units of electricity. Meanwhile, among renewable resources hydropower generated most units contributing 1,426,000 units out of 23,788,000 KW of total electricity. Solar and biomass contributed 475,000 KW of electricity. In terms of diversification, the value of diversity index has been increased in comparison to base scenario, i.e. (0.43 to 0.56) which shows less stability in the portfolio.

4.11.6 Optimum Power Generation Portfolio 2C

(Conventional 90%, Non-Conventional 10%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 2 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 2C consists of two segments conventional and nonconventional fuels contributing segmental share 90 and 10 percent respectively. Table 4.22 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.22
Scenario 1 Optimum portfolio 2C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	6,423,000	145.06	931,718,723	0.47
2	Gas	14,986,000	117.31	1,757,982,217	
3	Hydro	950,000	115.65	109,865,368	
6	biomass	713,000	141.71	101,036,239	
5	solar	713,000	241.81	172,412,621	
	Total Units	**23,788,000**		3,073,015,168	

Table 4.22 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Gas has dominated the portfolio occupying the share of 63 percent of shares. However, Coal remains in the second position with 6,423,000

units. Among the renewable resources, the share of solar and biomass has been increased from 475,000 to 713,000 KW. Meanwhile, hydropower still generates the highest units within the segment with the contribution of 950,000 units of electricity. Furthermore, the value of diversity index is higher (0.43 to 0.47) with respect to the base scenario.

4.11.7 Optimum Power Generation Portfolio 3A

(Conventional 80%, Non-Conventional 20%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 3A is consisting of 80% conventional power generation resources, i.e. (coal and gas) and only 20% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.23 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.23
Scenario 1 Optimum portfolio 3A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,902,000	145.06	275,903,629	0.56
2	Gas	17,128,000	117.31	2,009,256,600	
3	Hydro	4,208,000	115.65	486,645,755	
6	biomass	274,000	141.71	38,827,391	
5	solar	274,000	241.81	66,256,743	
	Total Units	**23,788,000**		2,876,890,118	

Table 4.23 shows that the highest no of units is generated through gas following by hydropower. Out of 23,788,000 KW of electricity 17,128,000 KW of electricity is generated through gas, which is the 72 percent share of total electricity generated in the portfolio. However, among renewable resources hydropower is the cheapest form of electricity generation and contributed 4,208,000 KW of electricity in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 274,000 KW of electricity. Finally, in comparison to the base scenario diversity index has increased from 0.43 to 0.56 which shows the low level of fuel diversification in the portfolio.

4.11.8 Optimum Power Generation Portfolio 3B

(Conventional 80%, Non-Conventional 20%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 3 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.24 concurrently fulfilling the applied conditions.

Table 4.24
Scenario 1 Optimum portfolio 3B

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	3,806,000	145.06	552,097,378	0.45
2	Gas	15,224,000	117.31	1,785,901,593	
3	Hydro	2,854,000	115.65	330,058,694	
6	biomass	951,000	141.71	134,762,221	
5	solar	951,000	241.81	229,964,098	
	Total Units	**23,788,000**		3,032,783,984	

In the above table 4.24, the highest no of electricity units has been generated by gas, i.e. 15,224,000 which is 64 percent of total electricity generated in the portfolio. However, coal acquires the second position with 3,806,000 units of electricity. Meanwhile, among renewable resources hydropower generated most units contributing 2,854,000 units out of 23,788,000 KW of total electricity. Solar and biomass contributed 951,000 KW of electricity. In terms of diversification, the value of diversity index has been increased in comparison to base scenario, i.e. (0.43 to 0.45) which shows less stability in the portfolio.

4.11.9 Optimum Power Generation Portfolio 3C

(Conventional 80%, Non-Conventional 20%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 3 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 3C consists of two segments conventional and non-conventional fuels contributing segmental share 80 and 20 percent respectively. Table 4.25 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.25
Scenario 1 Optimum portfolio 3C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	5,709,000	145.06	828,146,067	0.38
2	Gas	13,321,000	117.31	1,562,663,894	
3	Hydro	1,902,000	115.65	219,962,031	
6	biomass	1,427,000	141.71	202,214,184	
5	solar	1,427,000	241.81	345,067,054	

	Total Units	**23,788,000**		3,158,053,230

Table 4.25 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Gas has dominated the portfolio occupying the share of 56 percent of shares. However, coal remains in the second position with 5,709,000 units. Among the renewable resources, the share of solar and biomass has been increased from 951,000 to 1,427,000 KW. Meanwhile, hydropower still generates the highest units within the segment with the contribution of 1,902,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.38) with respect to the base scenario.

4.11.10 Optimum Power Generation Portfolio 4A

(Conventional 70%, Non-Conventional 30%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 4A is consisting of 70% conventional power generation resources i.e (coal and gas) and only 30% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.26 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.26
Scenario 1 Optimum portfolio 4A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,664,000	145.06	241,379,411	0.46
2	Gas	14,987,000	117.31	1,758,099,525	
3	Hydro	5,711,000	115.65	660,464,331	

6	biomass	712,000	141.71	100,894,533	
5	solar	712,000	241.81	172,170,808	
	Total Units	**23,788,000**		2,933,008,608	

Table 4.26 shows that the highest no of units is generated through gas following by hydropower. Out of 23,788,000 KW of electricity 14,987,000 KW of electricity is generated through gas, which is the 63 percent share of total electricity generated in the portfolio. However, among renewable resources hydropower is the cheapest form of electricity generation and contributed 5,711,000 KW of electricity in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 712,000 KW of electricity. Finally, in comparison to the base scenario diversity index has increased from 0.43 to 0.46 which shows the low level of fuel diversification in the portfolio.

4.11.11 Optimum Power Generation Portfolio 4B

(Conventional 70%, Non-Conventional 30%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 4 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.27 concurrently fulfilling the applied conditions.

Table 4.27
Scenario 1 Optimum portfolio 4B

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	3,330,000	145.06	483,048,941	0.37

2	Gas	13,321,000	117.31	1,562,663,894
3	Hydro	4,281,000	115.65	495,088,041
6	biomass	1,427,000	141.71	202,214,184
5	solar	1,427,000	241.81	345,067,054
	Total Units	**23,788,000**		3,088,082,114

In the above table 4.27, the highest no of electricity units has been generated by gas, i.e. 13,321,000 which is 56 percent of total electricity generated in the portfolio. On the other hand, coal generates 3,806,000 units of electricity. Meanwhile, among renewable resources hydropower generated most units contributing 4,281,000 units out of 23,788,000 KW of total electricity. Solar and biomass contributed 1,427,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to base scenario, i.e. (0.43 to 0.37) which shows high stability in the portfolio.

4.11.12 Optimum Power Generation Portfolio 4C

(Conventional 70%, Non-Conventional 30%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 4 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 4C consists of two segments conventional and non-conventional fuels contributing segmental share 70 and 30 percent respectively. Table 4.28 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.28
Scenario 1 Optimum portfolio 4C

Table 4.28 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Gas has dominated the portfolio occupying the share of 49 percent of shares. However, coal remains in the second position with 4,995,000 units. Among the renewable resources, the share of solar and biomass has been increased from 1,427,000 to 2,141,000 KW. Meanwhile, hydropower still generates the highest units within the segment with the contribution of 2,853,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.31) with respect to the base scenario.

4.11.13 Optimum Power Generation Portfolio 5A

(Conventional 60%, Non-Conventional 40%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 5A is consisting of 60% conventional power generation resources i.e (coal and gas) and 40% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.29 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.29

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	4,995,000	145.06	724,573,412	0.31
2	Gas	11,656,000	117.31	1,367,345,571	
3	Hydro	2,853,000	115.65	329,943,046	
6	biomass	2,141,000	141.71	303,392,129	
5	solar	2,141,000	241.81	517,721,488	
	Total Units	**23,788,000**		3,242,975,645	

Scenario 1 Optimum portfolio 5A

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,426,000	145.06	206,855,192	0.4
2	Gas	12,846,000	117.31	1,506,942,450	
3	Hydro	7,614,000	115.65	880,542,009	
6	biomass	950,000	141.71	134,620,515	
5	solar	950,000	241.81	229,722,286	
	Total Units	**23,788,000**		2,958,682,453	

Table 4.29 shows that the highest no of units is generated through gas following by hydropower. Out of 23,788,000 KW of electricity 12,846,000 KW of electricity is generated through gas, which is the 54 percent share of total electricity generated in the portfolio. However, among renewable resources hydropower is the cheapest form of electricity generation and contributed 7,614,000 KW of electricity in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 950,000 KW of electricity. Finally, in comparison to the base scenario diversity index has decreased from 0.43 to 0.40 which shows the moderate level of fuel diversification in the portfolio.

4.11.14 Optimum Power Generation Portfolio 5B

(Conventional 60%, Non-Conventional 40%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 5 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.30 concurrently fulfilling the applied conditions.

Table 4.30
Scenario 1 Optimum portfolio 5B

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	2,854,000	145.06	414,000,504	0.32
2	Gas	11,418,000	117.31	1,339,426,195	
3	Hydro	5,708,000	115.65	660,117,388	
6	biomass	1,903,000	141.71	269,666,148	
5	solar	1,903,000	241.81	460,170,010	
	Total Units	**23,788,000**		3,143,380,244	

In the above table 4.30, the highest no of electricity units has been generated by gas, i.e. 11,418,000 which is 48 percent of total electricity generated in the portfolio. On the other hand, coal generates 2,854,000 units of electricity. Meanwhile, among renewable resources hydropower generated most units contributing 5,708,000 units out of 23,788,000 KW of total electricity. Solar and biomass contributed 1,903,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to base scenario, i.e. (0.43 to 0.32) which shows high stability in the portfolio.

4.11.15 Optimum Power Generation Portfolio 5C

(Conventional 60%, Non-Conventional 40%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 5 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 5C consists of two segments conventional and non-conventional fuels contributing segmental share 60 and 40 percent respectively. Table 4.31 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.31
Scenario 1 Optimum portfolio 5C

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	4,282,000	145.06	621,145,815	0.26
2	Gas	9,990,000	117.31	1,171,909,939	
3	Hydro	3,806,000	115.65	440,155,357	
6	biomass	2,854,000	141.71	404,428,369	
5	solar	2,854,000	241.81	690,134,108	
	Total Units	**23,788,000**		3,327,773,589	

Table 4.31 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Gas has dominated the portfolio occupying the share of 42 percent of shares. However, coal remains in the second position with 4,282,000 units. Among the renewable resources, the share of solar and biomass has been increased from 1,903,000 to 2,854,000 KW. Meanwhile, hydropower still generates the highest units within the segment with the contribution of 3,806,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.26) with respect to the base scenario.

4.11.16 Optimum Power Generation Portfolio 6A

(Conventional 50%, Non-Conventional 50%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 6A is consisting of 50% conventional power generation resources, i.e. (coal and gas) and 50% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.32 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.32
Scenario 1 Optimum portfolio 6A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,188,000	145.06	172,330,974	0.37
2	Gas	10,705,000	117.31	1,255,785,375	
3	Hydro	9,517,000	115.65	1,100,619,688	
6	biomass	1,188,000	141.71	168,346,497	
5	solar	1,188,000	241.81	287,273,763	
	Total Units	**23,788,000**		2,984,356,297	

Table 4.32 shows that the highest no of units is generated through gas following by hydropower. Out of 23,788,000 KW of electricity 10,705,000 KW of electricity is generated through gas, which is the 45 percent share of total electricity generated in the portfolio. However, among renewable resources hydropower is the cheapest form of electricity generation and contributed 9,517,000 KW of electricity in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 1,188,000 KW of electricity. Finally, in comparison to the base scenario diversity index has decreased from 0.43 to 0.37 which shows the moderate level of fuel diversification in the portfolio.

4.11.17 Optimum Power Generation Portfolio 6B

(Conventional 50%, Non-Conventional 50%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 6 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.33 concurrently fulfilling the applied conditions.

Table 4.33
Scenario 1 Optimum portfolio 6B

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	2,379,000	the 145.06	345,097,126	0.28
2	Gas	9,514,000	117.31	1,116,071,187	
3	Hydro	7,135,000	115.65	825,146,735	
6	biomass	2,379,000	141.71	337,118,111	
5	solar	2,379,000	241.81	575,272,966	
	Total Units	**23,788,000**		3,198,706,125	

In the above table 4.33, the highest no of electricity units has been generated by gas, i.e. 9,514,000 which is 40 percent of total electricity generated in the portfolio. On the other hand, coal generates 2,379,000 units of electricity. Meanwhile, among renewable resources hydropower generated most units contributing 7,135,000 units out of 23,788,000 KW of total electricity. Solar and biomass contributed 2,379,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to base scenario, i.e. (0.43 to 0.28) which shows high stability in the portfolio.

4.11.18 Optimum Power Generation Portfolio 6C

(Conventional 50%, Non-Conventional 50%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 6 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 6C consists of two segments conventional and non-conventional fuels contributing segmental share 50 and 50 percent respectively. Table 4.34 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.34

Scenario 1 Optimum portfolio 6C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	3,568,000	145.06	517,573,160	0.23
2	Gas	8,325,000	117.31	976,591,616	
3	Hydro	4,757,000	115.65	550,136,372	
6	biomass	3,568,000	141.71	505,606,314	
5	solar	3,568,000	241.81	862,788,542	
	Total Units	**23,788,000**		3,412,696,003	

Table 4.34 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Gas has dominated the portfolio occupying the share of 35 percent by generating 8,325,000 units of electricity. However, on other hand coal generates 3,568,000 units. Together 50 % of electricity is generated through hydrocarbons in this portfolio. Among the renewable resources, the share of solar and biomass has been increased from 2,379,000 to 3,568,000 KW. Meanwhile, hydropower still generates the highest units within the segment with the contribution of 4,757,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.23) with respect to the base scenario.

4.11.19 Optimum Power Generation Portfolio 7A

(Conventional 40%, Non-Conventional 60%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 7A is consisting of 40% conventional power generation resources i.e (coal and gas) and 60% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.35 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.35
Scenario 1 Optimum portfolio 7A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	950,000	145.06	137,806,755	0.37
2	Gas	8,564,000	117.31	1,004,628,300	
3	Hydro	11,420,000	115.65	1,320,697,366	
6	biomass	1,426,000	141.71	202,072,478	
5	solar	1,426,000	241.81	344,825,241	
	Total Units	**23,788,000**		3,010,030,141	

Table 4.35 shows that the highest no of units is generated through hydropower following by gas. Out of 23,788,000 KW of electricity 11,420,000 KW of electricity is generated through hydropower, which is the 48 percent share of total electricity generated in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 1,426,000 KW of electricity. Furthermore, the share of gas and coal has been reduced, gas generates 8,564,000 KW of units, however, coal generates only 950,000 KW of electricity. Finally, in comparison to the base scenario diversity index has decreased from 0.43 to 0.37 which shows the moderate level of fuel diversification in the portfolio.

4.11.20 Optimum Power Generation Portfolio 7B

(Conventional 40%, Non-Conventional 60%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 7 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.36 concurrently fulfilling the applied conditions.

Table 4.36
Scenario 1 Optimum portfolio 7B

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,903,000	145.06	276,048,689	0.27
2	Gas	7,611,000	117.31	892,833,488	
3	Hydro	8,564,000	115.65	990,407,377	
6	biomass	2,854,000	141.71	404,428,369	
5	solar	2,854,000	241.81	690,134,108	
	Total Units	**23,788,000**		3,253,852,031	

In the above table 4.36, the highest no of electricity units has been generated by hydropower i.e. 8,564,000 which is 36 percent of total electricity generated in the portfolio. On the other hand, solar and biomass generate 2,854,000 units of electricity. Meanwhile, among the hydrocarbons gas generated most units contributing 7,611,000 units out of 23,788,000 KW of total electricity. However, coal contributed 1,903,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to the base scenario, i.e. (0.43 to 0.27) which shows high stability in the portfolio.

4.11.21 Optimum Power Generation Portfolio 7C

(Conventional 40%, Non-Conventional 60%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 7 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 7C consists of two segments conventional and non-conventional fuels contributing segmental share 40 and 60 percent respectively. Table 4.37 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.37
Scenario 1 Optimum portfolio 7C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	6,660,000	145.06	414,000,504	0.22
2	Gas	6,660,000	117.31	781,273,293	
3	Hydro	5,708,000	115.65	660,117,388	
6	biomass	4,282,000	141.71	606,784,259	
5	solar	4,282,000	241.81	1,035,442,976	
	Total Units	**23,788,000**		3,497,618,418	

Table 4.37 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Gas and coal generate the equal numbers of units occupying a share of 40 percent by generating 13,320,000 units of electricity commutatively. Among the renewable resources, the share of solar and biomass has been increased from 2,854,000 to 4,282,000 KW with respect to the previous scenario. Meanwhile, hydropower still generates the highest units within the segment with the contribution of 4,757,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.22) with respect to the base scenario.

4.11.22 Optimum Power Generation Portfolio 8A

(Conventional 30%, Non-Conventional 70%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 8A is consisting of 30% conventional power generation resources i.e (coal and gas) and 70% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.38 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.38
Scenario 1 Optimum portfolio 8A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	712,000	145.06	103,282,536	0.4
2	Gas	6,423,000	117.31	753,471,225	
3	Hydro	13,323,000	115.65	1,540,775,045	
6	biomass	1,664,000	141.71	235,798,460	
5	solar	1,664,000	241.81	402,376,719	
	Total Units	**23,788,000**		3,035,703,986	

Table 4.38 shows that the highest no of units is generated through hydropower following by gas. Out of 23,788,000 KW of electricity 13,323,000 KW of electricity is generated through hydropower, which is the 56 percent share of total electricity generated in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 1,664,000 KW of electricity. Furthermore, the share of gas and coal has been reduced, gas generates 6,423,000 KW of units. However, coal generates only 712,000 KW of electricity. Finally, in comparison to

the base scenario diversity index has decreased from 0.43 to 0.40 which shows the moderate level of fuel diversification in the portfolio.

4.11.23 Optimum Power Generation Portfolio 8B

(Conventional 30%, Non-Conventional 70%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 8 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.39 concurrently fulfilling the applied conditions.

Table 4.39
Scenario 1 Optimum portfolio 8B

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,427,000	145.06	207,000,252	0.28
2	Gas	5,708,000	117.31	669,595,789	
3	Hydro	9,991,000	115.65	1,155,436,724	
6	biomass	3,330,000	141.71	471,880,332	
5	solar	3,330,000	241.81	805,237,064	
	Total Units	**23,788,000**		3,309,150,161	

In the above table 4.39, the highest no of electricity units has been generated by hydropower i.e. 9,991,000 which is 42 percent of total electricity generated in the portfolio. On the other hand share of solar and biomass has significantly increased and generates 3,330,000 units of electricity. Meanwhile, among the hydrocarbons gas generated most units contributing 5,708,000 units out of 23,788,000 KW of total electricity. However, coal contributed 1,427,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to base scenario, i.e. (0.43 to 0.28) which shows high stability in the portfolio.

4.11.24 Optimum Power Generation Portfolio 8C

(Conventional 30%, Non-Conventional 70%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 8 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 8C consists of two segments conventional and non-conventional fuels contributing segmental share 30 and 70 percent respectively. Table 4.40 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.40

Scenario 1 Optimum portfolio 8C

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	2,141,000	145.06	310,572,908	0.22
2	Gas	4,994,000	117.31	585,837,661	
3	Hydro	6,661,000	115.65	770,329,699	
6	biomass	4,995,000	141.71	707,820,498	
5	solar	4,995,000	241.81	1,207,855,596	
	Total Units	**23,788,000**		3,582,416,362	

Table 4.40 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Hydropower has dominated the portfolio occupying the share of 28 percent by generating 6,661,000 units of electricity. However, on the other hand, solar and biomass generates 4,995,000 units. Together 70 % of electricity is generated through renewable resources in this portfolio. Among the hydrocarbons,

the share of gas has been reduced from 5,708,000 to 4,994,000 KW with respect to the previous scenario. Meanwhile, coal generates 2,141,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.22) with respect to the base scenario.

4.11.25 Optimum Power Generation Portfolio 9A

(Conventional 20%, Non-Conventional 80%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 9A is consisting of 20% conventional power the generation resources, i.e. (coal and gas) and 80% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.41 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.41
Scenario 1 Optimum portfolio 9A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	474,000	145.06	68,758,318	0.46
2	Gas	4,282,000	117.31	502,314,150	
3	Hydro	15,226,000	115.65	1,760,852,723	
6	biomass	1,902,000	141.71	269,524,442	
5	solar	1,902,000	241.81	459,928,197	
	Total Units	**23,788,000**		3,061,377,830	

Table 4.41 shows that the highest no of units is generated through hydropower following by gas. Out of 23,788,000 KW of electricity 15,226,000 KW of electricity is generated through hydropower, which is the 64 percent share of total electricity

generated in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 1,902,000 KW of electricity respectively. Furthermore, the share of gas and coal has been reduced, gas generates 4,282,000 KW of units. However, coal generates only 474,000 KW of electricity. Finally, in comparison to the base scenario diversity index has increased from 0.43 to 0.46 which shows the moderate level of fuel diversification in the portfolio.

4.11.26 Optimum Power Generation Portfolio 9B

(Conventional 20%, Non-Conventional 80%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 9 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.42 concurrently fulfilling the applied conditions.

Table 4.42
Scenario 1 Optimum portfolio 9B

Optimized Portfolio of Malaysian power Generation mix					
S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	951,000	145.06	137,951,815	0.31
2	Gas	3,805,000	117.31	446,358,090	
3	Hydro	11,418,000	115.65	1,320,466,071	
6	biomass	3,806,000	141.71	539,332,295	
5	solar	3,806,000	241.81	920,340,020	

In the above table 4.42, the highest no of electricity units has been generated by hydropower i.e. 11,418,000 which is 48 percent of total electricity generated in the portfolio. On the other hand share of solar and biomass has significantly increased and generates 3,806,000 units of electricity respectively. Meanwhile, among the hydrocarbon gas generated most units contributing 3,805,000 units out of 23,788,000 KW of total electricity. However, coal contributed 951,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to base scenario, i.e. (0.43 to 0.31) which shows high stability in the portfolio.

4.11.27 Optimum Power Generation Portfolio 9C

(Conventional 20%, Non-Conventional 80%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 9 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 9C consists of two segments conventional and non-conventional fuels contributing segmental share 20 and 80 percent respectively. Table 4.43 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.43
Scenario 1 Optimum portfolio 9C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	1,427,000	145.06	207,000,252	0.24
2	Gas	3,329,000	117.31	390,519,338	
3	Hydro	7,612,000	115.65	880,310,714	
6	biomass	5,709,000	141.71	808,998,443	
5	solar	5,709,000	241.81	1,380,510,030	

	Total Units	**23,788,000**		3,667,338,777	

Table 4.43 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Hydropower has dominated the portfolio occupying the share of 32 percent by generating 7,612,000 units of electricity. However, on the other hand, solar and biomass generates 5,709,000 units individually. Together 80 % of electricity is generated through renewable resources in this portfolio. Among the hydrocarbons, the share of gas has been reduced from 3,805,000 to 3,329,000 KW with respect to the previous scenario. Meanwhile, coal generates 1,427,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.24) with respect to the base scenario.

4.11.28 Optimum Power Generation Portfolio *10A*

(Conventional 10%, Non-Conventional 90%)

Scenario 1: (At least 10% electricity should be generated by each technology)

The portfolio 10A is consisting of 10% conventional power generation resources i.e (coal and gas) and 90% electricity is generated by non-conventional resources (Hydro, Biomass, and Solar). Among the segmental share, the condition of scenario is applied that is at least 10% of electricity must be generated by each fuel in the segment. Table 4.44 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.44
Scenario 1 Optimum portfolio 10A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	236,000	145.06	34,234,099	0.54

2	Gas	2,141,000	117.31	251,157,075
3	Hydro	17,129,000	115.65	1,980,930,402
6	biomass	2,140,000	141.71	303,250,424
5	solar	2,140,000	241.81	517,479,675
	Total Units	**23,788,000**		3,087,051,674

Table 4.44 shows that the highest no of units is generated through hydropower following by gas. Out of 23,788,000 KW of electricity 17,129,000 KW of electricity is generated through hydropower, which is the 72 percent share of total electricity generated in the portfolio. Solar and Biomass are considered as the most expensive form of generation and contributed 2,140,000 KW of electricity respectively. Furthermore, the share of gas and coal has been reduced, gas generates 2,141,000 KW of units. However, coal generates only 236,000 KW of electricity. Finally, in comparison to the base scenario diversity index has increased from 0.43 to 0.54 which shows the low level of fuel diversification in the portfolio.

4.11.29 Optimum Power Generation Portfolio 10B

(Conventional 10%, Non-Conventional 90%)

Scenario 2: (At least 20% electricity should be generated by each technology)

In scenario 2 of portfolio 10 the segmental share of minimum electricity generation has been increased from 10% to 20%, however, the total combination of conventional and non-conventional fuels remains unchanged. The optimum combination of units generated by each fuel has been represented in table 4.45 concurrently fulfilling the applied conditions.

Table 4.45
Scenario 1 Optimum portfolio 10B

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	475,000	145.06	68,903,377	0.36
2	Gas	1,902,000	117.31	223,120,391	
3	Hydro	12,845,000	115.65	1,485,495,418	
6	biomass	4,282,000	141.71	606,784,259	
5	solar	4,282,000	241.81	1,035,442,976	
	Total Units	**23,788,000**		3,419,746,420	

In the above table 4.45, the highest number of electricity units has been generated by hydropower i.e. 12,845,000 which is 54 percent of total electricity generated in the portfolio. On the other hand share of solar and biomass has significantly increased and generates 4,282,000 units of electricity respectively. Meanwhile, among the hydrocarbon gas generated most units contributing 1,902,000 units out of 23,788,000 KW of total electricity. However, coal contributed 475,000 KW of electricity. In terms of diversification, the value of diversity index has been decreased in comparison to base scenario, i.e. (0.43 to 0.36) which shows high stability in the portfolio.

4.11.30 Optimum Power Generation Portfolio 10C

(Conventional 10%, Non-Conventional 90%)

Scenario 3: (At least 30% electricity should be generated by each technology)

Scenario 3 is the last condition applied to the portfolio 10 restricting to at least generate 30% of electricity by each fuel within the segment. Portfolio 10C consists of two segments conventional and non-conventional fuels contributing segmental share 10 and 90 percent respectively. Table 4.46 shows the optimum combination of electricity units generated with each fuel at minimum possible cost.

Table 4.46

Scenario 1 Optimum portfolio 10C

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	713,000	145.06	103,427,596	0.28
2	Gas	1,664,000	117.31	195,201,015	
3	Hydro	8,563,000	115.65	990,291,729	
6	biomass	6,423,000	141.71	910,176,388	
5	solar	6,423,000	241.81	1,553,164,463	
	Total Units	**23,788,000**		3,752,261,191	

Table 4.46 illustrates the optimum combinations of fuels meanwhile fulfilling the applied conditions. Hydropower has dominated the portfolio occupying the share of 36 percent by generating 8,563,000 units of electricity. However, On the other hand solar and biomass generates 6,423,000 units individually. Together 90 % of electricity is generated through renewable resources in this portfolio. Among the hydrocarbons, the share of gas has been reduced from 1,902,000 to 1,664,000 KW with respect to the previous scenario. Meanwhile, coal generates 713,000 units of electricity. Furthermore, the value of diversity index is lower (0.43 to 0.28) with respect to the base scenario.

4.11.31 Optimum Power Generation Portfolio 11A

(Conventional 0%, Non-Conventional 100%)

Scenario 1: (At least 10% electricity should be generated by each technology)

Portfolio 11 is considered as the pure non-conventional power generation portfolio in which 100% of electricity is generated through hydropower, biomass, and solar power plants. Hydropower is the cheapest generation technology in the entire portfolio and considered as the most preferable to generate electricity. As per the condition in below scenario at least 10 percent of the segmental share must be generated by each fuel in the segment. Table 4.47 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.47
Scenario 1 Optimum portfolio 11A

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	-	145.06	0	0.66
2	Gas	-	117.31	0	
3	Hydro	19,032,000	115.65	2,201,008,080	
6	biomass	2,378,000	141.71	336,976,405	
5	solar	2,378,000	241.81	575,031,153	
	Total Units	**23,788,000**		3,113,015,638	

Table 4.47 illustrates that the above portfolio consists of three power generation resources only. The portfolio is heavily dependent upon the hydropower, which is the cheapest form of electricity generation. Approximately 90% of electricity has been generated by hydropower, which is about 19,032,000 Kilo Watts of units. In comparison to the base scenario (Malaysia’s current power generation mix), the above table shows that the total cost of generation has been increased from 3,063,593,309 per day to 3,113,015,638 per day. Meanwhile, the value of diversity index has been reduced with respect to base scenario, i.e. (0.43 to 0.66). The system with this value of diversification is considered as the least stable system and highly reactive to unforeseen events.

4.11.32 Optimum Power Generation Portfolio 11B

(Conventional 0%, Non-Conventional 100%)

Scenario 2: (At least 20% electricity should be generated by each technology)

The second scenario of portfolio 11 is restricted to the condition of at least 20% of electricity must be generated by each fuel in the segment. However, portfolio 11B is the pure conventional portfolio and has 0% of conventional fuels. Table 4.48 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.48
Scenario 1 Optimum portfolio 11B

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units G Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	-	145.06	0	0.44
2	Gas	-	117.31	0	
3	Hydro	14,272,000	115.65	1,650,524,765	
6	biomass	4,758,000	141.71	674,236,222	
5	solar	4,758,000	241.81	1,150,545,931	
	Total Units	**23,788,000**		3,475,306,918	

Table 4.48 is highly dominant by hydropower, which occupies the 80 percent share of the entire generation portfolio, i.e. 14,272,000 numbers of units have been generated by hydro out of 23,788,000 KW of electricity. As the above portfolio is pure non-conventional portfolio and has a zero contribution of hydrocarbon energy

resources. On the other hand, biomass and solar generate 4,758,000 KW of electricity respectively. In comparison to the base scenario, the total cost of generation has been reduced 2,922,571,244 from 3,475,306,918. In terms of diversification, the diversity index has increased (0.43 to 0.44) which reduced the stability against supply disruption in the portfolio.

Optimized Portfolio of Malaysian power Generation mix

S No.	Fuel Type	Units Capacity (KW)	Cost of unit generation (KWh)	Total Cost of generation	Diversity Index
1	Coal	-	145.06	0	0.34
2	Gas	-	117.31	0	
3	Hydro	9,516,000	115.65	1,100,504,040	
6	biomass	7,136,000	141.71	1,011,212,627	
5	solar	7,136,000	241.81	1,725,577,084	

4.11.33 Optimum Power Generation Portfolio 11C

(Conventional 0%, Non-Conventional 100%)

Scenario 3: (At least 30% electricity should be generated by each technology)

As the portfolio 11 is pure non-conventional portfolio the segmental share has restricted to at least generate 30% of electricity by each fuel wit in the segment. Table 4.49 shows the optimum combination of units generated at lowest cost simultaneously satisfying the conditions applied.

Table 4.49

Scenario 1 Optimum portfolio 11C

Total Units	23,788,000	3,837,293,751

In comparison to the base scenario (Malaysia’s current power generation mix), the above table shows that the total cost of generation has been increased from 3,063,593,309 per day to 3,837,293,751 per day. However, in comparison with the scenario 1 and 2 of the same portfolio, the slightly increase in generation cost can be observed. Hydropower has dominated the portfolio occupying the share of 40% percent by generating 9,516,000 units of electricity. However, on the other hand, solar and biomass generates 7,136,000 units individually. This portfolio is the most expensive combination of fuels for electricity generation. Finally, the diversity index has been increased as compared to the base case but more diversified in comparison to other two scenarios i.e. (0.43 to 0.34).

4.12 Ranking of Optimum Portfolios in Terms of Cost

In the above section, eleven portfolios have been generated in terms of cost and diversity index with three different scenarios for each. All of the eleven portfolios were optimized using solver with respect to the number of units generated by each fuel, simultaneously satisfying the given conditions. However, in the above results, it has been observed that cost and diversification have an inverse relationship. The portfolio has the least cost contains the maximum diversity index (lowest level of diversification) and vice versa. In this section, all the portfolios were ranked in terms of cost to assist the decision makers in strategic planning of optimum portfolio.

Table 4.50
Ranking of Optimized Portfolios in terms of Cost

Ranking of Portfolios in terms of Cost			
S no.	**Portfolios**	**Cost of Generation**	**Diversity Index**

1	Portfolio 1A	2,823,526,355	0.91
2	Portfolio 3A	2,876,890,118	0.56
3	Portfolio 2A	2,881,660,919	0.68
4	Portfolio 1B	2,922,571,244	0.68
5	Portfolio 4B	2,933,008,608	0.46
6	Portfolio 5B	2,958,682,453	0.4
7	Portfolio 2B	2,977,252,899	0.56
8	Portfolio 6A	2,984,356,297	0.37
9	Portfolio 1C	2,988,564,168	0.58
10	Portfolio 7C	3,010,030,141	0.37
11	Portfolio 3B	3,032,783,984	0.45
12	Portfolio 8A	3,035,703,986	0.4
13	Portfolio 9A	3,061,377,830	0.46
14	Portfolio 2C	3,073,015,168	0.47
15	Portfolio 10A	3,087,051,674	0.54
16	Portfolio 4B	3,088,082,114	0.37
17	Portfolio 11A	3,113,015,638	0.66
18	Portfolio 5B	3,143,380,244	0.32
19	Portfolio 3C	3,158,053,230	0.38
20	Portfolio 6B	3,198,706,125	0.28
21	Portfolio 4C	3,242,975,645	0.31
22	Portfolio 7B	3,253,852,031	0.27
23	Portfolio 8B	3,309,150,161	0.28
24	Portfolio 5C	3,327,773,589	0.26
25	Portfolio 9B	3,364,448,291	0.31
26	Portfolio 6C	3,412,696,003	0.23
27	Portfolio 10b	3,419,746,420	0.36
28	Portfolio 11B	3,475,306,918	0.44
29	Portfolio 7C	3,497,618,418	0.22
30	Portfolio 8C	3,582,416,362	0.22
31	Portfolio 9C	3,667,338,777	0.24
32	Portfolio 10C	3,752,261,191	0.28
33	Portfolio 11C	3,837,293,751	0.34

In the table 4.50 evaluation criteria is strictly based on cost. The Portfolio having lowest cost ranked as first, regardless the value of diversity index. From the table 4.50 , it can be observed that portfolio 1A is the cheapest portfolio with the total cost of 2,823,526,355 generation followed by 3A and 2A with values of 2,876,890,118 and 2,881,660,919 respectively.

4.13 Ranking of Optimum Portfolios in terms of Diversity Index (HHI)

Table 4.51
Ranking of Optimized Portfolios in terms of Diversity Index

Ranking of Portfolios in terms of Diversity Index

S no.	Portfolios	Cost of Generation	Diversity Index
1	Portfolio 7C	3,497,618,418	0.22

2	Portfolio 8C	3,582,416,362	0.22
3	Portfolio 6C	3,412,696,003	0.23
4	Portfolio 9C	3,667,338,777	0.24
5	Portfolio 5C	3,327,773,589	0.26
6	Portfolio 7B	3,253,852,031	0.27
7	Portfolio 6B	3,198,706,125	0.28
8	Portfolio 8B	3,309,150,161	0.28
9	Portfolio 10C	3,752,261,191	0.28
10	Portfolio 4C	3,242,975,645	0.31
11	Portfolio 9B	3,364,448,291	0.31
12	Portfolio 5B	3,143,380,244	0.32
13	Portfolio 11C	3,837,293,751	0.34
14	Portfolio 10B	3,419,746,420	0.36
15	Portfolio 6A	2,984,356,297	0.37
16	Portfolio 7A	3,010,030,141	0.37
17	Portfolio 4B	3,088,082,114	0.37
18	Portfolio 3C	3,158,053,230	0.38
19	Portfolio 5A	2,958,682,453	0.4
20	Portfolio 8A	3,035,703,986	0.4
21	Portfolio 11B	3,475,306,918	0.44
22	Portfolio B	3,032,783,984	0.45
23	Portfolio 4A	2,933,008,608	0.46
24	Portfolio 9A	3,061,377,830	0.46
25	Portfolio 2C	3,073,015,168	0.47
26	Portfolio 10A	3,087,051,674	0.54
27	Portfolio 3A	2,876,890,118	0.56
28	Portfolio 2B	2,977,252,899	0.56
29	Portfolio 1C	2,988,564,168	0.58
30	Portfolio 11A	3,113,015,638	0.66
31	Portfolio 2A	2,881,660,919	0.68
32	Portfolio 1B	2,922,571,244	0.68
33	Portfolio 1A	2,823,526,355	0.91

Table 4.50 ranks the portfolios with respect to the cost of generation. However, in this section, all the portfolios optimality was examined on the scale of diversity index. The portfolio having lowest diversity index (maximum level of diversification) has given the preference and ranked first. Table 4.51 shows the ranking of optimal portfolios with respect to diversity index.

From the above table, it has been concluded that a portfolio 7C and 8C are the maximum diversified portfolio having diversity index 0.22 followed by 6C with the value of 0.23 respectively.

4.14 Finding Optimum Portfolio Using Base Evaluation Graphical Method

The base evaluation graphical method 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.

$$\textbf{Optimal Portfolio} = [\textbf{Min} \{\textbf{Total Cost of Power Generation Mix}\}]\ \textbf{Diversity Index}_{\textbf{Min}} \tag{13}$$

To identify the optimum generation mix the entire eleven quantified portfolios with three different scenarios has been plotted on the graph (figure 4.3). 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 4.4.

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 figure 4.5.

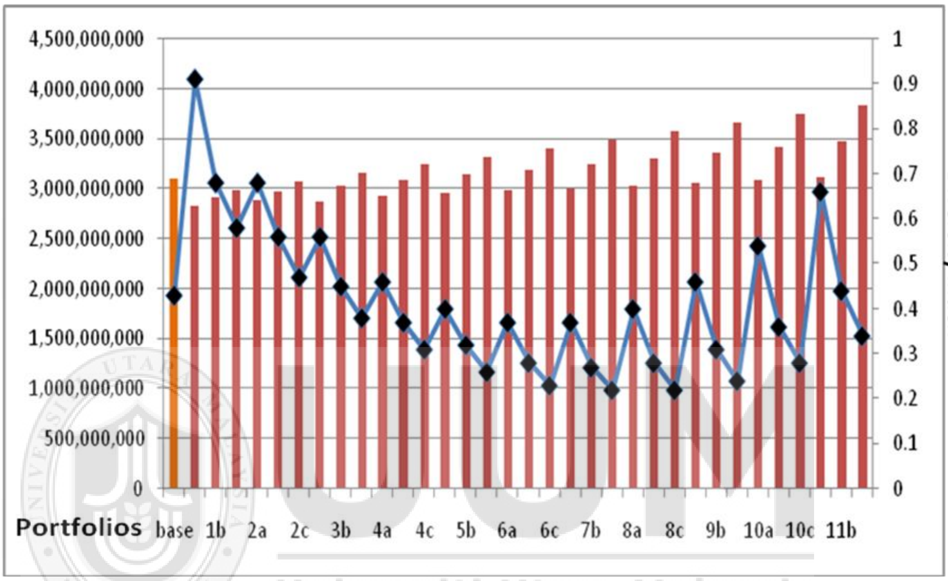


Figure 4.3
Graphical evaluation of optimum Power Generation Mix using baseline scenario.

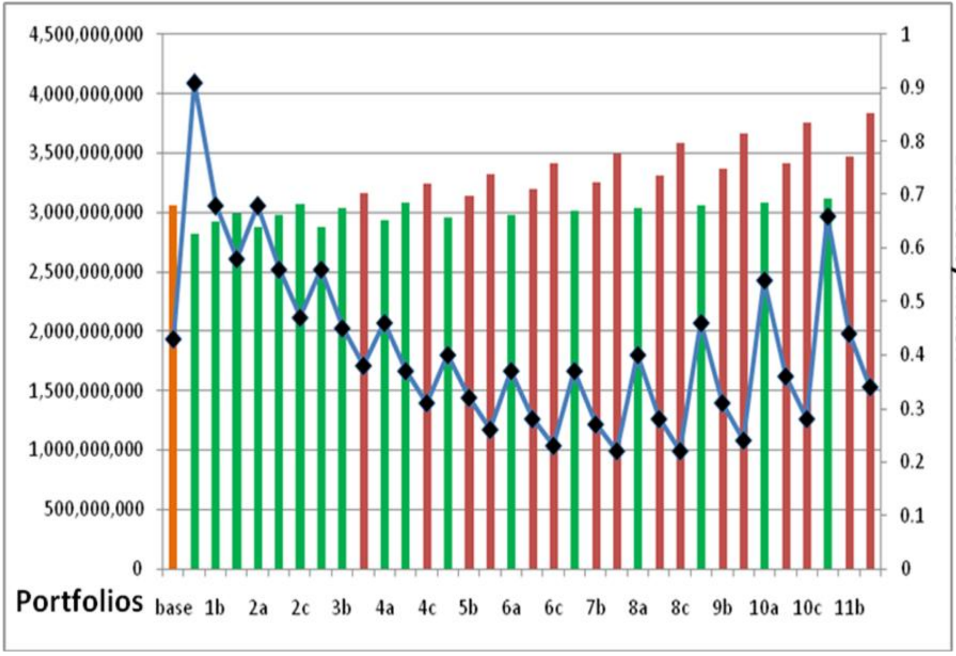


Figure 4.4

Step 1 Identification of lower cost values in comparison to base scenario (Consideration Set)

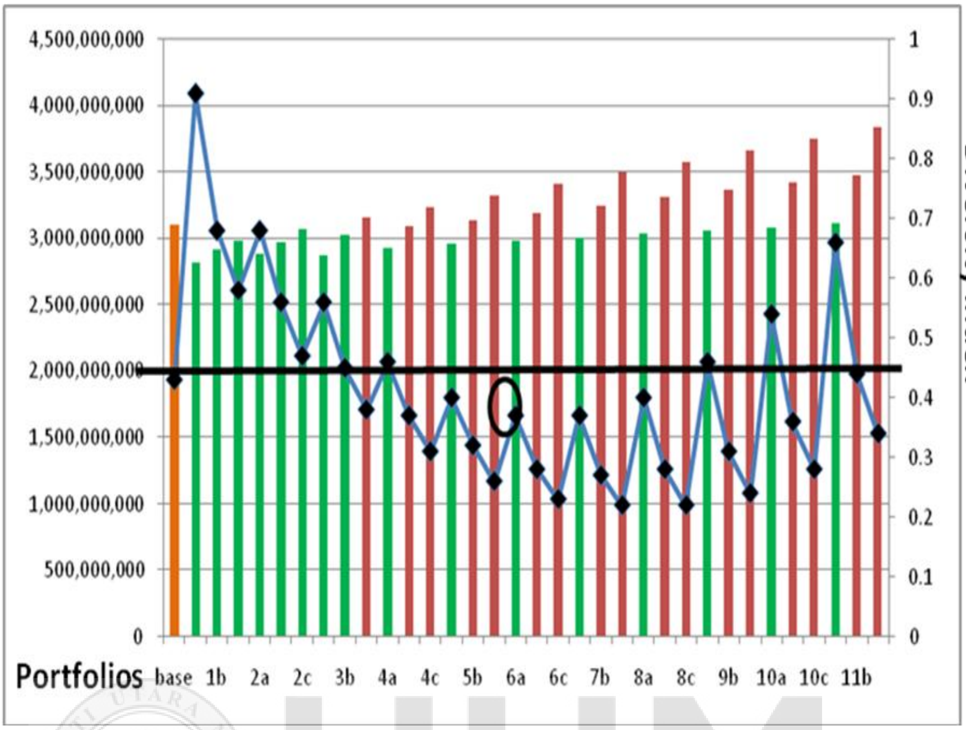


Figure 4.5
Step 2: Identifying Optimum Portfolio in terms of maximum diversity.

From the above figure, 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 4.52 below.

Table 4.52
Comparison of the Optimum portfolio with Base Scenario.

			Base Scenario			Optimum Portfolio		
S No	**Fuel Type**	**Cost of unit generation (KWh)**	**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**	

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.

4.15 Identifying Top 10 Optimum Portfolios for Malaysia Power Generation Mix

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.

Table 4.53
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 table 4.53, 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.

CHAPTER FIVE

CONCLUSION

5.1 Introduction

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. The current chapter presents and discusses the study findings, followed by highlighting the research contribution in academic, managerial and policy formulation levels. Next, the recommendation for future work is staged. Finally, a chapter conclusion is presented at the end.

5.2 Research Contribution

The study is based on the rising issue of energy security in terms of affordability, acceptability, and security in power generation system. The thesis is formulated in the form of five chapters which focuses and contributes to achieving the desired objectives. The study began by highlighting the challenges and global trend in the electricity market. It highlights the current challenges faced by energy security to maintain the affordable, acceptable and secure supplies of primary and secondary energy to its end users. In chapter 2 literature review shows that the previous study was usually based upon the quantification of generation cost with respect to supplies only. The impact of carbon emission in power generation was being ignored for a long time. Taking advantage of the vacuum in methodology and problem this study formulates an equation which not only accumulates the impact of carbon emission on cost but also quantifies the security risk of supplies in terms of monetary units, to quantify the total exposure. Quantifying risk in terms of monetary units is one of the core contributions of this thesis. The risk quantification method is consisting of three main components, namely risk identification, risk estimation and risk evaluation. In this study, all the three integrated components of risk were analyzed accordingly to quantify the impact of unforeseen events in the power generation process. After identification, the impact of risk has been evaluated and estimated, the final result is then presented in the terms of monetary units to quantify the impact of the excessive security cost of power generation system.

Moreover, the research gives the in-depth analysis of the electricity generation process and the method of quantifying generation cost which includes the factors of fixed and variable cost along with fuel, capital cost and discount rate factors. It is critical to evaluate all of these factors in sustainable power generation process. The electricity generation cost is a complex process and highly influenced by several internal and external parameters which impact directly on the generation process, Indepth analysis of these factors are always remain the priority of policymakers. After quantifying the economic parameters of cost, this study focuses on the environmental impact of power generation technologies. It has been acknowledged that the power generation process emits carbon dioxide, which is injurious to health and also responsible for seasonal variation. This study proposed the idea of implementing carbon-tax to restrict the power generation from fossil fuel and promote the use of renewable energy in electricity generation process. To implement the carbon-tax, the total amount of carbon emission was calculated in metric tons and then transformed into monetary units which add-ups with the total cost of power generation and also considered as the integral component.

This study proposed a unique method of risk quantification in power generation system. The definitions of energy security emphasize on the evaluation of risk in power generation but very few studies focus on the parameters of risk. In this study, a novel approach of risk quantification was proposed which not only quantify the possible risk but also transform it into monetary units to evaluate all the cost influence factors on a single platform, which provides in-depth knowledge for policymakers to develop strategic plans accordingly.

The cost of unit generation, a penalty of carbon emission and the excessive cost of security was evaluated, integrated and finally implemented to Malaysia power generation mix for total cost exposure.

Quantifying the total exposure of all three integrated parameters of energy security will provides the detailed picture of those factors which influence the supplies of fuels and resources for power generation process. However, to utilize these parameters in an effective and efficient manner, the quantified cost was further analyze and ranked in terms of fuel preference in the power generation process. Meanwhile, for effective and efficient policy making, the concept of diversification has an integral value. The portfolio is never considered as optimized until unless it is effective from both aspects in terms of cost and diversification. This study adopts an approach of optimization by minimizing the generation cost and maximizing the level of diversity. The diversity was measured by using HHI diversity index, which is a widely using method of measuring market concentration in business and economics. Finally, the add-on feature of Microsoft spreadsheet excels “Solver” was used to perform the optimization process. The result was generated by varying the weightage of generation technologies in the power generation mix simultaneously fixing the total number of units generated at the lowest level of total cost of generation.

5.2.1 Academic Contribution

Implementing carbon tax on carbon emission in the power generation process is a recent initiative for sustainable power generation process and has gained popularity in the last two or three years. After The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) it has been advised that a carbon penalty should be imposed in the form of carbon tax to restrict the rate of carbon emission. This study proposed a carbon restriction technique by implementing a carbon-tax on power generation process and considered it as an integral component of cost. Furthermore, the rising issue of global security is highly dependent upon the secure and reliable supplies of energy. This study proposed a novel technique to not only identify the risk but also to transform its impact in term of monetary units. The study also incorporates the concept of diversification of technologies in the power generation process to not only minimizes the risk but also to reduce the generation cost with maximum utilization of resources. The study focuses on the hybrid technique of optimization by utilizing three integrated parameters in terms of monetary units and diversity index.

5.2.2 Managerial and Policy Contribution

It has been proven that the uninterrupted supplies electricity is the key indicator of economic growth. Presently, the power plant is one of the biggest contributor to carbon emission because of high dependence on fossil fuels for electricity generation. On the other hand interruption in supplies of imported fuels like coal and LNG may significantly impact the generation process. From the management point of view the effective and efficient utilization of the available resource is the most critical task. This study proposed an idea to maintain the uninterrupted supplies of energy by utilizing the tool of risk identification, evaluation, and estimation. This tool will not only provide the detailed knowledge of unforeseen events but also help to measure the impact of those events in the power generation process. From the policy perspective the study provides the in-depth knowledge of different parameters which directly and indirectly impact the cost of generation. The application of the proposed method is not limited to power generation system only, but can also be utilized by other system which involves risk and the impact is to be measured in monetary units.

5.3 Future Work

This work is an initiative in the field of power generation to quantify the three key dimensions of energy security in terms of monetary units and formulate the total exposure, which not only help to reduce the risk, but also provide a detailed knowledge to policymakers for making long-term decisions in the power generation extension process. Although this work provides an original and significant contribution in the field of power generation in terms of cost evaluation, carbon taxation, security-related parameters, fuel and technology diversification and optimization, there are still some areas that can be improved in further studies. The following are some suggestion that may serve as the foundation for future work.

First, this study is based on the three key dimensions of energy security which accumulate and quantified in terms of monetary units. It is suggested that future researchers might choose to extend this work by including other dimensions of energy and quantify them in terms of cost which may reflect much better picture.

Secondly, this study is based on the five fuel policy of Malaysia's power generation mix the study can be including more fuels and technologies and can be implemented on the power generation mix of other countries of the world.

Thirdly, this study proposed a novel technique of risk quantification in terms of monetary units by adopting the approach of the risk impact matrix. The one limitation of RIM is it based on the expert opinions and gives estimated values; the approach can be modified by using other quantitative methods to make the tool more realistic.

Fourth, this study identifies six key factors of risk which influences on the power generation process, namely geological, geopolitical, technical, economical and climatical in terms of intermittency and extreme weather conditions. In future work, these factors may be modified and more influencing factor may be identified to enhance the risk identification process.

And finally, the optimization process can be improved by selecting different conditions (limitations) and using more appropriate optimization tools which may give much better results.

5.4 Conclusion

In summary, this thesis provides a novel approach of quantifying energy security in terms of economic, environmental and supply risk factors, compliance with the principle of sustainability, diversity, and applicability. The study aims to propose a new concept of energy security by introducing the measurement of supply disruption risk and its impact in terms of the monetary unit to evaluate the total cost exposure. It also highlights the impact of carbon emission on total generation cost. Regardless of the fact that energy security is one of the key contemporary issues, but still the accurate measuring of energy security is impossible. It has also been acknowledged that electricity has a direct impact on economic growth. Therefore policymakers around the world are looking for the effective and efficient tool to make their power system more secure, stable and affordable. The significant results obtained in this research suggested that the affordable, acceptable and secure power generation system can be achieved by incorporating the excessive cost of carbon-tax and secure supplies comply with the maximum level of diversity in generation portfolio. The ten optimum portfolios have been suggested with minimum cost at the maximum possible level of diversity. This technique is not difficult to apply because the practices originated by considering the current generation mix of Malaysia and also compliance with the 11th action plan 2020.

This study believes in the optimization of available resources for the sustainability of the power generation process. LCOE, carbon-taxes and excessive cost of secure supplies have been added up to give the total cost exposure of power generation mix. The novel approach can be further modified and include other cost related parameters to make the tool more realistic.

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APPENDIX A

Please rate the level of agreement with the following statements.

		Probability					**Risk Impact**				
#	**Questions**	Survey Scale: 1=Low 2=Moderate 3=High 4=Extreme 5=Not Related					Survey Scale: 1=Low 2=Moderate 3=High 4=Extreme 5=Not Related				
1	Risk/Impact of supply disruption due to geological events E.g. (Resource depletion/Shortage)	1	2	3	4	5	1	2	3	4	5
a	Coal	1	2	3	4	5	1	2	3	4	5
b	Gas	1	2	3	4	5	1	2	3	4	5
c	Hydro Power	1	2	3	4	5	1	2	3	4	5
d	Biomass	1	2	3	4	5	1	2	3	4	5
e	Solar Power	1	2	3	4	5	1	2	3	4	5
2	Risk/Impact of supply disruption due to geopolitical events E.g. Political instability (war, Terrorism) high import dependency	1	2	3	4	5	1	2	3	4	5
a	Coal	1	2	3	4	5	1	2	3	4	5
b	Gas	1	2	3	4	5	1	2	3	4	5
c	Hydro Power	1	2	3	4	5	1	2	3	4	5
d	Biomass	1	2	3	4	5	1	2	3	4	5
e	Solar Power	1	2	3	4	5	1	2	3	4	5
3	Risk/Impact of supply disruption due to Economical events E.g. Lack of investment on extraction of resources	1	2	3	4	5	1	2	3	4	5
a	Coal	1	2	3	4	5	1	2	3	4	5
b	Gas	1	2	3	4	5	1	2	3	4	5
c	Hydro Power	1	2	3	4	5	1	2	3	4	5
d	Biomass	1	2	3	4	5	1	2	3	4	5
e	Solar Power	1	2	3	4	5	1	2	3	4	5
4	Risk/Impact of supply disruption due to geopolitical events E.g. Political instability (war, Terrorism) high import dependence	1	2	3	4	5	1	2	3	4	5
a	Coal	1	2	3	4	5	1	2	3	4	5
b	Gas	1	2	3	4	5	1	2	3	4	5
c	Hydro Power	1	2	3	4	5	1	2	3	4	5
d	Biomass	1	2	3	4	5	1	2	3	4	5
e	Solar Power	1	2	3	4	5	1	2	3	4	5
5 (a)	Risk/Impact of supply disruption due to Climatic events E.g. Extreme Weather conditions	1	2	3	4	5	1	2	3	4	5
a	Coal	1	2	3	4	5	1	2	3	4	5

b	Gas	1	2	3	4	5		1	2	3	4	5	
c	Hydro Power	1	2	3	4	5		1	2	3	4	5	
d	Biomass	1	2	3	4	5		1	2	3	4	5	
e	Solar Power	1	2	3	4	5		1	2	3	4	5	
5 (b)	Risk/Impact of supply disruption due to Climatic events E.g. Intermittency Risk	1	2	3	4	5		1	2	3	4	5	
a	Coal	1	2	3	4	5		1	2	3	4	5	
b	Gas	1	2	3	4	5		1	2	3	4	5	
c	Hydro Power	1	2	3	4	5		1	2	3	4	5	
d	Biomass	1	2	3	4	5		1	2	3	4	5	
e	Solar Power	1	2	3	4	5		1	2	3	4	5	

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